Aspects of health-related microbiology of the Subin, an urban river in Kumasi, Ghana

K. Obiri-Danso, C. A. A. Weobong and K. Jones

ABSTRACT

The aim of this study was to assess the influence of urban waste, sewage and other human centred activities on the microbiological quality of the river Subin, which flows through the metropolis of Kumasi, Ghana, and serves as drinking water for communities downstream. Three sites, Racecourse, Asafo and Asago, on the Subin were monitored over a year for total coliforms, faecal coliforms, enterococci and biochemical oxygen demand. Bacterial indicator numbers (geometric mean 100 ml^{-1}) varied from 1.61×10^9 to 4.06×10^{13} for total coliforms, 9.75×10^8 to 8.98×10^{12} for faecal coliforms and 1.01×10^2 to 6.57×10^6 for enterococci. There was a consistent increase in bacterial loading as the river flows from the source (Racecourse) through Kumasi. Bacterial numbers were significantly ($p \leq 0.05$) higher during the rainy season compared with the dry (harmattan) season. The biochemical oxygen demand ranged from 8 mg l^{-1} at the source of the river to 419 mg l^{-1} at Asago; none of the sites achieved internationally accepted standards for water quality.

The River Subin becomes grossly polluted as it flows through Kumasi and at Asago, a rural community downstream of Kumasi that abstracts water from the river for drinking, this probably contributes to the observed high levels of diarrhoeal disease.

Key words | biological oxygen demand, coliforms, enterococci, urban river

K. Obiri-Danso
C. A. A. Weobong
Department of Biological Sciences,
Kwame Nkrumah University of Science & Technology,
Kumasi,
Ghana

K. Jones (corresponding author)
Department of Biological Sciences,
Lancaster Environment Centre,
Lancaster University,
Lancaster LA1 4YQ,
UK
Tel: 01524 593993
E-mail: *k.jones@lancaster.ac.uk*

INTRODUCTION

Faecal contamination of rivers is a major water quality issue in many fast growing cities where population growth far exceeds the rate of development of wastewater collection and treatment (Meybeck *et al.* 1989). Despite global efforts during the United Nations Water and Sanitation Decade of the 1980s, improvements in water and sanitation infrastructure have not kept pace with population growth and urbanisation in most developing countries (Mintz & Baier 2000).

The Subin is an urban river which runs through the commercial centre of metropolitan Kumasi, the second largest and fastest growing city in Ghana, with a growth rate of 2.6% and an estimated population of about a million (Statistical Service 2000). The river Subin receives untreated waste from two breweries, a soft drink factory, a teaching hospital, an abattoir, wood processing plants, outfall pipes from run-down sewage works and the city's refuse. Downstream, rural and peri-urban communities rely on it for domestic water supply and for watering livestock.

Unlike many developed countries, Ghana has no legislation on permitted microbial numbers in inland freshwater bodies, even though most are used extensively for various human contact activities. The need for higher inland water quality has been recognised by the Environmental Protection Agency of Ghana (GEPA), which is in the process of setting standards that will regulate the quality of inland water bodies. However, the GEPA has set limits for the permitted amount of microbial contamination in liquid effluent discharges to water bodies (GEPA Act 490 1994). Total coliforms in liquid effluent discharges should not exceed 400 per 100 ml and *E. coli* 10 per 100 ml.

This study examined the influence of urban waste, sewage effluent and human centred activities on the compliance of the Subin with internationally recognised water quality directives.

MATERIALS AND METHODS

Study area

The River Subin rises out of a spring at an abandoned racecourse (6° 45′N 1° 38′W) north of Kumasi and runs southwards through the city centre and merges with the River Oda at Asago (6° 45′N 1° 36′W), the site of a rural farming community (Dickson & Benneh 1980). The Subin covers an area of about 230 km^2 and has a mean flow rate of 0.243 $m^3 s^{-1}$ (*Meteorological Services Department Kumasi Airport Weather Station* 2000).

Kumasi is a metropolis centrally located in Ghana and most trade routes pass through it. It is the hub of trade, and the location for most food, textile and wood processing industries in Ghana. A small number of people, mostly at the periphery, are involved in growing food crops and grazing cattle and sheep.

Kumasi is located within moist semi-deciduous forest vegetation with a double maxima rainfall regime. The major rainfall season occurs between March and September, peaking in June and August. The mean annual rainfall is 1,300 mm and the mean temperature is 26 °C (*Meteorological Services Department Kumasi Airport Weather Station* 2000). Soils in Kumasi belong to the Bekwai, Nzema, Kokofu and Oda series. They are generally well drained except the Oda series, which is poorly drained, and is usually found in the low-lying areas or valley bottom. The soils are clayey or silt loams and are described as forest oxysols because of their 'sharp' or acidic nature (Adu 1992).

