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Assessment of dry season surface, ground, and treated water quality in the Cape Coast municipality of Ghana

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Abstract This aim of this monitoring was to assess water quality in a dry season for the Cape Coast municipality in Ghana, which has been experiencing chronic water shortages. Fifteen different sampling stations—four surface, five ground, and six tap water samples—were analyzed for physicochemical and microbiological parameters during January to April 2005. Levels or trends in water quality that may be deleterious to sensitive water uses, including drinking, irrigation, and livestock watering have been noted with reference to well-established guidelines. Exceedances to some health-based drinking water guidelines included positive coliform for various water samples; pH for all groundwater samples (pH 5.9 ± 0.3); conductivity for 50% groundwater; color for about a third of groundwater and tap water; Mn for 44% tap water, 67% groundwater, and 50% surface water samples. The World Health Organization laundry staining Fe guideline of 0.3 mg/l was exceeded by 75% of surface water, 44% tap water, and 53% groundwater samples. The corresponding Mn guideline of 0.1 mg/l was exceeded by all the water samples. Respectively, all surface water samples and also 75% of the surface water exceeded some known Cu and Zn guideline for the protection of aquatic life. Compared to some historic data for Fosu Lagoon, the current study shows a lowering of ~1 pH unit, increase of ~65% NH_3, one to two orders of magnitude increase in PO_4^{3-}, and more than two orders of magnitude increase in NO_3^-. In several instances, tap water samples collected at the consumers' end of the distribution system did not reflect on the true quality of the treated water. Mn, SO_4^{2-}, PO_4^{3-}, Cu, and Zn were among the chemical contaminations observed to occur in the distribution system.

Keywords Water quality · Dry season · Contaminants · Tap · Surface and groundwater · Ghana

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Introduction

The Cape Coast municipality (in Ghana) over the past few decades has been experiencing water shortages during the dry seasons and often leads to premature closure of schools in the area (Dodoo et al. 2006; Amamoo-Otchere and

Akuetteh 2005). Although a relatively high fraction of households have access to pipe-borne water, the capacity of the Brimsu dam which serves the municipality (as well as other surrounding communities) had fallen considerably and has been inadequate for the rising population in the area. In the heightened water shortage situations, both raw ground and surface waters are heavily depended upon for domestic and/or agricultural uses. Due to poor or non-existing waste sewage disposal, however, most of the water sources could be heavily polluted (Dodoo et al. 2006) and may be responsible for the outbreak of waterborne diseases such as cholera that occur during acute water shortages in the area (Amamoo-Otchere and Akuetteh 2005; Accra Mail 2002). It is also possible for the contaminants in these waters to also include trace toxic metals and other potentially harmful chemicals such as Hg (Ntow and Khwaja 1989), Cd, Se, Pb (Fianko et al. 2007), and polycyclic aromatic hydrocarbons (PAHs; Gilbert et al. 2006), which based on their concentration in the raw water, the nature of the raw water, and the control measures in place may not be thoroughly removed by the treatment process already installed to attain required drinking water quality standards (WHO 2004).

Surface waters in Ghana (with Cape Coast as no exception) typically also serve other purposes including fishing, irrigation, and livestock watering. Water pollution concerns within the municipality are therefore not limited to potable water criteria but include the effects on general health of humans, livestock, agriculture, and aquatic life. Vegetable farming in the area, for which the products could be eaten raw, is a typical example of a case where the quality of water applied has repercussions not only for crop and soil productivity but the consumers' health as well. The quality of the surface waters in the country is often influenced by activities inland and serves as traps for materials brought from inland as a result of flocculation, precipitation, and sedimentation or by careless/accidental direct waste (domestic and industrial) disposal into these water bodies (Dodoo et al. 2006; Biney 1982, 1985, 1986, 1990). For instance, Ghana has reported several incidences of contamination of surface water bodies in mining communities in the Western Region due to toxic elements like spillage of cyanide, mercury, and other heavy metals (Mining Watch 2003; Mines and Communities 2006; Kwarteng 2003). Quite recently, a report was released at the United Nations Environment Program (UNEP) marine pollution meeting in Beijing and identifies Fosu Lagoon (the main lagoon in the Cape Coast Municipality of Ghana) as one of the new dead zones included in the estimated 200 or more dead zones in the world (UNEP 2006; Environment News Service 2006).

In an attempt to improve the water supply and quality problems in the Cape Coast municipality especially during dry seasons and to avoid the consequential premature closure of educational institutions, there have been the installations of numerous hand-pump boreholes to serve most boarding schools in the area. Nearby villages to these institutions also have their fair share of these boreholes or at least have communal hand-dug wells. Unfortunately, water quality assessments of these boreholes are usually not available. Leaks from underground tanks and pipelines and leachates from landfills, dumpsites, septic systems, barnyards, and feedlots all represent potential sources of contaminants to groundwater supplies (Cheremisinoff et al. 1984; USEPA 1980). Not too long ago, a hand-dug well (~23 m deep) situated in a residential area of the capital city of Ghana, Accra, was reported to have been contaminated by a nearby fuel-filling station. Users were reported to suffer from dysentery, vision problems, eye itches, skin diseases, rashes, and other forms of ailment as a result of the pollution (Ghanaweb.com 2004).

Although both surface and ground waters in the Cape Coast municipality stand the risk of potential pollution from some currently known activities in the area, the extent of pollutions is not usually quantified. Published chemical data for the municipality's waters are lacking and the few available are limited mainly to the Fosu Lagoon (Biney 1982, 1986, 1990; Dodoo and Adjei 1995). These may probably be outdated and may not represent current pollution trends in the municipality. We had recently published the heavy metal and PAH levels in the sediment of the Fosu Lagoon (Gilbert et al. 2006), and an assessment of heavy metal pollution of one other surface water in the

municipality, Iture Estuary, was only recently reported in the course of writing this manuscript (Fianko et al. 2007). Recent general water quality data in water sources in the municipality are still lacking in the literature. The primary purpose of this study was therefore to collect an up-to-date baseline general water quality data in Cape Coast to represent the current state during the dry seasons and also to use that information to identify any water quality concerns in the municipality. The intent is that the study will promote awareness in the general public about the suitability or otherwise of water sources in the area for domestic and other uses during the dry seasons and to influence their treatment choices and decisions. The Government of Ghana is currently showing some commitment in the reduction of water-related diseases and the achievement of the "water for all by 2020" goal (Awuku 2007). It is therefore also anticipated that results such as these will help policy makers with respect to water quality management in the country as a whole.

Materials and methods

The study area

The study area (Fig. 1) was the Cape Coast municipality of Ghana in West Africa. Cape Coast is the capital of the Central Region of the country. It lies along the Atlantic Ocean and is on the

