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Water quality status of dugouts from five districts in Northern Ghana: implications for sustainable water resources management in a water stressed tropical savannah environment

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Abstract This study was primarily aimed at investigating the physicochemical and microbial quality of water in 14 such dugouts from five districts in the northern region of Ghana. Results obtained suggest that except for colour, turbidity, total iron and manganese, many physicochemical parameters were either within or close to the World Health Organisation's acceptable limits for drinking water. Generally, colour ranged from 5 to 750 Hz (mean 175 Hz), turbidity from 0.65 to 568 nephelometric turbidity units (NTU; mean 87.9 NTU), total iron from 0.07 to 7.85 mg/L (mean 1.0 mg/L) and manganese from 0.03 to 1.59 mg/L (mean 0.50 mg/L). Coliform counts in water from all the dugouts in both wet and dry seasons were, however, above the recommended limits for drinking water. Total and faecal coliforms ranged from 125 to 68,000 colony forming units (cfu)/100 mL (mean 10,623 cfu/100 mL) and <1 to 19,000 cfu/100 mL (mean 1,310 cfu /100 mL), respectively. The poor microbial quality, as indicated by the analytically significant presence of coliform bacteria in all samples of dugout water, strongly suggests susceptibility and exposure to waterborne diseases of, and consequent health implications on, the many people who continuously patronise these vital water resources throughout the year. In particular, more proactive sustainable water management options, such as introduction to communities of simple but cost-effective purification techniques for water drawn from dugouts for drinking purposes, education and information dissemination to the water users to ensure environmentally hygienic practices around dugouts, may be needed.

Keywords Northern Ghana · Dugouts · Water quality · Coliform bacteria

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Introduction

Most parts of northern Ghana lie within the tropical savannah belt which experiences relatively long dry weather and short but often torrential rainfall characteristic of tropical savannah ecosystems. Because water scarcity is an endemic problem throughout the region, many communities have, for centuries, depended heavily on water stored in dugouts which typically are shallow excavated areas or slightly raised embankments on a portion of land into which rain and/or runoff water collects or is channelled during the rainy season. Water stored in these dugouts is then available for use throughout the year for both domestic, including drinking, and agricultural activity. Because of extensive subsistence farming activities, unhygenienic and unsanitary conditions in and around such dugouts as well as competition for water from livestock, water from such sources are frequently prone to contamination by toxic agrochemicals and pathogenic bacteria often with potentially serious consequences on human and animal health. Waterborne diseases such as cholera, dysentery, infectious hepatitis and guinea worm infestation are therefore commonly reported in these areas especially during periods of scarce water availability.

Even though the Government of Ghana, development partners and various non-governmental organisations (NGOs) have made considerable progress by providing potable water in the form of boreholes and hand-dug wells, dugout water continues to be heavily patronised by many people throughout northern Ghana where, at present, well over 500 such storage dugouts occur. In spite of the extensive patronage and, by implication, its potential threat to human and animal health, very little studies have been devoted to water quality in these dugouts. This paper reports on a study carried out between May 2005 and March 2006 on the water quality status of highly patronised dugouts in the eastern corridor of Northern Ghana and further suggests the implications of the data on sustainable water resources management in a water-stressed rural–urban environment.

Study area and methods

Study area

The northern region of Ghana, with an approximate area of 70,348 km^2, is located between longitudes 5° W and 3° E and latitudes 8° N and 15° N. In terms of surface area, it is by far the biggest region in the whole country. The region is composed of 18 administrative districts with a population of 1,820,806 people (GSS 2002). The region is bounded in the north by the Upper East and Upper West regions, in the west by La Cote D'Ivoire and in the east by the Republic of Togo (Fig. 1). In the south, it shares boundaries with the Brong Ahafo and Volta regions. The main ethnic groups are Dagomba, Nanumba, Mamprusi, Gonja and Komkomba. Others are the Chekosi, Bimoba and Vagla (www.ghanaexpeditions.com). It is estimated that well over 70% of the people in the region are engaged in subsistence agriculture of food and cash crops. Subsistence to small-scale livestock farming is also a major activity due, in part, to the large expanse of low-lying grasslands.

It has a tropical climate which sustains the Guinea Savannah vegetation of grassland, clusters of shrubs, short trees and a sprinkling of big trees like mahogany and baobab. According to Kranjac-Berisavljevic et al. (1999), average annual rainfall varies from 780 to 1,200 mm. The region is influenced by two main climatic conditions, the rainy (wet) season which usually spans from May to October and the dry season from November to April. Temperatures vary between 14°C at night and 40°C during the day. Except for the Gambaga escarpment in the northeastern corner and also along the western corridor, the entire area is mostly low-lying, with an average elevation of 91 m above sea level. The land is drained by rivers Nasia, Daka, Oti and the Black and White Volta. Kwei (1997) reported that the water table generally varies from ground surface to about 45 m below land surface.

To the east, the region is underlain predominantly by the Voltaian rocks consisting mainly of sandstone, shale, mudstone, sandy and pebbly beds and limestone and to the west by the Birimian system of volcano-sedimentary rocks and associated granitoids (Kesse 1985). The Buem Formation which is made up of mafic volcanic rocks, shale, sandstone and jasper also occupies a narrow strip in the eastern portion of the region.

