*Letters in Applied Microbiology* 2003, **37**, 334–339 doi:10.1046/j.1472-765X.2003.01403.x

# The microbiological quality of drinking water sold on the streets in Kumasi, Ghana

**K. Obiri-Danso[1], A. Okore-Hanson[1] and K. Jones[2]**
[1]*Department of Biological Sciences, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, and* [2]*Department of Biological Sciences, Lancaster University, Lancaster, UK*

2003/0241: received 21 March 2003, revised 25 June 2003 and accepted 15 July 2003

## ABSTRACT

K. OBIRI-DANSO, A. OKORE-HANSON AND K. JONES. 2003.

**Aim:** The aim of this study was to assess the microbiological quality of Ghanaian bottled and plastic-bagged drinking water sold on the streets of Metropolitan Kumasi, Ghana.

**Methods and Results:** Eight bottled, 88 factory-filled plastic sachet and 40 hand-filled hand-tied polythene-bagged drinking waters were examined for the presence of heterotrophic bacteria total viable counts (TVCs), indicators of faecal contamination (total coliforms, faecal coliforms and enterococci) and for lead, manganese and iron. Heterotrophic bacteria were found in all three types of water with TVCs per millilitre ranging from 1 to 460 for bottled water, 2–$6{\cdot}33 \times 10^5$ for factory-bagged sachet water and $2{\cdot}33 \times 10^3$–$7{\cdot}33 \times 10^{12}$ for hand-filled hand-tied bagged water. None of the microbial indicators of faecal contamination were detected in bottled water, whereas 4·5% of the factory-bagged sachets contained total coliforms and 2·3% faecal coliforms, and 42·5% of the hand-filled hand-tied bags contained total coliforms, 22·5% faecal coliforms and 5% enterococci. Iron was found in all three types of drinking water but at concentrations well within the WHO recommendations. Lead and manganese were not detected.

**Conclusion:** Ghanaian bottled water is of good microbiological quality but some factory-bagged sachet and hand-filled hand-tied polythene-bagged drinking water are of doubtful quality.

**Significance and Impact of the Study:** Factory-bagged sachets and hand-filled hand-tied bags of drinking water sold in Ghana should be monitored for microbiological contamination, with the aim of raising standards in the industry and re-assuring the public.

**Keywords:** Factory plastic-bagged, hand-tied-hand-filled.

## INTRODUCTION

The past decade has seen a dramatic increase in the consumption of bottled and, more especially, plastic-bagged drinking water in Ghana. The increase in demand for these iced water products is driven by (a) changes in fashion towards the consumption of designer water, (b) increased concerns about the safety of the piped water supply, and (c) an increased influx of people into the major shopping areas with a requirement for good drinking water (Green and Green 1994; Hunter 1994). At present, there is inadequate information on the microbiological quality of these water products and it is important that the consumers can be assured of their quality and safety.

The proliferation of such water products raises the question as to whether they are hygienically produced, especially when the poor sanitary environment in urban Ghana is taken into account. Poverty and the absence of jobs in rural Ghana have increased the number of street children in the urban cities. Unfortunately, it this group of society, which has to look after itself and is lacking in basic human hygiene, that is involved in the ice water trade because the

*Correspondence to: Keith Jones, Department of Biological Sciences, Lancaster University, LA1 4YQ, UK (e-mail: k.jones@lancaster.ac.uk).*

starting capital is low and affordable (see Child Labour In Ghana http://www.iearn.org.au/clp/write82.htm).

Factory plastic-bagged sachet water was introduced into the Ghanaian market as an improvement on the types of vended waters produced in Ghana. Hitherto, water was sold either from a bucket with a single cup for all consumers or in hand-filled hand-tied polythene bags. The latter are still bought in large numbers because they are inexpensive. The standard of hygiene in the various stages in the production of the factory plastic-bagged sachet water is similar to bottled water. Most manufacturers use multicandle pressure filters (Berkefield, Doulton, UK), which employ an active carbon filter bed that removes sand, rusts, metal sediments, algal films and bacteria from the water (Hunter and Burge 1987). The bags are closed using heat-sealing machines.

