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Full Length Research Paper

Microbiological quality and metal levels in wells and boreholes water in some peri-urban communities in Kumasi, Ghana

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Many communities in Kumasi, Ghana, are increasingly dependent on boreholes and hand dug wells. The aim of this study was to examine the drinking water suitability of 6 wells and 3 boreholes in peri-urban communities in Kumasi, between December 2003 and January 2005. Total coliforms, faecal coliforms and enterococci were enumerated using the standard most probable number method and membrane filtration methods. The heavy metals in the water samples were determined using the atomic absorption spectrometry method. Overall, significantly higher bacterial counts were recorded during the wet (rainy) season compared to the dry (harmattan) season. Faecal coliforms counts (FCC) in 3 borehole samples ranged between 3 x 10^1 and 3.5 x 10^7 per 100 ml (geometric means 1.82, 1.75 and 2.8 x 10^4) while mean numbers of enterococci were 10^3-10^5 times lower. The range and geometric means of FCC was similar in samples from wells but levels of enterococci were 8 times higher than in boreholes. Manganese and iron levels were well within the WHO standards for all 9 sites but lead levels except for one site (Boadi) were all higher than the WHO standard. A brief sanitation survey at each site suggested that wells and boreholes were frequently cited near latrines, refuse tips and other social amenities, and in the vicinity of domestic or grazing animals. In Kumasi, the water from shallow wells and boreholes, upon which the local communities depend is of poor quality. The data are being used to advise the local government. An integrated approach is required to minimise faecal pollution of wells and boreholes within peri-urban communities.

Key words: Boreholes, enterococci, faecal coliforms, peri-urban communities, total coliforms, wells.

INTRODUCTION

A primary concern of people living in developing countries is that of obtaining clean drinking water. In Africa and Asia, most of the largest cities utilise surface water but many millions of people in peri-urban communities and rural areas are dependent on groundwater. The situation is not different in Ghana, particularly in the rural areas. The Kumasi metropolis, the population of 489,586 in 1984 (Ghana Statistical Service, 1984). This had risen to about a million at the end of 1999 (Ghana Statistical Service, 2000) representing an annual growth rate of 2.5%. It is now recognised that the metropolitan authorities will need enormous financial resources to match the provision of infrastructural development for the ever-growing population if the city is not to degenerate into a slum within the next decade.

The provision of clean and safe drinking water is one of the major infrastructure problems for the metropolis. In urban Kumasi, it is estimated that 95% of households have access to treated piped water, which is received directly in their homes or at community standpipes (Ghana Water Company, 1998). However, this is not the

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case in the peri-urban communities. Due to the frequent and sometimes lengthy periods of interruption in the supply of treated piped water, many households rely on other sources of water such as wells, boreholes, springs and surface waters. The use of groundwater as the only source of potable water supply is increasing worldwide. In the United States, 90 - 95% (Howell et al., 1995) of rural and suburban water comes from this source and in Ghana, it is 62 - 71% (GEMS/Water Project, 1997). In an effort to provide cheap, safe and potable water for rural communities, the government of Ghana in collaboration with some non governmental organisations (NGOs) have constructed boreholes and hand dug wells all over the country. These non-treated water sources are being increasingly used as drinking water yet, testing to see whether the water is of good quality is almost non-existent. Secondly, because Kumasi has an undulating topography with many low-lying areas, communities which are unable to attract donor support have sunk numerous shallow wells of doubtful water quality. It is generally perceived that wells, springs and boreholes are “clean” sources of water. Although it is true that soils generally function to attenuate microorganisms by a simple filtration mechanism, especially larger bacteria and protozoa, pollution of groundwater by microorganisms, including those of public health significance do occur (Ashbolt and Veal, 1994; Stanley et al., 1998).

This paper examines the drinking water suitability of wells and boreholes in some peri-urban communities in Kumasi and the extent of their contamination with total coliforms, faecal coliforms and enterococci. The concentrations of lead, iron and manganese have also been determined.