Because the region is exceptionally very large and also has over 500 water dugouts spread across a wide area, it was divided into western and

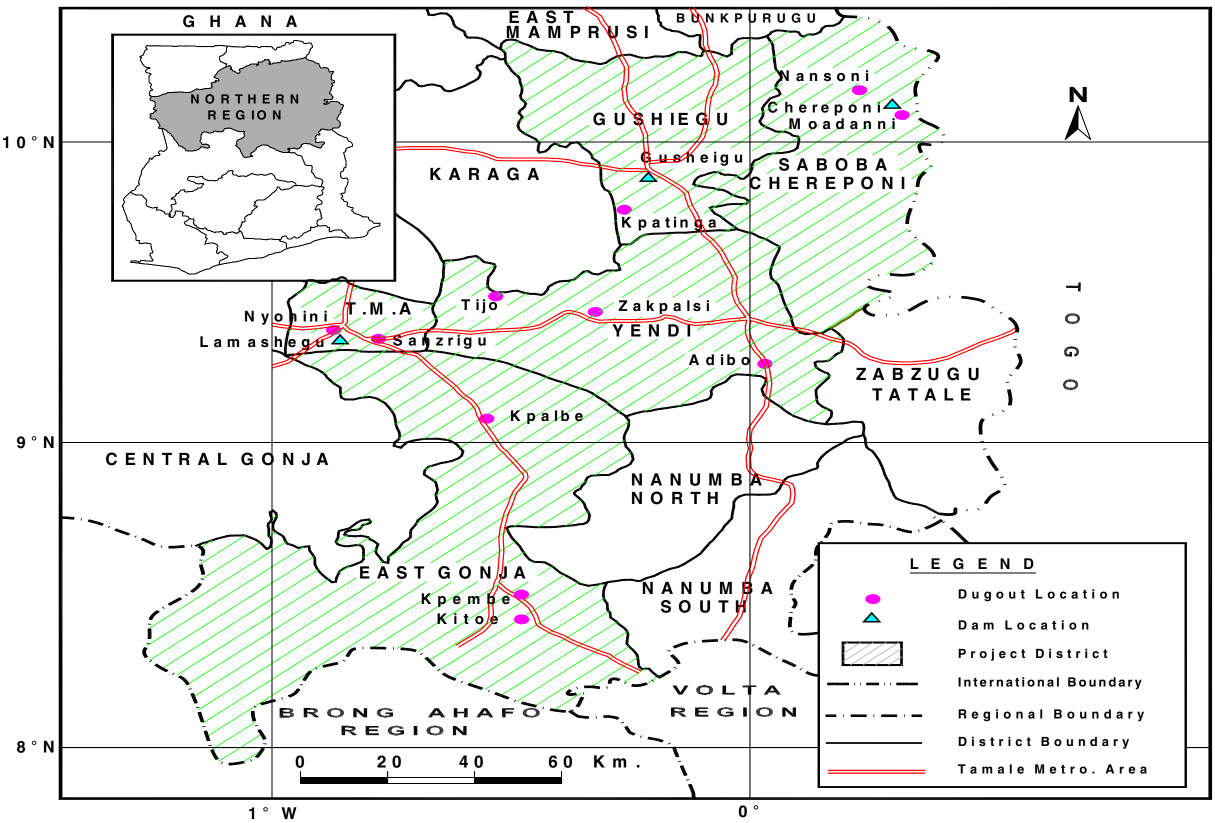

Fig. 1 Map showing sampling locations in the northern region of Ghana

eastern corridors. The latter, much more accessible than the former, was chosen for the study (Fig. 1). Within the eastern corridor, five out of 11 districts were selected for the study based on the estimated sizes of dugouts observed (generally $\geq$ 0.4 ha) in a preliminary survey in the districts and the population of the area. Mean depths of the dugouts could not be estimated, but they appear to exhibit variability both within individual dugouts (i.e. from outer to middle portions) and from one dugout to the other. Fourteen dugouts were randomly selected for the study, three from each of the five districts except for Gushegu where only two dugouts were selected (Table 1).

Water sampling and analysis

Sampling of water in the dugouts was done in the rainy and dry seasons in May and March 2005, respectively. Samples for microbial analyses were collected into sterilised screw-capped glass bottles, whilst those for trace metal analyses were collected into plastic bottles and acidified with drops of nitric acid. Sampling bottles used for the collection of water for chemical analyses were first rinsed with water (i.e. to be sampled) before the samples were collected. In each dugout in both the rainy and dry seasons, samples were collected for physicochemical and microbial analyses. In all, a total of 103 samples were collected during the study period. To ensure that samples were representative of water frequently used by the rural inhabitants, attempts were at all times made to sample from collection points where people usually draw water in the dugouts for domestic and agricultural purposes. All samples were stored at 4°C in ice chests and transported to the laboratory within 6 h. Samples for physicochemical (including trace metal) analyses were kept in a refrigerator until analyses were completed. Total and faecal coliform analyses were, however, done immediately on arrival at the CSIR Water Research laboratory. Each parameter was determined twice and the aver-

Table 1 Data on dugouts used in the study, Northern Ghana

District	Capital	Population	Approx. area (km^2)	Community/ site[a]	Population[b]	Size (ha)[c]
Yendi	Yendi	130,506	4,230	Tijo	996	2.0
				Zakpalsi	2,104	0.6
				Adibo	4,693	1.2
East Gonja	Salaga	174,500	9,351	Kpembe	2,907	1.2
				Kpalbe	17,691	0.5
				Kito	2,696	1.4
Saboba/ Chereponi	Saboba	93,100	3,439	Moadanni	5,663	2.5
				Chereponi	8,696	9.7
				Nansoni	1,877	30.6
Gushegu	Gushegu	125,430	5,761	Gushegu	13,693	4.8
				Kpatinga	3,855	1.0
				Lamashegu	17,127	1.5
Tamale Metropolis	Tamale	293,879	731	Nyohini	21,572	0.4
				Zanzrigu	1,861	0.7

[a]Dugout location/sampling site
[b]According to 2000 census
[c]Approximate size of dugout

age value taken to represent a particular water sample.

