EFFECT OF SUNLIGHT, TRANSPORT AND STORAGE VESSELS ON DRINKING WATER QUALITY IN RURAL GHANA

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ABSTRACT

The objective was to evaluate the effect of sunlight, transport and storage vessels on drinking water quality in rural Ghana with the aim of reducing the high demand for fuel wood in the household treatment of water. Well water was exposed for 6h to direct natural sunlight in aluminium, iron, and plastic receptacles and bisque-fired earthenware pots (pot and cooler) and then placed indoors at room temperature for 48h. Samples were also stored continuously indoors at room temperature for 20 days. Water samples exposed to sunlight were analyzed for total and faecal coliforms and enterococci at 2h intervals and those stored indoors at room temperature at 48h intervals. Enterococci die-off was 100% after 6h in sunlight and after 192h at room temperature in all types of storage vessels. Total and faecal coliforms die-off ranged between 43-91% after 6h in sunlight and 51-100% after 480h at room temperature. Microbial die-off in sunlight was higher in aluminium, iron and plastic vessels compared to earthenware vessels although the differences were not statistically significant ($p<0.05$). As there was no enterococcal re-growth when sunlight exposed water samples were transferred to room temperature for 48h, the enterococci were taken to be dead. Irrespective of storage vessels, significant relationships were found between indicator bacterial die-off and time of exposure to sunlight ($R^2 = 0.8606$-0.9969). Exposure to sunlight in Ghana improves the microbial quality of water compared with storage at room temperature indoors. Solar water disinfection, if practiced in rural Ghana, could improve drinking water quality and reduce the need for fuel wood for boiling water.

Keywords: water quality, sunlight, vessels, aluminium, plastic, iron, earthenware pot, microbial indicators

INTRODUCTION

The lack of satisfactory drinking water for many of Ghana's rural poor has been a major infrastructural challenge for successive governments. The Ghana government, in collaboration with some NGOs (DFID, DANIDA, WORLD VISION etc.), is providing rural communities with wells and boreholes. However, this is not enough and most people in northern Ghana continue to rely on hand dug wells, rivers and streams for their daily needs. These sources of water have been shown to be contaminated with microbial indicators of faecal pollution and therefore pose a risk to health (Obiri-Danso *et al.*, 2002; Obiri-Danso *et al.*, 2004). In developing countries, microbial contamination of household drinking water is implicated in the prevalence of various diseases (Gundry *et al.*, 2003). The massive death toll and burden of disease worldwide caused by unsafe drinking water is a

compelling reason for having safe drinking water delivered to individual homes (Hrudey and Hrudey, 2004).

Research in the United Kingdom and India has shown that exposure of water containing indicator bacteria to full-strength sunlight for several hours is sufficient to inactivate the bacteria (Davies-Colley *et al.*, 1994; Gameson, 1986; Sinton *et al.*, 1996; 1999; WRc. 1991). However, in making the water from these doubtful sources safe to drink, most of the rural poor use fuel wood in heating drinking water. A World Bank Report (Anderson, 1993) indicates that developing countries rely heavily on wood fuel as the major source for cooking and heating. In Africa, the statistics are striking: an estimated 90 percent of the entire continent's population uses fuel wood for cooking, and in sub-Saharan Africa, firewood and brush supply approximately 52 percent of all energy sources. Additionally, a major disadvantage of boiling water is its consumption of energy in relation to the availability, cost and sustainability of fuel wood. It is estimated that 1 kilogram of wood is needed to boil 1 litre of water (WHO, 2002). In areas of the world where wood, other biomass fuels or fossil fuels are in limited supply and must be purchased, the cost of boiling water are prohibitive. Therefore boiling household water to make it safe is unrealistic for many of the world's poorest people due to the scarcity and high cost of fuels and the lack of fuel wood sustainability in that community (WHO, 2002).

With the population in sub-Saharan Africa expected to double in a little over 20 years, it is not surprising that more and more forests are being cleared. Therefore finding alternative sources of achieving energy needs without resort to cutting down the forest is most appropriate for most developing countries. As sunlight is freely available and has been identified as the most important environmental factor responsible for the normal inactivation of faecal indicator bacteria and bacteriophages in both seawater (Sinton *et al.*, 1999; Obiri-Danso *et al.*, 1999) and freshwater supplies (Sinton *et al.*, 2002; Obiri-Danso *et al.*, 1999), it represents an ideal energy resource for use in most rural African countries in the purification of microbiologically contaminated water.

In this study, we describe a series of experiments aimed at evaluating the effect of natural sunlight, transport and storage vessels on drinking water quality in rural Ghana with the aim of reducing the high demand for fuel wood in the household treatment of water.