In contrast, bare hands are used at each stage in the production of the hand-filled hand-tied polythene-bagged water, bringing with it the risk of contamination at every stage. There is no form of sterilization. Filtration is carried out by the use of unsterilized foam fixed onto the end of a water hose. Polythene bags are opened by blowing air into them by mouth, with the obvious potential for introducing bacteria, and sealed by tying a knot at one end, again by hand. All three forms of water are termed 'iced water' because they are cooled in a refrigerator after bagging or bottling. Ice is not added as blocks or is iced water used to fill the bottles or bags.

The origin of the water for each of the three iced water products is treated piped water, or occasionally, well water. Although natural mineral waters, which are the usual source for bottled water in the developed world, may not be entirely free of bacterial contamination (Defives *et al.* 1999), most bacteria are thought to enter as contaminants during bottling or bagging.

The purpose of this study was to evaluate the safety of Ghanaian bottled and bagged drinking water by enumerating microbial indicators of faecal contamination (coliforms and enterococci) and the quality by measuring total heterotrophs and the concentrations of lead, iron and manganese.

## MATERIALS AND METHODS

### Water samples

Triplicate batches from the three types of water sold in Kumasi Metropolis were used for the study. Eight were plastic-bottled water brands, three of which were bottled locally and two from foreign manufacturers; 88 were factory plastic-bagged sachet drinking water brands from local Ghanaian manufacturers; and 40 were different unlabelled hand-filled hand-tied polythene bags of drinking water (Table 1).

### Sampling

Water samples of the various brands and from the different manufacturers were bought from markets, shop shelves and street vendors within the Kumasi Metropolis and transported to the laboratory in a cool box.

### Isolation and enumeration of total and faecal coliforms and enterococci

Total coliforms, faecal coliforms and enterococci were enumerated by membrane filtration using 100-ml aliquots of the water samples as described by Obiri-Danso and Jones (1999a,b) and Anon. (1994).

### Enumeration of total heterotrophic bacteria or total viable count (TVC)

Estimations of the total population of heterotrophic bacteria in the water samples were obtained using the pour plate technique. Dilutions of $10^{-1}$ to $10^{-6}$ of water samples were prepared in 0·1% buffered peptone water (Oxoid) and triplicate 1 ml aliquots of each dilution inoculated into 10 ml each of molten plate count agar (Lab M, Bury, UK) in universal bottles. These were then thoroughly mixed, poured into sterile Petri dishes and incubated for 48 h at 22°C. Petri dishes from dilutions containing between 20 and 50 discrete colonies were counted and the results expressed as the number of bacteria per millilitre (Anon. 1994).

### Identification of isolates

Forty-four isolates were selected and maintained at 4°C on brain heart infusion (Oxoid CM 225) for speciation. Representative isolates from the TVCs (20), total coliforms (14), faecal coliforms (eight) and faecal streptococci (two) were identified. Coliforms were identified phenotypically using API 20E, enterococci using API 20 STREP and heterotrophs using API 20 NE (bioMérieux, Lyon, France).

### Metal analysis

Iron, lead and manganese concentrations were analysed in all eight brands of bottled water, in 10 of the factory-bagged waters, and in 10 of the hand-filled hand-tied water samples using standard atomic absorption spectrophotometric methods (Perkin Elmer 5100PC, Perkin Elmer, Boston, MA, USA) (Anon. 1992).

## RESULTS

The numbers of heterotrophic bacteria contained in bottled, factory-bagged sachet and hand-filled hand-tied

Table 1 Bottled, factory-filled plastic sachets and hand-filled hand-tied polythene-bagged drinking waters sold on the streets of Metropolitan Kumasi, Ghana, and investigated in this study

