Ghana J. Sci **49** (2009), 77-88

BACTERIOLOGICAL QUALITY AND POSSIBLE HEALTH EFFECTS OF GRAVITY-PIPED WATER IN HOHOE DISTRICT OF GHANA

S. S. KORANTENG* AND C. M. AMOAH
(S. S. K.: Department of Botany, University of Ghana, P.O. Box LG 55, Legon- Accra, Ghana; C. M. A.: Volta Basin Research Project (VBRP), University of Ghana, P.O. Box LG 209, Legon-Accra, Ghana.)
**Corresponding author's Email:sskoranteng@yahoo.com*

Abstract

A simple technology termed Gravity-Piped Water System (GPWS) has been used in the Hohoe District in the Volta Region of Ghana to provide drinking water without any disinfection treatment. Ten years after the establishment of the GPWS, there were complains about the incidence of diarrhoea diseases, colouration of water and sediment in some of the systems put in place to provide potable water. The paper reports on bacteriological quality and health implications of water at various points (source, reservoir, standpipe and individual homes) of four GPWS in four communities in the Hohoe District over two seasonal regimes for three consecutive years, 2005–2007. Conventional cultural methods, as specified by APHA (1995), were used to detect the resident faecal and total coliform bacteria. Biochemical methods, employing API 20E identification kit and serological tests, were used to confirm the presence of bacteria species and diarrhoeagenic agents, respectively. Structured questionnaires were used to obtain medical information. With the exception of the source at one of the communities, Nyagbo Israel, all points of the GPWS were heavily contaminated with Enterobacteria. Ten gram-negative non-sporing bacteria of possible health consequences belonging to the family Enterobacteriaceae were isolated from water samples at all points. The presence of diarrhoeagenic agents, enterotoxigenic *E. coli* (ETEC), enteropathogenic *Escherichia coli* (EPEC), *Salmonella* and *Shigella* species were confirmed. All the systems showed a trend of reduction in parameters from source to tap, with no significant elevations in the homes. Enteric diseases peaked in rainy seasons (August-October). Medical reports support a strong link between diarrhoeal incidence and water used. The practical implications of the findings are discussed.

Introduction

Majority of the world's population does not have access to adequate supply of safe drinking water and proper sanitation. Higher child mortality, for example, is closely linked with inadequate supply of clean water (Young, Dooge & Rodday, 2004). An estimated 88 per cent of global disease burden is attributable to unsafe drinking water supply, inadequate sanitation, and poor hygiene (Gundry *et al*., 2006). Since 1990, the number of people without access to safe water sources has remained constant at approximately 1.1 billion (Clasen *et al.,* 2007; Mintz *et al.,* 2001) of whom approximately 2.2 million die of waterborne disease each year (Mintz *et al.*, 2001). For instance diarroheal diseases alone are responsible for an estimated 3.5 billion episodes and 1.8 million deaths annually worldwide (Benjamin *et al.* 2007; Clasen *et al.*, 2009). In developing countries, diarrhoea is a leading cause of mortality and morbidity and accounts for 17 per cent of deaths among children aged less than 5 years (Benjamin *et al.*, 2007).

In Ghana, conscious efforts are being made by the government, through the Danish International Development Agency (DANIDA), to provide potable water of good quality to the majority of the rural communities by taking advantage of ground water resources. DANIDA, under the Rural Water Supply and Sanitation Project (RWSSP), undertook to improve and make potable water accessible to many communities in the Volta Region of Ghana by exploiting the spring and ground water resources. Hohoe District of the Volta Region, in particular, is endowed with numerous springs that flow perennially and could be harnessed to solve water supply and sanitation problems. In accessing the spring water resources, a simple technology called the Gravity-Piped Water System (GPWS) was launched in 1993 (Fig. 1). Provision of GPWS under the RWSSP was based on Demand Responsive Approach and Community-based Management concept. Currently, the main sources

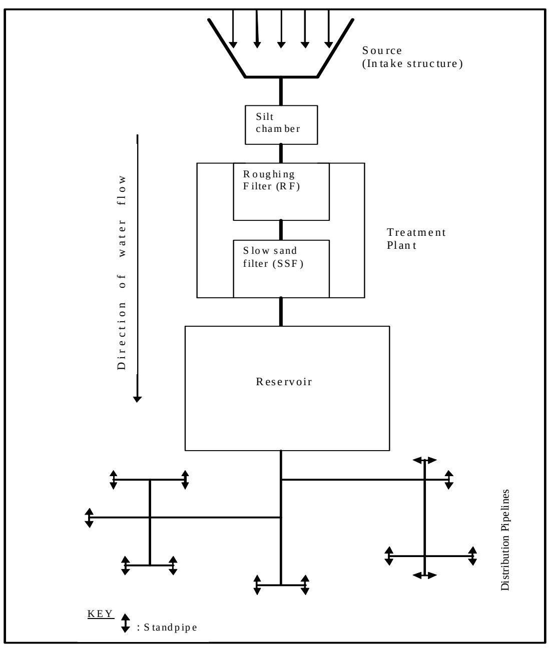

Fig. 1. A scheme of a typical Gravity-Piped Water System.

of water in the Hohoe District and the percentages of relative dependence on them for domestic use are as follows: pipe borne water (4%), boreholes (51%), GPWS (38%) and streams (7%) (Hohoe District Assembly, 2004). Apart from metropolitan Hohoe, (the district capital), provision of treated pipe borne water is not found anywhere else in the district.