Sampling sites

The three main sites sampled on the River Subin were: an abandoned racecourse, which is the source of the river; Asafo, downstream of the commercial centre of the city; and Asago, a rural farming community which is south and downstream of Kumasi (Figure 1).

The source of the river is in a large basin that receives water from surrounding hills. The river appears to ooze out at the Racecourse site in a sacred grove that is not accessible to anybody. It has been suggested that some of the fears, norms and customs that are put in place within African societies act as environmental protection measures. The sampling point for this study was a spring, which is used by the general public and dries up during the severe dry season (i.e. January to April). The river basin remains wet during this period and contributes to the overall flow of the river.

Two effluent outflow pipes, from the Asafo Sewage System (ASS) and the Komfo Anokye Teaching Hospital (KATH), which discharge into the river at the Asafo site, were also sampled. The ASS outfall pipe services a dysfunctional sewage system and the KATH outfall pipe, a dysfunctional stabilization pond.

Sample collection

Monthly water samples were collected from the Racecourse, Asafo and Asago sites between November 2000 and October 2001. In May and June 2001 samples were collected from the ASS and KATH outfall pipes. Triplicate samples were collected in 500 ml sterile Duran Schott glass bottles and transported to the laboratory in a cool box for analysis.

Enumeration of coliforms

Coliforms were estimated using a three-tube most probable number method (MPN) according to *Standard Methods* (1992). Depending on the water type, river water or outflow water, dilutions of 10^{-1} to 10^{-25} were prepared in 0.1% buffered peptone water (BPW) (Oxoid CM509) and 1 ml of each dilution inoculated into six tubes containing 5 ml of minerals modified glutamate medium (Oxoid CM607). Three tubes from each dilution were incubated at 37 °C and three at 44 °C. Tubes showing acid and gas production after incubation for 48 h at 37 °C were scored as total coliforms. Tubes showing acid and gas at 44 °C after 24 h were confirmed as faecal coliforms by plating on MacConkey No.3 agar (Oxoid CM115) and examining for typical colonies. Counts per 100 ml were calculated from most probable number tables.