| Water Type | | | |
|---|---|---|---|
| Bottled water | | | |
| Ghanaian | Aqua fill | Ice cool | Voltic |
| Astek | Yes | Bon Aqua | |
| International | Evian | La Vie | |
| Factory-filled plastic sachets | | | |
| Abodwo Nsuo | Onyame Na Aye | Vigimike | Century |
| Adams | Fountain | Foanco | Maame Forwaa |
| Adehye | Fresh | Obaapa | Lolly White |
| Adom Insu | Geoliza | Bresuo | Reindeer |
| Anthonious | Sir Duke | Precious stone | Oasis |
| Boadwo | Y2K | By His Grace | Roses |
| Christa | Ultimate | Frontiers | Shelter |
| Emmanuel's | Yerbisa | Quality | Ellen |
| Five star | Bosomtwe | Sanat | Volcano |
| Francophone | Davidia | Millennium | Praises |
| Genno | Cheers | Mo Maria | Francis |
| Blessed Treated | Ellena | O'one | Lovely |
| Anocumps | Wabos | Obey Your Thirst | Lord's |
| Calvary | Willis | Dove | Majesty |
| Elma | Totway | The Thirst | Medo Me Man |
| Hi-Bee | Akwaaba | Trampio | Mizu |
| Ideal | Love | Angels | Mobile |
| Jesus saves | Smile | Bensuo | Dancharty |
| Kube Nsuo | Kay | Pleasure | Asuo Kwaw |
| Sweetie | Lin | Lobito | Valentine |
| Original | For The Lord | Rainbow | Womborombo |
| Jepphir | Daily Hope | Winners | Rhema |
| Forty different unlabelled hand-filled hand-tied polythene-bagged water | | | |

polythene-bagged samples of drinking water sold within the Kumasi Metropolis, are shown in Table 2.

## Bottled drinking water

Total coliforms, faecal coliforms and enterococci were not isolated in any of the eight different brands (three batches) of bottled drinking water. However, TVCs ranged between 1 and 460 $ml^{-1}$ water (Table 2).

## Factory plastic-bagged sachet drinking water

Four (4·5%) of the 88 factory plastic-bagged sachet drinking water contained total coliforms, Blessed Treated (13 100 $ml^{-1}$), Mo Maria (10 100 $ml^{-1}$), Frontiers (10 100 $ml^{-1}$) and By His Grace (13 100 $ml^{-1}$); two (2·3%) contained faecal coliforms, Blessed Treated (10 100 $ml^{-1}$) and By His Grace (10 100 $ml^{-1}$); and none contained enterococci.

In the 10 factory-filled sachet brands selected at random and tested for TVCs, numbers of heterotrophic bacteria ranged between 2 and $6{\cdot}33 \times 10^5$ $ml^{-1}$ (Table 2).

## Hand-filled hand-tied polythene bags of drinking water

Seventeen (42·5%) of the hand-filled hand-tied polythene drinking waters were positive for total coliforms ranging from 10 to 67 100 $ml^{-1}$; nine (22·5%) were positive for faecal coliforms ranging from 10 to 20 100 $ml^{-1}$ and two (5%) were positive for enterococci (both 0·3 100 $ml^{-1}$). Of the 10 randomly selected hand-tied polythene drinking water samples chosen for analysis, numbers of heterotrophic bacteria ranged from $2{\cdot}23 \times 10^3$ to $7{\cdot}33 \times 10^{12}$ $ml^{-1}$ (Table 2).

## Speciation of bacteria isolated during total coliform, faecal coliform, enterococcal and TVC enumerations

Of the 14 isolates from total coliform analyses, nine were identified as *Escherichia coli*, biotype 5140552 (API 20E), three as *Klebsiella pneumoniae*, biotype 5015763 (API 20E) and two as *Citrobacter freundii* biotype 1644572 (API 20E).

All eight of the isolates from the faecal coliform analyses were *Escherichia coli* biotype 5140552 (API 20E) and both

**Table 2** Mean total viable counts in bottled, factory-filled plastic sachet and hand-filled hand-tied polythene-bagged drinking waters sold on the streets of Metropolitan Kumasi, Ghana