MATERIALS AND MEHTODS

Collection of well water samples

Well water samples were collected from Duase, a typical Ghanaian rural community that uses this water as its only source of drinking water. Duase is close to the Kwame Nkrumah University of Science and Technology, Kumasi in Ghana with a population of about 2114 people had been encouraged to move away from their traditional surface water supply to a well that had been dug through communal labour. These types of drinking water sources have been shown to be contaminated with natural populations of faecal indicator bacteria (Obiri-Danso *et al.*, 2002). Samples were collected in 20-litre containers that had been sterilised with alcohol and dried. Water was drawn from the well using alcohol sterilized plastic bags. Water samples were collected in the morning before sunrise and transported to the laboratory and analyzed within the hour.

Exposure of well Water Samples to Natural Sunlight

Twenty litres of the well water was exposed to direct natural sunlight in aluminium (Al), iron (Fe), plastic (Pl), bisque fired earthenware pot (Pt) and earthenware cooler (Cl) made vessels for 6h (10.00 to 16.00h GMT). Aliquots of 20 ml were taken from each vessel at 2h intervals and analyzed in triplicate for total and faecal coli-

forms and enterococci. The sunlight exposed water samples were then transferred indoors covered with alcohol sterile transparent polyethylene sheets to prevent contamination from the environment and analyzed after 24 and 48h.

Exposure of well water samples to room Temperature

Well water samples were also stored continuously indoors at room temperature for 20 days and analyzed at 2 day intervals.

Enumeration of Microbial Indicator Bacteria

Faecal coliforms were enumerated using the membrane filtration technique (Anon, 1992; Obiri-Danso *et al.*, 2001). Water sample dilutions of 10^{-1}-10^{-3} were prepared in 9 ml of sterile 0.1% buffered peptone water. Ten ml of sterile distilled water were put in each filtration chamber first and then 1 ml aliquots from each dilution (10^{-1}-10^{-3}) were filtered through white, grid marked 47mm diameter, Millipore HA – type cellulose filters with pore size of 0.45 µm using a vacuum pump pressure of 65 Kpa (500 mmHg) and a triple glass filtration unit (Millipore, Bedford). The membrane filters were placed with the grid side upward on Petri dishes of Lauryl sulphate broth with 2% agar using forceps sterilized in alcohol. This was done in triplicate.

Plates were incubated at 44°C for 24h. Golden green or yellow colonies were counted as presumptive faecal coliforms and the results expressed as cfu $100ml^{-1}$. The glass filtration unit was sterilized after each filtration by immersing in boiling distilled water for about 2 min.

Total coliforms were estimated following the same procedure as described for faecal coliforms. However, the plates were incubated at 37°C for 24h.

Enterococci were estimated using the same technique as described for faecal and total coliforms. However, 10 ml of the water samples were filtered and the membrane filters placed with the grid side upwards on Petri dishes of Slanetz and Bartley agar. The plates were incubated for 4h at 37°C and for 44h at 44°C. Red, maroon or pink colonies were counted as presumptive enterococci. Presumptive colonies were confirmed on MacConkey no. 2 agar (Oxoid). All counts were expressed as cfu$100ml^{-1}$.

Meteorological data

Standard meteorological data on sunshine hours for the University campus (KNUST) was obtained from the Kumasi Meteorological Services.

Temperature

Environmental and water temperatures were recorded each time water samples were being taken for analysis using a hand held thermometer (Orme, UK).

Colour

The colour of water samples was determined before and after exposure to natural sunlight using the Nessleriser. Fifty ml of each sample were put in a Nessler tube and placed in the right–hand compartment. The disc was rotated with the light on to obtain a colour match, which was read in degree Hazen (Arnold *et al.*, 1992).

Analysis

The statistical package MSTAT was used for testing the various statistical relationships between variables. Raw data were transformed by adding a value of 1 to all scores in order to eliminate zero data point, and then each datum point was converted to $\log_{10}$. A one–way analysis of variance (ANOVA) and regression were used to analyze the data.

RESULTS

Bacterial indicator numbers in well water exposed to natural sunlight in different transport and storage vessels

Enterococci numbers varied from 1.00×10^1 to 2.45×10^2 in well water samples depending on the time of month in which the sample was

taken. Significantly higher bacteria counts were recorded in the rainy (wet) season compared to the dry (harmattan) season ($p \leq 0.000$). Average geometric mean numbers ($100ml^{-1}$) were 2.32×10^2 in the rainy (wet) season compared to 2.57×10^1 in the dry (harmattan) season.

Enterococci numbers decreased significantly ($p \leq 0.0195$) by 100% after 4h exposure to natural sunlight in the different transport and storage vessels. Enterococci die-off rate did not vary significantly with respect to the different transport and storage vessels ($p \geq 0.05$) (Table 1). After 48h, no enterococci were recovered from the sunlight exposed water samples stored indoors at room temperature (Table 1).