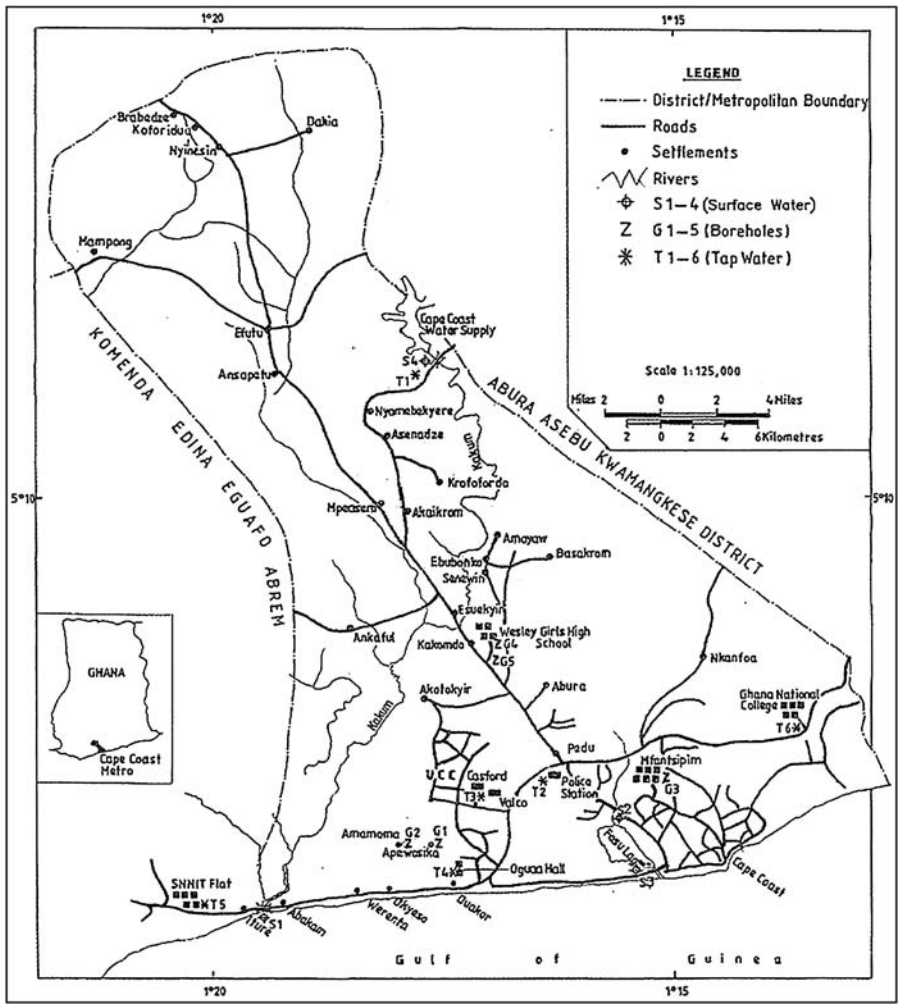

Fig. 1 Map of the sampling area

longitude 1° 15′ west of the Greenwich meridian and the latitude 5° 5′ north of the equator (Fig. 1). Cape Coast is an important tourist and educational town, having many of the country's finest and oldest secondary schools, as well as one university—University of Cape Coast (UCC). Temperatures are high and usually range between 25°C and 35°C with little variation throughout the year. There are two wet seasons in a year; the major one is typically from May to July and a minor season from September to November (Biney 1990). Across the country, the dry dusty Harmattan wind blows from the northeast from December to March, lowering the humidity. In the study area, the effects are felt most in January. April being a transition month between the dry season and the major wet season experience, depending upon a particular year, there are variations of rain outpour—from no rains, isolated, or fair rains. During the sampling period, some rains were recorded in the Cape Coast municipality as follows: 21.2, 48.4, 177.5, and 49.7 mm as total rains in the months of January, February, March, and April, respectively.

There are three main surface water bodies in the Cape Coast municipality. These are the Kakum River, Fosu Lagoon, and Iture Estuary; the latter water body, which borders the two twin cities of Cape Coast (in Cape Coast Municipal District) and Elmina (in Komenda Edina Eguafo Abrem District), receive water supply also from the Kakum River (see Fig. 1). The Kakum River is the main raw source of the Cape Coast municipality and surrounding districts' water treatment and supply system. Pollution concerns in the river include dumping of domestic waste, runoff from farmlands, fishing, and common habits such as bathing of both humans and animals. Water level in Brimsu dam, which is constructed over the Kakum River for raw source water supply to the water treatment plant, usually drops down below operational levels in the dry seasons.

The cultural life of the people of Cape Coast is linked to the Fosu Lagoon. The lagoon is only about 50 m from the Gulf of Guinea. The Lagoon is surrounded by many sites that can act as point sources for discharge of pollutants (Gilbert et al. 2006). These include: domestic waste discharges from a residential area in the northern side of the lagoon, industrial waste discharge from a mechanical workshop on the North Eastern side, drains from a college and a hospital on the Western and South Western side, and household dumping and effluents and sewage from the southern end.

Sample collection

Samples from 15 different sampling stations were collected as follows: four surface water samples (covering all three main surface water bodies in the municipality), five groundwater samples as hand-dug wells or boreholes and treated pipeline supplying water from six catchment taps. Since functionality of the educational boarding institutions in the municipality, particularly at the secondary and the tertiary level, is most affected during peak water shortages in the dry season, the groundwater and drinking water sampling locations were selected with the easy accessibility and proximity to such educational institutions in mind. However, the actual school selections or the sampling locations in the selected schools were randomly chosen and so were the site selections from the surface water bodies.

The sampling sites and codes as used in the study are as follows:

1. Surface water: Iture Estuary (S-1); Fosu Lagoon at the north side (i.e., in the vicinity of a mechanical workshop; S-2); Fosu Lagoon at the south side (i.e., near a children's recreational ground; S-3); and Kakum River (S-4) just before Brimsu Dam
2. Groundwater: A hand-dug well at Apewosika, a village close to UCC (G-1); borehole at Amamoma, another village near UCC (G-2); Mfantsipim School borehole (G-3), Wesley Girls High School (WGHS) borehole sited near the bungalows (G-4) and the flats (G-5)
3. Treated tap water: tap water from the treated water distribution system for the municipality were sampled at the following sites: the water treatment site—Brimsu Dam (T-1); Pedu, a suburb between the dam and UCC (T-2); Hall of Residence at the new site, UCC (T-3); Hall of Residence at the old site, UCC (T-4); SNNIT flat, Elmina (T-5), and Ghana National College at the main gate (T-6)

Treated water and borehole water samples were collected after running the water for 3 to 5 min to ensure a representative sample was collected. With the exception of the dissolved oxygen (DO) and 5-day biochemical oxygen demand (BOD) test samples, which were collected in dark-brown glass bottles, samples were generally collected in clean 1-l polyethylene sample bottles. Sampling for all the parameters were done during the dry season (January to April) of 2005.

The samplings for specific parameters within three main groups (metal ions; physicochemical/microbiological; and inorganic nutrients) were conducted by individual students (and directed by EK Quagraine) as part of undergraduate research projects. (Although the initial plan was for all parameters within the same group to be sampled at the same time, limitations due to student schedules and other logistics did not permit this for all the parameters.) Typically, samples were collected between the hours of 8.00 A.M. and 2.00 P.M. Sampling for the physicochemical parameters—pH, conductivity, color, turbidity, DO, BOD, and the microbiological, total coliform and total bacteria plate count analyses—were all done at the same time for two different months (i.e., January and March, 2005). Thus, these physicochemical and microbiological analyses were done for the same water, each sampling period. Samples for metal ion (i.e., Ca, Mg, Cu, Zn, Hg, Fe, and Mn) measurements were collected for January and February 2005. The last three metals were resampled in March 2005. Sampling for inorganic nutrients (i.e., NH_3-N, NO_3-N, PO_4^{3-} and SO_4^{2-}) were all done for January and April 2005, but additional sampling was done for the latter two parameters in February 2005. There were more rains in March than the remaining sampling months and about 96% of the total rains in that month occurred before sampling.

Methods of analysis

Bacteriological assessments

The total bacterial present in the water samples were conducted using the plate count method with agar medium, while the total coliform was determined by the multiple tube method using MacConkey broth as a culturing medium to determine the most probable number (MPN) as previously described (Dodoo et al. 2006).

The samples prior to culturing for the total coliform tests were diluted in different sterilized containers to 1:10; 1:100, and 1:1,000 with peptone water. Three 1-ml portions of each diluted sample were collected into three Durham tubes, with each containing 10-ml MacConkey broth solutions (double strength for the 1:10 and single strength for the other two dilutions). Thus, triplicate testing was done on each diluted sample and nine total solutions were obtained for each water sample. The solutions were incubated at 37°C in an oven for 24 h. The presence of coliform changed the wine color of the MacConkey culture solution to yellow due to the production of acids like acetic acid or succinic acid and the production of gas (either CO_2 or H_2).

With the plate count, three 1-ml aliquots from three consecutive tenfold serial dilutions were transferred into well-cleaned and sterilized Petri dishes containing plate count agar media. Thus, a total of nine Petri dishes for each sample was obtained. These were also incubated at 37°C in an oven for 24 h. The number of bacteria colonies grown per milliliter for the plate count method was counted using Stuart Scientific Colony counter (W-DO-1L).

Although fecal coliform and *Escherichia coli* bacteria are better indicators for sanitary quality (WHO 2004), we were not able to perform those tests due to some logistical constraint at the time of the study.

Physicochemical parameters

Color intensity was measured in Hazen units using Hach model DR/2000 spectrophotometer (Hach Company, Loveland, CO, USA). The turbidity of each sample was determined with a Hach Model 2100P portable turbid meter (Hach Company, Loveland, CO, USA). A Hach CO 150 conductivity meter was used for the measurement of conductivity. DO and BOD were determined by the use of a portable Dissolved Oxygen-14P meter (TOA Co. Ltd., Tokyo, Japan). Mettler Toledo MP 125 pH meter was used to measure pH of

samples which were immediately brought to the laboratory.

