Solar Disinfection Of Stream And Well Water

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ABSTRACT: Solar disinfection of stream and well water was studied. Raw stream and well water were collected and dispensed into transparent, colourless plastic PET bottles. These were then exposed to sunlight from for four hour (10:00 to 14:00). The atmospheric conditions (sky condition, relative humidity, total radiation, aerosol optical depth and temperature) and the bacteriological quality (total bacterial and total coliform counts) of the water samples were monitored during the exposure period. The sky was clear, total radiation was high (588 -1317Wm^{-2}), relative humidity and aerosol optical depth were low (15%- 39% and 4.3×10^{-1}-1.9 respectively); the corresponding atmospheric temperature was high. The initial bacterial counts of the water samples were high (1.8 to 2.4×10^{6} and 2.2 to 2.4×10^{6} for well and stream water respectively). They were reduced by between 78.7 to 86.3% for well water and between 77.4 to 81.2%. The rates of killing of bacteria varied in the water samples and also hourly (8.5 to 56.5%/hour and 8.2 to 50.0%/hour for the well water and stream water respectively). The influence of the atmospheric condition on the disinfection of water is discussed. The study confirms that solar radiation could be effectively used to disinfect contaminated water and hence water can be made safe using solar energy.
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INTRODUCTION

Although water is a very important commodity in the survival of man; about 1.2 billion or 20% of human population do not have access to safe water [1]. Globally, water crisis is experienced either as “having to walk long distances every day to fetch enough drinking water– clean or unclean; or as suffering from avoidable malnutrition or disease caused by drought, flood or inadequate sanitation; or in lack of funds, institutions or knowledge to solve local problems of water use and allocation.

Consumption of, and exposure to unsafe water accounts for about 80% of diseases in developing nations and 88% of diarrhoeal disease is attributed to unsafe water supply, inadequate sanitation and hygiene [1]. Safe water and good hygiene have been recognized as the best defense against diarrhoea and water related diseases; hence, one of the water-related targets of the Millennium Development Goals (MDGs) is improvement in access to safe drinking water [2].

There have been various efforts to make water safe, these include boiling for 10minutes or use of chlorine compounds available in tablets or solution to disinfect drinking at home. Energy cost and lack of resources or distribution infrastructure makes the application of these procedures extremely limited in application. Storage of water for 10 to 14 days has been found to improve the bacteriological quality of water due to depletion of nutrients and sedimentation due to gravitational pull [3,4,5]. Eniola *et al.* [6] proposed involvement of solar microcidal action during outdoor storage.

In day time, about 30% of the solar radiation that falls on the earth is immediately reflected by clouds and surfaces. The amount of radiation available is affected by aerosol optical depth and cloud parameters [7]. High clouds increase energy reflection hence low radiation, whereas low clouds increase energy absorption [8]. Nigeria is located between Latitude 4º and 14ºN; which lies within the optimum regions for solar radiation- between latitude 35ºN and 35ºS [9]. The 315-400nm wavelength on the UV range of solar radiation is effective at destroying bacteria, does not generate harmful by-products (as do chemically driven technologies) and is not expensive [10, 11].

Solar disinfection (SODIS) involves placing contaminated water in transparent containers in direct sunlight for some hours before consumption [12]. It has been used in reducing risk of water borne disease in children aged under 6years in a Massai community in Kenya [13]; in eradicating coliforms from highly contaminated water or wastewater [14] and inactivation of *Cryptosporidium parvum* oocytes [12]. This study investigates disinfection of streams and wells water using direct exposure of water in transparent PET bottles to sunlight.

MATERIAL AND METHODS

Water samples were dispensed into disinfected, transparent colourless 75cl PET bottles. A set of bottles were exposed to direct sunlight for four hours at the Baseline Surface Radiation Network (BSRN) station in the Department of Physics, University of Ilorin. Another set of the bottles containing water samples were wrapped with black cloth and kept indoors to serve as controls. Atmospheric condition (aerosol optical depth sky condition temperature relative humidity and total radiation) was determined at the BSRN station, Ilorin Nigeria (8^o 28'N, 4^o 38'E to 8^o 31'N, 4^o 40'E) between day 45 (February 14th) and day 72 (March 12th) of 2008. The total heterotrophic bacterial and enteric bacterial counts were determined by standard pour plate technique using Nutrient media and MacConkey agar respectively [15].

RESULTS

The atmospheric conditions in terms of the total radiation, atmospheric temperature, relative humidity, aerosol optical depth and sky condition during the periods of exposure are shown on Figure 1. The total radiation was high: 588- 1317Wm^{-2}, relative humidity and aerosol optical depth were low: 15%-39% and 4.3×10^{-1}-18.55×10^{-1}. The corresponding temperatures were high. The sky was generally clear during the periods of exposure. Variation in population of heterotrophic bacteria in the exposed water is shown in Figure 2. There was 68.89% and 81.98% reduction in heterotrophic bacteria population in the stream and well water respectively. The populations of enteric bacteria in the stream and well water were reduced by 79.18% and 82.01% respectively (Figure 3). The rate of killing of heterotrophic bacteria and enteric bacteria in the water samples during the exposure period varied on hourly basis (Figure 4 and 5).