Faecal and total coliform numbers followed the same trend as the enterococci with higher numbers of faecal coliforms (1.51×10^5) and total coliforms (1.60×10^7) in the wet (rainy) season compared to 4.88×10^4 and 7.65×10^5 in the dry (harmattan) season, respectively. However, these differences in seasonal numbers were not significantly different ($p \geq 0.05$).

After 6h exposure to natural sunlight, total coliforms numbers decreased by 67% in plastic storage vessels, 66% in iron, 61% in aluminium, 51% in bisque fired earthenware pots and 43% in earthenware cooler (Table 1). Comparably, faecal coliforms decreased by 91% in plastic, 81% in aluminium, 70% in iron, 63% in earthenware cooler and 58% in bisque fired earthenware pot (Table 1).

Table 1 Geometric mean microbial indicator bacteria numbers in well water exposed to natural sunlight for 6h and then stored at room temperature for 48h in different water transport and storage vessels

Bacteria	Vessel	Time of Exposure to natural sunlight (hrs)				Time of storage at room temperature		%↓
		0	2	4	6	24	48	
Enterococci								
	Aluminium	1.80×10^2	1.30×10^2	$1.9\,9 \times 10^1$	0	0	0	100
	Iron	1.80×10^2	1.10×10^2	1.99×10^1	0	0	0	100
	Plastic	1.80×10^2	1.30×10^2	0	0	0	0	100
	E. Pot	1.80×10^2	3.30×10^2	4.00×10^1	0	0	0	100
	E. Cooler	1.80×10^2	2.50×10^2	2.99×10^1	0	0	0	100
Faecal coliforms								
	Aluminium	1.10×10^5	1.39×10^4	1.20×10^2	1.20×10^1	4.00	1.99	79
	Iron	1.10×10^5	2.90×10^4	1.69×10^2	4.79×10^1	2.29×10^1	7.00	67
	Plastic	1.10×10^5	1.57×10^4	1.10×10^2	1.20×10^1	4.00	1.99	79
	E. Pot	1.10×10^5	2.09×10^4	1.39×10^2	2.39×10^1	8.99	4.00	73
	E. Cooler	1.10×10^5	1.83×10^4	1.20×10^2	1.69×10^1	6.00	2.99	76
Total coliforms								
	Aluminium	1.20×10^7	1.15×10^6	7.70×10^3	6.00×10^2	1.00×10^2	4.0×10^1	61
	Iron	1.20×10^7	1.77×10^6	1.00×10^4	2.39×10^2	7.00×10^1	2.0×10^1	66
	Plastic	1.20×10^7	5.70×10^5	2.99×10^3	2.29×10^2	1.00×10^2	2.0×10^1	67
	E. Pot	1.20×10^7	2.09×10^6	9.20×10^4	1.08×10^4	6.50×10^2	4.9×10^1	43
	E. Cooler	1.20×10^7	3.80×10^6	4.60×10^4	3.10×10^3	1.70×10^2	3.0×10^1	51

E. Pot – Earthenware pot *E. Cooler – Earthenware cooler*

Mean temperatures in well water samples exposed to natural sunlight

Mean water temperatures in the different transport and storage vessels exposed to sunlight were generally higher compared to the environmental temperatures. Mean atmospheric temperatures varied from 32.3°C to 35.7°C during the experimental period compared to 31.6°C to 46.6°C in the water samples. However, environmental and water sample temperatures decreased after 14.00h GMT, which is usually the time when the highest daily mean temperature for the day is recorded. The bisque fired earthenware pot and earthenware cooler recorded the lowest water temperatures after 6h of exposure to sunlight (32.4°C to 30.6°C).

Relationship between changes in indicator Bacteria Counts and Natural Sunlight

For all the different transport and storage vessels, regression analysis shows a highly significant relationship between the reduction in indicator bacterial numbers and natural sunlight (Fig. 1, 2, 3). It is evident from the slopes and correlations (R^2) that indicator bacterial reduction in aluminium had the greatest response to sunlight (R^2 = 0.8301 for enterococci, R^2 = 0.9428 for faecal coliforms and R^2 = 0.7304 for total coliforms) followed by plastic (R^2 = 0.8148 for enterococci, R^2 = 0.9321 for faecal coliforms and R^2 = 0.7399 for total coliforms) then iron (R^2 = 0.7738 for enterococci, R^2 = 0.8940 for faecal coliforms and R^2 = 0.7511 for total coliforms) followed by earthenware cooler (R^2 = 0.7344 for enterococci, R^2 = 0.8846 for faecal coliforms and R^2 = 0.6373 for total coliforms) and bisque fired earthenware pot (R^2 = 0.6812 for enterococci, R^2 = 0.8570 for faecal coliforms and R^2 = 0.5297 for total coliforms) (Figures 1, 2 and 3). However, the differences between aluminium, iron and plastic transport and storage vessels were not statistically significant ($p \geq 0.05$) (Fig. 1, 2 and 3).