Duplicate measurements for each water sample were performed for the physicochemical parameters.

Inorganic nutrients

Measurements of ammonia and the inorganic anions (i.e., the inorganic nutrients) were performed on a DR/2000 spectrophotometer (Hach Company, Loveland, CO, USA) using the following methods: phosphate (ascorbic acid method), nitrate-N (cadmium reduction method), sulfate (turbidimetric method using Hach Sulfa ver. 4 sulfate reagent powder pillows), and ammonia-N (Nessler method; Hach Company 1992). These nutrients were measured in triplicates for each sample.

Inorganic metals

Mn and Fe were determined spectrophotometrically by the periodate oxidation and phenanthroline complexation (FerroVer) methods, respectively (Hach Company 1992), and measured with the Hach DR/2000 spectrometer. Ca was determined by the EDTA titrimetric method. Measurements were done in duplicate for each water sample.

An atomic absorption spectrophotometer (AAS) model AA872AAS (Philips Electronics Company Limited, UK) was used to determine Cu, Zn, Hg, and Mg. Details of the sample preparations are outlined below.

Sample preparations for heavy metal

Two replicates of each collected sample were digested for the determination of the metal ions (using AAS) by the following procedure. Twenty-five milliliters of each water sample were pipetted and placed in evaporating dishes. Ten milliliters of 1:1 perchloric acid/hydrogen peroxide solution were added to each water sample in the dishes and the content of the dishes was digested until each was reduced to about 5 ml. The digested samples were then allowed to cool and then quantitatively transferred carefully into a 50-ml volumetric flask and diluted to the mark with distilled water, with the flask being shaken at short intervals to ensure even distribution of mixture. A blank determination using the same procedure was performed.

Accurately weighed analytical-grade reagents of the respective metals were digested to prepare known concentrations of the metal ions to serve as reference materials and AAS was used to perform recovery analysis as a check on the accuracy of the measurements.

Results and discussion

As indicated above, replicate measurements for the studied parameters were done on each sample collected for a particular month, which when averaged represent the monthly value. However, for the purposes of the discussion and especially since inadequate monthly results for the various parameters were collected within the short sampling period to establish trends, the results have been presented mainly as averages for the entire dry season. Nevertheless, results showing some more obvious monthly trends are also discussed.

Since most of these waters are potentially used for domestic purposes (including cooking and in some cases for drinking), the results have been compared with WHO (2004) guidelines for drinking water quality to assess their suitability for consumption. There are no formal standards in Ghana for drinking water, groundwater, or surface water quality. However, the Environmental Protection Agency of Ghana (GEPA) has set limits for effluent discharges to water bodies (GEPA 1994) and currently, or perhaps until surface water quality guidelines are also set, the effluent limits seem to be used also to ascertain the level of pollution to receiving water bodies (GEPA 2004). As far as is applicable and available, the surface water quality data obtained from the studies are compared to this guideline to assess compliance. Despite the fact that water quality standards vary among countries and regions, unavailability of applicable guidelines in Ghana has compelled assessment also with appropriate guidelines from other jurisdictions outside the country (Nagpal et al. 2006; OMOE 2002; CCREM 1999; USEPA 2004; BCMOE 2006). For example, the water quality

with respect to agricultural (irrigation or livestock watering) uses or for the protection of aquatic life is (arbitrarily) compared with limits set in the Canadian Environmental Quality Guidelines (CEQG) for these specific purposes (CCREM 1999).

Bacteriological and biochemical oxygen demand assessments

Bacteriological

Samples from all the 15 sampling stations (including the pipe-borne water) were contaminated with total coliform bacteria. However, apart from four sites (i.e., three surface and one groundwater), the total bacteria and total coliform were typically less than 24 colony counts per milliliter and 16 MPN (most probable number) per 100 ml, respectively (Table 1). The average plate count (colony-forming unit, CFU) per milliliter for the treated tap water was 10 ± 4. The allowable limit for general bacteria population in drinking water expressed as background colony counts on a heterotrophic plate count by Ontario Government (Canada) or USEPA is 500 CFU/ml (OMOE 2002; USEPA 2004). Nevertheless, the Ontario Drinking Water Quality standards and USEPA Drinking Water Standard and Health Advisory, as well as other known standards (e.g., WHO 2004; British Columbia Ministry of Environment 2006; Health Canada 2008), require test for total coliform to be undetectable and this was not the case for the pipe-borne, surface, or the groundwater samples taken in both sampling months of January and March of 2005.

Apart from the borehole water from Amamoma which had an uncountable number of bacteria, the average CFU per milliliter for groundwater was about double that in the treated water (i.e., 18 ± 3). The sampled surface waters were heavily infested with an uncountable number of bacteria, with Iture Estuary which recorded bacteria plate count of 8 CFU/ml as the only exception. The total coliform in these surface water samples as well as the Amamoma groundwater samples was greater than 1,800 MPN per 100 ml for each sampled month. The GEPA-set limit for total coliform in even liquid effluent to be discharged to water bodies is a maximum of 400 per 100 ml (GEPA 1994). The coliform bacteria contamination of the Kakum River sample is of notable concern considering that sampling was done at a site just before the water treatment

Table 1 Mean values of bacteriological parameters, DO and BOD5, in surface, tap, and groundwater samples during the dry months (January–April) of 2005

	Site codes	DO (mg/l)	BOD (mg/l)	Plate count (counts per milliliter)	Total coliform (MPN)
Surface water	Iture estuary-S1	9.0 ± 0.2	2.0 ± 0.2	8 ± 0	≤ 16
	Fosu Lagoon (North)-S2	6.9 ± 0.0	4.3 ± 0.5	##	$> 1,800$
	Fosu Lagoon (South)-S3	6.9 ± 0.3	4.0 ± 0.8	##	$> 1,800$
	Kakum river-S4	8.6 ± 0.1	1.6 ± 0.1	##	$> 1,800$
Tap water	Brimsu dam-T1	9.5 ± 0.3	1.0 ± 0.0	9 ± 1	≤ 16
	Pedu-T2	9.2 ± 0.2	1.2 ± 0.1	12 ± 0	≤ 16
	UCC (new site)-T3	9.4 ± 0.2	1.0 ± 0.0	8 ± 1	≤ 16
	UCC (old site)-T4	8.7 ± 0.2	1.0 ± 0.1	10 ± 0	≤ 16
	SNNIT FLATS-T5	9.5 ± 0.2	1.0 ± 0.1	6 ± 1	≤ 16
	Ghana national-T6	8.7 ± 0.2	1.0 ± 0.1	15 ± 3	≤ 16
Underground water	Apewosika-G1	9.0 ± 0.5	1.3 ± 0.2	21 ± 1	≤ 16
	Amamoma-G2	9.2 ± 0.2	1.0 ± 0.1	##	$> 1,800$
	Mfantsipim school-G3	9.5 ± 0.3	1.4 ± 0.2	15 ± 1	≤ 16
	WGHS bungalows-G4	9.4 ± 0.2	1.3 ± 0.2	21 ± 3	≤ 16
	WGHS flats-G5	9.4 ± 0.1	1.4 ± 0.2	17 ± 1	≤ 16

implies uncountable number of bacteria

plant for the municipality. Also, much of the concern are the potential uses of this river and the Fosu Lagoon for livestock or irrigational purposes (e.g., vegetable farming), especially during drought periods. The CEQG guideline for total coliform in water for agricultural uses is 1,000 counts per 100 ml (CCREM 1999).

Dissolved oxygen and biochemical oxygen demand

There was some slight increase of DO content in all 15 samples from January to March (~7% average increase). With the exception of Fosu Lagoon samples (6.9 ± 0.3 mg/l), DO in all samples were within the range of 8.3–9.3 mg/l in January and 8.8–9.9 mg/l in March. The mean DO and BOD concentrations for the 2 months are shown in Table 1. All the surface waters met the CEQG guideline (i.e., 5.5 to 9.5 mg/l) for the protection of aquatic life (CCREM 1999).

Apart from the Apewosika well (G-1), a general increase of BOD between 15% and 47% was observed for surface and groundwaters from January to March. The increase was more predominant at the Fosu Lagoon site near the recreational ground (S-3). This trend may suggest an increased microbial activity during the month of March.