MATERIALS AND METHODS

Sampling sites

The selected peri-urban communities were approximately within a 20 km radius of the Kwame Nkrumah University of Science and Technology, Kumasi. They lie between 6° 38' and 6° 41'N and 1° 32' and 1° 35'W in a forest belt (Figure 1). The soils of these areas are gravel deep, well drained and formed in sandy loam or gritty loam with a pH varying from 4.4 - 5.1 (Adu, 1992). The communities are characterised by poor housing, inadequate water and sanitation and overcrowding. The population in each of these communities ranges between 10,000 and 15,000 and many are mainly engaged in farming and petty trading. All the inhabitants rely solely on the wells and boreholes as there is no pipe borne water supply to these communities.

Sampling regime and collection

Monthly water samples were collected from all sites for one year from December 2000 to January 2001 (Figure 1). Sampling covered both the wet/rainy (April - June) and dry/ harmattan (November – February) seasons. A brief sanitation survey was carried out at each site.

Triplicate water samples were collected in sterile 500 ml Duran Schott glass bottles from each of the 9 community's well or borehole using a sterile plastic bag with a 10 m rope. Samples were kept in a cool box (8 - 10°C) during transportation to the laboratory and analysed within 6 h.

Enumeration of total coliforms, faecal coliforms and enterococci

Total coliforms, faecal coliforms and enterococci were enumerated by the standard most probable number method and membrane filtration methods (Anon, 1992; Obiri-Danso and Jones, 1999a). Results were expressed as the most probable number per 100 ml (MPN 100 ml^{-1}).

Determination of metal concentration

The concentrations of lead, iron and manganese in the water samples were determined using standard atomic absorption spectrophotometric methods. Sample collection, preservation and storage followed approved methods as outlined by APHA, AWWA, WEF (1998) and Eppinger et al. (2000). The water samples were collected in high-density linear polyethylene I-bottles. All water samples were filtered to remove particulate matter using a Sartorius polycarbonate filtering apparatus and 0.45 µm cellulose acetate filter membrane. The filtered samples were then acidified with pure nitric acid (HNO_3) to pH less than 2 (Appelo and Pootma, 1999). The determination of manganese, lead and iron was done using the VARIAN SpectraAA 220 Zeeman atomic absorption spectrometer (AAS) (Varian Canada Inc.).

Statistical analyses

The statistical packages of STATA and JMP were used for testing the various statistical relationships between variables (Anon, 1988). Raw data were transformed by adding a value of one to all scores in order to eliminate zero data points and then each datum point was converted to log_{10}. Multiple comparisons between sites were made by analysis of variance (ANOVA) and the Tukey-Kramer HSD test (Zar, 1984). Statistical significance was assessed at a = 0.05 (95% confidence).

RESULTS AND DISCUSSION

Microbiological quality of water samples from boreholes and wells

Microbial indicator organisms were present in all samples from the 9 wells and boreholes throughout the study irrespective of the time of sampling (Table 1). In boreholes at Ayeduase, Oduom and Kentinkrono geometric mean numbers of total coliforms were between 4.19×10^6 and 6.61×10^6 MPN 100 ml^{-1}. Average faecal coliform numbers were 100 times lower compared to total coliforms. Geometric mean (GM) faecal coliform numbers ranged between 1.75×10^4 and 2.80×10^4 while GM of enterococci was between 10^3 - 10^5 times lower. In well water samples, geometric mean numbers of microbial indicators were similar to boreholes. Geometric mean for total coliforms ranged between 3.07×10^6 and 1.68×10^7 MPN 100 ml^{-1} (Table 1). The geometric mean for faecal coliforms ranged 1.50×10^4 to 5.19×10^4. Geometric mean numbers of enterococci in the wells were eight

Table 1. Variations in microbial indicator numbers in boreholes and well water in peri-urban communities in Kumasi.