Indicator Bacteria Numbers in well Water Samples Stored Indoors at room temperature

Generally, enterococci numbers decreased significantly irrespective of the transport and storage vessels in which the water samples were stored over the period. Geometric mean numbers ($100ml^{-1}$) decreased from 1.69×10^{-2} to zero after 144h of storage indoors at room temperature (Table 2). However, between the different transport and storage vessels these decreases were not statistically significant ($p \geq 0.05$).

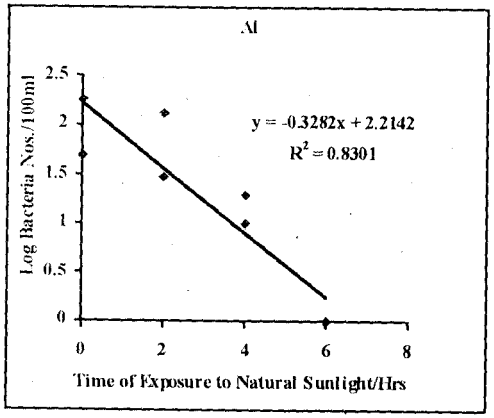
Similarly, after 384h there was a 100% reduction in faecal coliform numbers in water samples stored in bisque fired earthenware pots and coolers (Table 2). However, reduction rates in the other vessels were much slower. After 480h, faecal coliform numbers were 1.09×10^{-1} (84%) in plastic, 1.79×10^{-1} (80%) in iron and 2.80×10^{-1} (77%) in aluminium transport and storage vessels (Table 2).

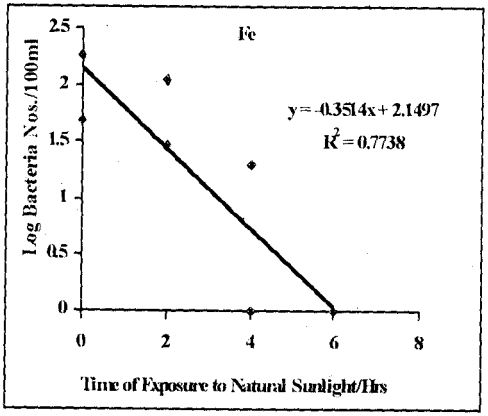
Additionally, after 480h there was a 100% reduction in total coliforms numbers in bisque fired earthenware pot and cooler. But reductions were from an initial 2.99×10^{-7} to 1.30×10^{1} in aluminium (85%), 1.39×10^{2} (71%) in iron and 4.30×10^{3} (51%) in plastic vessels stored indoors (Table 2).

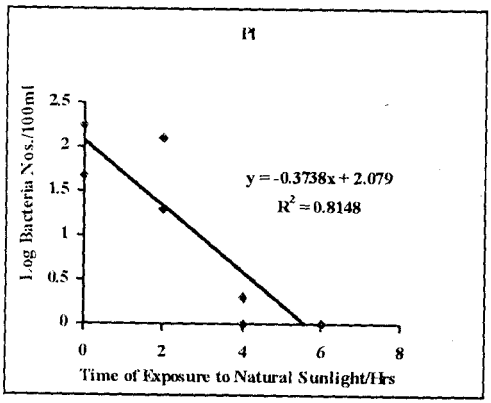
Mean temperatures of water samples stored indoors at room temperature.

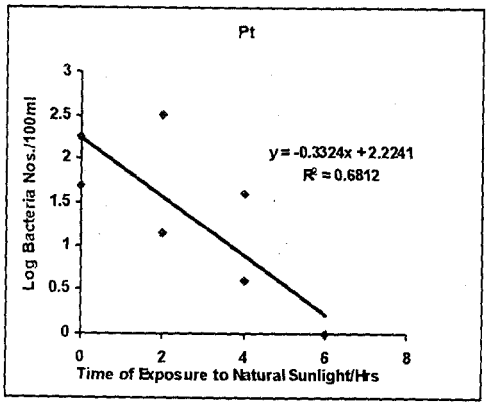
Mean indoor (room) environmental and water temperatures were 29.6 ± 0.58°C and 29.5 ± 1.32°C, respectively. The environmental temperatures increased slightly to 32.0 ± 1.00°C and water samples to 31.5 ± 0.10°C. However, water temperatures in the earthenware vessels were much lower, 27.0 ± 0.5°C for pots and 26.0 ± 0.00°C for cooler (Table 3).