There were fewer BOD variations in the tap water samples (1.0 ± 0.2 mg/l) and the groundwater samples (1.3 ± 0.2 mg/l) than the surface water samples (3.0 ± 1.4 mg/l). The Fosu Lagoon recorded the highest BOD of 4.8 mg/l. The BOD of the other two surface waters were within 1.5–2.2 mg/l. Biney (1982) has classified the pollution level of Ghanaian lagoons into three categories according to the BOD levels as follows: unpolluted (BOD < 4 mg/l), moderately polluted (BOD = 4 to 12 mg/l), grossly polluted (BOD > 12 mg/l). The Fosu Lagoon with a previous BOD measurement of 8.29 mg/l was therefore classified as moderately polluted (Biney 1982, 1986). The current BOD result is consistent with that conclusion even though the BOD concentration is lower in magnitude in the present study. The relatively higher level of BOD and bacterial activity in the Fosu Lagoon (see Table 1) is not surprising, and the measured BOD is actually less than expected considering some careless disposal of various (organic) wastes into the water body (GEPA 2004; Gilbert et al. 2006).

Limitations in accurately quantifying the enormous bacteria population in some of the water samples did not permit any meaningful correlation analysis between the bacteria population and BOD. Generally, however, with Iture Estuary and Amamoma borehole as exceptions, the higher BOD observed in the surface waters than the groundwater seems to correspond well with the enormous bacteria population in the former sample compared to the latter sample. It is uncertain at the moment why the Amamoma groundwater, with the high bacteria and total coliform population, recorded one of the least BOD.

Physical characteristics

Conductivity

The mean conductivities of the water samples during the dry period of January to April 2005 are shown in Table 1. The Fosu Lagoon, being a coastal lagoon, recorded the highest conductivity (i.e., 7,525 ± 75 and 7,605 ± 35 μS/cm for the two sampling sites of the lagoon, north side (S-2) and south side (S-3), respectively). The other two surface water bodies recorded lower average conductivity in the range 120–174 μS/cm, with Iture Estuary recording in the upper range of 173 ± 1 μS/cm and the Kakum River in the lower ranges of 123 ± 3 μS/cm (see Table 1). GEPA's recommended environmental water quality limit for conductivity is 1,500 μS/cm. With the exception of Fosu Lagoon, groundwater samples were generally of higher conductivity than surface and tap waters. Furthermore, significant variations were observed between various groundwater sites and as well as between sampling months for specific groundwater sites, ranging from 282 μS/cm (WGHS: G-5 in March) to 3,440 μS/cm (Amamoma: G-2 in January). Apart from the hand-dug well at Apewosika which showed an increase of about 81% in conductivity from January (1,785 μS/cm) to March (3,230 μS/cm), the other groundwater samples (i.e., the boreholes) generally showed a decrease of 45% to 82%

from January to March. The Mfantsipim borehole, however, was an exception and recorded an invariant conductivity of 643 μS/cm.

The significant variations in conductivity between the 2 months for the groundwater is attributed to preceding rains in March, which may have caused dilution of the underground borehole water table or conversely could also have caused runoffs of salty materials to the unprotected hand-dug well. Perhaps, the geology or soil type in the Mfantsipim area prevented any significant influence of the rains to the water table.

The average conductivity of the tap waters connected directly to the treated water distribution pipelines (i.e., without going through large storage tanks) was 180 ± 26 μS/cm. The tap water for Ghana National College (T-6) is received through the above metal storage tanks and showed a decrease of about 74% in conductivity from January (643 μS/cm) to March (170 μS/cm). Treated water from the distribution pipe line is also pumped into an aboveground reservoir at the SNNIT flats before entering the sampling tap (T-5). The water from this tap had the least conductivity of 49 ± 1 μS/cm.

All the tap water samples were less than the Province of British Columbia (BC), Canada, recommended maximum of 700 μS/cm for drinking water uses (BCMOE 2006). Only 50% of both groundwater and surface water met this conductivity guideline to be used for drinking purposes without treatment. The conductivities of all the groundwaters were however less than the recommended BC maximum working guideline of 4,200 and 5,000 μS/cm, respectively, for livestock and irrigational purposes (Nagpal et al. 2006). By the BC conductivity standards, the Fosu Lagoon water is not recommended for domestic, livestock, or irrigational purposes.

Color and turbidity

The average turbidity and color measurements for the various sites during the dry season of 2005 are shown in Table 2. Both the WHO and USEPA guidelines for turbidity and color in drinking water is a maximum of five nephelometric turbidity units (NTU) and 15 true color units (TCU), respectively. With the exception of some two exceedances that occurred for the Apewosika well and a WGHS borehole (G-4; both at 17 NTU and in March), all the ground and tap water samples were within the WHO drinking water guideline for turbidity. However, seven exceedances during the sample period were recorded for color in groundwater (three out of ten) and tap water (four out of 12) samples. The tap water from the Brimsu Dam site and the Apewosika well-recorded 20 TCU in January and thus were the only ground or tap water samples that exceeded the WHO guideline for that month. In March, however, these samples were within the WHO guideline. Fifty percent of tap water and samples from the two borehole sites in WGHS exceeded the guideline in March and ranged between 24 and 46 TCU.

The British Columbia guidelines (BCMOE 2006) for both turbidity and color are the same as that for the WHO and USEPA but specifies these as aesthetic objectives for treated drinking water; the BCMOE guideline for turbidity in untreated raw water is one NTU. With this latter guideline, none of the surface water sample met this guideline and only 60% of the groundwater sample (i.e., six out of ten samples) met this turbidity guideline.

Among the surface water samples, Iture Estuary was the clearest. It recorded on the average ten TCU for color and 4 ± 2 NTU for turbidity (see Table 2). Color measurements in the other surface water samples were 123 ± 28 TCU for Kakum River and in the range of 120–515 TCU for Fosu Lagoon (i.e., 216 ± 96 and 460 ± 55 TCU at sites S-2 and S-3, respectively). The turbidity for the Kakum River was 19 ± 2 NTU, while that of Fosu Lagoon's ranged from 12 to 84 NTU (i.e., 39 ± 27 and 77 ± 7, respectively, for sites S-2 and S-3). Only one Fosu Lagoon sample (S-3) exceeded the GEPA-recommended environmental quality limit of 75 NTU (GEPA 1994, 2004) and that occurred in March. A general increase in turbidity and color for the surface waters were observed from January to March with the color of Fosu Lagoon (S-3) sample as the only exception. Typically, with only few exceptions, this was a general trend for all the water sources. This may be associated with runoffs or perturbation of the

Table 2 Mean values of some physical–chemical parameters in surface, tap, and groundwater samples during the dry months (January–April) of 2005

	Site codes	pH	Conductivity (μs/cm)	Color (TCU)	Turbidity (NTU)	Mg (mg/l)	Ca (mg/l)
Surface water	Iture estuary-S1	6.7 ± 0.1	173 ± 1	10 ± 0	4 ± 2	3.7 ± 0.1	23 ± 3
	Fosu Lagoon (north)-S2	6.7 ± 0.5	7,525 ±75	216 ± 96	39 ± 27	4.0 ± 0.1	25 ± 0
	Fosu Lagoon (south)-S3	7.1 ± 0.6	7,605 ± 35	460 ± 55	77 ± 7	2.9 ± 0.7	22 ± 2
	Kakum river-S4	7.0 ± 0.2	123 ± 3	123 ± 28	19 ± 2	3.5 ± 0.2	21 ± 1
Tap water	Brimsu dam-T1	6.6 ± 0.0	169 ± 5	15 ± 5	3 ± 3	5.0 ± 0.0	32 ± 2
	Pedu-T2	6.9 ± 0.6	211 ± 33	2 ± 2	0 ± 0	2.2 ± 0.7	31 ± 6
	UCC (new site)-T3	6.4 ± 0.1	169 ± 0	23 ± 23	0 ± 0	3.9 ± 0.3	27 ± 1
	UCC (old site)-T4	6.4 ± 0.1	172 ± 4	12 ± 12	2 ± 2	6.8 ± 0.6	23 ± 3
	SNNIT FLATS-T5	7.8 ± 0.1	49 ± 1	12 ± 0	3 ± 1	4.0 ± 0.1	25 ± 1
	Ghana national-T6	6.5 ± 0.0	407 ± 237	23 ± 23	2 ± 2	3.1 ± 0.2	34 ± 14
Underground water	Apewosika-G1	5.8 ± 0.0	2,508 ± 723	15 ± 5	10 ± 7	3.7 ± 0.2	26 ± 2
	Amamoma-G2	6.3 ± 0.2	2,672 ± 768	8 ± 5	0 ± 0	4.9 ± 0.2	32 ± 6
	Mfantsipim school-G3	5.7 ± 0.0	643 ± 0	0 ± 0	0 ± 0	2.7 ± 0.6	38 ± 8
	WGHS bungalows-G4	6.1 ± 0.2	1,907 ± 1,313	26 ± 20	9 ± 8	3.4 ± 1.0	23 ± 3
	WGHS flats-G5	5.8 ± 0.2	406 ± 124	16 ± 11	1 ± 1	6.6 ± 0.3	29 ± 2
Guidelines	Drinking water	6.5–8.5[a–d]	≤ 700[d]	≤ 15[b–d]	≤ 1.0[d,e] ≤ 5[a,b,d,f]	≤ 100[d,g]	
	Livestock/irrigation or recreational	6.5–8.5 (recreational)[d]	4,200 (livestock)[h]; 5,000 (irrigation)[h]		≤ 50 (recreational)[d]		1,000 (livestock)[i]
	Effluent discharge	6–9[j]	≤ 1,500[j]		≤ 75[j]		