Wherever the gravity system is found, as in the case in the Hohoe Distrct of Ghana, it constitutes a main source of domestic water supply. Findings by Water Research Institute (WRI) of the Council for Scientific and Industrial Research (CSIR), Ghana, however, indicated the presence of faecal coliform bacteria (FC) in all samples of spring water from the District (WRI, 1994, 1996a, 1996b), suggesting permanent contamination and risk to human health. Moreover, there are reported incidence of sporadic outbreak of water-related diseases like diarrhoea, dysentery, cholera and subsequent deaths in some communities of the Hohoe District using GPWS (Hohoe District Assembly, 2004). The aim of the paper is, therefore, to investigate the bacteriological quality of water produced by the GPWS in four communities of the Hohoe District of Ghana and its possible health implications, especially with respect to their predisposal to diarrhoeal diseases.

Experimentals

Study area and rainfall data

The study area is located between longitude 0^{o} 15` E and latitude $6^{o}$ 45` E, and latitude 6^{o} 45` N and $7^{o}$15` N in the middle section of the Volta Region of Ghana and shares boundaries with the Republic of Togo in the east. Annual rainfall is between 1016 mm and 1210 mm. The area experiences 4–5 months dry season between December and April. The rainy season starts from late May and ends in November, with the first peak occurring in June/July and the second in September/October.

Gravity-Piped Water System in the following four communities were selected for the study:

Nyagbo Israel (NI), Tafi Agorme (TA), Santrokofi Bume (SM) and Santrokofi Gbordome (SG). The incidence of diarrhoea in each community presumably reflects the quality of water from the system that serves it. The two Santrokofi communities, Santrokofi Bume and Santrokofi Gbordome, experienced very high diarrhoea incidence and were, therefore, included in the studies to represent communities with GPWS where diarrhoea is highly endemic and the water quality considered very poor.

Water quality from the system at Nyagbo Israel has been established by Community Water and Sanitation Agency to be the best in the District and the diarrhoea incidence in this community was also very low. It was, therefore, chosen for the purpose of comparison. The system at Tafi Agorme was considered to be of intermediate quality, and diarrhoea incidence here was less severe. The systems in the four communities could, therefore, be representative of GPWSs in the entire District in general.

The Gravity-Piped Water System

The Gravity- Pipe Water System (GPWS) is a type of system where water is piped downhill from a source through gravitational action to communities (Jordan, 1980). Normally, spring and stream sources located at elevations higher than the communities are used for this purpose. The spring source is normally very remote and inaccessible. However, an intake structure is conveniently built across the stream at an appropriate point to dam and hygienically collect the water. The intake structure then serves as the source of the GPWS. From the intake structure, water is immediately passed through a silt chamber that removes about 80 per cent of suspended solids (CWSA, 1999). From here, water is piped down into a reservoir built at a lower elevation but just above the community, through a buried pipeline made of high density polyethylene. Water from the reservoir is then distributed to several public standtaps through distribution lines by gravity. Because of the presence of suspended particles, treatment plants may be included in the system (Fig.1). The treatment plant is a filtration medium usually made up of roughing filters (filled with layers of gravel of various sizes) and slow sand filters, consisting of ungraded fine sand free from clay and loam. It does not include any chemical treatment.

Sample collection

Water samples were collected from four sampling points: source, reservoir, standpipes and from individual homes in each of the four selected communities. Monthly water samples were collected over a period of 7 months, i.e. June–September (rainy season); December-February (dry season), for 3 years (2005–2007). Water samples were collected into wide-mouthed pre-sterilised 500 ml glass bottles and kept on ice and transported to Water Research Institute (WRI) laboratory.

