Chemical Characteristics of Groundwater in the Akatsi and Ketu Districts of the Volta Region, Ghana

C. K. Tay
CSIR-Water Research Institute, P. O. Box AH 38, Achimota-Accra, Ghana

Abstract

The physico-chemical characteristics of the groundwater at Akatsi and Ketu districts were investigated. Water samples were collected from 34 boreholes in the Akatsi District and 27 boreholes in the Ketu District and analysed for their quality parameters, using appropriate certified and acceptable international standard methods. Most of the water quality variables measured were within the WHO and GWCL guidelines for drinking water. The results showed that groundwater in the two districts are soft but slightly acidic with ranges 5.75–7.39 *p*H units and 5.14–7.15 *p*H units for Akatsi and Ketu districts, respectively, and mean 6.73 *p*H units for Akatsi and 6.5 *p*H units for Ketu. Groundwater in both districts were also mineralized with conductivity ranges 170–6440 μS/cm and 420-5180 μS/cm for Akatsi and Ketu districts, respectively, and mean 1450.9 μS/cm for Akatsi and 1737.1 μS/cm for Ketu. SO_4^{2-} and Cl^- ion concentrations in some boreholes in both districts were at such elevated levels that serious health effects and risks might arise after prolonged and continuous intake. The NO_3-N concentrations in some of the boreholes in the two districts were present at elevated levels (far above the critical value of 10 mg/l) and might cause cyanosis, a potential health risk in infants.

Introduction

Groundwater, surface waters (e.g. rivers, streams and ponds), rain-water and springs are the main sources of water available to the rural dwellers in Ghana. The qualities of these water bodies vary widely depending on location and environmental factors. Among the factors determining the qualities of natural waters, groundwaters in particular, are the chemical composition of the rocks with which they interact; soil formations and the length of time that the water body has been trapped underground (Van der Merwe, 1962). To monitor the water resources and ensure sustainability, national guideline (Ghana Water Company Limited guideline) and permissible limit (Ghana Water Company Limited permissible limits) and international criteria and guidelines established for water quality standards (WHO, 1984 and 1993) are being used.

The present study focuses on using the Ghana Water Company Limited (GWCL) guideline and permissible limits, and international criteria and guidelines established for water quality standards, to assess the water qualities of selected boreholes in the Akatsi and Ketu districts in the Volta Region of Ghana. These districts are potential tourist centres in the Region. Like all other districts in the Region these districts depend solely on groundwater for domestic water supply, yet little or no quality data on the groundwater in these areas is currently available. In addition to evaluating the suitability of water for domestic uses, it is also envisaged that the data generated will serve as baseline data that will contribute to the understanding of the physical and chemical behaviour of other boreholes in the districts.

Materials and methods

The study areas

The Akatsi and Ketu districts are located in the Volta Region of Ghana. Fig. 1 shows the Akatsi and Ketu districts and the sampling communities.

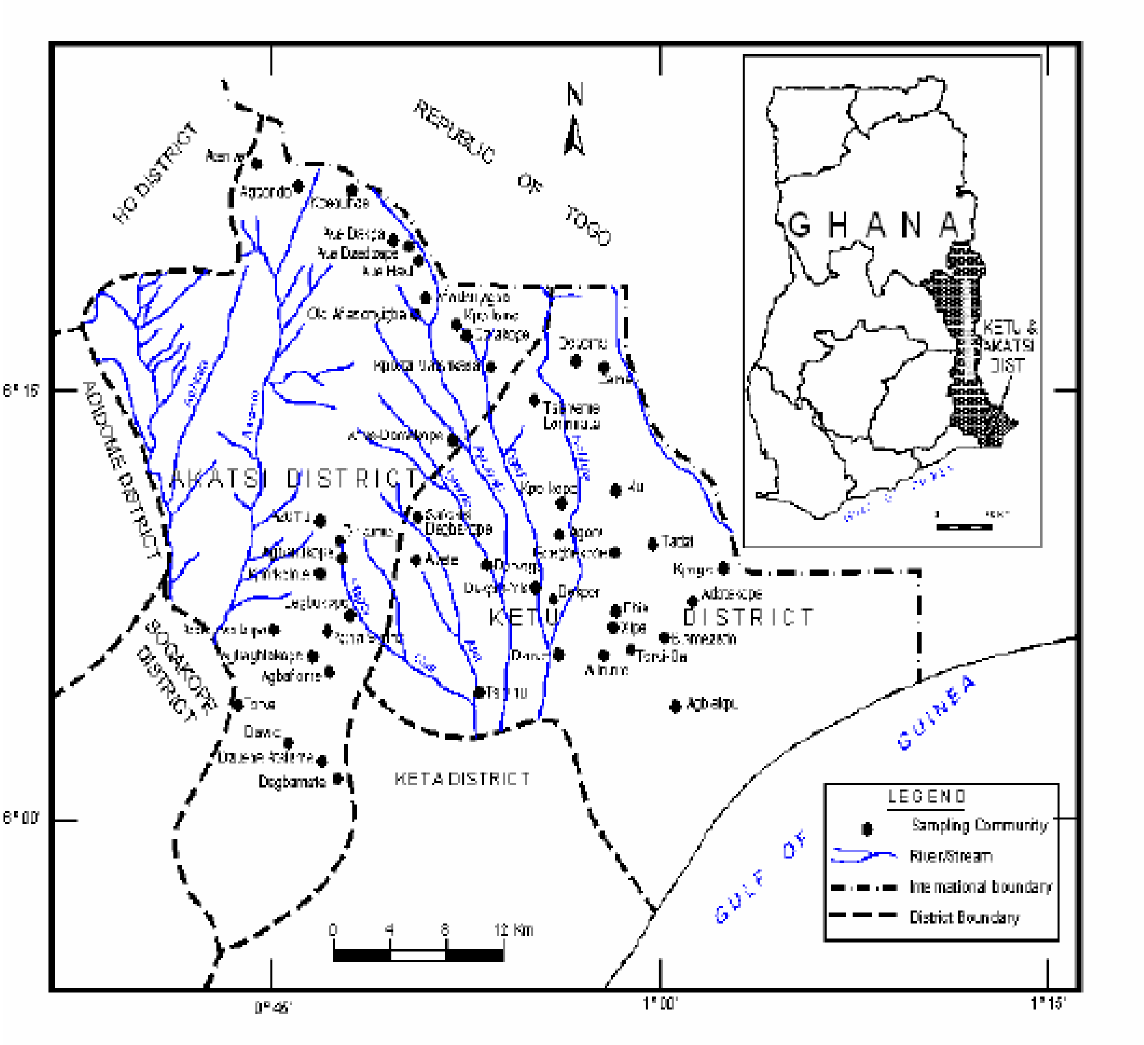


Fig. 1: Map of Ketu & Akatsi districts showing sampling communities

Akatsi District

Akatsi District is located in the south-eastern part of the Volta Region. It covers a total land area of about 906,455 square kilometres. It is bordered to the south by Keta, the east by Ketu, and west by both North and South Tongu districts. It has Akatsi as its district capital. Akatsi District has a number of water bodies such as Agblegbor, Wowoe – all streams, Lotor river and Tordzie river. These are the main sources of drainage in the area. The land is made up of peculiar coastal savanna soil, laterites and tropical black soil. Akatsi has an annual population growth rate of 2.6%. The capital (Akatsi) is the only urban settlement whiles the other major settle-ments: Avenorpeme, Lume, Agbedrafor, Wute, Dakpa, Torve and Gefia are rural.

Ketu District

Ketu District is the major gateway for tourists entering the country from Nigeria, Benin, and Togo. It covers a total land area of about 779 square kilometres. The District falls within the coastal savanna vegetation zone of the country. The Gulf of Guinea (the Atlantic Ocean) in the south washes a sandy and sparkling 30-km coastline, stretching from Horvi in the west to Aflao (on the Ghana-Togo boarder) in the east. The south-western portion of pocket lagoons forms part of the designated Ramsar sites – resting and feeding grounds of over 70 species of migratory and resident birds, marine turtle, and other reptiles. Indeed, the Keta lagoon covers a portion of the pocket lagoon also noted for salt, tilapia, and crabs. The sea and lagoon influence the overall weather conditions of the District.

Sampling and analysis

The data set for the study is a subset of the data collected by the Water Research Institute (WRI) in 2002 and 2003 during the Community Water and Sanitation Agency (CWSA) funded inventory and assessment of groundwater in selected districts in the Volta Region.

Sixty-one water samples were collected from the Akatsi and Ketu districts. Thirty-four boreholes in the Akatsi District and 27 boreholes in the Ketu District were sampled. Sampling protocols described by Claasen (1982) and Barcelona *et al*. (1985) were strictly adhered to during sample collection. Samples were collected using washed (with detergent and rinsed with distilled water) polypropylene containers. Boreholes were sampled only after pumping for sometime. For the determination of heavy metal, samples were collected using 4-litre acid- washed polypropylene containers. All samples were kept in an ice-chest and transported to the laboratory, stored in a refrigerator at a temperature of < 4 ^{o}C and analysed within 1 week. Temperature, *p*H and electrical conductivity were measured *in situ* using WTW-Multiline P4 Universal meter.

Samples were analysed by appropriate certified and acceptable international standard methods (Standard Methods, 1998) and the water quality assessment (UNESCO/WHO/UNEP, 1998). All the reagents used were of analytical grade and the instruments were pre-calibrated appropriately prior to determination.

Turbidity was determined using the Nephelometric method (APHA, 1998) in which the sample was shaken vigorously and transferred into a sample cell to at least two-thirds full, the sample cell was placed in the turbidimeter and the appropriate range on the turbidimeter was selected. The stable turbidity reading was then recorded.

Total dissolved solids (TDS) were determined using Gravimetric method (APHA, 1998) in which the sample was vigorously shaken and a measured volume transferred into a 100-ml graduated cylinder by means of a funnel. The sample was filtered through a glass fibre filter and a vacuum applied for about 3 min to ensure that water was removed as much as possible. The sample was washed with deionised water and suction continued for at least 3 min. The total filtrate was transferred (with washings) to a weighed evaporating dish and evaporated to dryness on a water bath. The evaporated sample was dried for at least 1 h at 180 ^{o}C. The dried sample was cooled in a desiccators and weighed. Drying and weighing process was repeated until a constant weight was obtained.

Fluoride was measured by the Ion Chromatograph (IC) method using Peaknet-Control Panel Dionex-80 System, while sodium and potassium were analysed by the Flame Photometric method using a Digital Flame Analyzer-Gallenkamp FGA-350L. Iron (Fe) and manganese (Mn) concentra-tions were determined using Unicam 969 Atomic Absorption Spectrophotometry (AAS). Calcium ion concentrations were determined using EDTA titrimetric method (APHA, 1998).