[a]WHO (2004) guidelines for drinking water quality
[b]USEPA (2004) drinking water standards and health advisories
[c]Guidelines for Canadian Drinking Water Quality (Health Canada 2008)
[d]British Columbia approved Water Quality Guidelines (BCMOE 2006)
[e]Maximum limit for raw untreated drinking water
[f]Aesthetic objective for treated drinking water
[g]Taste threshold for sensitive people
[h]British Columbia Guideline for livestock and irrigational purposes (Nagpal et al. 2006)
[i]Canadian Water Quality Guidelines for the Protection of Agricultural Water Uses (CCREM 1999)
[j]Ghana EPA effluent guidelines for discharge into natural waters (GEPA 1994)

surface and borehole/well underground water as a consequence of the preceding rains in March.

BCMOE (2006) has set turbidity guideline of 50 NTU for recreational water and the Fosu Lagoon does not generally meet this target, although all the other samples meet the turbidity requirement. It is noteworthy that the Fosu Lagoon serves lots of recreational purposes, including canoe activities as part of the annual Fetu Afehye and leisure fishing. In fact, none of the samples taken from the site close to the children's recreational park (S-3) meet this turbidity guideline.

Chemical characteristics

pH

Mean pH values of the 15 water samples are also shown in Table 1. The pH for the surface waters was generally comparable to those of the tap waters (i.e., 6.9 ± 0.5 and 6.7 ± 0.6, respectively). Although averages of both were generally within the WHO standard of 6.5–8.5 for drinking water, some individual tap water samples were marginally below the lower limit. The surface water

samples were all within the GEPA environmental quality guideline of 6–9. The groundwaters were slightly more acidic (pH 5.9 ± 0.3) than the surface and tap waters and did not meet the WHO minimum guideline for drinking water as a whole.

The mean pH for 24 Fosu Lagoon water samples collected in both dry and wet seasons between 1980 and 1985 has been reported as 7.8 ± 0.9 (Biney 1986, 1990).The mean pH for the lagoon samples during the current study (i.e., pH = 6.9 ± 0.9) shows some overlap with this historic average but seems to be generally about one pH unit lower for the current study. Biney (1985) has noted from studies of some Ghanaian estuaries that in general the pH turns more alkaline under the influence of seawater in the lower reaches. The Fosu Lagoon, as a "closed" type (Biney 1990; Gilbert et al. 2006), is closed to the sea during dry season and hence would be less under the alkaline influence from seawater during that season, as observed during the present study.

Calcium, magnesium, and hardness

Hardness in water is caused by dissolved calcium and, to a lesser extent, magnesium (WHO 2004). The mean Mg and Ca concentrations for the individual sites are shown in Table 1. The mean Mg concentrations (in milligram per liter) in the surface water, tap water, and the groundwater are 3.5 ± 0.6, 4.2 ± 1.6, and 4.3 ± 1.5, respectively. The respective Ca content (in milligram per liter) are also 23 ± 2, 28 ± 8, and 29 ± 8. These constitute to hardness of approximately 71, 88, and 91 mg/l $CaCO_3$ for the surface water, tap water, and the groundwater samples, respectively. No health-based WHO guideline has been proposed for hardness in drinking water, although hardness over 200 mg/l $CaCO_3$ is not recommended due to potential scale formation in the distribution system (WHO 2004). The British Columbia (Canada) water quality guideline defines an 80 to 100 mg/l $CaCO_3$ as acceptable for drinking, over 200 mg/l $CaCO_3$ as poor but tolerable, and over 500 mg/l $CaCO_3$ as normally unacceptable (BCMOE 2006). The hardness in the water samples from the municipality seems to be generally acceptable by these guidelines, although the relatively lower hardness concentration in the surface waters may be somewhat questionable. There is some indication that very soft waters may have an adverse effect on mineral balance, but more studies are required for confirmation (WHO 2004).

Ca concentrations in water, as high as 1,800 mg/l, are reported as harmless (Clayton, Randall, and Cotney Consulting 2000). Magnesium values greater than 125 mg/l can however exert cathartic and diuretic reactions (Noonan 1995). The BCMOE (2006) guidelines suggest a maximum limit of 100 mg/l Mg as taste threshold for sensitive people. The concentrations of Mg and Ca in all the water samples are at least an order of magnitude lower than the respective concentration limits for health concerns and therefore do not appear to pose any health dangers as far as these elements are concerned. The Ca levels are also about two to three orders of magnitudes less than the CEQG 1,000 mg/l Ca water guideline for the protection of livestock water uses.

Inorganic nutrients

Phosphate In potable water, phosphate should always appear in traces only. Higher concentrations than 2.2 mg/l P (or 6.7 PO_4^{3-}) can cause digestive troubles (Seibold Messtechnik und Projektentwicklung GmbH 2008). There seems to be no established health-based phosphate guideline for drinking water quality by GEPA, WHO, CEQG, or USEPA. High concentrations of phosphate in surface water are largely responsible for eutrophication conditions. Algae and other aquatic life will flourish eventually causing death of aquatic animals. The GEPA effluent quality guideline for phosphate is 2.0 mg/l (GEPA 1994).

The mean phosphate results for the dry season are presented in Fig. 2. The concentrations ranged from 0.71 ± 0.14 mg/l (tap water at the treatment plant (T-1)) to 18.12 ± 0.16 mg/l (Fosu Lagoon (S-3)). None of the tap and groundwater samples was more than 6.7 mg/l PO_4^{3-} to pose potential phosphate-related digestive troubles. On the contrary, drinking or livestock watering from the Fosu Lagoon and the Kakum River could potentially lead to digestive problems. The relatively lower phosphate concentration in the tap water samples

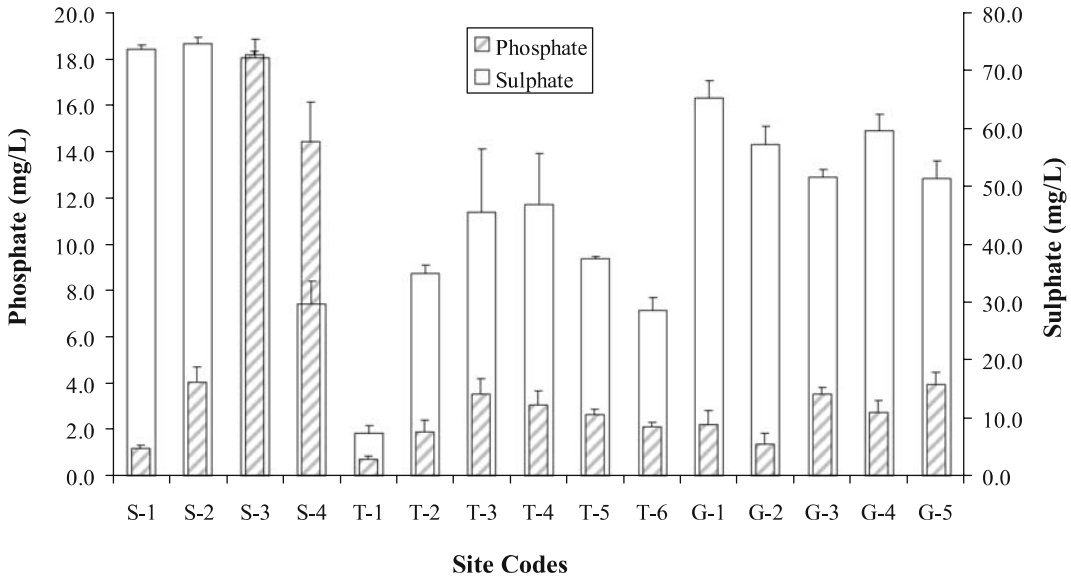

Fig. 2 The average phosphate and sulfate levels in surface (*S*), tap (*T*), and groundwater (*G*) samples from the Cape Coast Municipality in dry season (January to April) of 2005

reflects the water treatment efficiency to reduce phosphate levels from the untreated river source (i.e., 14.36 ± 1.68 mg/l for S-4).