Laboratory analyses

Suspended solid (SS) was analysed gravimetrically using glass-fibre filter papers. Total coliform (TC) and faecal coliform (FC) populations were determined by the membrane-filter technique using mEndo agar, and mFC agar respectively (APHA, 1995). Isolation and subsequent identification of bacteria were done using Eosin Methylene Blue (EMB) agar, standard biochemical tests (Cheesbrough, 1992) and API 20E Kit (Bio Merieux, 1992). *E. coli* (1) O sera (Denka Seiken No. 24506, Tokyo, Japan) were used to serologically type for enterotoxigenic (ETEC), enteropathogenic (EPEC), enterohaemorrhagic (EHEC), enteroinvasive (EIEC) and enteroaggregative (EAggEC) strains of *E. coli*. Laboratory data on diarrhoeal stool examination were collected from the Hohoe District hospital and the District Health Directorate. Structured questionnaires, as well as interviews, were conducted to gather information on some medical issues concerning possible causes of diarrhoea from the use of water from the GPWS in the study area. Results were analysed statistically using the SPSS and Microsoft Excel programmes. Analysis of variance was used to determine significant levels of TC and FC between various sampling points in communities whilst Paired sample t-tests was employed to determine the significance levels of their numbers between the seasons.

Results

Faecal coliforms (FC) and total coliform (TC) value reduced from sources to taps, (Fig. 2). Values were significantly higher in the rainy season (TC, 18 – 2886 and FC, 2 – 721 cfu/100 ml) than in the dry season (TC, 10 – 590 and FC, 0 – 181 cfu/100 ml). Sites at Nyagbo Israel recorded low values of TC and FC whilst sites at Santrokofi Bume and Santrokofi Gbordome recorded high values. About 70 per cent of respondents indicated they wash their water receptacles twice a week, 23 per cent weekly, 5 per cent fortnightly and 2 per cent daily. The levels of TC and FC in homes for both seasons were not significantly different from those from taps ($P \geq 0.05$) in most of the communities (Fig. 2). The TC load was reduced by 30 – 58 per cent between sources and taps of the systems during rainy seasons.

Table 1 shows the types of bacteria isolated from the various points of the system in each community. Gram-negative, non-sporing bacteria belonging to the Family Enterobacteriaceae were isolated from water samples at all points. These were *E. coli*, *K. pneumoniae*, *P. mirabilis*, *P. vulgaris*, *Aeromonas hydrophila*, *C. luteola* *P. cepacia*, *Acinetobacter* spp, *Salmonella* spp and *Shigella* spp. Serological tests on suspected *E. coli* colonies confirmed the presence of enterotoxigenic *E. coli* (ETEC) and enteropathogenic *E. coli* (EPEC). *Salmonella* and *Shigella* species were also confirmed from serological tests (Table 1). Table 2 presents medical records of diarrhoea cases from the studied communities, in 2002–2006. Over 90 per cent and 60 per cent of stools of

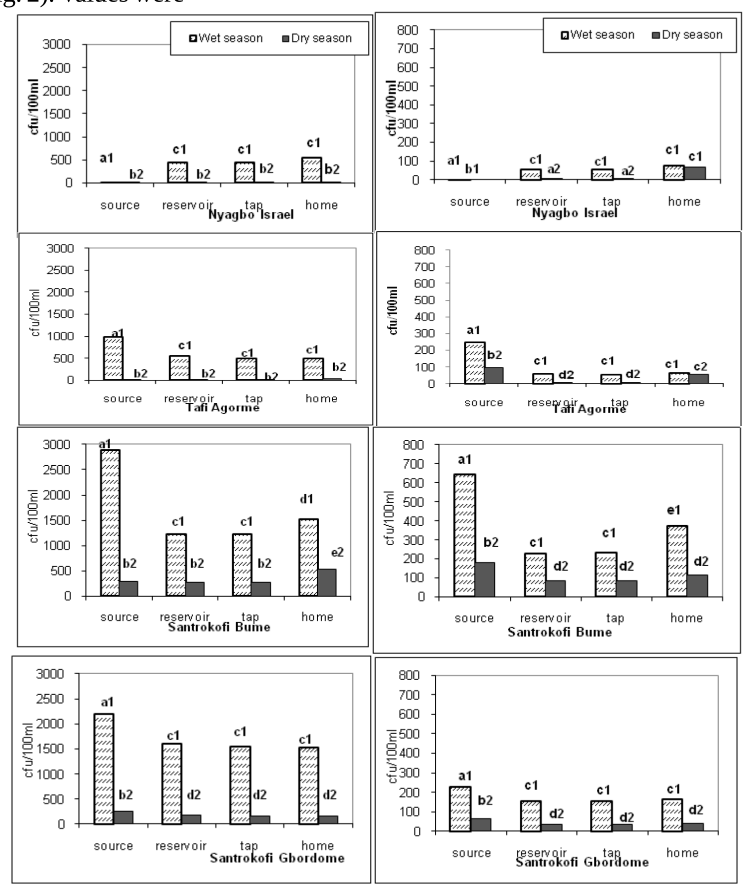

Fig. 2. Mean seasonal variation of total coliform (left column) and faecal coliform (right column) counts at various sampling points of GPWS in the study communities.