Magnesium ion concentrations were calculated from Mg hardness while sulphate ion (SO_4^{2-}) concentrations were determined using colorimetric method (APHA, 1998). Phosphate ion concentrations were determined using Stannous chloride method (APHA, 1998) in which about 0.05 ml (one drop) phenolphthalein indicator was added to about 100 ml sample. If sample turned pink, a strong acid solution (alcoholic sulphuric acid solution) was added drop-wise to discharge the colour. A 4-ml molybdate reagent I and 0.5 ml (10 drops) stannous chloride reagent I were added with thorough mixing after each addition. The absorbance was measured at a wavelength of 690 nm on a spectrophotometer after about 10 min.

Bicarbonate ion concentrations were calculated from alkalinity (strong acid titration). Total alkalinity (as mg/l $CaCO_3$), total hardness and the chloride concentra-tions were determined using titrimetric methods. Alkalinity was determined by titration of the sample with 0.1*M* hydrochloric acid to *p*H 4.5 using methyl orange indicator while the water hardness was analysed by titration of the buffered water sample with standard EDTA at *p*H 10 using Eriochrome Black-T as the indicator. The chloride content was determined by argentometric method. The sample was titrated under neutral conditions with a standard silver nitrate solution using potassium chromate as the indicator.

Results and discussion

The physical and chemical characteristics of groundwater in the Akatsi and Ketu districts are presented in Tables 1and 2. The mean concentrations of the borehole water quality in both districts are presented in Table 3 and compared with WHO (1984 and 1993) and the Ghana Water Company Limited (GWLC) guidelines in Table 4.

TABLE 1

Water quality of the Ketu District, Volta Region

				Parameter																
Site name	*pH*	*Cond.*	*Colour*	*Turbidity*	*PO_4*	*Tot. alk*	*NO_3-N*	*NO_2-N*	*Cl-*	*SO_4^{2}-*	*HCO_3-*	*NH_3-N*	*Na+*	*K+*	*Ca^{2+}*	*Mg^{2+}*	*Tot. Fe^{2+}*	*Mn^{2+}*	*Tot. hard.*	*TDS*
Afife	*5.79*	*420*	*5*	*3.9*	*0.01*	*56*	6.51	0.017	79.4	12.2	68.3	0.052	35	5.5	19.2	9.21	0.129	<0.01	86	230
Afife	7.1	1360	<5.00	5.9	0.3	280	0.01	<0.001	268	24.7	342	<0.001	NA	5.9	80.2	33.9	1.51	0.04	88	687
Devego	7.05	870	<5.00	0.4	0.02	322	13.1	<0.001	76.9	27.1	396	<0.001	45	4.5	109.8	11	0.069	11	N	435
Xipe	6.5	860	5	1.5	0.02	284	10.07	<0.001	42.1	129	NA	<0.001	33	6	128	19.8	0.02	<0.01	400	100
Tsyinu	6.72	1300	<5.00	1.2	<0.001	294	1.88	0.017	174	55.8	359	<0.001	88.5	3.5	126	7.54	0.335	<0.010	345	660
Ativedome Kofe	6.35	2240	5	0.6	0.01	320	14.5	0.001	203	162	390	<0.001	200	12.8	94.2	40	0.046	<0.010	400	113
Agorvi	6.83	3220	<5.00	2.3	0.01	400	0.122	0.002	54.6	920	488	<0.001	34.4	9.2	361	126	0.21	0.2	1420	619
Agorvi	7.02	1390	<5.00	0.8	0.01	376	0.639	<0.001	79.4	265	N	<0.001	120	4	143	54.1	<0.001	0.015	580	699
Kuli	6.56	1000	5	1.5	0.03	386	1.33	<0.001	69.4	32.2	471	0.23	45	2.9	138	7.53	0.387	0.012	375	540
Kpoglo	6.8	940	<5.00	3.5	<0.001	272	1.4	<0.001	111	32.1	332	<0.001	66.3	4.9	88.2	26.1	0.54	0.01	328	633
Ehi	7.15	940	<5.00	0.7	0.028	314	0.228	0.003	100	51.4	383	0.066	60.7	3.2	81	30	<0.001	0.031	326	470
Torvi-Ga	6.9	1310	<5.00	1	<0.001	320	1.1	<0.001	143	225	390	1.1	96.6	7.9	152	42.6	0.06	42.6	556	655
Gbegbekope	6.42	490	<5.00	4.8	0.269	96	0.536	0.002	56.1	NA	117	0.536	24.1	1.5	56.1	4.3	0.69	0.13	158	250
Adotekope	5.83	3920	<5.00	13.2	0.024	18	0.45	0.001	1260	188	22	0.4	600	9.3	76.2	87.4	0.29	0.3	550	197
Blamezado	5.6	1480	<5.00	0.8	0.001	26	0.766	0.012	383	51.6	31.7	0.175	136	3.2	48.1	51	0.21	0.025	330	740
Agblekpui	5.14	1510	5	2.6	0.019	16	0.786	0.004	340	69.2	19.5	<0.001	182	1	33.4	17	1.94	0.101	153.3	765
Adrume	7.11	1090	20	23.5	0.038	300	0.115	0.003	137	48.6	366	0.12	102	5.6	103	18.5	1.68	<0.001	333.3	550
Tadzi	6.95	770	5	4.8	0.017	242	0.288	<0.001	53.6	54	295	0.288	39.5	5.8	54.5	35.4	0.39	0.025	282	389
Dzove	6.89	1960	<5.00	0.7	0.025	308	0.141	0.001	307	236	376	0.127	181	4.2	80.16	72	0.02	0.024	496.7	940
Dzove	7.06	1490	<5.00	0.6	0.009	362	0.149	<0.001	162	138	442	0.236	155	3.1	46.8	51.8	0.001	0.034	330	750
Dekpor Yia	5.4	1630	<5.00	0.9	<.001	48	324	<0.001	223	111	58.6	<0.001	138	40.2	104	39.7	<0.010	0.14	424	824
Deme	6.2	570	<5.00	0.4	<0.001	100	57.3	<0.001	60.8	14.7	122	<0.001	34	2.8	35.3	<0.01	<0.011	<0.010	176	300
Kpelikope	6.7	1300	<5.00	0.5	<0.001	232	15.8	<0.001	157	30.4	283	<0.001	41.6	3.99	157	13.4	0.02	<0.010	448	653
Tornu Mlianu	6.3	1210	<5.00	0.4	0.45	192	127	<0.001	153	43.9	234	<0.001	78.8	7.35	73.7	44.6	0.05	0.02	368	634
Tornu Mlianu	6.6	940	<5.00	0.4	0.45	260	46.1	<0.001	72.5	54.3	317	<0.001	108	11	48	32	0.01	0.42	252	564
Dorwuime	6.8	2460	<5.00	0.6	<0.001	764	92.3	<0.001	347	92.6	932	<0.001	196	15.3	140	121	0.16	0.18	848	123
Tsiaveme-Lormnava	6.6	2340	<5.00	0.5	<0.001	516	180	<0.001	428	30.7	629	<0.001	135	13.6	143	183	0.05	0.07	1108	117

NA: Not available

TABLE 2

Water quality of Akatsi District, Volta Region

Site name	*Parameter*																				
	pH	*Cond.*	*Colour*	*Turb*	*PO_4*	*Total alk.*	*NO_3-*	*NO_2-N*	*Cl-*	*$SO_4$2-*	*HCO_3-*	*NH_3-N*	*Na+*	*K+*	*Ca^{2}+*	*Mg^{2}+*	*Tot. Fe^{2}+*	*Mn^{2}+*	*Tot. Hard.*	*TDS*	*F-*
	pH-unit	*(μs/cm)*	*Hz*	*(NTU)*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg/l*	*mg*
Avenorpedo	6.1	370	<5.00	1	0.9	24	7.6	<0.001	59.6	7.9	30	<0.001	14.3	0.2	16	9.7	0.07	0.06	80	185	0.1
Dzuepe Gbodome	7.3	860	5	3.2	0.11	268	0.5	0.68	85.5	12.4	327	0.015	40.4	5.37	86.6	13	3.12	0.14	300	430	0.3
Old Afiadenyigba	7.35	970	<5.00	0.46	0.016	465	0.14	0.009	55.6	12.5	567	0.474	110	8.81	36.1	40.1	0.093	0.14	255	435	0.3
Ave Dzadzepe	6.6	760	<5.00	0.45	0.11	190	0.171	0.001	52.6	21.8	232	0.053	16	5.43	40.1	29.1	0.032	<0.010	220	380	<0
Dzrekope	7.31	2160	<5.00	0.42	0.01	260	0.972	0.032	233	66.3	317	0.461	105	10.1	68.1	69.6	0.01	0.083	456	1080	0.2
Agornu kporklote	6.7	2440	<5.00	0.66	<0.010	364	0.991	0.129	268	88.9	444	0.304	93.8	10.3	132	52.1	0.01	1.45	545	1225	0.0
Agornu kporklote	7.39	3260	<5.00	0.75	<0.010	292	0.1	0.076	586	49.5	356	0.1	124	13.3	138	121	0.19	0.24	845	1630	0.0
Abadzivorkope	6.4	640	<5.00	0.72	<0.010	114	0.437	0.007	44.7	18.8	139	0.01	17.8	4.84	36.1	19.4	0.03	0.036	170	320	0.2
Agbalixorme	6.08	640	<5.00	0.62	0.032	104	0.202	0.007	56.6	18.8	127	0.202	38	3.88	24	15.8	0.026	0.04	125	320	0.1
Dawlo	7.02	1130	5	2.25	<0.010	268	1.24	0.006	99.3	74.4	327	0.263	17.5	2.53	170	16.8	0.098	0.022	475	565	0.4
Torve	7.02	6440	<5.00	0.53	<0.010	620	0.463	0.116	992	41.8	756.4	2.09	471	6.1	246	139	0.047	0.011	1190	3220	0.6
Agbagblakorpe	6.15	270	5	2.89	0.131	46	0.353	0.06	38.7	25.6	56.1	0.127	11.5	0.89	20	6.1	0.822	0.052	75	165	0.0
Dzuepe Atsiame	5.75	170	5	3	0.037	30	0.347	0.006	6	7.56	36.6	0.257	2.34	0.7	12.8	2.9	0.026	0.194	44	80	0.0
Dagbamatey	6.07	470	<5.00	1	<0.010	30	0.481	0.012	90.3	7.94	36.6	0.427	38	1.09	23.2	9.2	0.026	<0.010	96	280	0.0
Lume Avete	5.83	990	<5.00	2	0.144	74	0.769	0.014	163	50.3	90.3	0.345	79.2	5.81	48.1	20.6	0.044	0.206	206	540	0.3
Asafoatsi Amenopekope	6.27	760	<5.00	1.13	0.031	98	0.755	0.018	92.3	39.8	120	0.611	55.5	4.95	30.1	20.6	0.035	3	160	380	0.2
Asafoatsi Dagbakope	6.94	760	<5.00	0.41	0.06	234	0.358	0.008	91.3	20.3	285.5	0.236	60.1	6.97	48.1	31	0.025	0.01	248	380	0.2
Ave Dakpa	7.26	880	5	2.44	0.051	122	0.475	0.004	180	51.4	148.8	0.012	78.2	3.88	52.1	32.7	0.654	<0.010	265	440	0.2
New Afiadenyigba	6.47	460	<5.00	0.64	0.135	135	0.266	0.032	64.5	4.38	165	0.013	37.5	2.83	48.1	1.2	0.105	0.06	125	230	0.2
Adidokpui	6.96	1920	5	8.9	<0.001	455	0.13	<0.001	208	196	555	0.604	194	9.96	126	54.5	0.251	0.081	540	960	0.0
Ave Kpedunoe	6.74	1960	5	1.8	0.094	180	0.59	0.011	328	141	220	0.42	25	10.1	136	76.4	0.321	0.33	655	985	0.0
Zemutekpa-kope	6.9	1430	<5.00	1	<0.001	200	88.3	<0.001	157	14.6	244	<0.001	35.7	4.5	99.4	47.5	0.05	0.01	444	723	0.0
Dagbamatey	5.9	510	<5.00	1.54	<0.001	34	56.6	<0.001	97.2	9.2	41.5	0.035	38.5	1.03	24	17	0.2	0.03	130	250	<0
Agbanukope	6.55	1120	<5.00	0.54	0.017	164	0.412	0.012	189	75.5	200	<0.001	107	6.1	52.1	23	0.06	0.02	225	560	0.3
Alagbokope	6.68	530	<5.00	0.77	0.03	164	0.177	0.072	43.7	15.2	200	<0.001	35	5.04	20	21.8	0.02	0.058	140	265	0.1
Dawlo	7.33	640	5	2.44	<0.001	252	0.601	0.009	31.8	10.5	307	<0.001	11.6	1.47	94.6	8.1	<0.010	0.011	270	320	0.2
Agbonodo	7.24	2720	5	8.99	<0.001	328	0.01	0.01	81.4	152	400.2	0.059	12.6	13.5	158	52.1	1.824	0.284	610	1360	0.5
Ave Atanve	7.19	1850	<5.00	0.59	<0.001	270	0.621	0.02	181	176	329.4	0.059	178	20	104	59.4	0.11	1.56	380	925	0.8
Kpodzi Matsrikasa	7.1	2600	<5.00	0.72	<0.001	486	1.71	0.024	367	73.8	529.9	0.127	177	12.6	64.1	111.7	0.044	0.29	620	1300	0.4
Agbaflome	7.1	1540	<5.00	1.2	<0.001	116	127	<0.001	233	26.6	142	0.056	38.2	4.48	162	13.4	0.03	0.03	460	780	<0
Agornu kporklote	6.46	1570	<5.00	0.45	<0.001	252	0.625	0.031	184	40.7	307	<0.001	116	4.59	52.1	27.9	0.01	1.45	245	785	0.0
Adzikame	7.1	2240	<5.00	0.5	<0.001	364	8.3	<0.001	78.3	19.1	444	<0.001	69.2	2.1	86.6	42.7	0.1	0.19	392	1125	0.1
Ave Havi	6.4	1870	<5.00	0.7	<0.001	188	475	<0.001	161	80	229	0.055	76	10.2	125	103.9	<0.010	0.01	740	940	0.1
Torve	6.99	2400	<5.00	0.9	0.16	304	313	<0.001	268	107	371	0.051	200	10.9	136	77.6	<0.010	0.01	304	1230	1.3