Nine out of 12 (i.e., 75%) of the surface water samples exceeded the GEPA environmental quality guideline for phosphate. Only Iture Estuary was in compliance with the guideline among the surface water sources. As compared to a historic mean of 0.094 PO_4^{3-} P in the Fosu Lagoon (Biney 1990), the phosphate measured during the sampling period is about an order to two orders of magnitude greater. The current high phosphate content in the Fosu Lagoon may have to do with the increasing habitual dumping of domestic, human, and agricultural waste (e.g., plant leaves) into the lagoon. UNEP has recently identified Fosu Lagoon as one of the new dead zones included in the estimated 200 or more dead zones in the world (UNEP 2006; ENS 2006).

Sulfate Sulfate is among the major anions usually found in drinking water sources. Both taste and health-based guidlines for sulfate in drinking water (i.e., 400 and 500 mg/l, respectively) have been recommended by WHO (2004). The latter is due to gastrointestinal effects resulting from ingestion of drinking water containing high sulfate levels.

The mean sulfate concentrations are also shown in Fig. 2. Generally, with the exception of the Kakum River, the trend in sulfate concentrations for the various water types was surface waters > groundwater > treated water. Iture Estuary and the Fosu Lagoon (at both sites) recorded the highest sulfate concentration of approximately 70–75 mg/l, but these concentrations are far lower than the WHO-recommended maximum for drinking water and the CEQG guideline for agricultural uses. The CEQG guideline for the protection of livestock water uses is 1,000 mg/l. Apart from a recorded lower sulfate for the Mfantsipim borehole in January, there was a general decreasing trend of sulfate concentrations in the groundwater samples from January to April. As explained earlier, there were some fair amount of rains in March and this could have resulted in the dilution of dissolved salts in the groundwater sources. The decreasing sulfate concentration trend was also observed in the Kakum River and to a lesser extent in the Iture Estuary but not in the Fosu Lagoon. Like phosphate, there was a reduction of sulfate from the untreated source to the tap water at the water treatment (i.e., from S-4 to T-1 as shown in Fig. 2). Perhaps due to limitations in the distribution system, the tap waters

from the different localities in the municipality were of worsened quality in terms of sulfate. This is discussed further below.

Ammonia/nitrate-nitrogen Nitrogen-containing compounds act as nutrients in streams, rivers, and reservoirs. Ammonia is extremely toxic and even low levels pose a threat to fish health. The (pH and temperature dependent) CEQG guideline of total ammonia for the protection of freshwater aquatic life at pH close to that of the surface waters (i.e., ~7) is ≤3.37 mg/l NH_3 (or 2.81 mg/l NH_3-N) and 2.39 mg/l NH_3 (or 1.99 mg/l NH_3-N), respectively, for the temperatures 25°C and 30°C (i.e., the temperature range typically expected for the water samples; CCREM 1999). The GEPA environmental guideline for ammonia is 1.00 mg/l (GEPA 1994, 2004).

Figure 3 shows the average NH_3-N and NO_3^--N concentrations for the water samples measured during the dry season. A significant variation of NH_3-N concentration is observed between the three surface water bodies: 0.06 ± 0.01, 0.43 ± 0.06, and 0.73 ± 0.01 for Iture Estuary, Fosu Lagoon, and Kakum River, respectively. The coefficient of variation (CV) for the surface water samples is 63%. These surface water (as well as the ground and tap water) concentrations are all less than the recommended limit by GEPA and substantially lower than CEQG guideline for the protection of aquatic life; but it should be noted that natural levels in groundwater and surface water are usually below 0.2 mg/l (WHO 2004). As compared to a historic mean of 0.26 mg/l NH_3-N in the Fosu Lagoon (i.e., an average for samples from 1980 to 1985 Biney 1986, 1990), the current level shows an increase of about 65%. As in the case of the surface water samples, significant variation in ammonia concentration is also noted with the groundwaters (CV = 73%). There was less variation between the tap water samples (CV = 15%). No health-based ammonia guideline has been recommended by WHO. WHO guideline of 1.5 mg/l has however been recommended based on odor reasons. None of the water samples tested exceeded this guideline.

High nitrates in drinking water can cause digestive disturbances in people. WHO drinking water quality guideline of ≤50 mg/l NO_3^- (or 11.3 mg/l NO_3^--N) has been proposed to protect against methemoglobinemia in bottled-fed infants on short exposure (WHO 2004). The Canadian and USEPA Drinking water quality for nitrate is

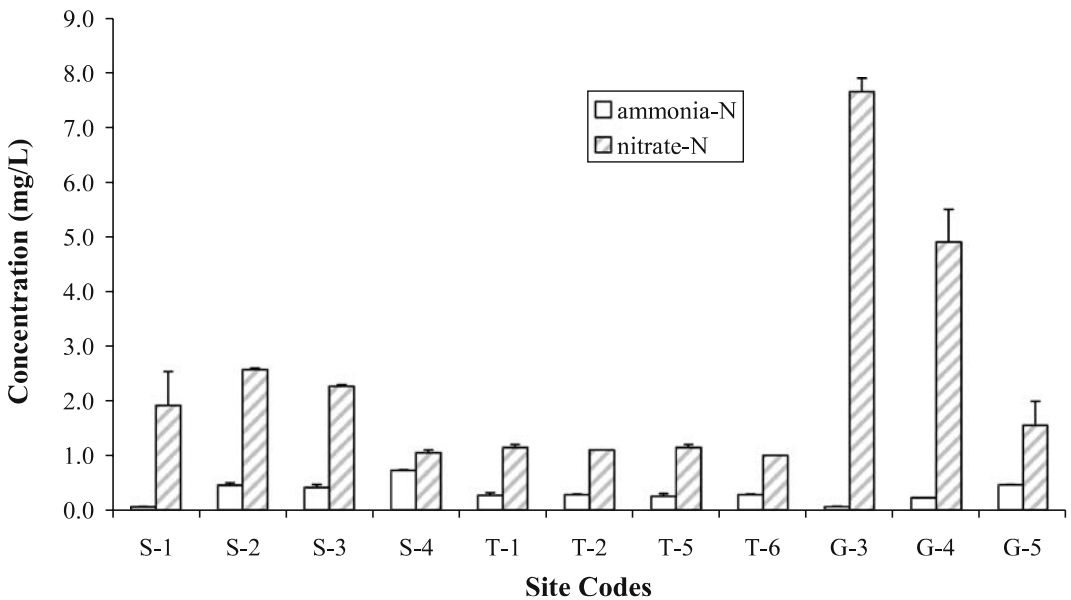

Fig. 3 The average ammonia-N and nitrate-N in surface (*S*), tap (*T*), and groundwater (*G*) samples from the Cape Coast Municipality in the dry season (January to April) of 2005

45 mg/l (or 10 mg/l NO_3^--N) and the GEPA effluent water quality guideline is 30 mg/l. None of the water samples exceeded any of these guidelines. The Mfantsipim borehole recorded the highest NO_3^--N concentration of 7.65 ± 0.25 mg/l. A less stringent guideline of 100 mg/l (nitrate + nitrite) is set for water intended for livestock watering and thus all the water samples met this guideline also.