Sampling site	Total coliforms (MPN 100 ml^{-1})		Faecal coliforms (MPN 100 ml^{-1})		Enterococci (MPN 100 ml^{-1})	
	GM	Range	GM	Range	GM	Range
Borehole						
Ayeduase	5.46×10^6	3.00×10^1 - 3.60×10^8	1.82×10^4	4.00×10^1 - 3.5×10^6	1.29	0 - 10
Oduom	4.19×10^6	1.10×10^4 - 3.50×10^8	1.75×10^4	4.00×10^1 - 1.50×10^7	1.74	0 - 6
Kentinkrono	6.61×10^6	$1.50.\times 10^2$ - 1.50×10^9	2.8×10^4	3.00×10^1 - 2.10×10^7	12.26	1 - 36
Wells						
Bomso	5.84×10^6	3.00×10^3 - 2.10×10^9	5.19×10^4	1.50×10^2 - 2.10×10^7	53.46	4 - 145
Anwomanso	5.16×10^6	1.50×10^4 - 1.50×10^9	3.74×10^4	7.00×10^1 - 3.50×10^6	7.47	6 - 26
Ayigya	3.07×10^6	3.50×10^4 - 2.10×10^9	1.50×10^4	4.00×10^1 - 3.50×10^8	52.19	9 - 211
Emena	3.44×0^6	2.40×10^4 - 4.60×10^9	2.04×10^4	9.60×10^1 - 2.10×10^7	74.79	0 - 1152
Boadi	1.68×10^7	1.50×10^4 - 1.10×10^{10}	4.37×10^4	4.00×10^1 - 2.10×10^7	41.84	4 - 146
Kotei	3.60×10^6	1.50×10^2 - 1.20×10^9	1.70×10^4	3.00×10^1 - 1.20×10^7	19.31	5 -142

MPN- most probable number; GM- geometric mean.

times higher compared to the boreholes (Table 1).

Statistical analyses were carried out in order to detect differences between water qualities at the different sites Statistical analyses on borehole water showed no significant differences in total coliform ($p \leq 0.8862$) and faecal coliform ($p \leq 0.7120$) numbers between sites but enterococci counts were statistically significant between Ayeduase and Kentinkrono, and Oduom and Kentinkrono ($p \leq 0.0001$). There were no statistically significant differences in total coliform ($p \leq 0.6773$) and faecal coliform ($p \leq 0.7477$) numbers among all the wells studied.

Although WHO guidelines recommend the absence of microbial indicators in any 100 ml of drinking water this study recorded high numbers of total coliforms (10^6 - 10^7), faecal coliforms (10^4) and enterococci (10^1) for boreholes and wells. Treated pipe water received in consumer homes within the Kumasi metropolis sometimes contain coliform bacteria varying from 30 - 78 MPN 100 ml^{-1} total coliforms and 0 -18 MPN 100 ml^{-1} faecal coliforms (Quist, 1999). In a similar work on wells within urban Kumasi, Quist (1999) recorded lower faecal coliform counts of 1.45×10^5, 2.5×10^5 and 4.5×10^2. Musa et al. (1999), working on peri-urban and rural well water in Sudan, have also shown that faecal coliform counts in peri-urban water supplies were less than in rural water sources. They explained that this might be because these wells were better protected from surface contamination.

High microbial counts for potable water have been found in several earlier studies in the tropics. Thielman and Geurrant (1996), Feachem (1980), Cairncross and Cliff (1987) and Cairncross (1987) have all reported faecal coliform counts greater than 10^4 from rivers, ponds and wells in tropical countries. The proximity of domestic and grazing animals to water sources have been shown to play a role in the severity of faecal contamination of water sources (Tiedemann et al., 1988; Doran and Linn, 1979; Gary et al., 1983). All the communities in the present study raised their domestic animals (sheep, goat, cattle and poultry) through the free-range system. These animals roam the community in search of food and water and in the process indiscriminately contaminate with their faeces.