TABLE 3

The mean values and range of the water quality of the boreholes in the Akatsi and Ketu districts.

Parameter	*Akatsi*		*Ketu*	
	Mean	*Range*	*Mean*	*Range*
*p*H-unit	6.73	5.75-7.39	6.5	5.14-7.15
Conductivity (us/cm)	1450.88	170-6440	1737.1	420-5180
Turbidity (NTU)	1.64	0.41-8.99	2.65	0.4-23.5
PO_4 (mg/l)	0.12	0.01-0.9	0.11	0.001-0.6
Total alkalinity (mg/l)	220.44	24-620	262.52	16-764
NO_2-N (mg/l)	0.05	0.001-0.68	0.006	0.001-0.017
NO_3-N (mg/l)	32.05	0.01-475	29.99	0.01-324
Cl^- (mg/l)	172.64	6.0-992.6	246.68	42.1-1260
SO_4^{2-} (mg/l)	51.69	4.38-196	144.85	12.2-920
HCO_3- (mg/l)	267.1	30.0-756.	306.2	19.5-935
NH_3-N (mg/l)	0.28	0.01-2.09	0.31	0.052-1.1
Na^+ (mg/l)	80.12	2.34-471	140.75	24.1-668

K^+ (mg/l)	6.31	0.2-20	7.1	1.0-40.2
Ca^{2+} (mg/l)	79.9	12.8-246.	107.5	19.2-361
Mg^{2+} (mg/l)	40.79	1.2-139	47.39	4.3-183
Tot. Fe^{2+} (mg/l)	0.27	0.01-3.12	0.35	0.001–1.94
Mn^{2+} (mg/l)	0.33	0.01-3.0	2.35	0.005-42.6
Tot. hardness (mg/l)	353.97	44.0-1190	443.88	86-1420
TDS (mg/l)	729.21	80-3220	869.03	230-2600
F^- (mg/l)	0.28	0.04-1.3	0.26	0.001-1.5

TABLE 4

Water quality of the ground waters of the Akatsi and Ketu districts compared with the limits recommended for drinking waters

Parameter	*Akatsi District*	*Ketu District*	*WHO Guideline*	*GWCL Guideline*
pH-unit	6.73	6.5	6.5-8.5	6.5-8.5
Conductivity (us/cm)	1450.88	1737.1		
colour (Hz)	Nd	Nd	15	0-15.0
Turbidity (NTU)	1.64	2.65	5	0-15.0
PO_4 (mg/l)	0.12	0.11		
Total alkalinity (mg/l)	220.44	262.52		
NO_2-N (mg/l)	0.05	0.006	0-0.3	
NO_3-N (mg/l)	32.05	29.99	10	0-10.0
Cl- (mg/l)	172.64	246.68	250	0-600
SO_4^{2-} (mg/l)	51.69	144.85	250	0-400
HCO_3^- (mg/l)	267.1	306.2		
NH_3-N (mg/l)	0.28	0.31	0-0.5	
Na^+ (mg/l)	80.12	140.75	200	
K^+ (mg/l)	6.31	7.1	30	
Ca^{2+} (mg/l)	79.9	107.5	200	
Mg^{2+} (mg/l)	40.79	47.39	150	
Tot Fe^{2+} (mg/l)	0.27	0.35	0.3	0-0.3
Mn^{2+} (mg/l)	0.33	2.35	0.5(P)	
Tot Hardness (mg/l)	353.97	443.88		
TDS (mg/l)	729.21	869.03	1000	1000
F- (mg/l)	0.28	0.26	1.5	0-1.5

Nd: Not determined

General characteristics

p*H.* The *p*H of the boreholes in the Akatsi District varied from 5.75 to 7.39 whilst boreholes in the Ketu District recorded *p*H varying from 5.14 to 7.15. Boreholes in both districts generally had *p*H values within the range of 6–9 *p*H range of natural waters (Stumn & Morgan, 1981) and did not vary significantly, although the boreholes sampled at Dzuepe Atsiame (*p*H 5.75), Lume Avete (*p*H 5.83) and Dagbamatey (*p*H 5.9) in the Akatsi District, and Afife (*p*H 5.79), Blamezado (*p*H 5.6), Agblekpui (*p*H 5.14) and Dekpor Yia (*p*H 5.4) in the Ketu District were slightly acidic. The box plot (Fig. 2) of the two districts indicates that Ketu District recorded the minimum *p*H value, while Akatsi District recorded the maximum *p*H value with a slightly higher median *p*H value.

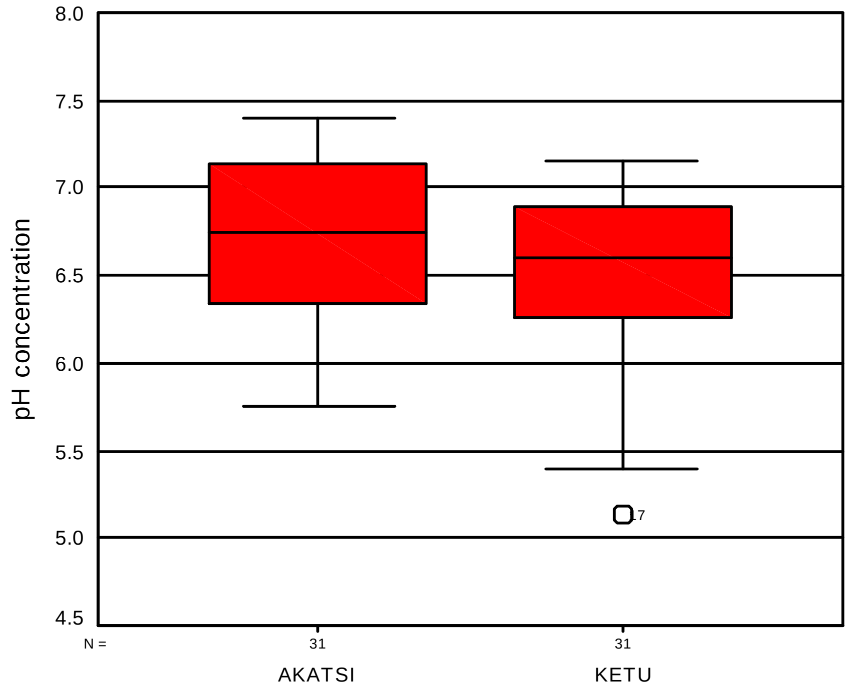


Fig. 2. Variations of *p*H (*p*H units) in the groundwaters of the Akatsi and Ketu districts

Conductivity. The conductivity of groundwater in the two districts is within the limits of acceptable standards for drinking and domestic water and did not vary significantly. Boreholes in the Akatsi District recorded conductivity values varying from 170 to 6440 mS/cm with a mean of 1451 mS/cm, whilst boreholes in the Ketu district recorded conductivity values varying from 420 to 5180 mS/cm with a mean of 1737 mS/cm. The box plot (Fig. 3) of the two districts indicates that Akatsi District recorded the minimum conductivity value, while Ketu District recorded the maximum conductivity value with a higher median conductivity value.