As in the case of the nutrients phosphate and ammonia, increased nitrate concentration was observed for the Fosu Lagoon in the current study as compared to the previous measurements about two decades ago. The current nitrate concentration in the lagoon is more than two orders of magnitude greater than the previous level (Biney 1986, 1990). The generally high nitrogen content in water samples from the Fosu Lagoon and the Kakum River may be attributed to various sources of contamination. Major point sources of combined nitrogen into bodies of water are municipal and/or industrial wastewaters, refuse dumps, animal feed lot discharges, and septic tanks. Diffuse sources include runoff or leachate from manure and urban drainage (NAS 1977). Current activities in the area make almost all of these listed sources as potential nitrogen origins to both surface water bodies.

Heavy/trace metals

Iron/manganese Fe and Mn occur naturally from rocks and are found in many surface water and groundwater sources at levels ranging 0.5 to 50 mg/l and 1 μg/l to 10 mg/l, respectively (WHO 2004). The recommended WHO guidelines for Fe and Mn concentrations in water based on laundry staining concerns are 0.3 and 0.1 mg/l, respectively (WHO 2004). There is also a WHO health-based guideline of 0.4 mg/l for Mn in drinking water but not for Fe. However, a value of 2 mg/l has been proposed as a precaution against excessive iron storage in the body (WHO 2004). The CEQG Fe guideline for the protection of freshwater aquatic life is 0.3 mg/l. The CEQG guideline for the protection of irrigational water uses, with respect to Mn, is 0.2 mg/l.

The mean Fe concentrations in the water samples for the dry season of 2005 are presented in Fig. 4. Significant variations are observed between the four surface water samples (CV = 91%), the five groundwater samples (CV = 114%), and more so for the six tap water samples (CV = 141%). The Fe levels in the surface waters were in general comparable to that of the groundwaters. The Fe concentrations ranged from 0.17 ±

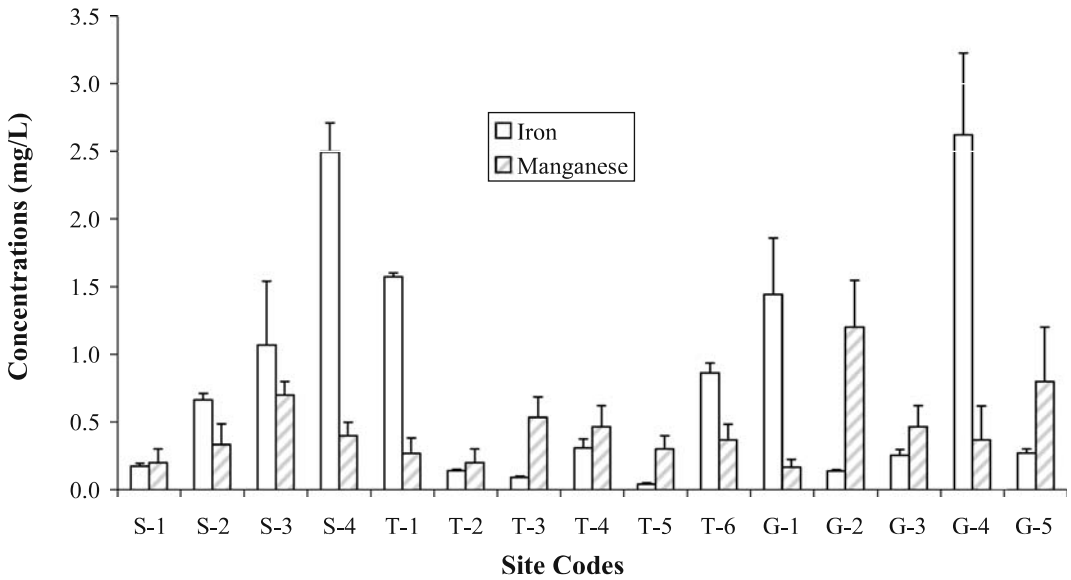

Fig. 4 The iron and manganese concentrations in surface (*S*), tap (*T*), and groundwater (*G*) samples from the Cape Coast Municipality in the dry season (January to April) of 2005

0.02 mg/l (Iture Estuary) to 2.50 ± 0.21 mg/l (Kakum River) for the surface waters and from 0.14 ± 0.01 mg/l (Amamoma borehole) to 2.62 ± 0.61 mg/l (WGHS Borehole:G-4) for the groundwater sources.

Nine out of the 12 individual monthly surface water samples (i.e., 75%) exceeded the CEQG guideline for the protection of aquatic life and the WHO guideline based on the staining properties of iron. Based on the potential risk of excessive iron storage in the body, the Kakum River is not recommended for drinking without treatments to remove iron. The mean Fe results for the raw Kakum River source water sampled for the dry months of January to March of 2001–2004 is 2.56 ± 0.90 mg/l (GWCL 2004), and this is consistent with the high Fe results as observed in this study for the same dry months in 2005.

The treated tap waters ranged from 0.03 ± 0.01 mg/l (SSNIT) to 1.57 ± 0.03 mg/l (Brimsu dam) and seemed to address the health-based concerns of drinking from the Kakum River source water. However, the treatment process does not eliminate the staining concerns. Eight out of 18 tap water samples (i.e., ~44%) exceeded the staining-based WHO guideline for iron. The Fe content as measured in the tap water at the treatment site (T-1) is high as compared to previously (2001–2004) gathered results for the months of January–March, which averaged to 0.4 ± 0.2 mg/l (GWCL 2004). It is not certain what the reason is for the higher results obtained in this study (repeatedly for all three sampling month periods) as compared to results for preceding years; but it should also be noted that, despite the differences, monthly averages as high as 0.95 mg/l (January 2003) and 1.22 mg /l (October 2001) have, for instance, also been previously recorded after final water treatment (GWCL 2004). The higher Fe content from the tap at the treatment plant as compared to the other distribution point is also uncertain, but it is not uncommon for early-morning collected tap water in the homes of the municipality to be highly colored and of metallic taste, despite allowing them to run to waste for the first few minutes. Typically, tap water sampling for the day was done first from the treatment site (8–9 A. M.) before the other sites. The sufficient variation in the Fe contents in the various sampling points of the distribution system is also particularly noteworthy. It is also possible that the significant variations of Fe and the inconsistencies in the distribution system may be related to poor conditions of some of the distribution pipe lines or any intervening storage tanks after the water treatment.

Eight out of 15 groundwater samples (i.e., ~53%) exceeded the laundry-staining-based WHO guideline for iron. All three WGHS borehole samples collected at site G-4 (i.e., in January, March, and April 2005) exceeded 2 mg/l and, thus, water consumption from this borehole, without treatment for Fe, may stand a long-term health risk involving excessive iron storage. All the water samples met the CEQG Fe guideline for irrigation water quality (5 mg/l).

The mean manganese concentrations are presented in Fig. 4 alongside the iron concentrations. As in the case of Fe, but to a lesser extent, there were significant variations in Mn concentrations between the five groundwater (CV = 68%) and the four surface water (CV = 52%) samples. Unlike Fe, however, difference in Mn concentrations in the treated water at the various points of the distribution system (T1 to T6) were not drastically different (CV = 35%) and measured 0.36 ± 0.13 mg/l. With only a few exceptions, there was an increasing trend of Mn content in the surface waters and the tap waters from January to March. All samples analyzed violated the WHO laundry-staining-based Mn guideline of 0.1 mg/l. Six out of 12 (i.e., 50%) surface water, eight out of 18 (i.e., ~44%) tap water, and ten out of 15 (i.e., ~67%) groundwater sources exceeded the WHO health-based provisional guideline. The Mn concentrations of 1.2 ± 0.4 and 0.8 ± 0.4 mg/l, respectively, found in the Amamoma (G-2) and the WGHS (G-5) boreholes are particularly high and would require some form of Mn treatment prior to potable uses (including cooking).

Mn is an essential element for metalloproteins, such as glutamate synthetase, mitochondrial superoxide dismutase (Prohaska 1987; Baek et al. 2004). However, excessive Mn is also toxic to the brain and can produce an irreversible syndrome resembling Parkinson's disease (Donaldson 1987; Baek et al. 2003, 2004; Olanow 2006). This neurologic syndrome, known as "manganism"

(Latchoumycandane et al. 2005; Wasserman et al. 2006) is thus characterized by a Parkinson-like condition with weakness, anorexia, apathy, slowed speech, emotionless facial expression, and slow movement of the limbs. Adverse neurological effects of Mn are reported to occur in both adults (Kondakis et al. 1985; Latchoumycandane et al. 2005) and children (Wasserman et al. 2006) exposed to high Mn in drinking water.