Sanitation survey

The sanitation survey revealed that wells did not have cover slabs. Well water was drawn normally using various receptacles (plastic or aluminium buckets) with varying degrees of hygiene. These receptacles were also used for other purposes including bathing and laundering. Similarly, there were no windlass on these wells and all users had to use one rope for drawing water which was often left in water that had been spilt around the well head. It is recommended that wells should be raised well above the surrounding ground level to divert run-off water but this was not the case with any of the wells included in this study. The construction and depth of the wells could further explain contamination levels. All the 6 wells studied were shallow, approximately 1.2 - 3.4 m in depth. The lining of all the wells was defective as they were fissured. Ideally, wells should be constructed with concrete ring pipes but due to financial constraints only the upper 2 m were cemented thus allowing easy seepage. Kumasi is a low lying area and one need not dig deep to hit the water table. Hence filtration, adsorption and trapping of bacteria by fine sandy materials, clays and organic matter is not effective (Wilson et al., 1983).

In comparison, boreholes had aprons that carried wastewater away from their immediate vicinity into a seepage area downhill. All 3 boreholes studied were fitted with hand pumps, thus preventing any human and animal contact with the water body. However, due to lack of regular maintenance of the hand pumps on these boreholes, they were not tightly mounted or fitted on their concrete platforms and the walls had cracks, which could allow dirty water back into them.

Lastly, all the studied wells and boreholes were sited within the communities' utility area. They were all approximately within a 10 m or less radius from pit latrines, refuse tips and other social amenities.