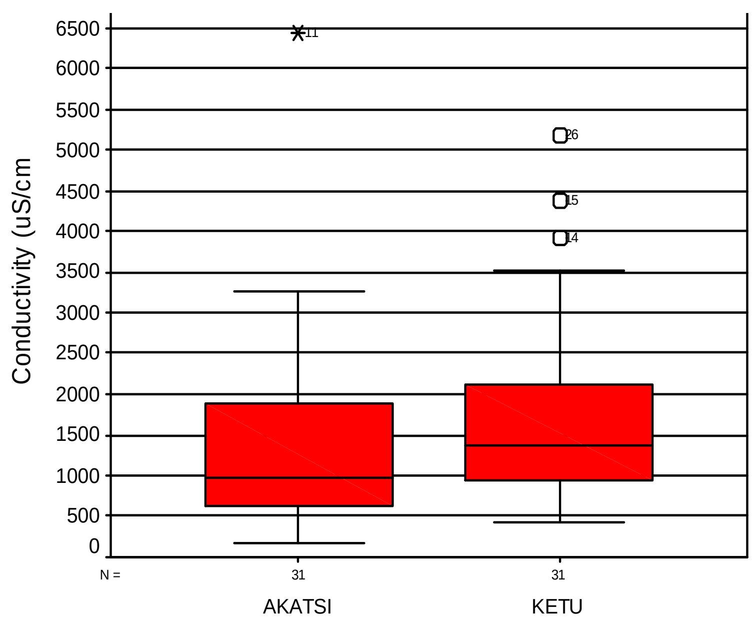


Fig. 3. Variations of conductivity (uS/cm) in the groundwaters of the Akatsi and Ketu districts

Turbidity and TDS. Tables 1 and 2 show that the turbidity values in the two districts are within the limits of acceptable standards for drinking and domestic water except for the boreholes at Agbonodo (8.99 NTU) and Adidokpui (8.9 NTU) in the Akatsi District and Afife (5.9 NTU), Detokope (13.2 NTU) and Adrume (23.5 NTU) in the Ketu District, which recorded turbidity values outside acceptable limits. The turbidity values in the Akatsi District varied from 0.41 to 8.99 NTU with a mean of 1.64 NTU, whilst the Ketu District recorded turbidity values varying from 0.4 to 23.5 NTU. The box plot (Fig. 4) indicates that both districts had almost the same minimum turbidity concentrations. However, Ketu district recorded the highest turbidity concentration.

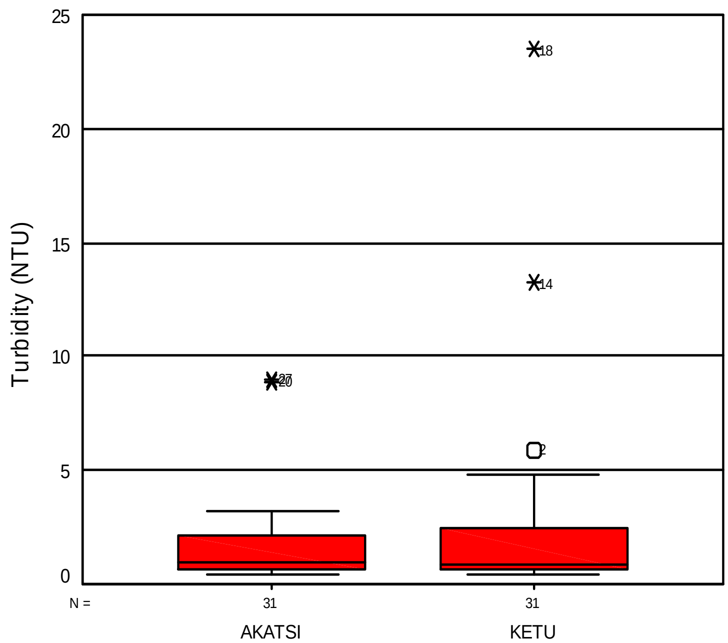


Fig. 4. Variations of turbidity (NTU) in the groundwaters of the Akatsi and Ketu districts

TDS is a common indicator of polluted waters. As shown in Table 4, the maximum acceptable limits for TDS in drinking waters by WHO (1993) and GWCL guideline is 1000 mg/l. TDS concentrations in the groundwater of the Akatsi District varied from 80 to 3220 mg/l with a mean value of 729.21 mg/l, whilst the Ketu District recorded TDS concentrations varying from 230 to 2600 mg/l with a mean value of 869 mg/l. Although TDS concentrations of groundwater from many parts of the two districts are within the limits of acceptable standards for drinking and domestic water, boreholes at Dzrekope (1080 mg/l), Agornu Kporklote (1225 and 1630 mg/l), Torve (3220 mg/l), Agbonodo (1360 mg/l), Kpodzi Matsrikasa (1300 mg/l), Adzikame (1125 mg/l) and, Atiglime (1230 mg/l) in the Akatsi District, and Ativedomekofe (1130 mg/l), Detokope (1978 mg/l), Zuime (2190 mg/l), Dekpor-Dome (1765 and 2600 mg/l), Dorwuime (1238 mg/l) and Tsiaveme-Lormnava (1172 mg/l) in the Ketu District recorded concentrations higher than acceptable limits.

TDS concentrations at Torve in the Akatsi District and Dekpor-Dome in the Ketu District not only exceeded the maximum acceptable limits but also greater than 2450 mg/l, considered to be the critical value above which some long-term health problems might be anticipated due to excessive concentrations of dissolved particles in the water (Kempster *et al.*, 1997). The box plot

(Fig. 5) of the two districts indicates that Akatsi District recorded the minimum TDS concentration while Ketu District recorded the maximum TDS concentration with a higher mean TDS concentration.

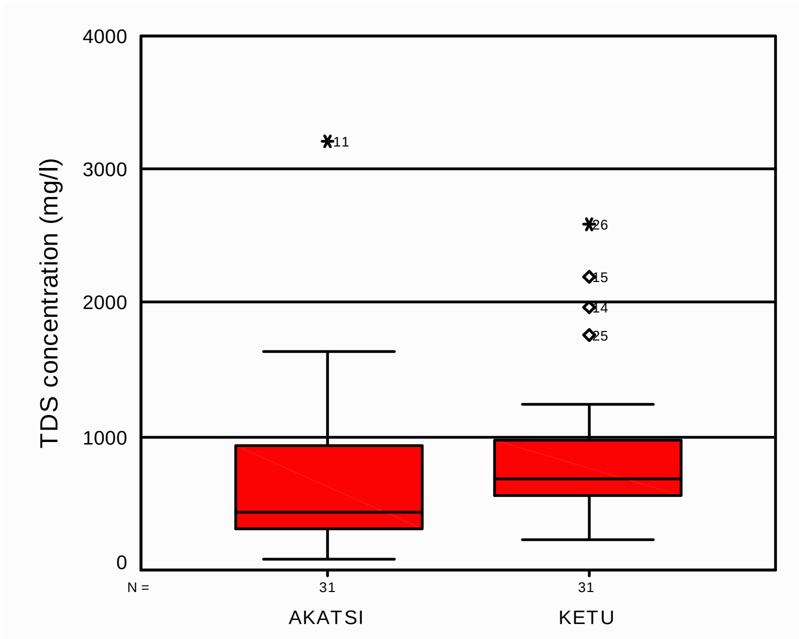


Fig. 5. Variations of TDS (mg/l) in the groundwaters of the Akatsi and Ketu districts

Total alkalinity and total hardness

The alkalinity of groundwater in the two districts is within the limits of acceptable standards for drinking and domestic water and did not vary significantly. The Akatsi District recorded alkalinity values varying from 24 to 620 mg/l with a mean value of 220.4 mg/l whilst boreholes in the Ketu District recorded alkalinity values varying from 16 to 764 mg/l with a mean value of 262.5 mg/l. The box plot (Fig. 6) of the two districts shows that Ketu District recorded both the minimum and maximum values with a higher median alkalinity value, while Akatsi District recorded concentrations within the range of concentrations in the Ketu District.

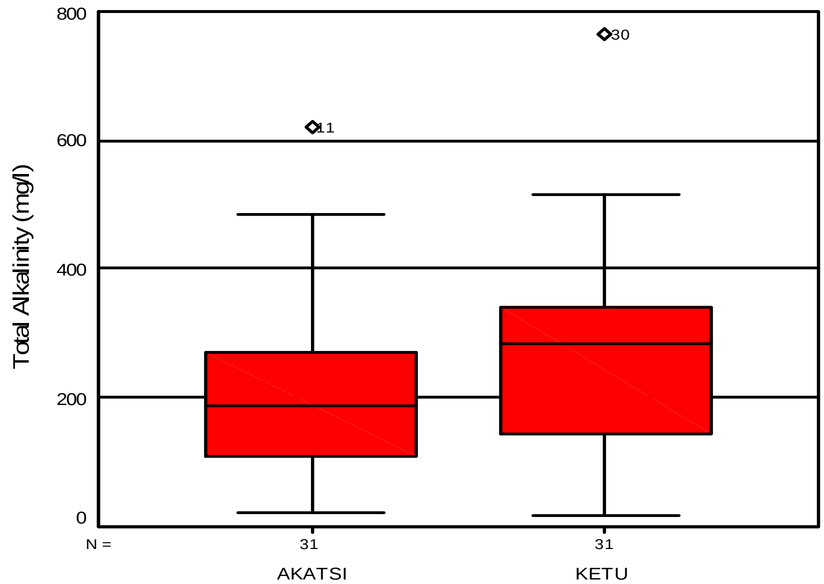


Fig. 6. Variations of alkalinity (mg/l) in the groundwaters of the Akatsi and Ketu districts

Groundwater of the two districts are generally soft, although boreholes at Agornu Kporkplote (545 mg/l and 845 mg/l), Torve (1190 mg/l), Adidokpui (540 mg/l), Ave Kpedunoe (655 mg/l), Agbonodo (610 mg/l), Kpodzi
Matsrikasa (620 mg/l) and Ave Havi (740 mg/l) in the Akatsi District, and Agorvi (580 mg/l and 1420 mg/l), Torviga (556 mg/l), Detokope (550 mg/l), Dekpor-Dome (708 mg/l and 960 mg/l), Dorwuime (848 mg/l) and Tsiaveme-Lormnava (1108 mg/l) in the Ketu District recorded concentrations higher than acceptable limits.

Water hardness in the Akatsi District varied widely with values ranging from 44 to 1190 mg/l and mean 354 mg/l. However, boreholes in the Ketu District recorded a narrower range of values from 86 to 1420 mg/l with a mean value of 443.88 mg/l. The box plot (Fig. 7) of water hardness of the two districts shows that Akatsi District recorded both the minimum and maximum hardness concentrations while Ketu District recorded hardness concentrations within the range of concentration in the Akatsi District. This result explains the presence of higher concentration of dissolved Ca and Mg in the groundwater of the Ketu District than in the Akatsi District as presented in the mean and range values (Table 3).