| Water brand | Mean total | Range |
|---|---|---|
| Bottled | | |
| Ice Cool | $3{\cdot}06 \times 10^1 \pm 0{\cdot}227$ | 4–460 |
| Yes | $8{\cdot}75 \times 10^1 \pm 0{\cdot}222$ | 1–220 |
| Voltic | $6{\cdot}55 \times 10^1 \pm 0{\cdot}121$ | 8–130 |
| Aquafill | $2{\cdot}75 \times 10^1 \pm 0{\cdot}139$ | 4–100 |
| Evian | $2{\cdot}35 \times 10^1 \pm 0{\cdot}146$ | 1–120 |
| La Vie | $6{\cdot}25 \times 10^1 \pm 0{\cdot}198$ | 2–100 |
| Astek | $7{\cdot}25 \times 10^1 \pm 0{\cdot}136$ | 5–150 |
| Bon Aqua | $1{\cdot}25 \times 10^1 \pm 0{\cdot}254$ | 4–200 |
| Factory-filled plastic | | |
| Nice | $2{\cdot}10 \times 10^3 \pm 0{\cdot}272$ | $2{\cdot}17 \times 10^1$–$6{\cdot}33 \times 10^6$ |
| O'one | $1{\cdot}52 \times 10^3 \pm 0{\cdot}244$ | $2{\cdot}13 \times 10^2$–$5{\cdot}67 \times 10^6$ |
| Daily Hope | $6{\cdot}70 \times 10^2 \pm 0{\cdot}249$ | $2{\cdot}00 \times 10^1$–$6{\cdot}33 \times 10^7$ |
| Geoliza | $1{\cdot}72 \times 10^3 \pm 0{\cdot}171$ | $2{\cdot}23 \times 10^2$–$5{\cdot}00 \times 10^6$ |
| Life | $1{\cdot}97 \times 10^3 \pm 0{\cdot}186$ | $2{\cdot}00 \times 10^2$–$4{\cdot}33 \times 10^6$ |
| Century | $2{\cdot}68 \times 10^3 \pm 0{\cdot}287$ | $2{\cdot}20 \times 10^2$–$6{\cdot}67 \times 10^6$ |
| Blessed Treated | $1{\cdot}10 \times 10^3 \pm 0{\cdot}272$ | $2{\cdot}17 \times 10^2$–$6{\cdot}33 \times 10^6$ |
| Onyame Na Aye | $7{\cdot}30 \times 10^2 \pm 0{\cdot}272$ | 2–$7{\cdot}33 \times 10^4$ |
| Mo Maria | $5{\cdot}80 \times 10^2 \pm 0{\cdot}266$ | 2–$5{\cdot}57 \times 10^4$ |
| Francophone | $5{\cdot}00 \times 10^2 \pm 0{\cdot}217$ | 2–$6{\cdot}37 \times 10^4$ |
| Hand-filled hand-tied polythene-bagged water | | |
| 1 | $1{\cdot}53 \times 10^8 \pm 0{\cdot}462$ | $2{\cdot}17 \times 10^4$–$6{\cdot}33 \times 10^{11}$ |
| 2 | $1{\cdot}38 \times 10^8 \pm 0{\cdot}014$ | $2{\cdot}13 \times 10^4$–$5{\cdot}67 \times 10^{11}$ |
| 3 | $1{\cdot}65 \times 10^7 \pm 0{\cdot}303$ | $2{\cdot}00 \times 10^4$–$6{\cdot}33 \times 10^{11}$ |
| 4 | $2{\cdot}83 \times 10^7 \pm 0{\cdot}192$ | $2{\cdot}23 \times 10^3$–$5{\cdot}00 \times 10^{12}$ |
| 5 | $1{\cdot}08 \times 10^7 \pm 0{\cdot}167$ | $2{\cdot}00 \times 10^4$–$4{\cdot}33 \times 10^{11}$ |
| 6 | $1{\cdot}59 \times 10^8 \pm 0{\cdot}091$ | $2{\cdot}20 \times 10^4$–$6{\cdot}67 \times 10^{11}$ |
| 7 | $1{\cdot}66 \times 10^8 \pm 0{\cdot}246$ | $2{\cdot}17 \times 10^5$–$6{\cdot}33 \times 10^{12}$ |
| 8 | $1{\cdot}15 \times 10^7 \pm 0{\cdot}163$ | $2{\cdot}37 \times 10^4$–$7{\cdot}33 \times 10^{12}$ |
| 9 | $1{\cdot}73 \times 10^7 \pm 0{\cdot}145$ | $2{\cdot}00 \times 10^4$–$5{\cdot}57 \times 10^{11}$ |
| 10 | $1{\cdot}90 \times 10^7 \pm 0{\cdot}236$ | $1{\cdot}76 \times 10^5$–$6{\cdot}37 \times 10^{11}$ |

Total viable counts (TVCs) were performed on 10 samples each of factory plastic-bagged sachets and hand-filled hand-tied polythene bags of water. Bacterial numbers are expressed as the TVCs per millilitre water.

the enterococci were *Enterococcus avium* biotype 5143321 (STREP).