Procedures for analyses were based on the Standard Methods for the Examination of Water and Wastewater (APHA 1998). pH and electrical conductivity were determined using potable meters. Visual comparison and turbidimeter were used, respectively, to determine colour and turbidity. Turbidity was measured employing the principle of nephelometry (Sawyer et al. 1994). Silica, fluoride, orthophosphate, nitrate–nitrogen and sulphate contents were analysed using the molybdosilicate, SPADNS, stannous chloride, hydrazine reduction and turbidimetric methods, respectively. Flame emission photometry was used for sodium and potassium whilst EDTA titration was used for calcium and total hardness. Chloride contents were also determined by argentometric titration, but total alkalinity by strong acid titration. Calcium and magnesium hardness, on the other hand, were determined by calculation. Total iron and manganese were also determined using an atomic absorption spectrophotometer. Total and faecal coliform bacteria were determined by membrane filtration technique using M-Endo Agar-Les (Difco) at 37°C and on MFC Agar at 44°C, respectively.

Statistical analysis was performed using SPSS version 10.1 for Windows. One half of the value of the respective limit of detection was substituted for those values below the limit of detection and used in statistical analysis. The Spearman's rank correlation was used to examine correlation between selected parameters; all tests were two-tailed.

Results

Data obtained from the study are presented in Tables 1, 2, 3, 4 and 5. The 14 communities in five administrative districts where samples of dugout water were taken are given in Table 1. The dugouts exhibit variations in size from less than 0.4 to about 30.6 ha. Analyses of physicochemical parameters from all the water samples collected in both the dry and wet (rainy) seasons are given in Tables 2, 3 and 4. Bacteriological results are presented in Table 5.

Physicochemical parameters

Physicochemical parameters of dugout water analysed in the wet season, presented in Table 2, show wide variability in almost all parameters determined. Colour of the water ranges from 50.0 Hz at Kitoe and Moadanni to 750.0 Hz at Sanzrigu. pH similarly varied from about 6.7 at Zakpalsi to 8.6 at Nansoni. The lowest conductivity values were recorded at Zakpalsi (25.6 μS/cm) and the highest at Nyohini (1,494.0 μS/cm), whilst within the same period, minimum and maximum turbidity values of 9.4 nephelometric turbidity units (NTU) and 205 NTU were obtained at Kpatinga and Sanzrigu, respectively.

Table 2 Mean physicochemical parameters measured in dugouts (wet season)

Site	Cond. (µS/cm)	pH (pH units)	T/A	HCO_3	SO_4	Cl	NO_3–N	PO_4	F^-	Ca	Mg	Na	K	SiO_2	T/H	Col	Turb
Kpalbe	43.3	6.97	26.0	31.7	34.90	4.0	1.74	0.076	0.02	7.2	4.4	10.4	2.6	26.1	36.0	625	82.9
Kpembe	30.2	6.77	20.0	24.4	13.4	5.0	0.90	0.030	< 0.10	2.4	3.4	8.2	2.10	17.3	20.0	110	24.1
Kitoe	28.1	7.04	18.0	22.0	11.0	4.0	0.33	0.034	0.10	2.4	4.4	3.2	1.30	16.7	24.0	50.0	11.9
Adibo	26.5	6.75	16.0	19.5	24.1	5.0	1.13	0.054	< 0.10	2.4	2.4	12.1	1.9	27.4	16.0	188	70.4
Tijo	37.2	6.90	24.0	29.3	17.5	5.0	0.56	0.017	0.20	4.8	2.4	1.2	10.1	19.0	22.0	188	36.8
Zakpalsi	25.6	6.69	18.0	22.0	29.0	6.0	2.67	0.051	0.10	3.2	1.0	1.0	18.7	32.7	12.0	188	68.9
Kpatinga	101	6.96	64.0	78.1	9.3	11.0	0.12	< 0.001	0.30	12.0	4.4	1.0	18.7	32.7	12.0	188	9.4
Gushegu	124	7.33	74.0	90.3	11.4	14.0	0.81	0.034	0.30	12.8	7.8	5.6	11.9	12.5	64.0	125	31.0
Moadanni	35.1	6.71	24.0	29.3	13.0	3.0	0.40	0.023	0.09	4.0	1.9	7.0	4.9	19.5	18.0	50.0	16.0
Chereponi	73.8	7.71	42.0	51.2	32.0	7.0	1.40	0.085	< 0.10	8.0	3.9	18.2	3.9	23.9	36.0	100	70.3
Nansoni	102	8.59	62.0	80.5	13.9	5.0	0.70	0.037	0.30	9.6	3.4	15.2	7.5	23.8	38.0	62.5	24.8
Lamashegu	152	7.23	60.0	73.2	38.3	28.0	2.66	0.116	0.10	24.1	2.9	13.1	18.4	21.0	72.0	375	124
Nyohini	1,494	8.07	112	137	75.1	228	10.10	< 0.001	0.40	32.1	54.4	101	9.5	16.9	304	125	13.7
Zanzrigu	50.6	7.36	28.0	34.2	35.0	7.0	4.95	0.228	< 0.10	6.4	4.4	13.1	7.4	40.1	34.0	750	205
WHO limit	–	6.5–8.5	–	–	400	250	10	–	1.5	200	150	200	30	–	500	15	5

Concentration (mg/L), unless otherwise stated

Table 3 Mean physicochemical parameters measured in dugouts (dry season)