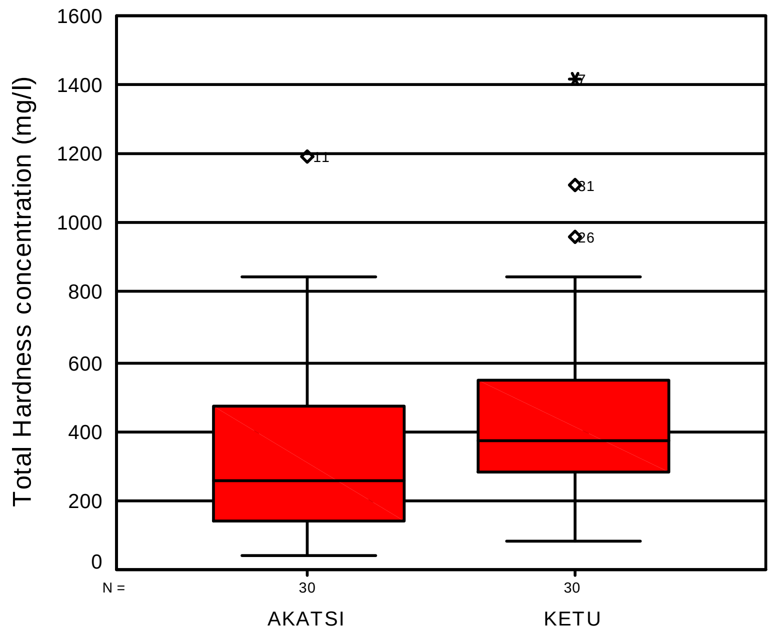


Fig. 7. Variations of hardness (mg/l) in the groundwaters of the Akatsi and Ketu districts

The micronutrients

The amounts of nitrate, nitrite and ammonia present in natural waters in the form of nitrogen are of great interest because of their nutrient levels. NH_3-N, NO_3-N and NO_2-N are considered to be non-cumulative toxins (Dallas & Day, 1993). When present in high concentrations, NO_3-N and NO_2-N may give rise to potential health risks, particularly in pregnant women and bottle-fed infants (Kempster *et al.*, 1997; Kelter *et al.*, 1997; Cotruvo, 1988; Bush & Mayer, 1982). NO_2-N poisoning causes the blue baby syndrome (methaemoglobinaemia). Unconfirmed scientific reports also indicate that livestock can also be affected by nitrite poisoning (Kelter *et al.*, 1997). At elevated concentrations, NO_3-N is also known to result in cyanosis in infants (Comly, 1945). Ammonia is naturally present in surface water and groundwater, and can be produced by the de-amination of organic nitrogen containing compounds. It can also be produced from the hydrolysis of urea. The problem of taste and odour may, however, arise when the NH_3-N level is greater than 2 mg/l. Above 10 mg/l, appreciable amounts of NO_3-N may be produced from NH_3-N under suitable anaerobic conditions (WHO, 1993; Kempster *et al.*, 1997).

The mean concentrations and ranges of these micronutrients are listed in Table 3. Groundwater in both districts had very low concentrations of NO_2-N. NH_3-N concen-trations in the two districts were also generally low, although

Torve (2.09 mg/l) in the Akatsi District and Torvi-ga (1.1 mg/l) in the Ketu District recorded concentrations higher than acceptable limits. The concentrations of NO_3-N in both districts were within acceptable Ghana Water Company Limited (GWCL) limits (0–10 mg/l), although Dekpor Yia (324 mg/l), Deme (57.3 mg/l), Dekpor-Dome (22.2 mg/l), Dorwuime (92.3 mg/l) and Tsiaveme-Lormnava (18 mg/l) in the Ketu District, and Zemutekpakofe (88.3 mg/l), Dagbamatey (56.6 mg/l), Agbaflome (127 mg/l), Ave Havi (475 mg/l) and Torve (313 mg/l) in the Akatsi District recorded concentrations higher than the acceptable limits.

Chloride ion content

Groundwater in the two districts were characterised by low chloride concentra-tions. According to the classification of Dallas & Day (1993), Cl- ions are non-cumulative toxins, an excessive amount of which, if taken over a period of time, can constitute a health hazard (WHO, 1984 and 1993). As can be observed in Tables 1 and 2, the Cl^- levels in the two districts were low, although Torve (992.6 mg/l), Ave-kpedunoe (328 mg/l) and Kpodzi Matsrikasa (367.8 mg/l) in the Akatsi District, and Detokope (1260 mg/l), Zuime (665 mg/l), Blamezado (383 mg/l), Agblekpui (340 mg/l), Dzove (307 mg/l), Dekpor Dome (328 mg/l and 718 mg/l), Dorwuime (347 mg/l) and Tsiaveme-Lormnava (428 mg/l) in the Ketu District recorded concentrations higher than acceptable limits. The box plot (Fig. 8) of the two districts indicates that Akatsi District recorded the minimum chloride ion concen-tration, while Ketu District recorded the maximum chloride ion concentration with a slightly higher median chloride ion concentration.

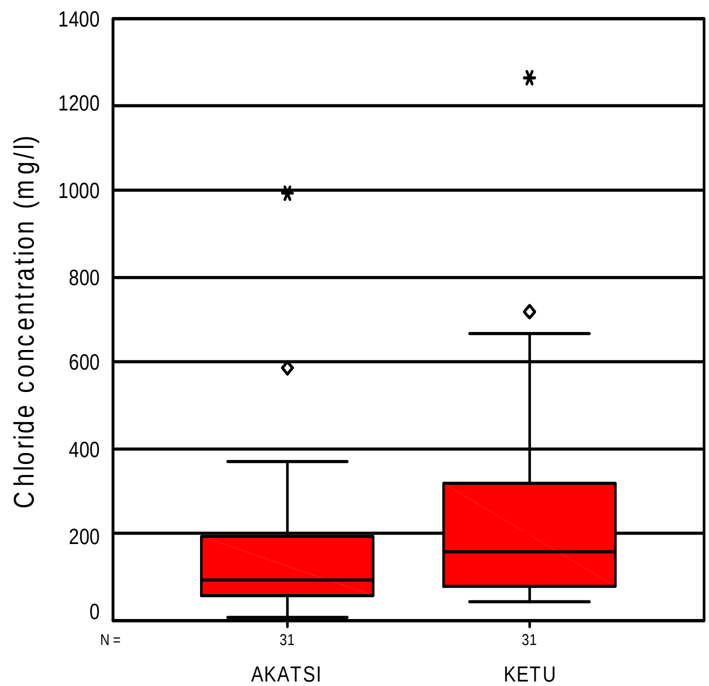


Fig. 8. Variations of chloride (mg/l) in the groundwaters of the Akatsi and Ketu districts

Fluoride ion content

Groundwater in the two districts were characterised by low fluoride ion concentra-tions and fell within WHO and GWCL acceptable limits of drinking and potable water (1.5 mg/l). The Akatsi District recorded fluoride concentrations ranging from 0.04 to 1.3 mg/l with a mean value of 0.28 mg/l whilst boreholes from the Ketu District recorded fluoride concentrations ranging from 0.001 to 1.5 mg/l with a mean value of 0.26 mg/l. The box plot (Fig. 9) of the two districts shows that Ketu District recorded the minimum fluoride ion concentration, while Akatsi District recorded the maximum fluoride ion concentration with a higher median fluoride ion concentration.

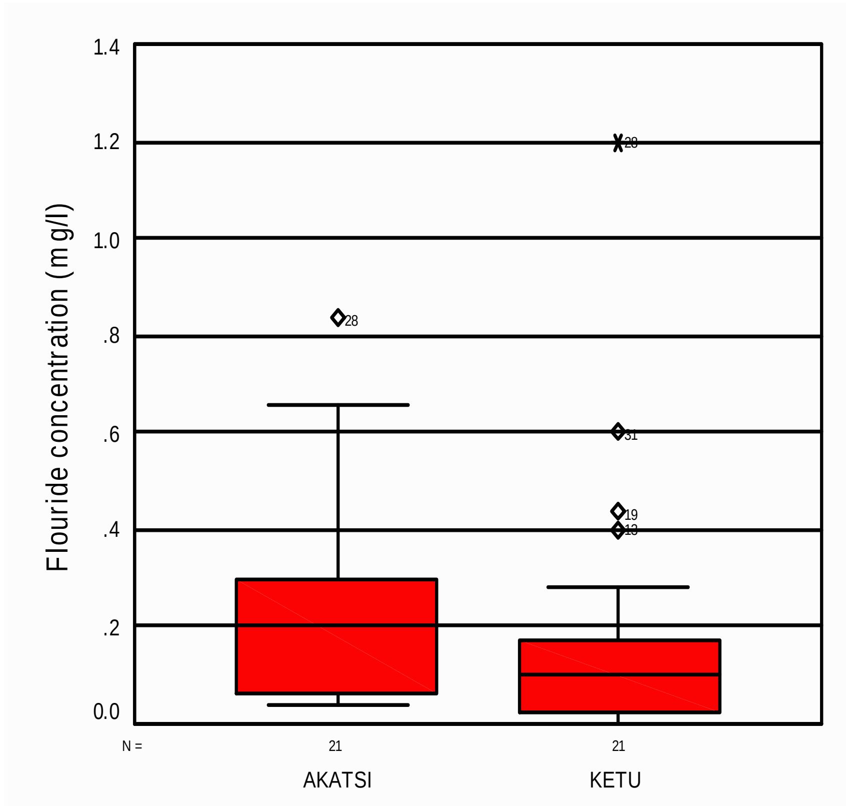


Fig. 9. Variations of fluoride (mg/l) in the groundwaters of the Akatsi and Ketu districts

Sulphate and phosphate contents

Groundwater from the Akatsi District generally had low SO_4^{2}- ion concentrations ranging from 4.38 to 196 mg/l with a mean value of 55 mg/l. Boreholes from the Ketu District also had low concentrations of SO_4^{2}- ions ranging from 12.2 to 920 mg/l with a mean value of 145 mg/l, although Agorvi (920 mg/l) and Dekpor-Dome (768 mg/l) recorded concentrations higher than acceptable limits. The box plot (Fig. 10) of the two districts shows that Akatsi District recorded the minimum sulphate ion concentration, while Ketu District recorded the maximum sulphate ion concentration with a slightly higher median sulphate ion concentration.