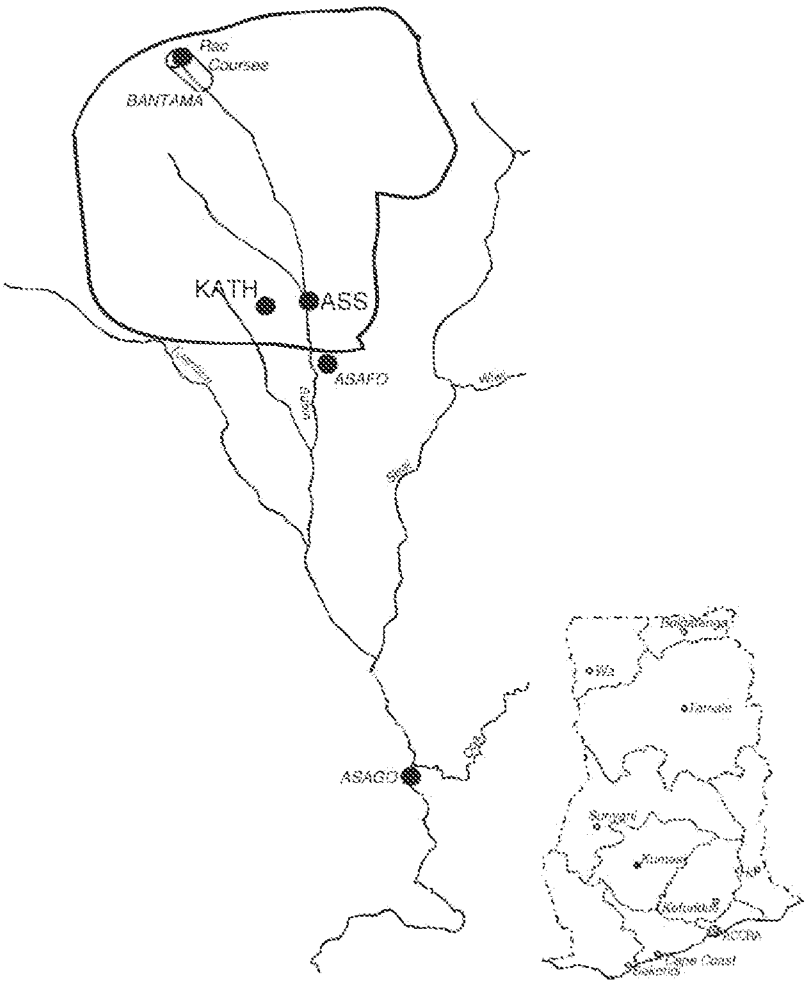

Figure 1 | Map of the River Subin and sampling points (●) with an insert showing Kumasi in relation to the rest of Ghana. Scale of the River Subin map is 1:62, 500.

Enumeration of enterococci

A membrane filtration technique was used in enumerating enterococci (*Standard Methods* 1992). Triplicate 10 ml water samples were filtered through white, grid marked, 47 mm diameter, Millipore HA-type, cellulose filters with a pore size of 0.45 μm. Samples were filtered using a vacuum pump at a pressure of 65 kPa (500 mmHg) and a triple glass filtration unit (Millipore, Bedford). The filters were placed with the grid side upwards on Petri dishes of Slanetz and Bartley agar (Oxoid CM377) and incubated for 4 h at 37 °C and for 44 h at 44 °C. Red, maroon or pink colonies were counted as presumptive streptococci. Presumptive colonies were confirmed on MacConkey No. 2 agar (Oxoid CM109). Counts were expressed as cfu 100 ml^{-1}.

Biochemical oxygen demand (BOD)

Five-day biochemical oxygen demand (BOD) levels in water samples were determined using the Winkler's method (azide modification) and standard laboratory procedures (*Standard Methods* 1992).

Health survey

Two sets of data on the prevalence of diarrhoeal diseases among children (0–15 yr), which had been collected over the two-year period preceding this study, were obtained from the Medical Field Unit, Ministry of Health, Kumasi. The first set was from the Asago Health Centre, which treats people whose main source of water is the Subin downstream of Kumasi, and the other was from the University (KNUST) hospital, which treats people with access to treated, piped water.

Statistical analysis

The statistical package for social sciences (SPSS) was used for testing the various statistical relationships between variables (Anon 1988). Raw data for coliforms and enterococci were transformed by adding a value of one to all scores in order to eliminate zero data points, then each datum point was converted to $\log_{10}$. A one-way randomised analysis of variance (ANOVA) was used to analyse the data.

RESULTS

Quality of the River Subin

The geometric mean numbers and ranges of indicator bacteria at the three sites on the River Subin are shown in Table 1 and Figure 2. There was a consistent increase in bacterial loading as the Subin flowed downstream from its source (Racecourse) although differences in indicator numbers between the Asafo and Asago sites were not statistically significant for total coliforms ($p \leq 0.797$), faecal coliforms ($p \leq 0.649$) or enterococci ($p \leq 0.860$). The river dries up at its source (Racecourse) in the months of December to April (Figure 2).

Biochemical oxygen demand levels

Mean BOD levels ranged between 8 and 419 $\mathrm{mg\,l^{-1}}$ (Table 2). In general, BOD levels increased as the river flowed downstream with Asago recording the highest value at 419 $\mathrm{mg\,l^{-1}}$.

Bacterial quality of inflows into Subin

Geometric means (100 $\mathrm{ml^{-1}}$) of bacterial contamination of effluent outflows from the KATH and ASS outfall pipes into the Subin close to the Asafo sampling site are shown in Table 3.

Seasonality of microbial indicators

The seasonal variation in bacterial indicators during the dry (November to February) and wet (March to June) seasons is

Table 1 | Bacterial indicator counts (geometric means and ranges) from the Racecourse, Asafo and Asago sites on the River Subin, Kumasi, Ghana

Bacteria	Sampling site	Geometric mean (log S.D.)	Range
Total coliforms	Racecourse	4.11×10^{10} (1.11)	1.61×10^{9}–2.27×10^{12}
	Asafo	5.05×10^{11} (1.46)	2.71×10^{9}–4.06×10^{13}
	Asago	5.57×10^{11} (1.52)	3.79×10^{9}–3.70×10^{13}
Faecal coliforms	Racecourse	1.67×10^{10} (1.18)	9.75×10^{8}–1.10×10^{12}
	Asafo	1.04×10^{11}(1.20)	2.11×10^{9}–8.98×10^{12}
	Asago	1.49×10^{11} (1.40)	1.09×10^{9}–5.87×10^{12}
Enterococci	Racecourse	4.03×10^{2} (0.94)	1.01×10^{2}–3.04×10^{4}
	Asafo	2.61×10^{4} (0.68)	9.01×10^{2}–2.54×10^{5}
	Asago	3.46×10^{4} (1.35)	1.59×10^{2}–6.57×10^{6}

n = 72 for Asafo and Asgo sites and 42 for the Racecourse site.
Total coliforms and faecal coliforms results are average geometric means of MPN estimations per 100 ml of river water.
Enterococci results are average geometric means of cfu 100 $\mathrm{ml^{-1}}$.