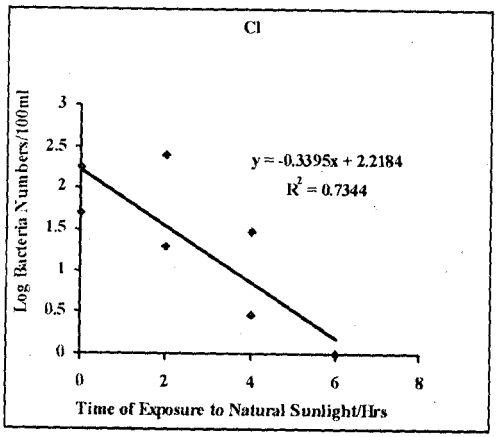
Figure 1 **Relationship between enterococci numbers (Log_{10}) in well water in different water transport and storage vessels and exposure to natural sunlight**







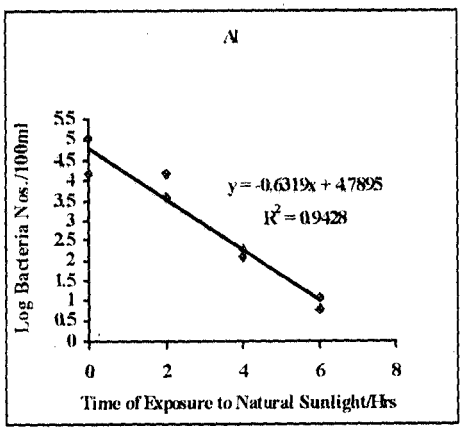


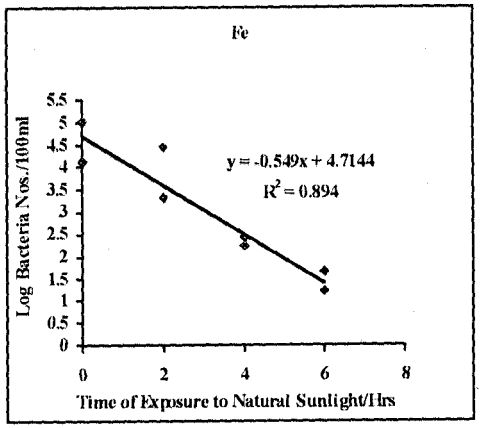


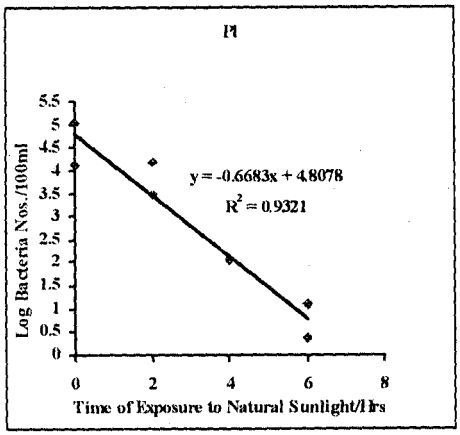
Al – Aluminium **Fe** – Iron

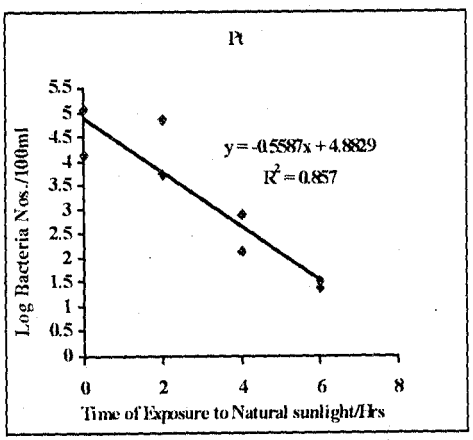
Pl – Plastic **Pt**–Earthenware Pot

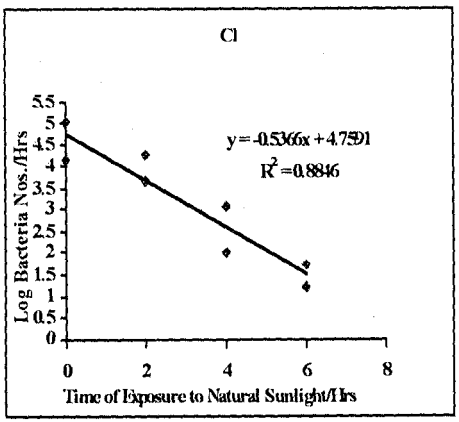
Figure 2 **Relationship between faecal coliform numbers (Log_{10}) in well water in different water**