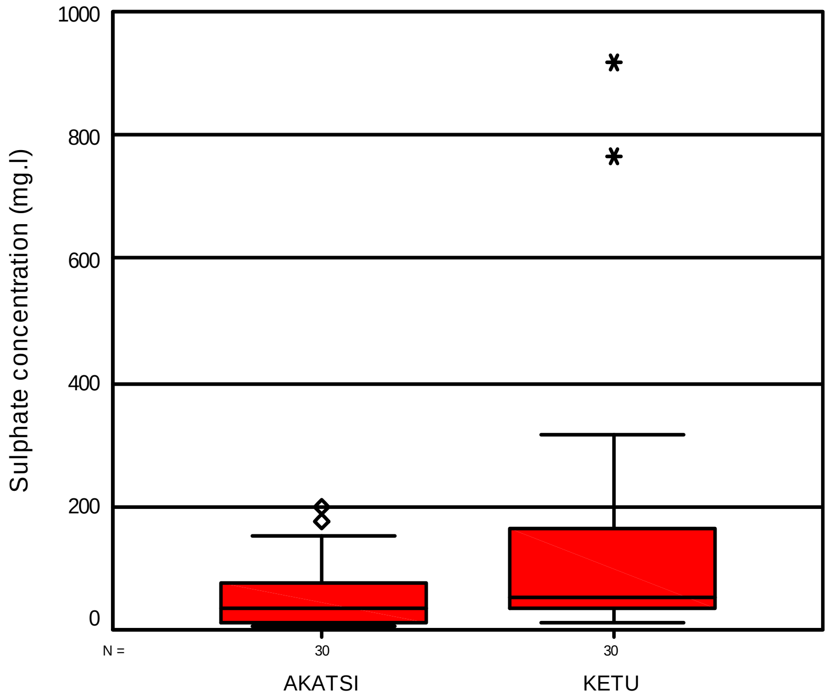


Fig. 10. Variations of sulphate (mg/l) in the groundwaters of the Akatsi and Ketu districts

Phosphate ion concentrations in the Akatsi and Ketu districts were appreciably low and fell within acceptable limits of drinking and potable water. Phosphate levels varied from 0.01 to 0.9 mg/l with a mean value of 0.12 mg/l in the Akatsi District. Boreholes in the Ketu District, however, recorded phosphate concentrations ranging from 0.001 to 0.6 mg/l with a mean value of 0.11 mg/l. The box plot (Fig. 11) of the two districts shows that Ketu District recorded the minimum phosphate ion concentration, while Akatsi District recorded the maximum phosphate ion concentration with a slightly higher median phosphate ion concentration. This could be due to relatively stronger correlations between the ions that constitute the minerals of the aquifer in the Akatsi District.

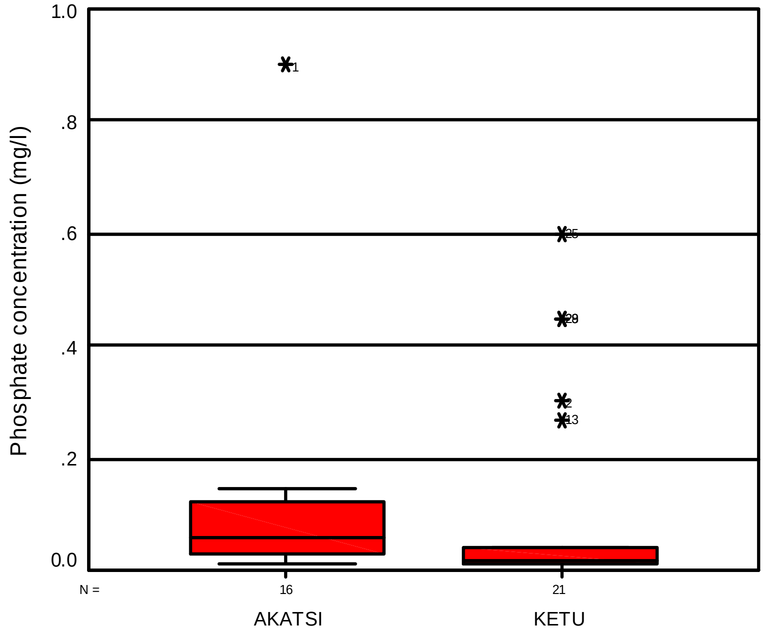


Fig. 11. Variations of phosphate (mg/l) in the groundwaters of the Akatsi and Ketu districts

Sodium ion contents

Groundwater in the Akatsi and Ketu districts had appreciably low sodium ion levels and fell within WHO maximum acceptable limits for drinking and potable water (200 mg/l), although Detokope (600 mg/l), Zuime (291 mg/l), Dekpor-Dome (668 mg/l) and Torve (471 mg/l) in the Akatsi District recorded values higher than the acceptable limits. Tables 1 and 2 show sodium ion levels in the ground waters of the Ketu and Akatsi districts, respectively. The box plot (Fig. 12) of the two districts shows that Akatsi District recorded the minimum sodium ion concentration, while Ketu District recorded the maximum sodium ion concentration with a slightly higher median sodium ion concentration.

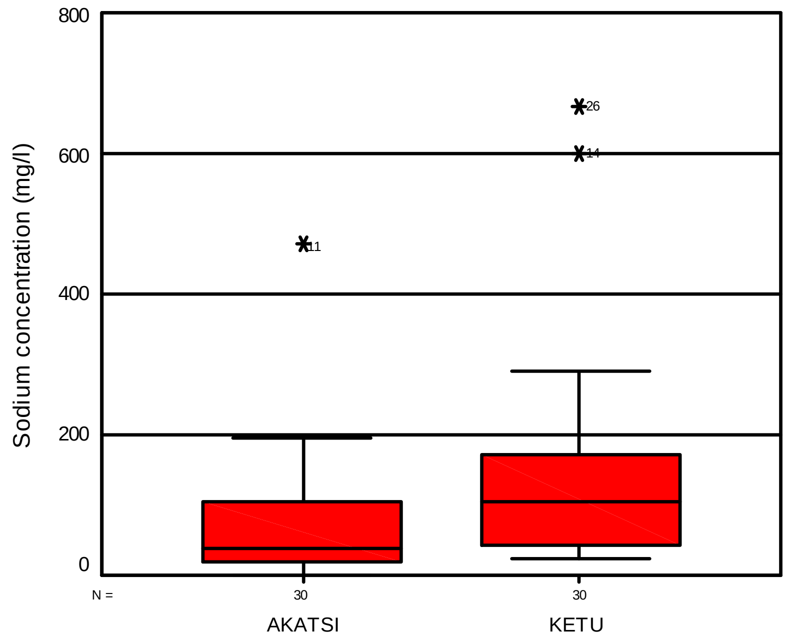


Fig. 12. Variations of sodium (mg/l) in the groundwaters of the Akatsi and Ketu districts.

Potassium ion contents

The Akatsi and Ketu districts had low potassium ion concentrations and fell within WHO maximum acceptable limits for drinking and potable water (30 mg/l) although Dekpor Yia (40.2 mg/l) in the Ketu District recorded values higher than the acceptable limits . Tables 1 and 2 show potassium ion levels in the ground waters of the Ketu and Akatsi districts, respectively. The box plot (Fig. 13) of the two districts shows that boreholes in the Akatsi District recorded the minimum potassium ion concentration, while Ketu District recorded the maximum potassium ion concentration with a slightly higher median potassium ion concentration.

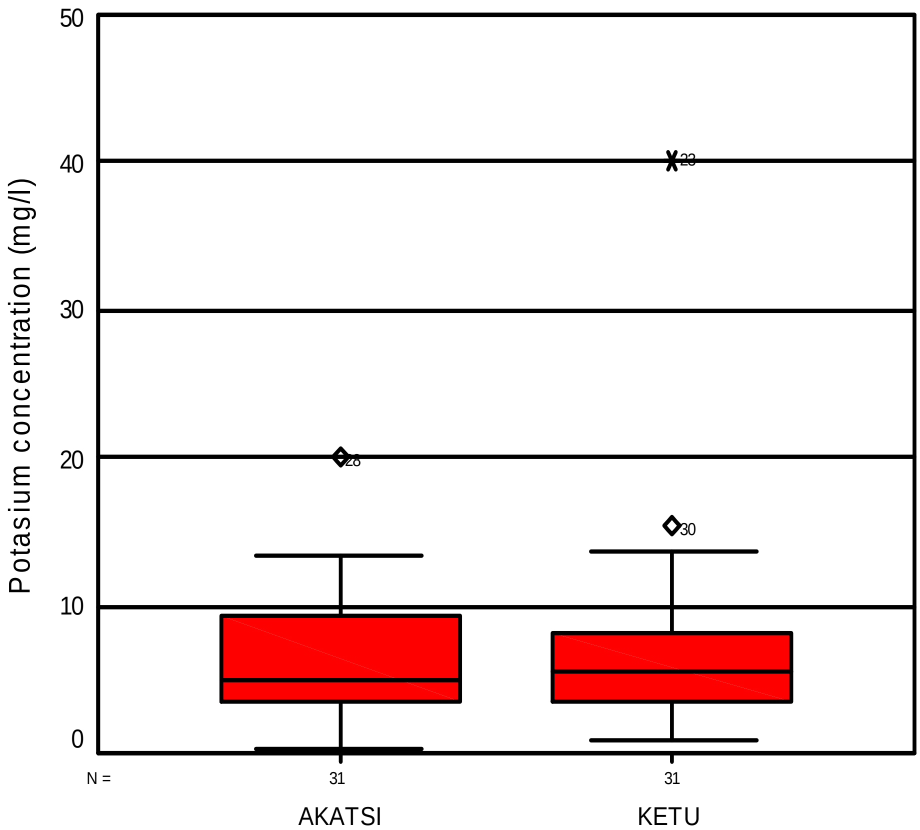


Fig. 13. Variations of potassium (mg/l) in the groundwaters of the Akatsi and Ketu districts

Calcium and magnesium ion contents

No evidence of adverse health effects specifically attributable to calcium and magnesium in drinking water has been established. However, undesirable effects due to the presence of calcium and magnesium in drinking water may result from their ability to render water hard. Groundwater in the Akatsi and Ketu districts were characterised by low calcium ion concentrations and fell within the WHO maximum acceptable limits for drinking and potable water (200 mg/l) although Agorvi (361 mg/l) and Dekpor-Dome (281 mg/l) in the Ketu District, and Torve (246.5 mg/l) in the Akatsi District recorded values higher than the acceptable limits. Calcium concen-trations in the Akatsi District ranged from 12.8 to 246.5 mg/l with a mean value of 79.9 mg/l.

The Ketu District recorded calcium values ranging from 19.2 to 361 mg/l with a mean value of 107.5 mg/l. The box plot (Fig. 14) of the two districts shows that Akatsi District recorded the minimum calcium ion concentration, while Ketu District recorded the maximum calcium ion concentration with a slightly higher median calcium ion concentration.