shown in Figure 2. Generally, significantly higher bacterial counts ($p \leq 0.05$) were recorded during the wet season compared with the dry harmattan season (Figure 2).

Health survey

The prevalence of diarrhoeal diseases was highest in children in the 4–7 year age group and lowest in the 12–15 year group (Table 4). The prevalence of diarrhoea in all age groups was much higher in the patients attending the Asago Health Centre, which treats mainly people deriving their water from the Subin, compared with those attending the University (KNUST) hospital, which treats mainly people with access to treated, piped water.

DISCUSSION

The results of the study show that the River Subin is extremely polluted with faecal material and that the quality substantially deteriorates as it flows from the source (Racecourse), through the commercial centre of Kumasi (Asafo) to the south of the metropolis (Asago). Ideally, the water would be expected to be pristine in quality at its source, but average bacterial numbers were high for total coliforms (10^{11}) and faecal coliforms (10^{10}) (Table 1). The reason for the high bacterial counts at the source of the Subin could be several. Firstly, a cluster of first cycle schools located within a 15–30 metre radius of the Racecourse site have no built latrines and pupils defecate in the open during school hours. Their faeces are eventually washed into the river as the Racecourse is on lower ground relative to the schools. Secondly, a large flock of white-headed vultures (*Trigonoceps occipitalis*) and hooded vultures (*Necrosyrtes monarchus*) forage and drink in the source basin during the day. Birds shed substantial amounts of indicator bacteria in their faeces (Jones & Obiri-Danso 1999) and in a nearby abattoir Ghanaian hooded vultures have been shown to shed faecal coliforms at a rate of 2.35×10^9 to 4.65×10^{13} per gram wet weight of faeces, enterococci at a rate of 1.27×10^4 to 1.37×10^7 and campylobacters at a rate of 2.10×10^4 to 2.40×10^5 (Obiri-Danso & Jones 2002).

The Asafo sampling site, which is just south (downstream) of the heart of the city's commercial activity, generally has insufficient public toilets and garbage bins to accommodate the large daily influx of traders. Consequently, traders and buyers resort to unsanitary practices, urinate and defecate into open gutters and other open spaces and into polythene bags, which ultimately find their way into the river. Other sources of pollution include faeces from the different species of animals housed at the Kumasi zoological museum, and waste from traditional chop bars