Of the 20 randomly selected colonies from the TVC medium six were identified as *E. coli* biotype 5140552 (API20E), 11 as *Pseudomonas aeruginosa* biotype 2012006 (API 20NE) and three as *Aeromonas hydrophila* biotype 3044137 (API 20NE).

## Metal analysis

*Bottled drinking water.* All the brands of bottled water were negative for lead and manganese. Iron was found in one brand, Astek, at a concentration of 0·001 mg $l^{-1}$.

*Factory plastic-bagged sachet drinking water.* Lead and manganese were not detected in any of the brands. Iron was detected in all 10 samples analysed, at concentrations ranging from 0·01 to 0·10 mg $l^{-1}$ (Table 3). The highest concentrations were recorded in the Francophone and Life brands and the lowest in the Daily Hope, Onyame Na Aye, and Nice brands (Table 3).

*Hand-tied-hand-filled polythene-bagged drinking water.* Lead and manganese were not detected in any of the hand-filled hand tied polythene water samples. Iron concentrations were 20 times higher than in the factory plastic-bagged sachet water and 200 times higher than in the bottled water.

## DISCUSSION

This study shows that drinking water sold on the streets and outlets in the Kumasi Metropolis, Ghana, is of variable microbial safety and quality. Of the water sold in polythene

**Table 3** Concentration of lead, manganese and iron in factory-filled plastic sachets and hand-filled hand-tied polythene bags of drinking waters sold on the streets of Metropolitan Kumasi, Ghana

| | Iron concentration (mg $l^{-1}$) |
|---|---|
| Factory-filled plastic sachet water | |
| Nice | 0·01 ± 0·001 |
| O'One | 0·02 ± 0·001 |
| Daily Hope | 0·01 ± 0·001 |
| Geoliza | 0·02 ± 0·001 |
| Life | 0·10 ± 0·001 |
| Century | 0·03 ± 0·001 |
| Blessed Treated | 0·01 ± 0·001 |
| Onyame Na Aye | 0·01 ± 0·001 |
| Mo Maria | 0·03 ± 0·001 |
| Francophone | 0·10 ± 0·001 |
| Hand-filled hand-tied polythene-bagged water | |
| Type 1 | 0·02 ± 0·001 |
| Type 2 | 0·01 ± 0·001 |
| Type 3 | 0·20 ± 0·001 |
| Type 4 | 0·10 ± 0·001 |
| Type 5 | 0·20 ± 0·001 |
| Type 6 | 0·20 ± 0·001 |
| Type 7 | 0·10 ± 0·001 |
| Type 8 | 0·10 ± 0·001 |
| Type 9 | 0·10 ± 0·001 |
| Type 10 | 0·20 ± 0·001 |

Metal analysis was performed on 10 samples each of factory plastic-bagged sachets and hand-filled hand-tied polythene bags of water.

bags, almost half (43%) of the hand-filled hand-tied and 5% of the factory-bagged sachet waters were contaminated with bacteria of faecal origin. These results are confirmed by the data for the numbers of heterotrophic bacteria, which are indicative of quality standards in general. TVCs were much higher in the hand-filled hand-tied waters and on occasion were very high indeed ($7{\cdot}33 \times 10^{12}$ $ml^{-1}$).

The factory-bottled waters were all of good microbial quality with the local brands (Astek, Aqua fill, Ice Cool, Yes, Bon Aqua and Voltic) comparing favourably with foreign imported brands (Evian and La Vie) (Table 2). The absence of faecal indicator bacteria in bottled water is attributed to good hygienic practices in the industry, which include, use of protective sealed caps on bottles, improved dispenser designs, nonreturnable plastic containers, brand labels, and manufacturing and expiry dates.

The presence of faecal indicators, *P. aeruginosa* and *Aeromonas* in bagged waters has been reported to be due to poor hygienic practices of producers, failure to wash hands, illiteracy and sheep and goats in the vicinity of factories (Coroler *et al.* 1996). In Kumasi, the use of bare hands at every stage in the production of the hand-filled hand-tied polythene-bagged water is a probable source of bacterial contamination. The contribution made by hands has been emphasized by research in South America, where the quality of vended polythene-bagged water was much improved by filling the bags through a funnel instead of by hand (K. Stanley, personal communication). However, as Ghanaian bottled and plastic bagged water comes mainly from treated piped water supplies and Quist (1999) has demonstrated that, of 120 treated tap water samples collected from domestic and public standpipes in seven suburbs of Kumasi, 35 were positive for faecal coliforms at levels of between 10 and 28 of bacteria 100 $ml^{-1}$, this can be an additional source of contamination.