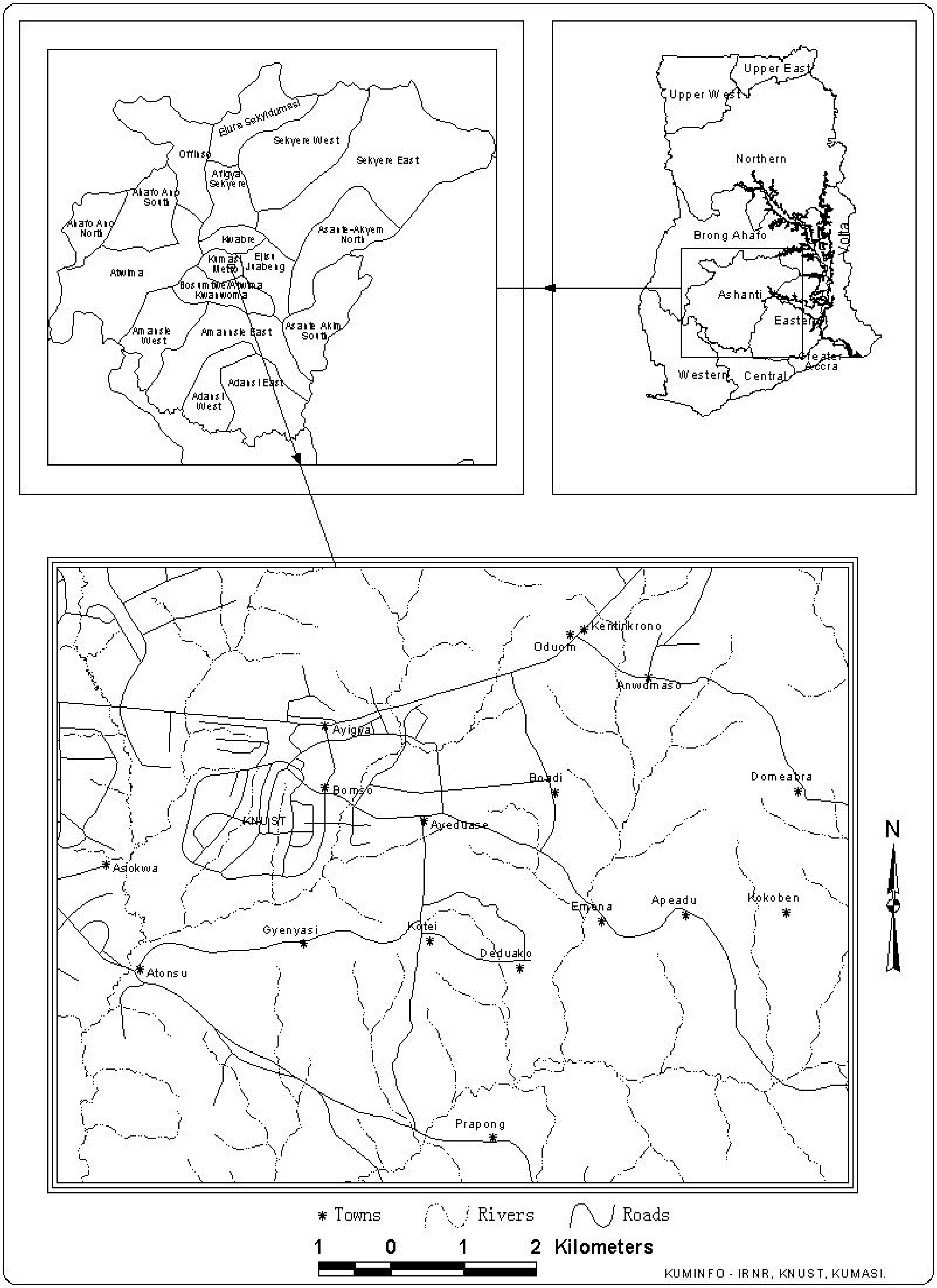

Figure 1. Map of the Kumasi metropolitan area showing the peri-urban sampling points with an insert of Ghana's map showing Kumasi in relation to the rest of the country. ●- the well/borehole water sampling points.

Table 2. Concentration of manganese, lead and iron in boreholes and wells in some peri-urban communities in Kumasi.

Sampling site	Concentration of metals mg l^{-1} (S.D)		
	Manganese	Lead	Iron
Borehole			
Ayeduase	0.018 ± (0.001)	0.074 ± (0.014)	0.001 ± (0.011)
Oduom	0.021 ± (0.001)	0.017 ± (0.004)	0.472 ± (0.030)
Kentinkrono	0.012 ± (0.001)	0.058 ± (0.042)	0.116 ± (0.002)
Well			
Bomso	0.028 ± (0.001)	0.059 ± (0.031)	0.274 ± (0.014)
Anwomaso	0.238 ± (0.003)	0.058 ± (0.026)	0.548 ± (0.007)
Ayigya	0.073 ± (0.001)	0.033 ± (0.018)	0.138 ± (0.004)
Emena	0.062 ± (0.005)	0.071 ± (0.020)	0.955 ± (0.010)
Boadi	0.077 ± (0.004)	0.005 ± (0.012)	0.354 ± (0.007)
Kotei	0.038 ± (0.004)	0.012 ± (0.022)	0.325 ± (0.013)

Cairncross and Cliff (1987) have shown that soakage pits and pit latrines can extend their influence on groundwater quality up to 10 m or more as groundwater flow is either lateral or vertical. Additionally, filtration does not occur during lateral flow and could carry faecal pollution for much longer distances (Cairncross, 1987) possibly resulting in contamination of well water with pathogens (Zoeteman, 1980; Craun, 1984). Pye and Patrick (1983) have shown that land disposal of sewage sludge, illegal dumping of septic tank pumpage, improper toxic waste disposal and runoff from agricultural operations all contribute to groundwater contamination with chemicals and microorganisms. The sample sites at Bomso, Ayigya, Emena and Boadi were all within 5 m of the community's open pit latrines and mountainous refuse dumps.

Occurrence and seasonality of microbial indicators

All wells and boreholes sampled showed a similar pattern of occurrence in microbial indicator bacteria numbers (Figures 2 and 3). Generally, higher bacteria counts were recorded during the rainy season compared to the dry harmattan season (Figures 2 and 3). The geometric mean numbers for total coliforms, faecal coliforms and enterococci in the boreholes and wells were about 10^4, 10^4 and six times higher respectively in the wet/rainy season compared to the dry/harmattan season and these differences were all statistically significant ($p \leq 0.0001$). However, seasonal differences in enterococci numbers in the Kentinkrono borehole were not statistically significant ($p \leq 0.8531$). Several researchers have reported seasonal variations in water quality. Works in north west England (Obiri-Danso and Jones, 1999a; 1999b; 2000), Nigeria (Blum et al., 1987), Gambia (Barrel and Rowland, 1987) and Kenya (Muhammed and Morrison, 1975) have all shown higher microbial counts in water sources during the wet season or after periods of rainfall compared to the dry season. This may be due to increased run-off from faecally polluted dry soils (Brooks and Cech, 1988). Similarly, water in the aquifer is "topped up" more rapidly after heavy rains and both the horizontal and vertical migrations of water are accelerated at such times. Bacteria held in the water are also carried through greater distances after periods of rain (Morgan, 1990).