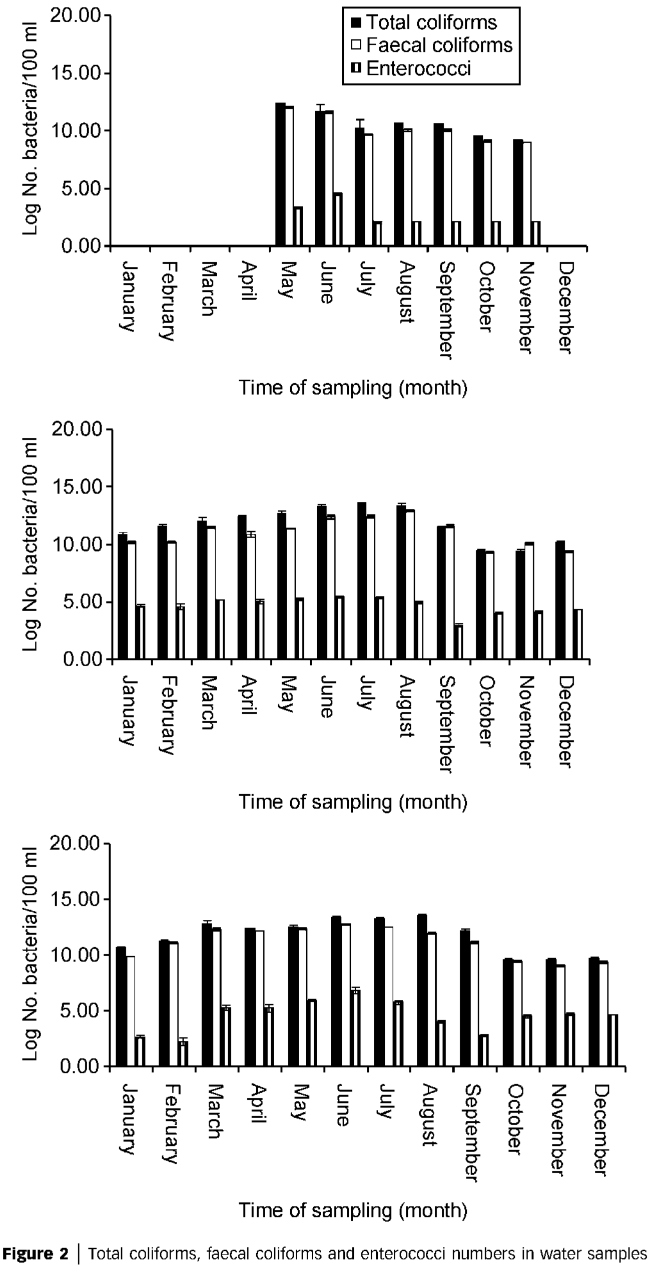

Figure 2 | Total coliforms, faecal coliforms and enterococci numbers in water samples from the Racecourse, Asafo and Asago sites on the River Subin.

Table 2 | Mean levels of biochemical oxidation demand in the River Subin at the Racecourse, Asafo and Asago sampling sites

Sampling site	Mean BOD levels ($mg\,l^{-1}$)	Range ($mg\,l^{-1}$)
Racecourse	13.00	8.02–48.05
Asafo	156.00	21.00–217.00
Asago	315.05	29.00–419.00

and restaurants. The river at Asafo is greatly influenced by point source effluents discharged from the Komfo Anokye Teaching Hospital (KATH) and Asafo Sewage System (ASS) outfall pipes (Table 3) which are a few metres upstream of the sampling site. Untreated wastewater from hospitals is known to be rich in microorganisms, including pathogenic species (Tsai *et al.* 1998). In Ghana, the Environmental Protection Agency (GEPA) Directive (GEPA Act 490 1994) has limits for permissible numbers of microbial indicators in liquid effluents discharged into natural water bodies. This should not exceed 400 total coliforms $100\,ml^{-1}$ and 10 faecal coliforms (*E. coli*) $100\,ml^{-1}$. However, effluents from the ASS outfall pipe contained 10^{25} total coliforms and 10^{22} faecal coliforms and the KATH effluents contained 10^{19} total coliforms and 10^{15} faecal coliforms (Table 3) and far exceed what is recommended by the GEPA (GEPA Act 490 1994).

A study in Ghana by Salifu and Mumuni (2000) revealed that abstraction of water from rivers is the main source of potable water supply for most urban centres. The third sampling site of this study was Asago, which is a rural community that relies heavily on the river Subin for its water needs. Unfortunately, 500 metres upstream of this site, the Kumasi Metropolitan Authority discharges untreated human sewage and animal faeces from the main abattoir onto an open field close to the banks of the river. The loading of ruminant faeces with faecal coliforms and enterococci is similar to that of humans (Standridge *et al.* 1979; Yogasundram *et al.* 1989; Wyer *et al.* 1994; Kudva *et al.* 1997; Jones & Obiri-Danso 1999; Jones *et al.* 1999). In addition, effluents from three major food industries (Ghana Breweries, Guinness Ghana, Coca-Cola Bottling) and over 30 wood processing industries discharge their untreated waste into the Subin close to the Asago site.

The bulk of the city's refuse is carried into the Subin River. This refuse is mainly organic in nature. Organic industrial wastes from the food and beverages industry, the many foodstuff sellers and wood wastes from the timber processing industries are washed into the river during periods of heavy or extended precipitation. This may explain why higher indicator bacterial numbers were recorded during the rainy season compared with the dry harmattan period. All three sites had high BOD with values ranging from 8.00 to $419.00\,mg\,l^{-1}$. The source, at least fell within the average value of $12\,mg\,l^{-1}$ recommended for tropical inland water bodies (Biney 1986) but the Asafo and Asago sites show progressive pollution with BOD values of several times the recommended value (Table 2). Other urban rivers in Ghana have similar BOD values: for example, $8.29\,mg\,l^{-1}$ for the river Fosu in Cape Coast, 80.00 for the Korle Lagoon in Accra, and 153.00 for the Agbobloshie river in Accra (Biney 1986). These results are in