Table 1
Bacterial identification from the various samples

Sampling sites	*API 20E*	*Bacteria identified Frequency (%)*	*Serology*
Nyagbo Israel			
(1) Standpipe	*Pseudomonas cepacia*	48	
	Klebsiella pneumoniae	20	
	Escherichia coli	32	ETEC
(2) Individual home	*E. coli*	40	
	Klebsiella pneumonia	16	
	Proteus mirabilis	20	EPEC
	Aeromonas hydrophila	24	
Tafi Agorme			
(1) Source	*E. coli*	48	
	Salmonella sp.	4	
	Aeromonas hydrophila	32	ETEC, EPEC
	Klebsiella pneumoniae	16	
(2) Standpipe	*Proteus mirabilis*	24	
	E. coli	60	EPEC
	Klebsiella pneumoniae	16	
(3) Individual home	*Aeromonas hydrophila*	16	EPEC, ETEC
	Shigella spp.	8	
	Proteus vulgaris	16	
	E. coli	40	
	Klebsiella pneumoniae	20	
Santrokofi Bume			
(1) Source	*Chryseomonas luteola*	40	EPEC, ETEC
	Shigella spp.	8	
	E. coli	48	
	Salmonella spp.	4	
(2) Standpipe	*Pseudomonas cepacia*	56	EPEC, ETEC
	Proteus vulgaris	20	
	Klebsiella pneumoniae	16	
	Shigella sp.	8	
(3) Individual home	*Proteus vulgaris*	16	
	Salmonella sp.	4	ETEC, EPEC
	E. coli,	56	
	Klebsiella pneumoniae	24	
Santrokofi Gbordome			
(1) Source	*Pseudomonas cepacia*	60	- ETEC, EPEC
	Shigella spp.	8	
	C .hryseomonas luteola	32	

(2) Standpipe	*Klebsiella pneumoniae*	32	
	Chryseomonas luteola	16	ETEC, EPEC
	E. coli	48	
	Salmonella spp.	4	
(3) Individual home	*Klebsiella pneumoniae*	28	
	E. coli	40	
	Salmonella sp.	8	ETEC, EPEC
	Shigella spp.	4	
	Proteus mirabilis	8	
	Chryseomonas luteola.	12	

TABLE 2

District hospital laboratory report on diarrhoeal stool examination

Year	*Community*	*Total number of stools examined*	*Percentage stools testing positive to* E. coli
	SG	95	94
2002	SM	90	92
	TA	87	61
	NI	20	9
	SG	112	98
2003	SM	106	91
	TA	77	63
	NI	15	15
	SG	88	91
2004	SM	79	97
	TA	73	60
	NI	11	23
	SG	77	94
2005	SM	88	94
	TA	52	67
	NI	7	26
	SG	77	93
2006	SM	82	95
	TA	79	65
	NI	25	19

NB: SG- Santrokofi Gbordome, SM- Santrokofi Bume, TA- Tafi Agorme and NI- Nyagbo Israel

diarrhoea patients from the Santrokofi communities and Tafi Agorme, respectively, tested positive to the presence of *E. coli* during the period.

Malaria was the most prevalent disease that occurred in the study area. Diarrhoea, dysentery, abdominal problems and upper respiratory health problems were predominant in Santrokofi Bume, Santrokofi Gbordome and, to a lesser extent, in Tafi Agorme. Also, 69 per cent , 63 per cent, 30 per cent and 3 per cent of respondents listed diarrhoea as endemic in Santrokofi Bume, Santrokofi Gbordome, Tafi Agorme and Nyagbo Israel, respectively. Forty eight per cent of respondents from Santrokofi Gbordome, 51per cent from Santrokofi Bume, 21 per cent from Tafi Agorme and 15 per cent from Nyagbo Israel acknowledged the occurrence of upper respiratory health problems. Medical record from the District hospital listed malaria (57%), upper respiratory tract infection (8.3%) and diarrhoea (7.5%) as the three topmost diseases reported at the Out Patients' Department for medical attention.

Discussion

The high numbers of TC and FC bacteria populations in the rainy season could be mainly due to the extensive surface run-off water usually associated with rains (Bartram & Balance, 2001; Chapman, 2001). The remarkable reduction in coliform bacteria numbers from sources to taps in the communities (especially in Tafi Agorme, Santrokofi Bume and Santrokofi Gbordome) may be due to the combine effects of filtration sedimentation processes taking place in the silt chamber, as well as ultraviolet radiation and natural die-off of the coliforms in reservoirs during storage. Faecal coliform counts from all the sampling points of the systems exceeded the WHO and Ghana standards of zero coliform bacteria per 100 ml for treated water (WHO, 2002, 1985, 1984ab; GSB, 1997) and acceptable range of 1– 10 total coliform per 100 ml for water from unchlorinated sources (Cheesbrough, 1992). This presents a worrying risk to human health.