Site	Cond. (µS/cm)	pH (pH units)	T/A	HCO_3	SO_4	Cl	NO_3–N	PO_4	F^-	Ca	Mg	Na	K	SiO_2	T/H	Col	Turb
Kpalbe	75.7	7.61	58.0	70.8	8.9	7.0	0.37	< 0.001	0.02	17.6	1.9	10.2	1.3	12.3	52.0	25	19.3
Kpembe	27.9	7.66	14.0	17.1	5.4	6.0	0.16	< 0.001	0.20	3.2	3.9	9.3	1.2	12.1	24.0	15.0	7.6
Kitoe	36.4	7.57	24.0	29.3	10.1	5.0	0.34	< 0.001	0.40	5.6	2.4	8.1	1.3	17.6	24.0	10.0	4.7
Adibo	41.2	7.47	24.0	29.3	10.1	5.0	0.34	< 0.001	0.10	24.0	3.9	9.2	1.3	27.5	22.0	25.0	19.0
Tijo	45.1	6.36	18.0	22.0	64.7	7.9	6.40	0.707	0.10	4.8	1.0	10.5	1.3	24.7	16.0	250	207
Zakpalsi	164	7.36	92.0	112	4.1	7.9	8.70	0.077	0.10	36.1	1.4	21.3	1.2	25.6	96.0	7.5	3.9
Kpatinga	315	6.93	68.0	83.0	6.3	24.8	140	0.162	0.10	15.2	8.7	25.1	1.8	22.8	74.0	5.0	2.8
Gushegu	426	7.81	134	161	7.9	49.6	1.70	0.105	0.20	26.5	15.5	31.4	1.4	13.9	130	5.0	1.7
Moadanni	51.8	7.30	18.0	22.0	3.7	5.0	17.70	0.180	0.20	8.8	2.9	9.2	1.1	18.4	34.0	5.0	2.6
Chereponi	159	8.04	90.0	110	3.9	8.9	3.80	0.083	0.30	26.5	6.8	15.1	1.2	11.7	94.0	5.0	1.6
Nansoni	170	7.98	114	134	3.9	7.9	3.20	0.159	0.40	28.9	7.3	14.1	1.8	23.9	102	5.0	1.3
Lamashegu	410	7.35	100	122	111	73.0	3.33	0.414	< 0.10	24.9	9.2	25.6	1.5	50.5	100	250	531
Nyohini	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Zanzrigu	110	8.06	70.0	85.4	87.9	10.9	5.40	0.558	< 0.10	24.9	2.9	7.3	2.1	51.7	74.0	625	625
WHO limit	–	6.5–8.5	–	–	400	250	10	–	1.5	200	150	200	30	–	500	15	5

Concentration (mg/L), unless otherwise stated

*Dugout got dried up and therefore no sample could be taken

Table 4 Mean Fe and Mn concentrations (mg/L) in dugouts in wet and dry seasons

Site	Wet		Dry	
	Fe	Mn	Fe	Mn
Kpalbe	0.53	0.90	0.37	0.33
Kpembe	0.26	0.13	0.12	0.05
Kito	0.44	0.11	0.11	0.04
Adibo	0.40	0.18	0.28	0.06
Tijo	3.27	0.37	0.36	0.23
Zakpalsi	0.68	0.02	0.30	0.17
Kpatinga	2.58	1.41	0.66	0.43
Gushegu	2.26	0.38	0.65	0.70
Moadanni	0.66	0.36	0.54	0.08
Chereponi	2.39	0.63	0.26	0.22
Nansoni	0.44	0.61	0.31	0.41
Lamashegu	1.85	0.23	7.58	1.46
Nyohini	0.52	0.03	–[a]	–[a]
Zanzrigu	0.48	0.01	3.7	0.13
WHO limit	0.3	0.5	0.3	0.5

[a]Dugout got dried up and therefore no sample could be taken

The chemical parameters Ca, Mg, Na, K, SiO_2, Cl, SO_4, and HCO_3 also show wide variations in concentration. A low value of 2.40 mg/L was obtained for Ca at three sites (Kpembe, Kitoe and Adibo) and a high of 32.10 mg/L at Nyohini. Both Mg and Na recorded low values of 1.00 mg/L at Zakpalsi and highs of 54.40 and 101.00 mg/L, respectively, at Nyohini. Potassium (K) concentrations in water ranged from 1.30 mg/L at Kitoe to 18.70 mg/L at Zakpalsi. SiO_2 values varied from 12.50 mg/L at Gushiegu to 40.10 mg/L at Sanzrigu, Cl from 3.00 mg/L at Moadanni to 228.00 mg/L at Nyohini, SO_4 from 9.30 mg/L at Kpatinga to 75.10 mg/L at Nyohini and HCO_3 from 19.50 mg/L at Adibo to 137.00 mg/L at Nyohini. Values for NO_3–N (0.12 mg/L at Kpatinga and 10.10 mg/L at Nyohini), PO_4 ($<$0.001 mg/L at Nyohini and 0.228 mg/L at Sanzrigu) and F ($<$0.10 and 0.40 mg/L at Nyohini) were also obtained (Table 2). Total alkalinity, total hardness, Ca hardness and Mg hardness also showed considerable variations. For example, total alkalinity ranged from a low of 16.0 mg/L at Adibo to 112 mg/L at Nyohini; total hardness from 12.0 mg/L at Zakpalsi to 304 mg/L at Nyohini; Ca hardness from 6.0 mg/L at three sites (Kpembe, Kitoe and Adibo) to 80.2 mg/L at Nyohini and Mg hardness from 4.0 mg/L at Zakpalsi to 31.9 mg/L at Gushiegu. Except for Fe and Mn, the concentrations of other trace metals analysed were very low.