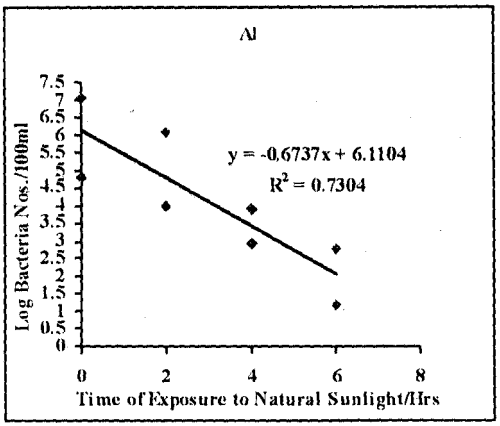


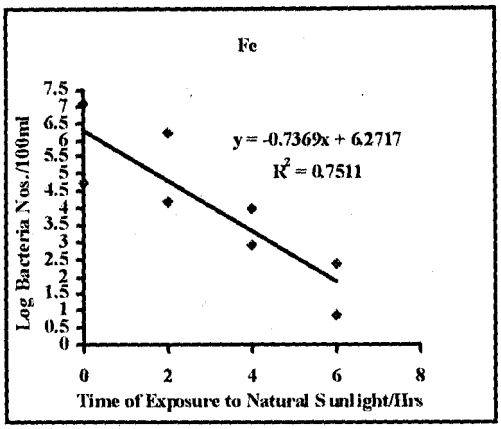
Al – Aluminium **Fe** – Iron

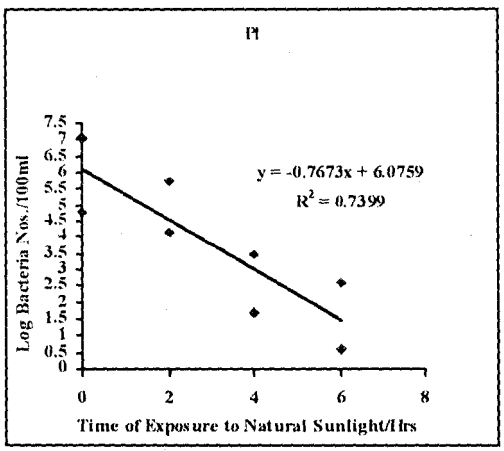
Pl – Plastic **Pt** – Earthenware Pot

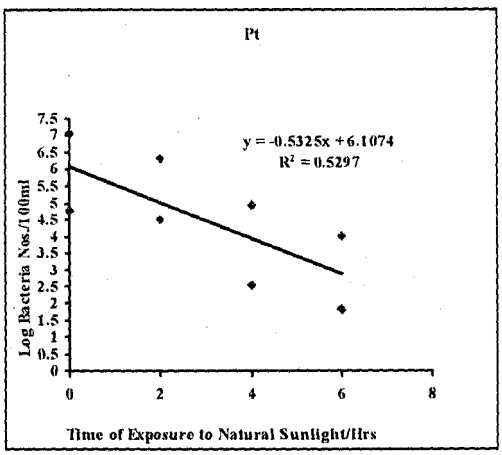
Cl – Earthenware Cooler

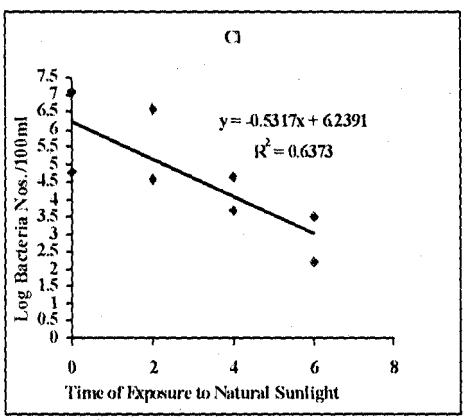
Figure 3 **Relationship between total coliform numbers (Log_{10}) in well water in different water transport and storage vessels and exposure to natural sunlight**











Al – Aluminium **Fe** – Iron

Pl – Plastic **Pt** – Earthenware Pot

Cl – Earthenware Cooler

Table 2 Geometric mean indicator bacteria numbers in well water stored at room temperature in different water transport and storage vessels