Only one out of 12 (~8%) surface water; one out of 18 (~6%) tap water, and two out of 15 (~13%) groundwater samples met the 0.2 mg/l Mn CEQG guideline for irrigational purposes.

Copper/zinc/mercury The percentage recoveries of the elements from spiked water samples were Hg 98.3 ± 1.4%, Cu 100.8 ± 3.8%, and Zn 98.5 ± 2.4% which validate the AAS measurements. The mean concentrations of Cu, Zn, and Hg in the various water sources for the sampling periods are presented in Fig. 5. Cu and Zn levels in the samples ranged from not detected to 0.26 mg/l and 0.02 to 0.21 mg/l, respectively. These values are respectively about an order of magnitude lower than the WHO health-based Cu guideline of 2 mg/l and a recommended 3 mg/l Zn in drinking water (WHO 2004). Likewise, all the samples met the CEQG aesthetic objectives of 1 and 5 mg/l, respectively, for Cu and Zn (CCREM 1999). Only one sample (a groundwater sample from WGHS borehole collected in January) exceeded the 0.2 g/l Cu guideline for cereal irrigation water; nevertheless, the water quality met the 1 g/l Cu guideline for irrigating more tolerant crops. The Cu levels in all the water samples met the CEQG guideline for various livestock watering: 0.5, 1.0, and 5.0 mg/l, respectively for sheep, cattle, and swine/poultry. The Zn levels in all the water samples were also lower than the CEQG guidelines for irrigational (1–5 mg/l) and livestock watering (50 mg/l) purposes. However, all the surface water samples and also 75% of the surface water exceeded the CEQG Cu guideline (0.002–0.004 mg/l) and Zn guideline (0.03 mg/l) for the protection of aquatic life, respectively. The mean Zn concentration of 0.11 ± 0.02 mg/l in Iture Estuary for the present study (Fig. 5) falls within the 0.040–2.45 mg/l Zn concentration recently reported in the literature (Fianko et al. 2007) and confirms concerns of ill health of aquatic lives in the water body due to Zn loadings.

Both inorganic and organic mercuric compounds have some toxic effect on humans and a guideline of 1 μg/l total Hg has been proposed by WHO for quality drinking water (WHO 2004).

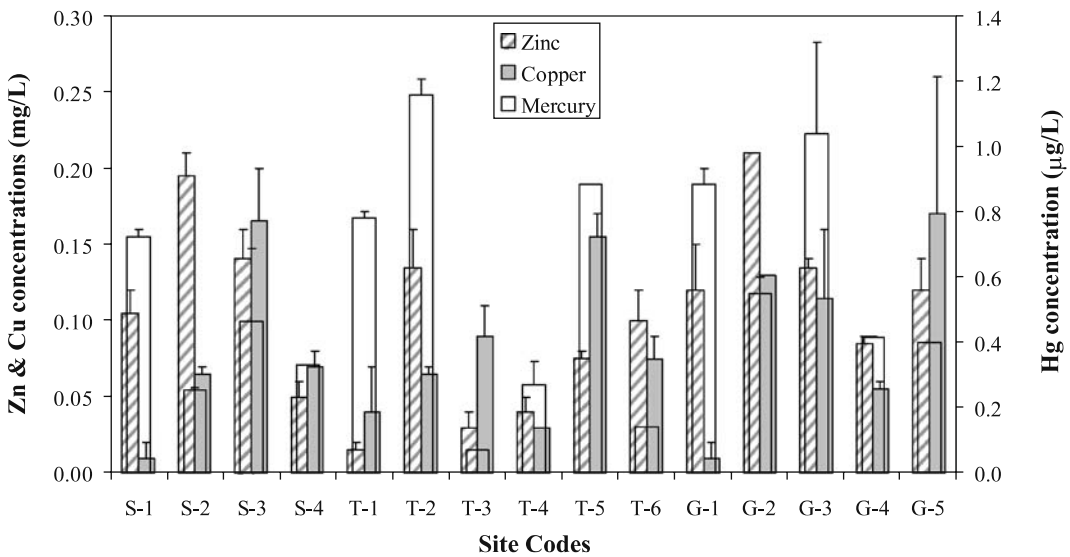

Fig. 5 The average concentrations of Cu, Zn, and Hg in surface (*S*), tap (*T*) and groundwater (G) samples from the Cape Coast Municipality in the dry season (January to April) of 2005

Three (two surface water and one groundwater) out of the 30 samples tested for Hg exceeded the WHO guideline, but only marginally. The entire water samples met the CEQG Hg guideline (3 μg/l) for livestock water.

Water treatment and distribution system

The results indicate improvements in concentrations of several parameters after the treatment process at the Brimsu dam: these include approximately 79% and 71% reduction in color and turbidity; 95%, 75%, and 63% reduction of the inorganic nutrients phosphate, sulfate, and ammonia; and 70%, 43%, 37%, and 33% reduction in concentration of the metal ions zinc, copper, iron, and manganese, respectively. There was however no exhibition of mercury removal from the source water.

Despite the demonstrated treatment efficiency above, there seems to be deficiencies in the distribution system and, in some cases, contaminants appear to be picked from the outside environment into the distribution system. For example, the results indicate significant contamination of phosphate, sulfate, and manganese into the distribution pipe lines around the University of Cape Coast (at both the new and old sites). A good correlation ($R^2 = 0.89$) occurs between the phosphate and sulfate concentration in the taps at the various distribution points suggesting the likelihood that these contaminants may be originating from a common source into the distribution system. Although the manganese contamination, like the sulfate and phosphate, is more prevalent in the University area, it appears its actual source is different from that of sulfate. There is however a reason to believe that there is another source of phosphate contamination into the distribution system, which relates to manganese. The correlation coefficient between manganese and sulfate at the five consumer locations in the distribution system (i.e., with the exclusion of the tap water at the treatment site) is only fair ($R^2 = 0.44$) as compared to $R^2 = 0.81$ for manganese and phosphate. Apart from manganese, phosphate, and sulfate, there were also trace element contaminations (e.g., Cu and Zn) in the distribution system. Significant variation of Fe concentration was found at the various point of the distribution system, which may also be attributable to contamination in the distribution system. The parameters pH, DO, BOD, NH_3-N, NO_3-N, and Ca were the least affected by contamination in the distribution system.

Contamination of the distribution pipe line could be caused by the following; (a) pipe leakages as a result of pipe burst along contaminating sources (e.g., gutters and drainages) and rusted/old pipes. (b) Pressure differential from water rationing may also lead to back sucking of stagnant waters and sandy sediments which may contain plant and animal waste and thereby increase phosphate and manganese levels in tap water. (c) The occurrence of corrosion in the distribution piping may also add trace metals to finished water before reaching the consumer.

Conclusion

Generally, the groundwater samples were higher in conductivity and lower in pH than the surface water and tap water samples. The pH of the groundwater samples did not generally meet the WHO guideline for drinking water. The Fosu Lagoon and the Kakum River were particularly contaminated, being infested with uncountable number of bacteria and of coliform counts greater than 1,800 counts per milliliter and generally worse in water quality with respect to phosphate, color, turbidity, and BOD.

With exception of Kakum River which recorded relatively lower sulfate, the general trend in sulfate concentrations for the various water types was surface waters > groundwater > treated water. Significant variation of NH_3-N, Fe, and Mn concentrations was observed between the surface water bodies, as well as the groundwater sources. Variations in NO_3-N concentrations are also observed for the groundwater samples. Some parameters were noted to change from January–February to March–April likely due to some significant rains in March. These include (with only few exceptions) decreases in conductivity and sulfate for boreholes and increases in turbidity, color, and BOD for groundwater and surface waters.

Tap water samples collected at the consumers' end of the distribution system did not in general reflect on the true quality of the treated water. Mn, SO_4^{2-}, PO_4^{3-}, Cu, and Zn were among the chemical contaminations observed to occur in the distribution system. It is recommended that the local potable water supplying company or other interested parties conduct further investigation into the distribution system in the municipality to identify various points that could be acting as source contamination to the system and rectify the problem. There is also a general need for implementation or improvements in Mn and Fe removal in the various water sources to make them more suitable for general domestic usage.

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