If TVCs are taken as a measure of general standards of cleanliness in assessing the different types of water, the Ghanaian bottled and factory-bagged sachet water compares very well with the European Community standards. The European Community sets an upper limit of 100 heterotrophic bacteria per millilitre for spring water and $10^5$–$10^6$ $ml^{-1}$ for still mineral water (Anon. 1998). The Kumasi study shows that TVCs in bottled water varied from 1 to 460 $ml^{-1}$ and in factory plastic-bagged sachet water from 2 to $6{\cdot}33 \times 10^5$ $ml^{-1}$ and hand-tied polythene water ($2{\cdot}23 \times 10^3$ to $7{\cdot}33 \times 10^{12}$). The reason for the varying counts in the three brands of water could be several. First, the high TVCs in the hand-filled hand-tied polythene-bagged water will be mainly due to the original contamination of the piped water and poor hygienic practices used in its preparation. They are normally produced and consumed within 24 h and this should prevent extensive bacterial growth. However, in bottled and factory-bagged sachet water, the containers used in packaging are produced in very large quantities, stored over a long period of time and used when needed. Ferreira *et al.* (1994) and Leclerc (1994) have shown that TVCs in natural mineral waters are low at around 10 CFU $ml^{-1}$, but Warburton *et al.* (1992) have demonstrated that the numbers increase after bottling to $10^3$–$10^5$ bacteria $ml^{-1}$ and occasionally to $10^7$ within 2–7 days. This compares well with our study although the Ghanaian bottled water comes from piped water and not natural mineral waters. Warburton *et al.* (1992) have also shown that stored, unused bottles can contain bacteria and may be a factor in the overall contamination of the finished product. Secondly, the length of time and conditions that bottled and factory plastic-bagged water remain in distribution before reaching the consumer provides an opportunity for already established bacteria to grow and increase in number. Thirdly, Hunter and Burge (1987) have shown that charcoal filters used in removing objectionable tastes and odours from drinking water can support large bacterial populations as they concentrate both bacteria and organic nutrients. Bacterial numbers as high as $7 \times 10^6$ $ml^1$ were detected in the effluent from a charcoal filter 6 days after installation. Most Ghanaian manufacturers use beds or columns of ion-exchange resins or activated carbon, but these can also support similar bacterial growths unless properly maintained and serviced. Fourthly, polythene bags used in bagging sachet water are imported as hoses that are cut into appropriate sizes and one side heat sealed before being sent to printing houses for labelling, all of which can lead further contamination. There is no evidence that high counts of heterotrophic bacteria have had health effects but TVCs are good indicators of the overall quality of production (Ferreira *et al.* 1994).

Lead, iron and manganese are the biggest sources of consumer complaints in the water industry (Anon. 1995). No lead and manganese were detected in the three water types although iron was present in all three. The detection limit for lead was 0·05 mg $l^{-1}$ and for manganese 0·01 mg $l^{-1}$. Water distribution pipes in Ghana and most developing countries are mainly made of iron. They have frequently undergone considerable corrosion and have been shown to readily contaminate the water supply with metal particulates or turbidity-producing materials (Pelig-Ba *et al.* 1991). High concentrations of iron in groundwater occur in many places in Ghana and can be as high as 21·50 mg $l^{-1}$ (Adzaku 1989). The use of metal buckets in the ice water trade and the generally high levels of iron in Ghanaian waters could explain the levels of iron in the three types of water (Pelig-Ba *et al.* 1991). High iron concentrations are not directly a health risk but can cause unpleasant odour and taste (Smedley *et al.* 1995). Fortunately, the levels of iron found in this study were all within the WHO recommended standard (WHO 1993).

Overall, it would seem prudent for Ghanaians to select their iced water with care and to opt for the more expensive bottled waters. This is also the case with street vended foods, which have been shown to be a source of enteropathogens in Ghana (Mensah *et al.* 2002). The authors suggest that vendors should receive education in food hygiene and a similar case can be made for the street vended water in Kumasi.

## ACKNOWLEDGEMENTS

We are grateful to the Society of General Microbiology and UNESCO for the funding of equipment and consumables used in this research.