Dry season values of physicochemical parameters in dugout water samples similarly show considerable variability (Table 3). Five sampling sites (i.e. Kpatinga, Gushiegu, Moadanni, Chireponi and Nansoni) had the lowest values of water colour, i.e. 5.0 Hz, whilst Sanzrigu had the highest, i.e. 625 Hz. The following range in values were also obtained for pH, conductivity, turbidity and the chemical parameters Ca, Mg, Na, K, SiO_2, Cl, SO_4, HCO_3 at the respective localities; pH 6.36 (Tijo) to 8.06 (Sanzrigu), conductivity 27.9 μS/cm (Kpembe) to 426.0 μS/cm (Gushiegu), turbidity 1.3 NTU (Nansoni) to 531.0 NTU (Lamashegu), Ca 3.20 mg/L (Kpembe) to 36.1 mg/L (Zakpalsi), Mg 1.00 mg/L (Tijo) to 15.50 mg/L (Gushiegu), Na 7.30 mg/L (Sanzrigu) to 31.4 mg/L (Gushiegu), K 1.10 mg/L (Moadanni) to 2.10 mg/L (Sanzrigu), SiO_2 12.10 mg/L (Kpembe) to 51.70 mg/L (Sanzrigu), Cl 5.0 mg/L (Kitoe, Adibo and Moadanni) to 73.0 mg/L (Lamashegu), SO_4 3.70 mg/L (Moadanni) to 111 mg/L (Lamashegu) and HCO_3 17.1 mg/L (Kpembe) to 161 mg/L (Gushiegu). In the same period, NO_3–N recorded a minimum of 0.16 mg/L (Kpembe) and maximum of 140 mg/L (Kpatinga). Total alkalinity (14 mg/L

Table 5 Coliform bacteria counts (cfu/100 mL) during wet and dry seasons

Site	Wet season		Dry season	
	Total coli.	Faecal coli.	Total coli.	Faecal coli.
Kpalbe	7,000	700	2,750	238
Kpembe	5,900	150	1,013	122
Kito	13,000	500	1,132	214
Adibo	9,300	200	2,160	143
Tijo	1,500	700	11,864	4,500
Zakpalsi	3,700	1,550	11,345	1,000
Kpatinga	4,400	3,450	11,621	6,720
Gushegu	6,200	1,650	11,942	2,000
Moadanni	6,250	105	1,600	860
Chereponi	16,950	763	1,760	500
Nansoni	11,700	137	125	55
Lamashegu	21,000	1,400	1,860	900
Nyohini	14,550	4,000	–[a]	–[a]
Zanzrigu	9,550	771	1,258	7
WHO limit	0	0	0	0

[a]Dugout got dried up therefore no sample could be taken

Table 6 Correlation coefficients for the analysed physicochemical parameters (dry season and wet season)

	Dry season															
	Cond	pH	T/A	HCO_3	SO_4	Cl	NO_3–N	Ca	Na	T/hard	Col	Turb	T/Coli	F/Coli	T/Fe	Mn
Cond		0.071	*0.887*	*0.887*	−0.052	*0.850*	0.432	*0.711*	*0.809*	*0.895*	−0.337	−0.291	0.396	0.418	0.659	*0.879*
pH	*0.780*		0.388	0.388	−0.127	0.122	−0.437	0.438	−0.179	0.394	−0.071	−0.319	−0.473	−0.681	−0.181	−0.104
T/A	*0.960*	*0.729*		*0.999*	−0.022	*0.716*	0.135	*0.892*	**0.651**	*0.938*	−0.273	−0.342	0.176	0.091	0.388	*0.694*
HCO_3	*0.965*	*0.764*	*0.996*		−0.022	*0.716*	0.135	*0.892*	**0.651**	*0.938*	−0.273	−0.342	0.176	0.091	0.388	*0.694*
SO_4	0.288	0.319	0.154	0.174		0.262	−0.218	−0.214	−0.131	−0.231	*0.846*	*0.851*	0.220	0.041	0.342	0.113
Cl	*0.702*	0.474	*0.694*	*0.670*	0.379		0.367	0.474	*0.723*	*0.705*	0.003	0.033	0.394	0.417	**0.678**	*0.817*
NO_3–N	0.196	0.248	0.123	0.141	*0.912*	0.466		0.185	0.269	0.194	−0.223	−0.127	0.360	**0.580**	0.520	0.330
Ca	*0.960*	*0.673*	*0.951*	*0.947*	0.329	*0.745*	0.254		0.469	*0.822*	−0.280	−0.405	0.099	−0.052	0.193	0.444
Na	**0.628**	*0.714*	**0.541**	**0.561**	**0.555**	0.435	0.436	**0.544**		**0.679**	−0.385	−0.256	**0.564**	**0.644**	0.338	*0.828*
T/hard	*0.957*	*0.783*	*0.917*	*0.913*	0.224	*0.680*	0.150	*0.924*	**0.570**		−0.418	−0.455	0.066	0.091	0.419	**0.680**
Col	0.046	−0.031	−0.044	−0.049	*0.699*	0.293	*0.708*	0.120	0.075	0.027		*0.952*	0.001	−0.201	0.187	−0.145
Turb	−0.240	0.055	−0.159	−0.137	*0.666*	0.100	*0.622*	0.011	0.200	−0.095	*0.825*		0.154	0.033	0.275	−0.055
T/Coli	0.455	*0.675*	0.284	0.315	0.486	0.258	0.358	0.360	*0.744*	0.491	−0.038	0.213		*0.846*	0.368	0.500
F/Coli	0.502	0.266	**0.570**	0.521	0.284	*0.847*	0.403	**0.639**	0.125	**0.565**	0.346	0.007	0.015		0.357	0.489
T/Fe	0.301	0.117	0.354	0.316	0.090	0.388	0.009	0.391	−0.093	0.220	0.302	0.253	−0.211	0.502		*0.687*
Mn	0.292	0.226	0.385	0.372	−0.112	0.013	−0.204	0.351	0.163	0.251	0.084	0.231	−0.138	0.079	0.559	