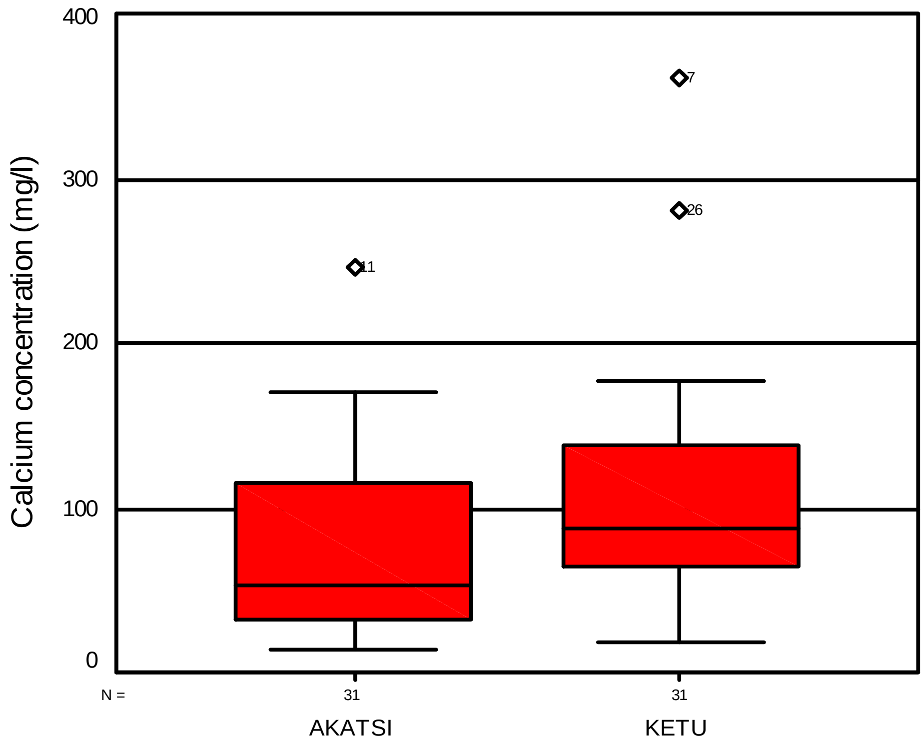


Fig. 14. Variations of calcium (mg/l) in the groundwater's of the Akatsi and Ketu districts

The boreholes in the Akatsi and Ketu districts were also characterised by low magnesium ion concentrations and fell within the WHO maximum acceptable limits for drinking and potable water (150 mg/l), except at Tsiaveme-Lormnava (183 mg/l) in the Ketu District. The box plot (Fig. 15) of the two districts shows that Akatsi District recorded the minimum magnesium ion concentration, while Ketu District recorded the maximum magnesium ion concentration with a slightly higher median magnesium ion concentration.

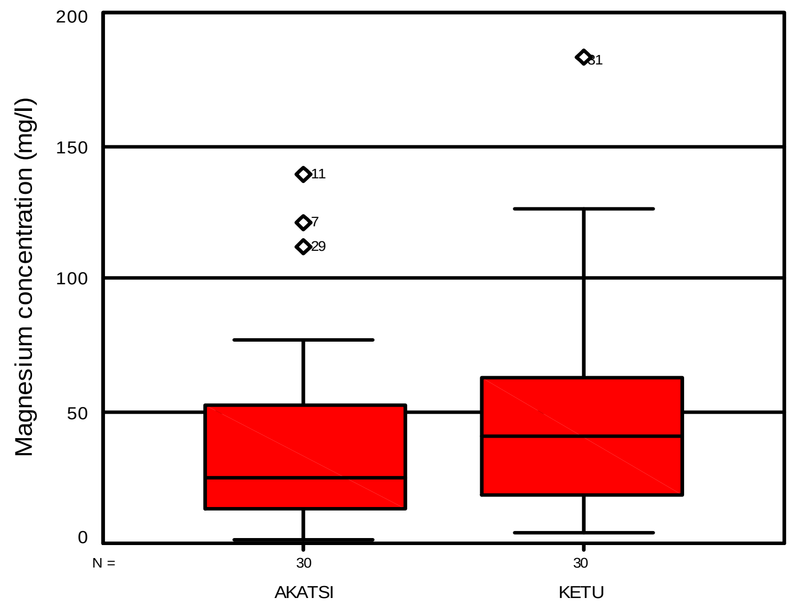


Fig. 15.Variations of magnesium (mg/l) in the groundwaters of the Akatsi and Ketu districts

Iron contents

The groundwater in the Akatsi and Ketu districts were characterised by low iron concentrations and fell within the WHO maximum acceptable limits for potable and domestic water (0.3 mg/l), although Afife (1.51 mg/l), Tsyinu (0.335 mg/l), Kuli (0.387 mg/l), Kpoglu (0.54 mg/l), Gbegbekope (0.69 mg/l), Agblekpui (1.94 mg/l), Adrume (1.68 mg/l), Tadzi (0.39 mg/l), Ativekofe Yiame (0.334 mg/l) in the Ketu District, and Dzuefe Gbodome (3.12 mg/l) and Agbonodo (1.8 mg/l) in the Akatsi District recorded values higher than the acceptable limits. Iron concentrations in the Akatsi District ranged from 0.01 to 3.12 mg/l with a mean value of 0.27 mg/l. Boreholes from the Ketu District recorded iron values ranging from 0.001 to 1.94 mg/l with a mean value of 0.35 mg/l. The box plot (Fig. 16) of the two districts shows that Ketu District recorded the minimum Fe concentration, while Akatsi District recorded the maximum Fe concentration with a higher median Fe concentration.

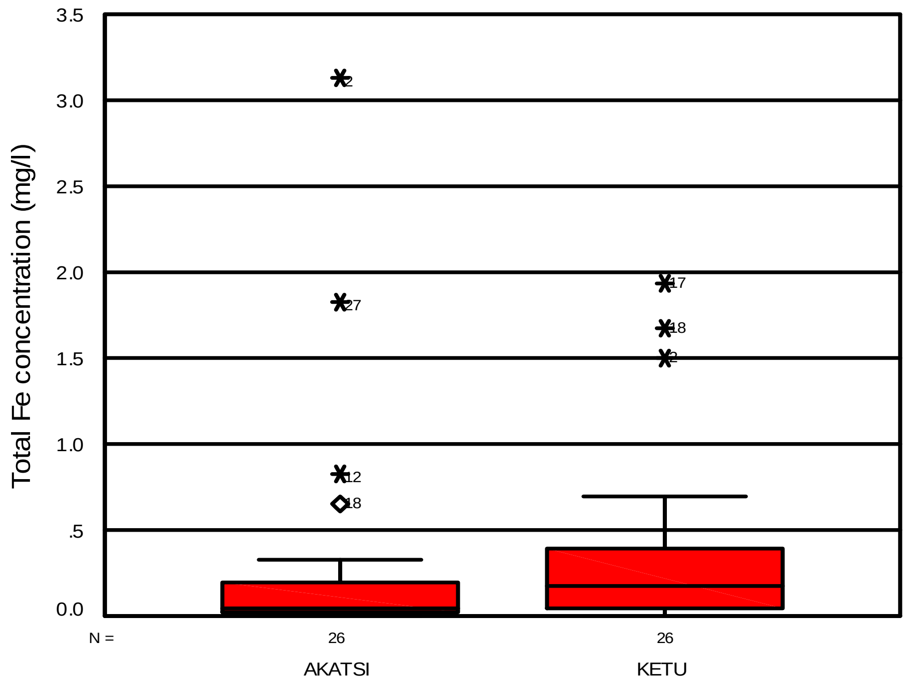
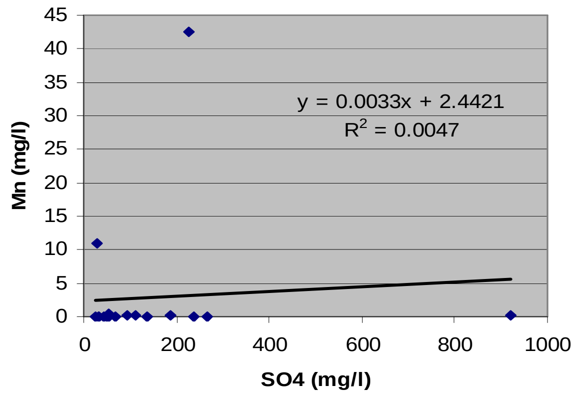


Fig. 16. Variations of iron (mg/l) in the groundwaters of the Akatsi and Ketu districts

Manganese ion contents

Tables 1 and 2 show that the manganese values in the two districts is within the limits of acceptable standards for drinking and domestic water (0.3 mg/l), although Devego (11 mg/l), Tornu Mlianu (0.42 mg/l), Torviga (42.6 mg/l) and Zuime (0.85 mg/l) in the Ketu District, and Agornu Kporklote (1.45 mg/l), Ave Kpedunoe (0.33 mg/l), Ave Atanve (1.56 mg/l) and Agornu Kporklote (1.45 mg/l) in the Akatsi District recorded values higher than the acceptable limits. Boreholes from the Ketu District recorded manganese concentrations ranging from 0.005 to 42.6 mg/l with a mean value of 2.35 mg/l whilst boreholes from the Akatsi District recorded manganese concentrations ranging from 0.01 to 3.0 mg/l with a mean value of 0.33 mg/l.

Correlation analyses between Mn^{2+} and SO_4^{2}-, and Fe^{2+} and SO_4^{2}- for both Akatsi and Ketu districts (Fig. 17a–b and 18a–b) showed a negative correlation between Fe^{2+} and SO_4^{2}- in the Ketu District and a weak positive correlation between Fe^{2+} and SO_4^{2}- in the Akatsi District. The weak positive correlation between Fe^{2+} and SO_4^{2}- in the Akatsi District could be due to the dissolution of the minerals in the aquifer. The low levels Fe^{2+} and SO_4^{2-} in the groundwaters of both districts could be due to reducing conditions within the aquifer. H_2S precipitates forming a more stable iron sulphide (FeS_2). Fe^{2+} and Mn^{2+} can also act as redox couples.



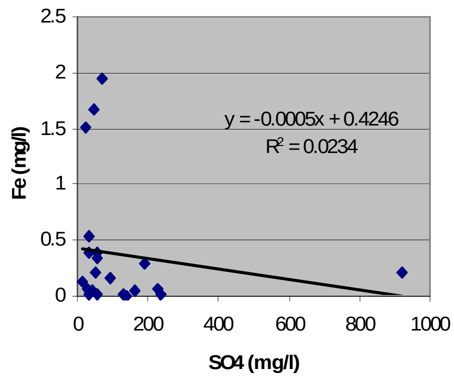
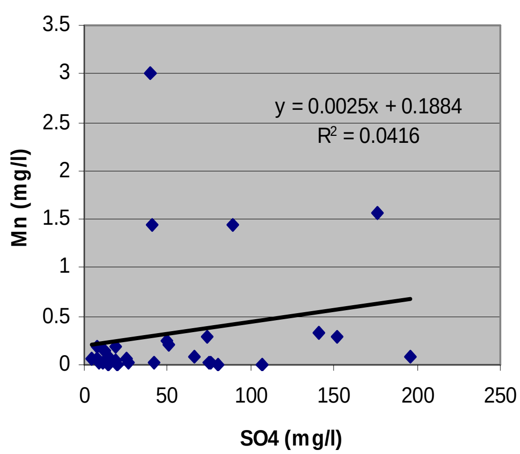


Fig. 17a-b. Scatter plots showing correlations between Mn^{2+} and SO_4^{2-} and Fe^{2+} and SO_4^{2-} in groundwater in the Ketu district



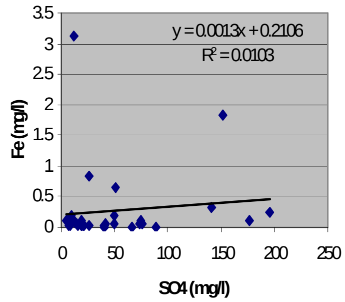
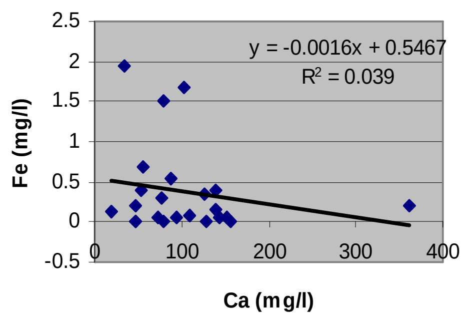


Fig. 18 a-b. Scatter plots showing correlations between Mn^{2+} and SO_4^{2}-, and Fe^{2+} and SO_4^{2}- in groundwater in the Akatsi District

Mn is reduced, Mn $^{4+}$ Mn^{2+} , and Fe is oxidised, Fe^{2+} Fe^{3+}.