Water Research Institute (WRI) of the Council for Scientific and Industrial Research (CSIR) Ghana assessed spring and small streams in the Volta Region between 1993 and 1996 and reported permanent contamination of the streams by coliforms (WRI, 1994, 1996a, 1996b). The exact cause of the pollution is not clear since the sources of these systems are far removed from the communities; neither are there human settlements nor extensive farming activities around the sources. The faecal pollution could possibly come from faecal droppings from roaming animals in the area. Similar observations were made in Sao Paulo, Brazil (Fagundes-Neto *et al*., 1989), and Metropolitan Baltimore (Higgins *et al.*, 2005), where high faecal coliform in streams could not be traced to a specific source, but data indicated these organisms came from gastrointestinal micro flora of warm-blooded animals and humans.

The bacterial species identified in the study were members of the Family Enterobacteriaceae known to potentially produce enterotoxins that give rise to diarrhoea (Prescott, Harley & Klein, 2005), mild gastroenteritis or severe and sometimes fatal dysentery, cholera and general abdominal problems when ingested in significant doses (WHO, 1984b, 2002). These bacteria have been implicated by various authors in the occurrence of diarrhoeal diseases. ETEC produces two distinct enterotoxins: a heat-labile toxin that causes diarrhoea in a manner identical to cholera and a heat-stable toxin that causes intestinal secretion of fluid and electrolyte (Rubinoff & Field, 1999). EPEC strains cause specific damage to intestinal epithelial cells that, subsequently, lead to diarrhoea (Prescott, Harley & Klein, 2005), and this type of *E. coli* is an important agent of diarrhoea in both children and adults in developing countries (Prescott, Harley & Klein, 2005); Nataro & Kaper, 1998). *Salmonella* produces enterotoxins that cause abdominal pain, cramps, diarrhoea, fever and headaches (Darwin and Miller, 1999). *Shigella* species produce both enterotoxins and exotoxins that cause diarrhoea resulting from acute inflammatory reaction of the intestinal tract (Prescott, Harley & Klein, 2005);

Sansonetti, 1999). *K. pneumoniae*, causes various respiratory tract infections (Obiamiwe, 2006) and also produces enterotoxins similar to the heat-stable *E.coli* toxins (Rubinoff & Field, 1999).

Diarrhoea has become a daily and normal experience of the inhabitants of these communities, especially Santrokofi Bume and Santrokofi Gbordome, and the period between July and October each year records the highest number of outpatients with diarrhoea and general abdominal problems.Residents of these communities generally do not report most diarrhoea cases for medical examination; they resort mostly to traditional herbal treatment. Only the severe cases are reported for medical attention. Documented cases, therefore, represent only a fraction of the actual prevalence level of the disease in these communities. In the early 90s, before the construction of GPWS, there was annual incidence of deaths due to diarrhoea diseases, especially in the rainy season (Hohoe District Assembly, 2004). After the construction of the GPWS, diarrhoea, dysentery, and general abdominal problems continue to be endemic ailments of the people.

In Japan, contaminated well water and water supply aboard cruise ships have been implicated in several ETEC outbreaks; so also food borne outbreaks of ETEC have occurred in restaurants where food became contaminated with ETEC through the use of contaminated water (Garcia and Labbe, (2001). Studies carried out by Herbst, Faviera & Kistemann (2008) and Graf *et al.* (2008), respectively indicated recontamination of drinking water during storage in Aral Sea area of Uzbekistan, and in an urban slum in Kenya. Investigations conducted by Gundry *et al*. (2006) in South Africa and Zimbabwe, and other investigators such as Clasen & Barnstable (2003) and Trevett, Carter & Tyrrel (2005), all indicated that microbial water quality at improved sources of collection was always better than at points of use (homes), and the differences were significant.

Furthermore, post-collection contamination did not necessarily occur at points of use. The significant deterioration that occurred was attributable to mechanisms inside the transport and, or storage vessels. For instance, recontamination may occur through dipping by hands during transport or by the presence of biofilms on the inner surfaces of vessels. Findings from the study showed slight elevation of coliform numbers in water at points of use. However, the differences in microbial loads of water samples directly from the taps and at points of use (homes) were mostly not significant (Fig. 2). Bacteria loads in household storage water, therefore, do not necessarily suggest recontamination so as to attribute diarrhoea incidence solely to poor hygiene practices in handling water.

Hygiene education that accompanied provision of water supply facility seemed to have registered well, for instance, drinking water was separated from water for other uses and specific containers were designated for fetching it. Also, water containers were generally covered, and children under the age of 5 years are normally denied the direct access to drinking water to prevent dipping of unkempt hands. Covering of water containers is found to have reduced faecal and total coliform counts in stored water by 50 per cent (Wright, 2004). Good hygiene practice of washing water receptacles twice a week by most members of the communities is also commendable.