Bold—correlation significant at the 0.05 level; Italics—correlation significant at the 0.01 level at Kpembe and 134 mg/L at Gushiegu), total hardness (16 mg/L at Tijo and 130 mg/L at Gushiegu), Ca hardness (6.0 mg/L at Adibo and 90.2 mg/L at Zakpalsi) and Mg hardness (4.0 mg/L at Tijo and 63.9 mg/L at Gushiegu) were also obtained. A characteristically high Fe value of 7.58 mg/L was obtained in the water sample from Lamashegu, at which same site Mn also recorded a value of 1.46 mg/L (Table 4), probably reflecting the underlying geology of Fe/Mn-rich rocks

Bacteriological parameters

Total and faecal coliform data from dugout water at various localities in the wet and dry seasons are also presented in Table 5. It is seen that total coliform values from water in the wet season vary from 1,500 colony forming units (cfu)/100 mL at Tijo to 21,000 cfu/100 mL at Lamashegu whilst those of the dry season vary from 125 cfu/100 mL at Nansoni to 11,942 cfu/100 mL at Gushiegu. Faecal coliforms also vary from 105 cfu/100 mL at Moadanni to 4,000 cfu/100 mL at Nyohini in the wet season and 55 cfu/100 mL at Nansoni to 6,720 cfu/100 mL at Kpatinga.

Correlation coefficients

Table 6, which gives the correlation coefficients between analysed parameters, suggests moderate to strongly positive relationships between parameters such as conductivity and total alkalinity, HCO_3, Cl, Ca, Na, total hardness, total iron and Mn in dry season dugout water. In the wet season, conductivity correlates strongly with pH and most of the parameters indicated, but not total iron and Mn. pH negatively correlates with faecal coliforms in the dry season ($r = 0.681$), but positively with total alkalinity, HCO_3, Ca, Na, total hardness and total coliforms in the wet season (Table 6). Total alkalinity values of dry season dugout water also correlate positively with HCO_3, Cl, Ca, Na, total hardness and Mn. In the wet season, they again correlate with almost all these parameters as well as faecal coliforms, but not Mn. Except for a moderately negative correlation between pH and faecal coliforms, dry season pH of water did not show much discernible relationship with most of the parameters analysed. In the wet season, however, pH correlated positively with total alkalinity, HCO_3, Ca, Na, total hardness and total coliform values. Other interesting relationships, mainly positive correlations, occur between analysed parameters in both the dry and wet seasons (Table 6). For example, there are possible associations of total iron with conductivity, Cl and Mn in the dry season water but none whatsoever with any of the analysed parameters in the wet season. Mn of water in the dry season similarly correlates positively with conductivity, total alkalinity, HCO_3, Cl, Na, total hardness and total iron, but no such relationship with these or any of the other parameters in the wet season. Again, total coliforms in water taken during the dry season exhibited positive correlations with faecal coliforms and Na, but in the wet season with pH in addition to Na and faecal coliforms. Dry season faecal coliform contents in water correlates negatively with pH but positively with NO_3–N, Na and total coliforms whereas in the wet season, they rather correlate positively with total alkalinity, Cl, Ca and total hardness (Table 6).

Discussion

Apart from colour and turbidity, many physicochemical parameters obtained from the dugout water fell within the World Health Organisation's (WHO) recommended values for potable water. Increased colour and turbidity levels irrespective of the location and/or season, but particularly in the wet season (Figs. 2 and 3), have undesirable effect on the aesthetic quality of the water. In the wet season, influx of dissolved and suspended particles through runoff from increased precipitation likely influenced the colour and turbid nature of dugout water (Figs. 2 and 3). In the dry season, however, inadequate mixing or flow, stagnation and increased biogenic activity may have contributed to the observed colour and turbidity levels. In addition, herds of cattle frequently wade into and muddy pools of dugout water in their search for water under the intense heat of the savannah environment. Turbid water, in particular, may contain suspended and colloidal matter with the tendency to accommodate disease-causing microscopic organisms. High turbidity might also

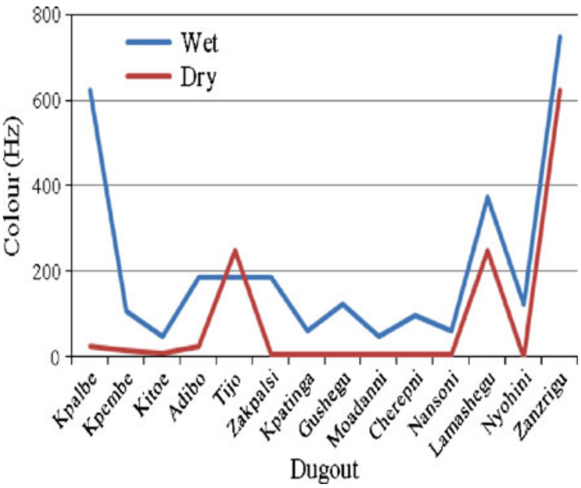

Fig. 2 Seasonal variation of colour

affect growth of aquatic organisms in the dugouts. Biological activities such as the growth of phytoplankton in the dugouts probably contributed to the high turbidity recorded.

Mean nitrate–nitrogen (NO_3–N) concentrations of dugout water were generally low, but at Kpatinga and Moadanni, values obtained in water sampled in the dry season could be a source of concern since they were higher than the WHO limit of 10 mg/L (Table 3). High NO_3–N may have emanated from human and animal waste or through runoff from nearby fertiliser-laden agricultural fields. The scarcity of water in the study area, especially during the dry season, drives livestock to any available water body.