Fe^{3+} can precipitate as, for example, in ferryhydrite which can act as a sink for Fe (tot). Another reaction which could possibly govern the concentration of Fe^{2+} is precipitation of siderite ($FeCO_3$). This is not the case for Mn^{2+} and SO_4^{2}-, as magnesium sulphides are much more soluble. Both the Akatsi and Ketu districts showed weak positive correlations between Mn^{2+} and SO_4^{2}-. The positive trend between Mn^{2+} and SO_4^{2}- could be due to dissolution of the minerals in the aquifer.

Correlation analyses between Ca^{2+} and Fe^{2+}, and Ca^{2+} and Mn_4^{2+} for both Akatsi and Ketu districts (Fig. 19a-b and 20a-b) showed a weak positive correlation between Mn and Ca, and a weak negative correlation between Ca and Fe in the Ketu District. On the contrary, the Akatsi District showed a weak negative correlation between Mn and Ca, and a weak positive correlation between Ca and Fe. This could indicate that Fe is replaced by Ca at cation exchange sites, but not Mn in the groundwaters of the Ketu District while Mn is replaced by Ca at the cation exchange sites, but not Fe in the groundwaters of the Akatsi District. The correlation between Mn and Ca in the Ketu District and that between Ca and Fe in the Akatsi District could be due to the dissolution of these minerals within the aquifer.



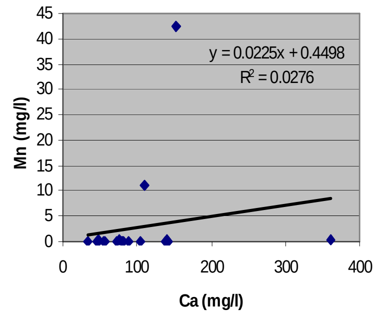


Fig. 19a-b. Scatter plots showing correlations between Ca^{2+} and Fe^{2+}, and Ca^{2+} and Mn_4^{2+} in groundwater in the Ketu District

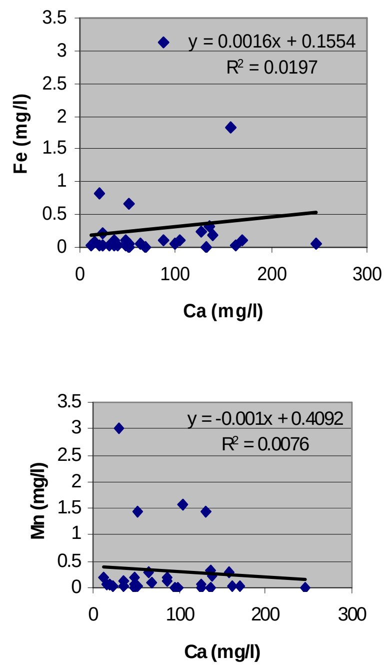
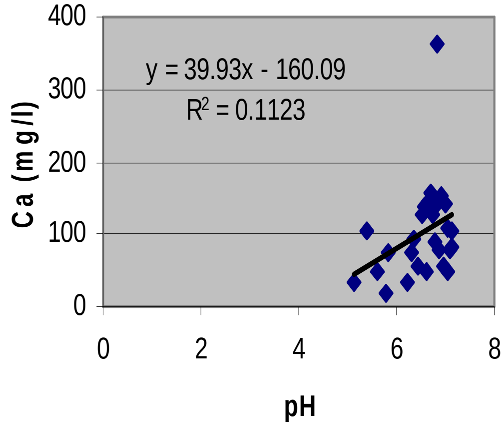


Fig. 20a-b. Scatter plots showing correlations between Ca^{2+} and Fe^{2+}, and Ca^{2+} and Mn_4^{2+} in groundwater in the Akatsi District

Calcium shows positive correlations between *p*H and HCO_3- for both districts (Fig. 21a-b and 22a-b). This could indicate that the origin of Ca in the aquifers of both districts is the presence of $CaCO_3$. Correlation analyses between HCO_3- and other major ions in both districts showed the following R^2 values; 0.0193, 0.2531, 0.0085, 0.0193 for Na, Mg, Mn and K, respectively, in the aquifers of the Ketu District, and 0.0002, 0.5215, 0.2767, 0.4548 for Mn, Na, K and Mg, respectively, in the aquifers of the Akatsi District. Though weak, these values (R^2 values) indicate the presence of minerals containing these cations which contributes to cations in the groundwaters of the two districts.



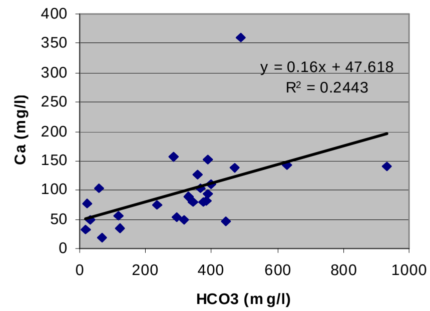
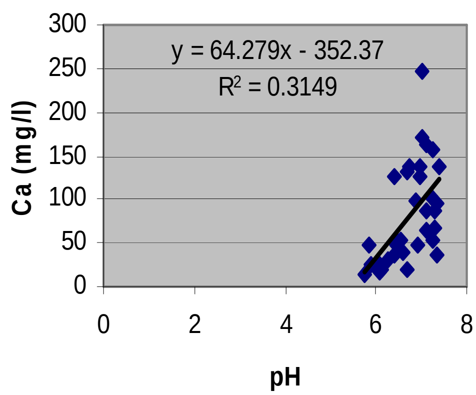


Fig. 21a–b. Scatter plots showing correlations between *p*H and Ca $^{2+}$, and HCO_3^{2-}-and Ca^{2+} in ground-waters in the Ketu District



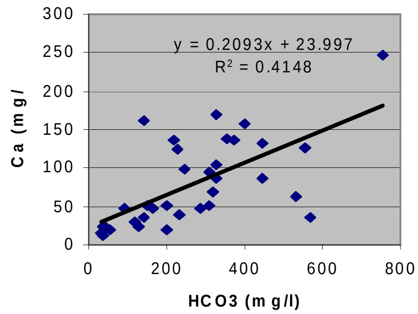


Fig. 22a–b: Scatter plots showing correlations between *p*H and Ca^{2+}, and HCO_3^- and Ca^{2+} in groundwater in the Akatsi District

Conclusion

The study indicates that the groundwaters of the Akatsi and Ketu districts are generally soft and mineralized. Most of the physical and chemical constituents of the ground-waters of the districts were generally within acceptable limits for drinking purposes. However, the concentrations of TDS and NH_3-N in some boreholes in both districts were above the maximum acceptable limits for drinking water. These parameters should be monitored over a period of time because of possible threats to health at elevated concentrations.

SO_4^{2-} and Cl^- ion concentrations in some boreholes in both districts were at such elevated levels that serious health effects and risks might arise after prolonged and continuous intake. The results also showed that NO_3-N concentrations in some boreholes in the two districts were present at elevated levels (above 10 mg/l) and might cause cyanosis in infants. Generally, the Ketu District tended to have higher concentrations of the physico-chemical parameters considered in this study. This could be due to relatively stronger correlations between the ions that constitute the minerals of the aquifer in the Akatsi District.

Acknowledgement

The author gratefully acknowledges the Community Water and Sanitation Agency (CWSA) for providing funds and the efforts of Mr Rex John Sapah and Mr Harrison Komladzei, Principal Draftsmen, CSIR- Water Research Institute, for drawing the map of the study areas.

References

APHA (1998). *Standards Methods for the Examination of Water and Wastewater*, 20th edn. American Public Health Association, Washington, D.C.

Barcelona M., Gibb J. P., Helfrich J. A and **Garske E. E.** (1985). Practical guide for groundwater sampling. *Ilinois State Water Survey ISWS Contract Report 374.*

Bush D. and **Mayer M.** (1982) A case of infantile methemoglobimia in South Dakota. *J. Envir. Hlth* **44**(6): 310–311.

Claasen H. C. (1982). Guidelines and techniques for obtaining water samples that accurately represent the quality of an aquifer. *U.S. Geological Survey Open File Report 82–1024.* 49 pp.

Comly H. H. (1945). Cyanosis in infants by nitrates in well water. *Am. Med. Ass. J.* **129**(2): 112–116.

Cotruvo J. A. (1988). Drinking water standards and risk assessment. *Regul. Toxicol. Pharmacol.* **8**(3): 288.

Dalas H. F. and **Day J. A**. (1993). The effect of Water Quality Variables on River and ecosystem. *Water Research Commission Report No TT 61/93.*

Kempster P. L., Van Vliet H. R. and **Kuhn A.** (1997). The need for guidelines to bridge the gap between ideal drinking-water quality and that quality which is practically available and acceptable. *Water SA* **23**(2): 163–167.

Kelter P. B., Grundman J., Hage D. S. and **Carr J. D.** (1997). A discussion of water pollution in the US and Mexico with High School laboratory activities of lead, anthrazine and nitrate. *Chem. Educ.* **74**(12): 1413–1418.

Stumn W. and **Morgan, J. J.** (1981). *Aquatic Chemistry*. Willey, New York. 780 pp.

Standard Methods (1975). *Standard Methods for the Examination of Water and Wastewater,* 14th edn. American Public Health Association (APHA), Washington DC.

WHO (1984). *Guidelines for Drinking Water Quality – Health Criteria and other Supporting Information.* World Health Organization, Geneva, Switzerland.

WHO (1993) *Guidelines for Drinking Water Quality*. World Healthy Organization, Genava, Switzerland.

Van Der Merwe C. R. (1962). *Soil Groups and Sub-groups of South Africa*. Div. of Chem. Services, Dept. of Agriculture, RSA.