## REFERENCES

Adzaku, J.C. (1989) *A Study of the Effect of Groundwater Quality on Pump Materials in the Tropical Rain Forest Zone of Ghana*. Water Research Institute Annual Report. Accra: CSIR.

Anon. (1992) *Standard Methods for the Examination of Water and Wastewater*, 18th edn ed. Greenberg, A.E., Clesceri, L.S. and Eaton, A.D. Washington, DC: Baltimore, American Public Health Association, APHA/AWWA/WPCF.

Anon. (1994) *The Microbiology of Water 1994. Part 1: Drinking Water, Report on Public Health and Medical Subjects, no. 71. Methods for the Examination of Waters and Associated Materials*. London: HMSO.

Anon. (1995) *Drinking Water and Environmental Quality 1995: Safeguarding the Environment*. North West Water Quarterly Report, 1995. Warrington: North West Water Limited.

Anon. (1998) Council Directive of 3 November 1998 Concerning the Quality of Water Intended for Human Consumption (98/83/EC). *Official Journal of the European Communities* **L330**, 32–54.

Coroler, L., Elomari, M., Hoste, B., Gillis, M., Izard, D. and Leclerc, H. (1996) *Pseudomonas rhodesiae* sp. nov., a new species isolated from natural mineral waters. *Systematic and Applied Microbiology* **19**, 600–607.

Defives, C., Guyard, S., Oularé, M.M., Mary, P. and Hornez, J.P. (1999) Total counts, culturable and viable, and non-culturable microflora of a French mineral water: a case study. *Journal of Applied Microbiology* **86**, 1033–1038.

Ferreira, A.C., Morais, P.V., Gomes, C. and Da Costa, M.S. (1994) Alterations in total bacteria, iodonitrophenyltetrazolium (INT) positive bacteria and heterotrophic plate counts of bottled mineral water. *Canadian Journal of Microbiology* **40**, 72–77.

Green, M. and Green, T. (1994) Water the boom. In *The Good Water Guide* ed. Green, G. and Green, T. pp. 6–7. London: Rosendale Press.

Hunter, P.R. (1994) Bottled natural mineral water and other bottled waters. *Microbiology Europe* **2**, 8–9.

Hunter, P.R. and Burge, S.H. (1987) The bacteriological quality of natural mineral waters. *Epidemiology and Infection* **99**, 439–443.

Leclerc, H. (1994) Les eaux minerales naturelles: flore bacteriénne native, nature et signification. *Eaux Minérales* **94**, 49–60.

Mensah, P., Yeboah-Manu, D., Owuso-Darko, K. and Ablordey, A. (2002) Street foods in Accra, Ghana: how safe are they? *Bulletin of the World Health Organisation* **80**, 546–554.

Obiri-Danso K. and Jones, K. (1999a) The effect of a new sewage treatment plant on faecal indicator numbers, campylobacters and bathing water compliance in Morecambe Bay. *Journal of Applied Microbiology* **86**, 603–614.

Obiri-Danso, K. and Jones, K. (1999b) Distribution and seasonality of microbial indicators and thermophilic campylobacters in two freshwater bathing sites on the River Lune in northwest England. *Journal of Applied Microbiology* **87**, 822–832.

Pelig-Ba, K.B., Biney, C.A. and Antwi, L.A. (1991) Trace metal concentration in borehole waters from the Upper regions and the Accra plains of Ghana. *Water, Air and Soil Pollution* **103**, 71–89.

Quist, K.A. (1999) Faecal indicators in drinking water in the urban area of Kumasi. *MSc dissertation*, Biological Sciences, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

Smedley, P.L., Edmunds, W.M., West, J.M., Gardner, S.J. and Pelig-Ba, K.B. (1995) *Health Problems Related to Groundwater in the Obuasi and Bolgatanga Areas, Ghana*. British Geological Survey Technical Report WC/95/43, 122 pp.

Warburton, D.W., Dodds, K.L., Burke, R., Johnston, M.A. and Laffay, P.S. (1992) A review of the microbiological quality of bottled water sold in Canada between 1981 and 1989. *Canadian Journal of Microbiology* **38**, 12–19.

WHO (1993) *Guidelines for Drinking Water Quality*, Vol. 1, Recommendations. Geneva: WHO Publication.