Storage Time/Hrs Vessel	0	48	96	144	192	240	288	336	384	432	480	%↓
Enterococci												
Aluminium	1.69×10^2	1.29×10^2	2.99	0	0	0	0	0	0	0	0	100
Iron	1.69×10^2	1.10×10^2	0	0	0	0	0	0	0	0	0	100
Plastic	1.69×10^2	7.00×10^1	4.98	0	0	0	0	0	0	0	0	100
E. pot	1.69×10^2	1.10×10^2	1.99	0	0	0	0	0	0	0	0	100
E. cooler	1.69×10^2	2.29×10^2	0	0	0	0	0	0	0	0	0	100
Faecal coliforms												
Aluminium	2.25×10^6	1.97×10^6	1.20×10^6	4.40×10^5	2.80×10^4	5.50×10^4	1.80×10^4	1.41×10^3	3.50×10^2	8.70×10^1	2.90×10^1	77
Iron	2.25×10^6	3.59×10^6	1.84×10^6	6.70×10^5	3.80×10^4	1.46×10^3	1.80×10^3	1.17×10^3	6.50×10^1	3.00×10^1	1.80×10^1	80
Plastic	2.25×10^6	2.60×10^6	1.30×10^6	3.90×10^5	4.10×10^4	4.30×10^4	2.70×10^4	1.40×10^3	4.00×10^1	2.00×10^1	1.10×10^1	84
E. pot	2.25×10^6	1.65×10^6	1.30×10^6	1.94×10^5	1.42×10^4	6.90×10^4	2.50×10^3	0	0	0	0	100
E. cooler	2.25×10^6	2.81×10^6	2.50×10^6	1.11×10^5	1.40×10^4	1.30×10^4	1.40×10^3	1.80×10^1	0	0	0	100
Total coliforms												
Aluminium	2.99×10^7	1.70×10^7	4.20×10^6	6.60×10^5	2.80×10^5	5.70×10^5	5.30×10^3	3.30×10^3	2.00×10^2	1.90×10^1	1.30×10^1	85
Iron	2.99×10^7	2.40×10^7	1.41×10^7	7.60×10^5	8.80×10^5	1.67×10^6	2.99×10^3	4.00×10^3	2.20×10^3	1.90×10^2	1.40×10^2	71
Plastic	2.99×10^7	4.09×10^6	2.13×10^6	8.80×10^5	1.66×10^6	1.35×10^6	4.10×10^3	2.60×10^3	4.80×10^2	3.70×10^2	4.30×10^3	51
E. pot	2.99×10^7	2.80×10^7	1.90×10^7	2.40×10^5	2.60×10^5	2.10×10^5	1.70×10^3	8.30×10^2	4.10×10^2	2.00	0	100
E. cooler	2.99×10^7	1.22×10^6	1.40×10^6	3.60×10^5	2.70×10^5	7.70×10^4	1.31×10^3	7.50×10^2	2.00×10^1	0	0	100

E. pot – Earthenware Pot E. Cooler – Earthenware Cooler

Table 3 Mean atmospheric and water temperatures and colour of well water samples exposed to natural sunlight in different water transport and storage

Time/Hrs	Temperature °C					Colour of water °H		
	Aluminium	Iron	Plastic	Earthenware Pot	Earthen ware cooler	Atmosphere	Tap	Well
0	31.6	31.6	31.6	31.0	31.6	32.3	<5	5
2	41.5	40.0	42.2	30.0	30.6	34.7	<5	5
4	45.7	43.6	46.6	32.8	31.4	35.7	<5	5
6	44.0	42.4	45.6	32.4	30.6	34.5	<5	5

DISCUSSION

This study shows that well water exposed to continuous natural sunlight for more than 6h significantly reduced indicator bacterial numbers. Enterococci numbers were reduced by 100% after only 4h and faecal coliforms by 58-91% and total coliforms by 43-67% after 6h. This may be due to the high sunlight intensity within the hours of 10.00 and 14.00 GMT which is the hours of maximum sunlight in Ghana. These reductions in microbial populations compares with a study by Reed *et al.*, (2000) who showed that 99.99% reduction was achieved in both faecal and total coliforms within 4 to 6h with no subsequent reactivation of growth after 24h when a 20 litre well water was exposed to direct sunlight. Similarly, researches conducted by Joyce *et al.*, (1996) also revealed that water placed in clear plastic or glass bottles and exposed to daylight disinfected in 4 to 5h in full mid-day sun and a full day in a cloudy weather. Additionally, other studies have shown that bacteria, such as faecal coliforms, *E. coli* and enterococci and viruses such as coliphages f2, rotavirus and encephalomyocarditis (EMC) virus, in water are reduced by several orders of magnitude when exposed to sunlight for periods of several hours and sufficiently high temperatures are achieved (WHO, 2002). Wegelin *et al.*, (1994) showed that synergism between water temperature and sunlight with temperatures above 55°C enhances the solar fluency germicidal effect by a factor of approximately 2 for *Enterococci faecalis* and *E. coli*.

In most rural African homes, it is the tradition to often keep drinking water indoors after fetching from its source (well, borehole or surface water) but this study demonstrates that there is the need to expose the water meant for drinking to natural sunlight at no cost or fuel wood requirement for at least 4h before returning it for storage indoors at room temperature. This practice effectively renders the water safe for human consumption as there was no re-growth or increase in bacterial numbers after sunlight exposure.

After 48h of storing the sunlight exposed water samples indoors at room temperature, the enterococci count remained at zero while faecal and total coliforms counts decreased further. This is also in line with the findings of Reed *et al.*, (2000) who reported that after a 24h lag period, solar photo-oxidative disinfection of (SOLAR disinfected) water showed no growth on the respective inoculated agar plates. This indicates that enterococci cells were irreversibly damaged or killed by sunlight. Secondly, the higher enterococci die-off rate may be due to their low numbers in the environment and the fact that they are easily deactivated by sunlight and temperature. Bordner and Winter, (1987) reported that unlike coliforms, enterococci are not known to multiply in the environment and tend to die-off more

quickly than coliforms which explains why enterococci are more useful guides than coliforms as indicators of disease burden (Kay *et al.*, 1994).