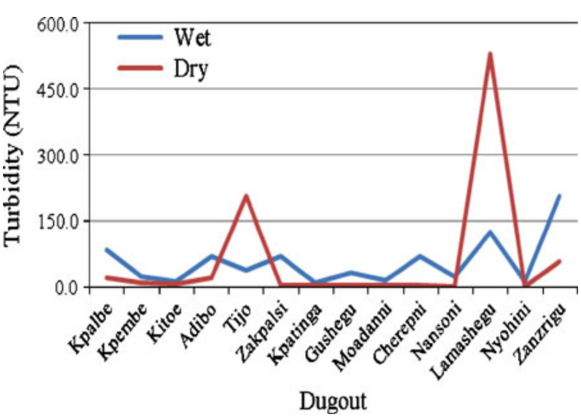

Fig. 3 Seasonal variation of turbidity

In the process of drinking from these dugouts, animal droppings are released into them, thus polluting the water. Application of nitrate-rich fertilisers could also be likely sources of nitrate in dugout water. NO_3–N at elevated concentrations may cause cyanosis or asphyxia in infants (Karikari et al. 2007; WHO 2003). An increase in the risk of acquiring non-Hodgkin's lymphoma has been found for persons consuming drinking water with high nitrate (Baird 1999). The moderately positive correlation between NO_3–N and faecal coliform ($r = +0.580$, $p < 0.05$) in dry season dugout water (Table 6) suggests a common source. In the wet season, water from Nyohini also recorded a mean NO_3–N concentration (10.10 mg/L) slightly above the WHO recommended value. PO_4–P concentrations recorded during the study were generally low except in water from Tijo (0.707 mg/L), Lamashagu (0.414 mg/L) and Zanzrigu (0.558 mg/L) where high PO_4–P were recorded during the dry season (Table 3). The presence of phosphorous is the limiting nutrient for algal growth in water bodies. Phosphorus in most natural surface waters range from 0.005 to 0.020 mg/L PO_4–P (Chapman 1992). High phosphate in water may lead to eutrophication of the water body. According to Rast and Thornton (1996), eutrophication-related problems in warm water systems begin at P concentrations of the order 0.34–0.70 mg/L, suggesting similar eutrophication in dry season dugout water at these localities.

Total iron concentrations in water at many of the localities sampled were above the WHO limit (see Table 4). In the wet season, 13 out of the 14 sites recorded values above 0.3 mg/L, probably reflecting more input of dissolved Fe in runoff or increased dissolution of Fe-bearing minerals in rocks and soils of the area. Nearly half of the sampling sites also recorded mean Fe values above WHO levels in the dry season. Except for two sites, however (i.e. Lamashegu and Zanzrigu), wet season dugout water had comparatively higher mean Fe values than the dry season (Fig. 4). Some localities, e.g. Kpatinga and Lamashegu, also recorded fairly high mean Mn compared to WHO values (Table 4). The high total iron and manganese contents were likely sourced through weathering, erosion and/or dissolution of the

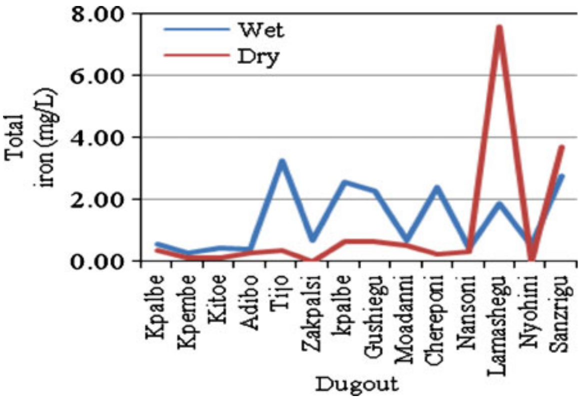

Fig. 4 Seasonal variation of mean total iron

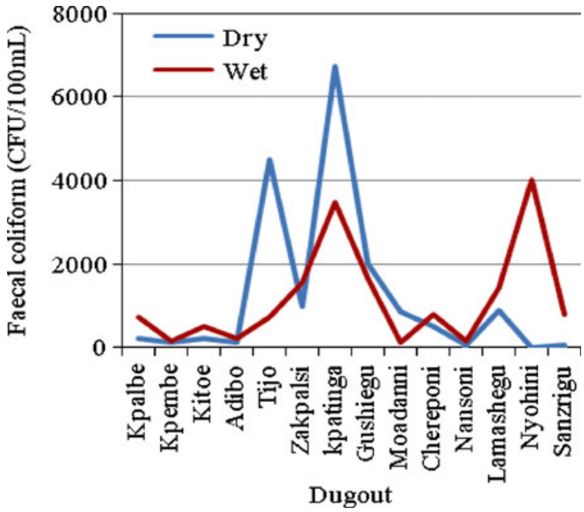

Fig. 6 Seasonal variation of mean faecal coliform bacteria

underlying Birimian rocks (and derived soils). Mn concentration were generally higher in the wet season than in the dry, a trend that was also exhibited by Fe (Fig. 5). Birimian rocks are known to host Fe- and Mn-bearing minerals (Kesse 1985; Obiri 2007).

The most important observation concerns the unacceptably high contents of coliform bacteria, both total and faecal, in dugout water irrespective of the locality or season. Samples from all dugouts contained coliform bacteria well above the WHO recommended limit 0 cfu/100 mL (WHO 2006). It was observed that coliform bacteria recorded during the study were generally high in wet than in dry season water samples (Figs. 6 and 7), suggesting the impact of runoffs on the quality of water in the dugouts. The presence of coliform bacteria, an indication of microbial contamination of water in the dugouts (Grabow 1996), renders the water unwholesome for domestic use without some form of treatment. High total and faecal coliform bacteria recorded may have resulted from the disposal of both human and animal waste near or into dugouts by local communities or cattle that compete for dugout water with people.