Table 3 | Range of indicator bacteria numbers in outflows pipes from the Asafo sewage system and the Komfo Anokye Teaching Hospital

	Asafo sewage system		Komfo Anokye Teaching Hospital	
Bacteria	Geometric mean (log S.D.)	Range	Geometric mean (log S.D.)	Range
Total coliforms	4.09×10^{25} (0.67)	5.81×10^{24}–2.38×10^{26}	3.45×10^{19} (0.51)	2.30×10^{19}–4.60×10^{20}
Faecal coliforms	1.47×10^{22} (0.81)	1.53×10^{21}–1.41×10^{24}	6.73×10^{15} (0.63)	9.15×10^{14}–4.30×10^{17}
Enterococci	2.28×10^{10} (0.35)	3.53×10^{9}–1.02×10^{11}	2.31×10^{8} (0.20)	1.32×10^{7}–3.30×10^{9}

n = 12.
Total coliforms and faecal coliforms results are average geometric means of MPN estimations per $100\,ml^{-1}$.
Enterococci results are average geometric means of cfu $100\,ml^{-1}$.

Table 4 | Prevalence (%) of diarrhoeal-related illnesses in children reporting sick at the Asago Health Post and the University (KNUST) Hospital between 1998 and 2000

	Prevalence (%) of diarrhoeal diseases	
Age (years)	Asago Health Post	University Hospital
0–3	45.42	15.36
4–7	67.71	21.58
8–11	41.77	9.23
12–15	28.58	5.17

Source: Medical Field Unit, Ministry of Health, Kumasi.

marked contrast to those obtained for the river Odzi, a clean, non-urban African river in the Eastern Highlands of Zimbabwe (Jonnalagadda & Mhere 2001). When polluted with agricultural run-off and effluents from fisheries, BOD levels in the Odzi approached $5\,\mathrm{mg\,l^{-1}}$ but normally they were much lower, with values of $1.50\,\mathrm{mg\,l^{-1}}$ in the dry season and 2.90 in the wet season.

In developing countries, the incidence of diarrhoeal diseases due to water consumption varies substantially between communities because of varying water quality and other behavioural and socio-economic factors (Esrey *et al.* 1991). For example, in south-eastern China, where the incidence of diarrhoea was related to the source of drinking water (Chen *et al.* 1991), the attack rate was 0.575 per person per year in those drinking piped water, 0.846 in those drinking well water and 4.580 in people drinking river water. van Derslice and Briscoe (1995) reported that, in areas with poor environmental sanitation, improved drinking water would have little or no effect; however, in areas with good community sanitation, reducing faecal coliform counts by two orders of magnitude would reduce the incidence of diarrhoea by 40%. In this study there was a strikingly higher rate of diarrhoeal diseases in the Asago community, which mainly uses water extracted from the Subin, compared with the rate in the KNUST (University) community, which uses treated, piped water (Table 4).

There are no formal standards in Ghana for inland river water quality. It is, however, instructive to check the compliance of the Subin with the EU Bathing Water Quality Directive (76/160/EEC) (Official Journal of the European Communities 1976) on recreational water quality. All three sampling sites, Racecourse, Asafo and Asago sites, scored zero passes when measured against the EU Guideline Directive of less than 100 faecal coliforms per 100 ml and 100 enterococci per 100 ml of water, or when the Imperative Directive of less than 2,000 faecal coliforms per 100 ml was used (Figure 2). The situation with drinking water is even bleaker. Treated, piped water supplies should contain no faecal coliforms per 100 ml of water (WHO 1993). Ramteke *et al.* (1992) highlight the problems small communities in tropical developing countries have in meeting drinking water standards and discuss the rationale of increasing the permitted level of total coliforms from 10 to 50 per 100 ml and faecal coliforms from 1 to 5 per 100 ml. At Asago, where water is abstracted for community use, the Subin contains 1.49×10^{11} faecal coliforms per 100 ml, higher even than the worst cases cited by Feacham (1980) for other countries in Africa. The Subin is not unique. Amuzu (1997) has reported that most urban river sources in Ghana are highly polluted.

Faecal pollution in the Subin is significantly higher in the rainy season than in the drier harmattan season, presumably due to higher run-off rates. This appears to be the situation in several tropical areas where it has been shown to be associated with higher rates of diarrhoea (Musa *et al.* 1999).

This study confirms that the river Subin becomes grossly polluted as it flows through Kumasi and that it poses risks to health for people abstracting the water downstream.

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