Concentration of metals in boreholes and wells

The concentrations of manganese, lead and iron in the boreholes and wells varied between sites (Table 2). Values for manganese, lead and iron ranged 0.012 - 0.238, 0.005 - 0.074, and 0.001 - 0.955 mg l^{-1} respectively (Table 2). Highest concentrations of iron (0.955 mg l^{-1}) were recorded in the Emena well, lead (0.074 mg l^{-1}) in Ayeduase borehole and manganese (0.238 mg l^{-1}) in Anwomaso well. Generally, the concentration of manganese and iron were higher in the wells compared to the boreholes while lead concentrations were higher in the boreholes. The lowest manganese concentration (0.012 mg l^{-1}) was found in the Kentinkrono borehole, lowest lead (0.005 mg l^{-1}) in Boadi well and lowest iron (0.001 mg l^{-1}) in Ayeduase borehole. The WHO (2006; 2003) guideline on drinking water quality sets standards on permissible amounts of metals that are tolerable. These metals are often present in varying concentrations depending on prevailing factors (pH, temperature, water hardness and standing time of the water). Manganese, iron and lead were monitored because they account for most consumer complaints. WHO (2006; 2003) recommended standards for drinking water are 0.4, 2.0 and 0.01 mg l^{-1} for manganese, iron and lead, respectively. Manganese levels in all the 3 boreholes and 6 wells were within WHO (2006) standard (0.4 mg l^{-1}) (Table 2). Lead levels in all the boreholes and wells except the Boadi well were above WHO (2006) standard of 0.1 mg l^{-1}. All the wells and boreholes passed WHO (2003) standard for iron of 2.0 mg l^{-1} (Table 2). Iron is not harmful when at its appropriate concentration but gives a bitter taste to the water when present in large amounts. Unlike most orga-