The drastic reduction in bacteria load, between sources and taps is also commendable and this might explain the cessation of death due to diarrhoea as observed in of Santrokofi Bume and Santrokofi Gbordome before the construction of the systems. However, the numbers still present in water from the taps (improved sources) fall short of the WHO standards, and present a worrying health risk, especially as the diarrhoea incidence and the associated abdominal problems are still endemic in some of these communities, now accentuated by the detection of diarrhoegenic agents.

Whereas further investigation is needed to conclusively establish the cause or causes of upper respiratory tract infections, the preponderance of *Klebsiella* spp. in the main source of water could suggest one possible source for investigation. Rather the residents of these communities regard the occurrence of fever, accompanied by headache, as symptoms of malaria. These symptoms could as well be attributed to typhoid fever, considering the heavy presence of *Salmonella* spp. This, however, needs further investigation.

The Gravity-Piped Water Systems, from their inception to date, are still operating though not without much challenges. Distribution pipelines are often choked with silt and have to be regularly desilted. The roughing filters that should be washed every 2 months are often left for several months without cleaning. On some occasions, the gravels that have been scooped out of filtration medium for washing are left unattended to for several weeks, because of the tedious nature of the work involved. Frequent clogging of the slow sand filters occurs, and it is also common to observe thick scum forming on their surfaces; this often resulted in the failure of the treatment systems. By far, the most daunting challenge is the regular occurrence of heavy siltation in the intake structures and silt chambers of almost all the systems visited. The siltation occurs as soon as it is removed through communal labour. After several attempts of desilting, the communities give up. The result is that filtration at the silt chamber is very slow and enough water is not stored in the reservoirs, leading to water shortage or, alternatively, water is piped directly into reservoirs (by-passing intake structures and silt chambers and the filtration processes that should occur there). In situations such as these, the bacteria load and sediment in water at public taps naturally became heavy, exposing consumers to greater health risks. Siltation at the intake structure was reported to be a major challenge to the optimum operation of the Mpira/Balaka GPWS in Malawi (Matamula, 2008).

Unfortunately, because of the community ownership principle underlying the establishment of these systems, the communities were to operate, manage and sustain the system, and soon community management structures collapsed. After 15 years of operation, less than 20 per cent of these systems were fully operational. The rest were reduced to vestiges; not operating according to their initial design. Communities were worn-out by fatigue in attempting to sustain the systems. They looked on helplessly as the systems deteriorated. However, as long as water was delivered at their door steps, communities were grateful, irrespective of the quality and health implications of the water delivered.

Of the four systems investigated in the study, only the one at Nyagbo Israel is still fully operational. Unlike the system in other communities, the eye of the spring here was located very close to the community. It was, therefore, protected from pollution and water from it appropriately piped into silt chamber, and consequently, to the reservoir. This accounted for the comparatively low bacterial load and explains the very low incidence of diarrhoea. Undoubtedly, one way to reduce bacteria pollution will be to pipe the water from the very eye of the spring as in Nyagbo Israel. Unfortunately, however, the spring sources in the other communities are located very far and at very high elevations.

Gravity-Piped Water System constitutes a major source of water and its operation should be encouraged, especially as it is an excellent opportunity to harness cheap supply of water to solve rural water supply and sanitation problems. In order to sustain effective performance of the systems and to avert potential health hazards associated with them, disinfection stage must be made an integral part of the system. Continuous routine monitoring of water supply from the taps for microbiological quality should be done. The incidence of increasing numbers of coliform bacteria should be an indication for the system to be examined and remedial action taken. Farming and other possible human activities around the intake structures of the GPWS in each community must be banned as a matter of policy. Concrete walls could also be built around the intake structures to reduce intake of run-offs when it rains. Considering possible recontamination of water during transport between source and point-of-use, it is recommended that point-of-use chemical agents like sodium hypochlorite be used as disinfectant since this has been found to be effective in reducing diarrhoea (Clasen *et al.*, 2009; Benjamin *et al.*, 2007; Wright *et al.*, 2004). These type of disinfectants are generally safe, effective, and least expensive.

Regular courses for caretakers must also be organised to build capacity to face challenges that may crop up periodically. The courses will offer caretakers opportunities to appraise the systems in their individual communities, exchange ideas with colleagues and receive new technological insight. Finally, for sustainability of the water supply systems, communal spirit must be sustained, and the need for comprehensive community sensitisation meetings. This is necessary because the responsibilities can only be undertaken through communal labour. Community members must be educated to appreciate their water provision facility and be willing to pay the price through regular communal labour to sustain its proper functioning. The District Assemblies must also strengthen the structures by providing the necessary support. Malawi's success in community-based management approach to rural water supply and sanitation programme (Matamula, 2008) is an evidence of how rural communities can overcome their own water supply challenges when given the necessary aid.