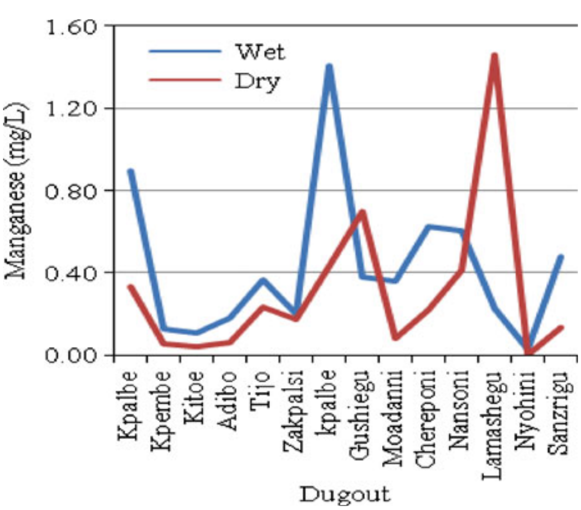

Fig. 5 Seasonal variation of mean manganese

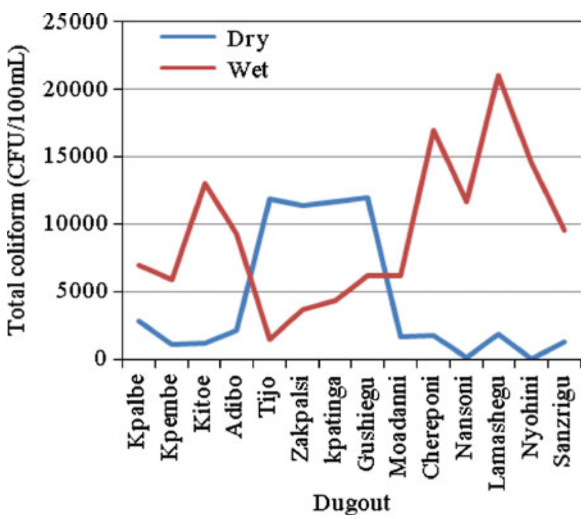

Fig. 7 Seasonal variation of mean total coliform bacteria

Table 7 Prevalence of waterborne diseases in the study districts

District	Disease	Year				
		2003	2004	2005	2006	2007
East Gonja	Diarrhoea	3,029	3,189	45,575	1,111	1,354
	Typhoid fever	124	20	9,845	49	55
	Intestinal worms	509	361	9,311	348	626
	Bilhazia	6	6	153	1	10
Yendi	Diarrhoea	7,129	7,820	9,122	5,936	6,088
	Typhoid fever	208	1,694	682	320	271
	Intestinal worms	941	1,055	651	534	580
	Bilhazia	2	8	0	0	5
Saboba/Chereponi	Diarrhoea	–	4,577	6,589	1,100	899
	Typhoid fever	–	3,273	7,486	15,686	1,715
	Intestinal worms	–	1,205	1,905	238	193
	Bilhazia	–	6	1	3	0
Gushegu	Diarrhoea	2,384	1,556	1,714	914	1,194
	Typhoid fever	65	28	105	33	13
	Intestinal worms	559	636	122	40	30
	Bilhazia	3	5	1	0	0
Tamale	Diarrhoea	3,590	3,385	4,920	5,459	3,709
	Typhoid fever	285	618	697	440	414
	Intestinal worms	1,954	2,094	2,491	2,827	2,783
	Bilhazia	59	104	82	71	41

Source: Regional Biostats Office (northern region)

Together with the extent of patronage, the coliform levels in dugout water present important challenges to water resources management in the areas studied and indeed in the entire northern part of the country. The direct public health impact, and possible socioeconomic effects that may result from ingesting coliform-infested water, may be far more disastrous on an already vulnerable and predominantly poor population. Data sourced from the Regional Health/Biostas Office on disease prevalence indicates that diseases such as diarrhoea, typhoid fever and intestinal worm infestations are commonly recorded (Table 7) throughout the districts where the study was undertaken. Though the data are not segmented into disease versus seasonal occurrence, it does provide useful information on a possible linkage between water quality and disease prevalence since many of the inhabitants in the districts depend largely on dugout water throughout the year.

Conclusion

Data obtained from a study of water in dugouts in northern Ghana suggests rather fair physicochemical but unacceptably poor bacteriological qualities, respectively, of dugout water. Even though data at present may not allow concrete deductions to be made, it would nevertheless be interesting to investigate the relationship between dugout water patronage and public health impact. The extensive patronage of dugout water, the presence of coliform bacteria in all water samples irrespective of the location or season suggests exposure, and hence high vulnerability, of the water users or people to pathogenic bacteria that could cause gastro-enteric and other diseases. These observations suggest the urgent need for policy direction or restructuring, at least to take into consideration efforts by stakeholders concerned with water delivery, i.e. national and local governments, development partners and NGOs to prioritise and make available to the communities simple but cost-effective purification techniques for water drawn from dugouts for drinking purposes. In addition, education, training and dissemination of basic but relevant information to people in the areas would create the necessary awareness in the populace on the need to ensure environmentally hygienic practices around dugouts. These could, in the long term, not only help minimise but greatly prevent outbreaks of otherwise preventable waterborne diseases, reduce overall socioeconomic cost and detrimental health impacts on already vulnerable populations. Finally, it would be helpful if continuous monitoring of dugout water quality could form an important part of water management strategies in the entire northern Ghana since the perennial water scarcity obviously serves as an incentive to patronise whatever source of water available especially for many poor inhabitants. Among others, buffer zones could be created around dugouts, which will be off limits to farming and domestic chores such as washing and bathing. In addition, creating separate dugouts for livestock could help minimise possibilities of faecal pollution.

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