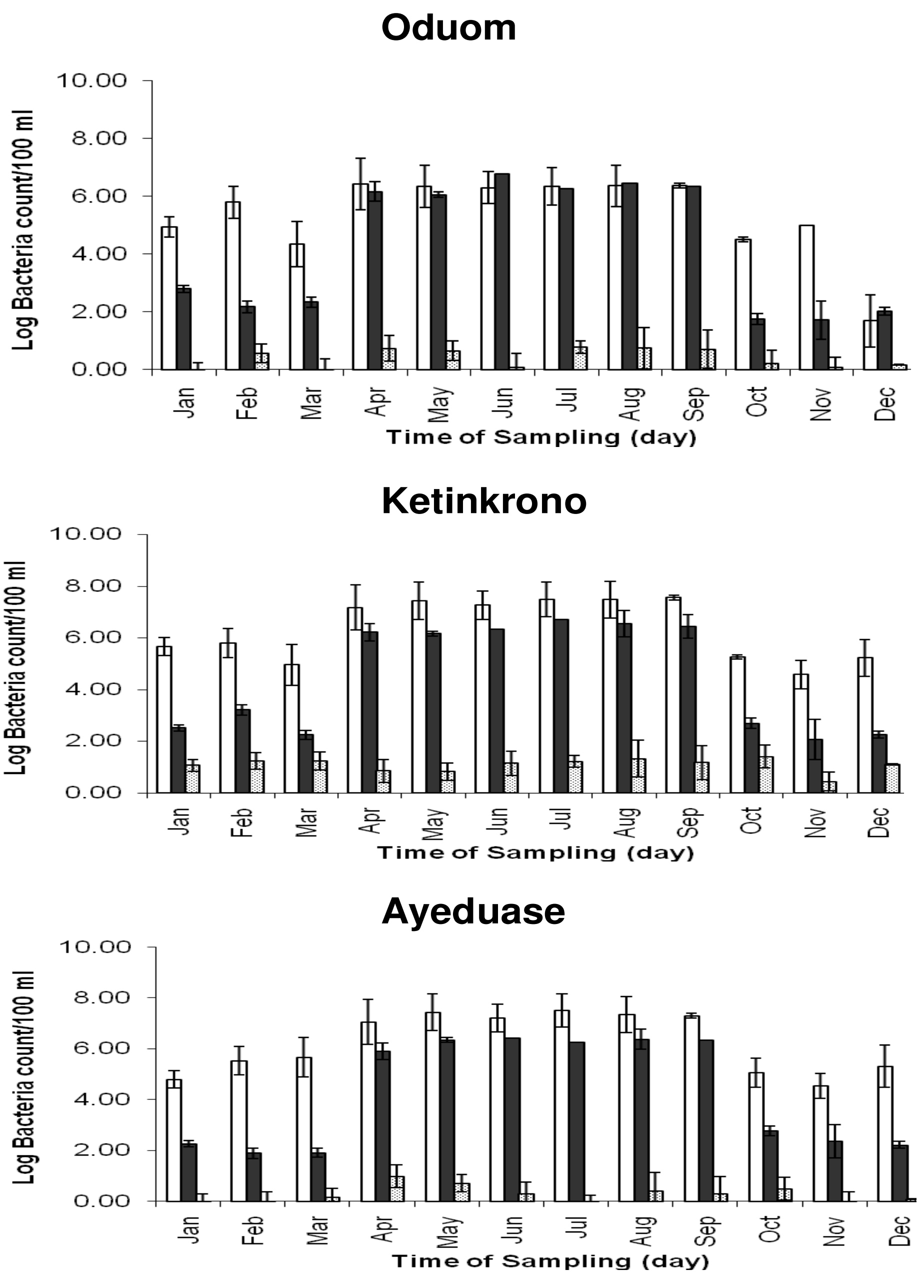

Figure 2. Microbial indicator numbers (100 ml^{-1}) in borehole water in some peri-urban communities in Kumasi. Each sample point is the mean triplicate monthly samples. Data are for total coliforms (open symbols), faecal coliforms (filled symbols) and enterococci (dotted symbols). Error bars represent standard errors.

nic and microbiological contaminants, many metals tend to accumulate in the top layer of the soil, which aggravates their effects on the local ecosystem (WHO, 2006).

Conclusion and Recommendations

The boreholes and wells analysed in the present study contained high microbial indicator counts which were considerably in excess of WHO recommended guidelines for drinking water (WHO, 2006). All microbial counts were higher during the rainy season. Groundwater contamination often correlates with areas of poor hygienic standards and sanitation. Minimising faecal pollution of wells and boreholes within communities must be an integrated approach. Developing sound water resource management programmes will be crucial to Ghana's poverty reduction, economic growth, food security and maintenance of natural systems. There is the need for greater community participation in water management.