Conclusion

The study provides evidence that with the exception of the system at Nyagbo Israel, all other spring sources were permanently contaminated with total and faecal coliform bacteria and the level of contamination was significantly ($P \geq 0.05$) higher during the rainy season. Although the GPWS greatly reduced bacterial flora, their levels at the taps (improved sources) still far exceeded the maximum limits recommended by WHO for even untreated drinking water. Identification of potential enteropathogenic bacteria and diarrhoegenic agents at all points of the individual systems, coupled with the high diarrhoea cases from the communities registered at the District Hospital and the heavy presence of *E. coli* in the stools of the diarrhoea patients, suggested a strong link between the diarrhoea incidence in the communities and the use of water from GPWS. There is, therefore, an urgent need to introduce a disinfection process stage in the operation of the GPWS if the present health hazard identified is to be averted. Point-of-use chemical disinfection is particularly recommended. Continuous routine monitoring of water supply from the taps for microbiological quality should be done. The incidence of increasing numbers of coliform bacteria should be an indication for the system to be examined and remedial action taken.

Acknowledgement

The authors are grateful for the financial assistance from the Royal Danish Embassy, Accra, Ghana. They also wish to acknowledge CSIR–Water Research Institute, Accra and Ecological Laboratory Unit of the University of Ghana, Legon whose facilities were used to carry out the laboratory analyses.

References

AMERICAN PUBLIC HEALTH ASSOCIATION (APHA) (1995) *Standard Methods for the Examination of Water and Waste Water, 19th edn.* (A. E. Greenberg, L. S.

Clesceri, A. D. Eaton and M. A. H. Fransod, eds) ESP Group Inc. Hanover, USA.

Bartram, J. & Balance, R. (2001) *Water quality monitoring – A practical guide to the Design and implementation of freshwater quality studies and monitoring programmes*. TJ International Ltd, Cornwall, Great Britain. 383 pp.

Benjamin, F., Arnold, J. M. & Colford, J. R. (2007) Treating water with chlorine at point-of-use to improve water quality and reduce child diarrhoea in developing countries: A systematic review and meta-analysis. *Am. J. Trop. Med. Hyg.* **76** (2), 354-364.

Bio Merieux S. A. (1992) *Analytical Profile Index 20E.* Marcy-l'Etoile, Lyon, France.

Chapman, D. (2001) *Water quality assessment; A guide to the use of biota, sediments and water in environmental monitoring*. Chapman and Hall Ltd., London, UK. 585 pp.

Cheesbrough, M. (1992) *Medical Laboratory Manual for Tropical Countries*. Vol. II: *Microbiology*. Butterworth-Heineman Ltd. Oxford, UK. 221 pp.

Clasen, F. T., Roberts, G. I., Rabie, T., Schmidt, W. & Cairncross, S. (2009) *Interventions to improve water quality for preventing diarrhoea* (Review). *The Cochrane Library Issue 2*. John Wiley & Sons, Ltd.

Clasen, F. T., Roberts, G. I., Rabie, T., Schmidt, W. & Cairncross, S. (2007) Interventions to improve water quality for preventing diarrhoea: Systematic review and meta-analysis. *BMJ, doi. 101136/ bmj. 39118.489931.BE.*

Clasen, T. F. & Barnstable, A. (2003) Faecal contamination of drinking water during collection and household storage: the need to extend protection to the point of use. *J. Wat. Hlth* **1** (2),1-7.

CWSA-Volta Region (1999) T*raining of caretakers in operation and maintenance of piped water supply systems (Gravity with roughing filters).* EDSAM Ltd Ho, Ghana. 56 pp.

Darwin, K. H. & Miller, V. (1999) Molecular basis of the interaction of *Salmonella* with intestinal mucosa. *Clin. Microbiol. Rev.* **12**(3), 405-28

Fagundes-Neto, U., Ferreira, V. C., Patricio, F. R. S., Mostaco, V. L. & Trabulsi, L. R. (1999) Protracted diarrhoea: The importance of the enteropathogenic *E. coli* (EPEC) strains and *Salmonella* I: its genesis. *J. Pediatr. Gastroenterol. Nutrl.* **8**, 207-11.

Garcia, S. & Labbe, R. G. (2001) *Guide to Foodborne Pathogens.* John Wiley & Sons Inc. New York. *http://books.google.com.gh/books? 14/04/2009*

Ghana Standards Board. (1997) *Water quality – Requirements for Drinking Water.* 10 pp.