The quality of drinking water is still a matter of great concern for most developing African countries. Obiri-Danso *et al.*, (2002) reported of high numbers of total coliforms (10^8-10^9), faecal coliform (10^4) and enterococci (10^1) in well and borehole water collected from nine peri-urban communities in Kumasi, Ghana. They attributed these high microbial indicator numbers to the fact that these water sources are often sited near unsanitary areas such as latrines, septic tanks, run-off ways and rubbish dumps and in the vicinity of free range livestock and poultry birds (Obiri-Danso *et al.*, 2002). Obiri-Danso *et al.*, (2002) also reported that these contaminations may result from the use of contaminated water drawing containers and the lack of maintenance on the head works of most boreholes. The present study also recorded similar indicator microbial numbers in well water. Diarrhoea kills an estimated 2.2 million people each year, of which the majority are children under five. The Millennium Development Goals aim to reduce the number of persons without access to safe water by 50% by 2015 and household water treatment could have a role in achieving this. The World Health Organization has therefore founded an International Network to Promote Household Water Treatment and Safe Storage.

For well water samples stored continuously indoors at room temperature without the effect of direct natural sunlight, there was a 100% reduction in enterococci numbers after 144h and a 77-100% reduction in faecal coliforms and 51-100% reduction in total coliforms after 480h. These reductions may have been achieved by simple sedimentation, which removes turbidity and bacteria (Springthorpe *et al.*, 1993). However, most African homes would consume the contents of the normal transport and storage vessels before it can be rendered safe (i.e. after 20 days). Godfree (1997) reports trials by the Metropolitan Water Board which showed that 7 to 10 weeks of storage produced *E. coli* reductions of 95.7 to 99.8% in spring, 90.7 to 99.7 in summer and 85.7 to 98.2 % in winter. The lower reductions in winter were ascribed to the lower density of sunlight. It was also shown that bacteria morbidity was reduced in low water temperatures.

In most developing African countries, the rural poor use fuel wood in heating their drinking water which makes these societies heavily reliant on wood fuel (Anderson, 1993; Chatterji, 1981). It is estimated that 1 kilogram of wood is needed to boil 1 litre of water which makes the boiling of household water to make it safe unrealistic and inaccessible for many of the world's poorest people due to its scarcity and high cost (WHO, 2002). The scarcity of wood in most rural, Saharan and sub-Saharan African counties means that women in an average household spend 192h a year collecting wood fuel. As a rural community, this works out to 18,816h on this one task (Browder, 1989).

As shown in this work, the use of the sun's energy in disinfecting drinking water within 4-6h for our poor rural community which otherwise would have to spend 18,816h in a year searching for fuel wood for the same purpose with its concomitant effect on the vegetation and the environment cannot be over emphasized. Secondly, wood smoke has been recognised by the World Health Organisation as a major contributor to poor health in developing countries (Bruce *et al.*, 2000).

Various water transporting and storing vessels are employed in rural and peri-urban homes in Ghana. Research by the Ghana Village Project II (http://www.ifsa.net/~ifsaweb/activities/vcp/docs/Ghana_VCPII_Final.doc) indicated that these transport and storage vessels are made of materials like clay, aluminium, concrete, plastics, iron and others which have different rates of heat absorption as wells as retentions. This study observed that microbial indicator die-off rate in water samples exposed to natural sunlight in aluminium, iron and plastic vessels were significantly higher compared to the earthenware vessels (Cooler and pot) (Figure 1, 2, 3). However, for

water samples stored continuously indoors at room temperature, samples in the earthenware materials experienced a higher microbial die-off rate compared to the aluminium, iron and plastic vessels (Table 2). This may be due to the material make up of the vessels and the combined effect of sunlight and temperature in these vessels. Aluminium and iron are known to retain approximately over 93% of the heat energy it receives. Similarly, plastics, composed of polymers of ethlyene which are tightly joined together also tend to retain a lot of heat (Gebelein, 1997). On the other hand earthenware pots and coolers, which are made up of clay have much more pores and hence most of the heat absorbed by the water escapes outside through these pores leaving the water cool (Rose *et al.*, 1988).

This study also shows that well water is relatively clear as the water colour values were far below the Ghana Water Company Limited (GWCL) guideline values of ≤ 15°H for treated public pipe borne water throughout the experimental period (Table 3). Sunlight is also known to bleach coloured water exposed to it for several hours and penetrates clear water to depths of several meters.

CONCLUSION

The results of this study shows that exposure of well water samples to sunlight in Ghana can effectively improve the microbial quality of the water compared to storage at room temperature indoors. This means that solar water disinfection if practised in rural Ghana could improve drinking water quality and reduce the need for fuel wood used for boiling. Secondly, the main factors contributing to natural sunlight disinfection of the well water are natural sunlight and temperature and probably not the receptacles.

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