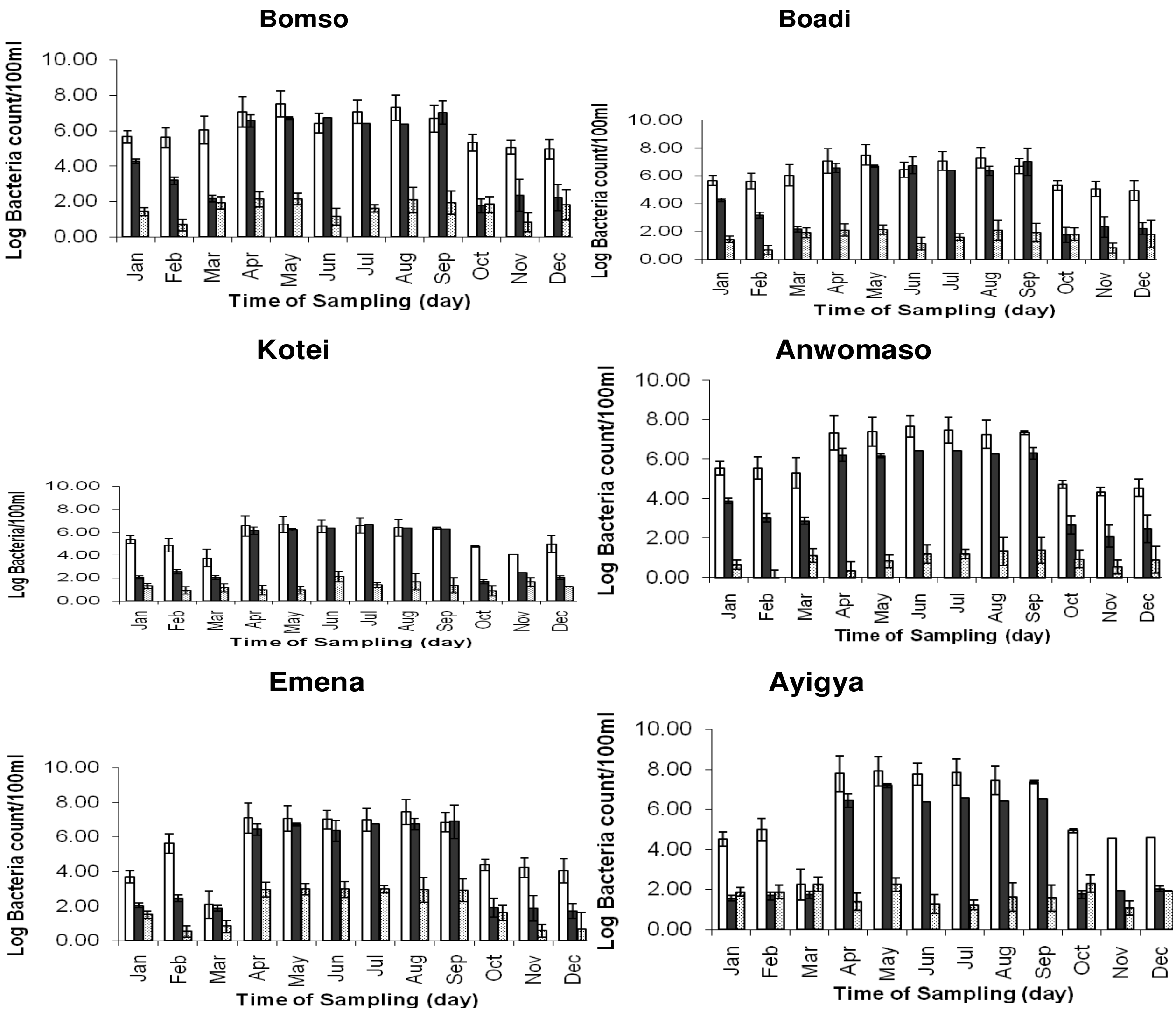

Figure 3. Microbial indicator numbers (100 ml^{-1}) in well water in some peri-urban communities in Kumasi. Each sample point is the mean triplicate monthly samples. Data are for total coliforms (open symbols), faecal coliforms (filled symbols) and enterococci (dotted symbols). Error bars represent standard.

Receptacles for drawing water from open wells should be kept clean and permanently attached to a windlass when not in use; well lids must be kept dry and clean and should be constructed as a single unit and not in pieces with openings at the joints to allow water through; the apron run-off and seepage area should be kept clean; wells must be well lined with concrete rings instead of cementing the upper 1 - 2 m as this would prevent the development of fissures within wells; hand pumps offer a greater degree of protection because they seal off the well/borehole from external sources of contamination and should thus be maintained; wells should be sited at higher elevations so as not to serve as a sink during rainfall; wells should be sited at least 30 m away from septic tanks, latrines and rubbish dumps; wells and boreholes aprons should be well reinforced with steel wire to avoid cracking and; access to wells and boreholes by domestic and grazing animals should be restricted by fencing.

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