Graf, J., Meierhofer, R., Wegelin, M. & Mosler, H. J. (2008) Water disinfection and hygiene behavior in an urban slum in Kenya: impact on child diarrhoea and influence of beliefs. *IJEHR* **18** (5), 335-355.

Gundry, S., Wright, J., Conroy, R., Genthe, B., Moyo, S., Mutisi, C., Ndamba, J. & Potgieter, N. (2006) Contamination of drinking water between source and point-of-use in rural households of South Africa and Zimbabwe: Implications for monitoring the Millennium Development Goal for Water. *Water Practice & Technology*, Vol 1 No. 2. *doi: 10.2166/WPT.2006032.*

Herbst, S., Fayzieva, D. & Kistemann, T. (2008) Risk factor analysis of diarrhoeal diseases in the Aral Sea area (Khorezm, Uzbekistan). *IJEHR* **18** (5), 305-321.

Higgins, J. A., Belt, K. T., Karns, J. S., Russell-Anelli, J. & Shelton, D. (2005) *tir*- and *str*- Positive *Escherichia coli* in stream waters in Metropolitan Area. *App. Envir. Microbiol.* **71** (5), 2511-19.

Hohoe District Assembly. (2004) *Medium term Development Plan* (2004-2008). 52pp.

Jordan, J. T. D. (1980) *A handbook of Gravity-flow water system for small communities*. Russell Press, Nottingham, UK. 210 pp.

Matamula, S. (2008) Community Based Management for Sustainable Water Supply in Malawi. In : *Proceedings of the 33^rd WEDC International Conference on Access to Sanitation and Safe Water: Global Partnerships and Local Actions*. Accra, Ghana. pp. 408 – 410.

Mintz, E., Bartram, J., Lochery, P. & Wegelin, M. (2001) Not just a drop in the bucket: Expanding access to point-of-use water treatment systems. *Am, J. Public Health* **91**(10), 1565–1570.

Nataro, J. P. & Kaper, J. B. (1998) Diarrheoagenic *Escherichia coli. Clin. Microbiol. Rev.* **11**(1), 142-201

Obiamiwe, U. (2006) Overview: *Klebsiella* infections. *eMedicine. http://emedicine.medscape.com/article/219907-diagnosis.*

Prescott, L. M., Harley, J. P. & Klein, D. A. (2005) *Microbiology.* McGraw-Hill Companies Inc., New-York. 992 pp.

RUBINOFF, M. J. & FIELD, M. (1999) Infectious diarrheoa. *Annu.Rev. Med.***42**, 403-10.*http://arjournal.annualreviews.org/doi/pdf*.

SANSONETTI, P. (1999). Shigella plays dangerous games. *ASM News* **65** (9), 611-17.

TREVETT, A. F., CARTER, R. C. & TYRREL, S. F. (2005) The importance of domestic water quality management in the context of faecal-oral disease transmission. *J. Wat. Hlth* **3** (3), 221-228.

WATER RESEARCH INSTITUTE.(1994) *Water Resources Monitoring - Low Flows of Springs and Streams in the Volta Region.* WRI Tech. Publication, Council for Scientific and Industrial Research (CSIR), Accra. 96 pp.

WATER RESEARCH INSTITUTE. (1996a) *Water Resources Monitoring - Low Flows of Springs and Streams in the Volta Region.* WRI Tech. Publication, Council for Scientific and Industrial Research (CSIR), Accra. 174 pp.

WATER RESEARCH INSTITUTE (1996b) *Inventory of data for Water Resources Assessment in the Northern Part of Volta Region.* WRI Tech. Publication Vols.2a-2f, Nos. 4-9, Council for Scientific and Industrial Research (CSIR), Accra.

WHO (1984a) *Guidelines for Drinking-Water Quality. Vol.1. Health Criteria and other Supporting Information.* WHO, Geneva, 335 pp.

WHO (1984b) Guidelines for Drinking-Water Quality. *Vol. 2, Recommendations.* WHO, Geneva. 130 pp.

WHO (1985) *Guidelines for Drinking-Water Quality. Vol.3, Drinking Water Quality Control in Small Community Supplies.* WHO, Geneva, 121 pp.

WHO (2002) *Guidelines for Drinking-Water Quality, Addendum: Microbiological agents in drinking water.* WHO, Geneva. 220 pp.

WRIGHT, J.A**.**, GUNDRY, S. W. & CONROY, R. (2004) Household drinking water in developing countries: a systematic review of microbiological contamination between source and point-of-use. *Trop. Med. Int. Hlth* **9** (1), 106-117.

YOUNG, G. J., DOOGE, J. C. I. & RODDA, J. C. (2004) *Global Water Resources Issues.* Cambridge University Press, Cambridge, Great Britain. 194 pp.

Received 6 Aug 09; revised 25 Feb 10.