DISCUSSION

The prevailing atmospheric conditions favoured high total radiation. This is due to the clear sky and low aerosol optical depth (index of the amount of dust present in the atmosphere) which allowed easy penetration by the in-coming radiation. The high atmospheric temperature was reflective of the high radiation intensity. It is also indicative of retention of long waves (products of reflection of short waves off the earth surface) due to low relative humidity. Statistical analysis confirmed a direct relationship between the total radiation and atmospheric temperature (r= 0.8526) and an inverse relationship between the atmospheric temperature and relative humidity (r= -0.6109).

Exposure to solar radiation reduced population of heterotrophic bacteria in the stream and well water by 68.89% and 81.98% respectively. Similarly, the population of enteric bacteria in the stream and well water were reduced by 79.18% and 82.01% respectively. The rate of killing of bacteria in the water samples by solar radiation varied hourly and in direct relation to the intensity of the total radiation ($r_{well\ water}$ = 0.9797; $r_{stream\ water}$ = 0.9478). The overall (cumulative) rate of killing similarly showed a direct relationship with the total radiation ($r_{well\ water}$ = 0.9965; $r_{stream\ water}$ = 0.9927). The reduction in populations of heterotrophic and enteric bacteria followed an exponential decline curve.

The destruction of bacteria by solar radiation is reported to be directly related to the intensity of the sunlight at the time of exposure. The intensities of radiation obtained were consistently higher than the recommended minimum of 500Wm^{-2} for application of SODIS. Destruction of bacteria by solar radiation involves synergy of three radiation mechanisms. Production of highly reactive oxygen (singlet oxygen) intermediates (superoxides [O_2^-], hydrogen peroxides [H_2O_2], and hydroxyl radicals [OH·]) from reaction of the UV-A (λ= 320-400nm) with dissolved ground state oxygen (triplet oxygen). Another is damage of bacterial DNA by UV-A and heat generation by absorption of red and infrared light by water. The increased water temperature contributes to killing of the bacteria, which results in pasteurization [9, 11, 14, 16].

Conclusion

This study shows substantial disinfection of the raw waters using solar radiation. The simple nature of the process makes solar disinfection (SODIS technology) practicable at household level. Although total elimination of bacteria was not obtained in this study, a longer exposure period and amplification of solar radiation could improve the level of disinfection. Considering the realities on ground in developing nations; solar disinfection of water, or SODIS, may be the key to achieving some of the water related MDGs.

RH: Relative humidity Temp: Atmospheric Temperature AOD: Aerosol optical depth TR: Total Radiation

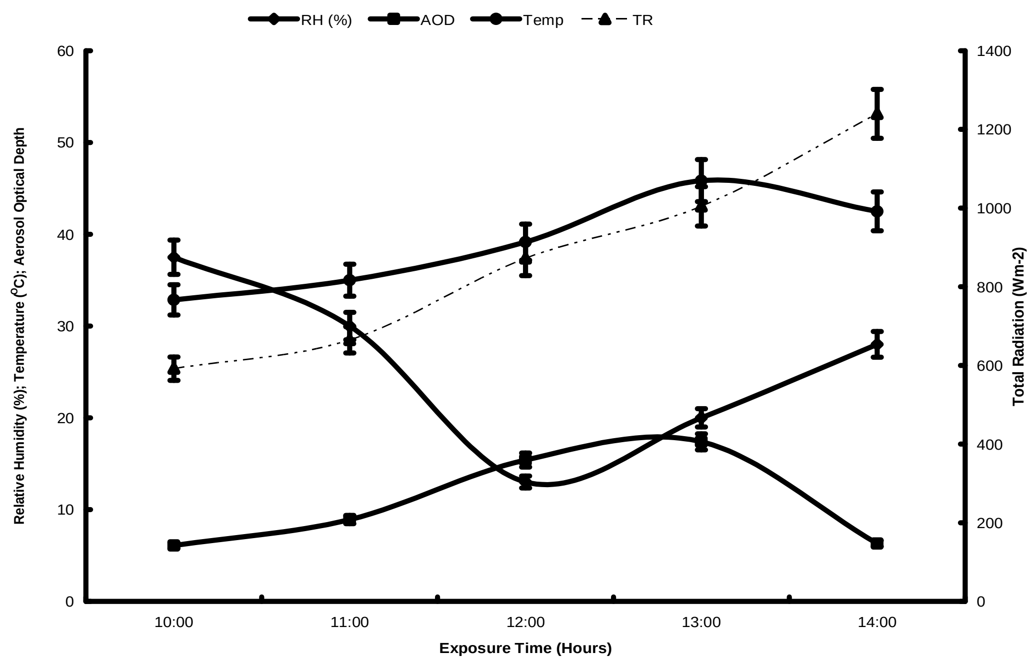

Figure 1: Variations in atmospheric conditions during the exposure period

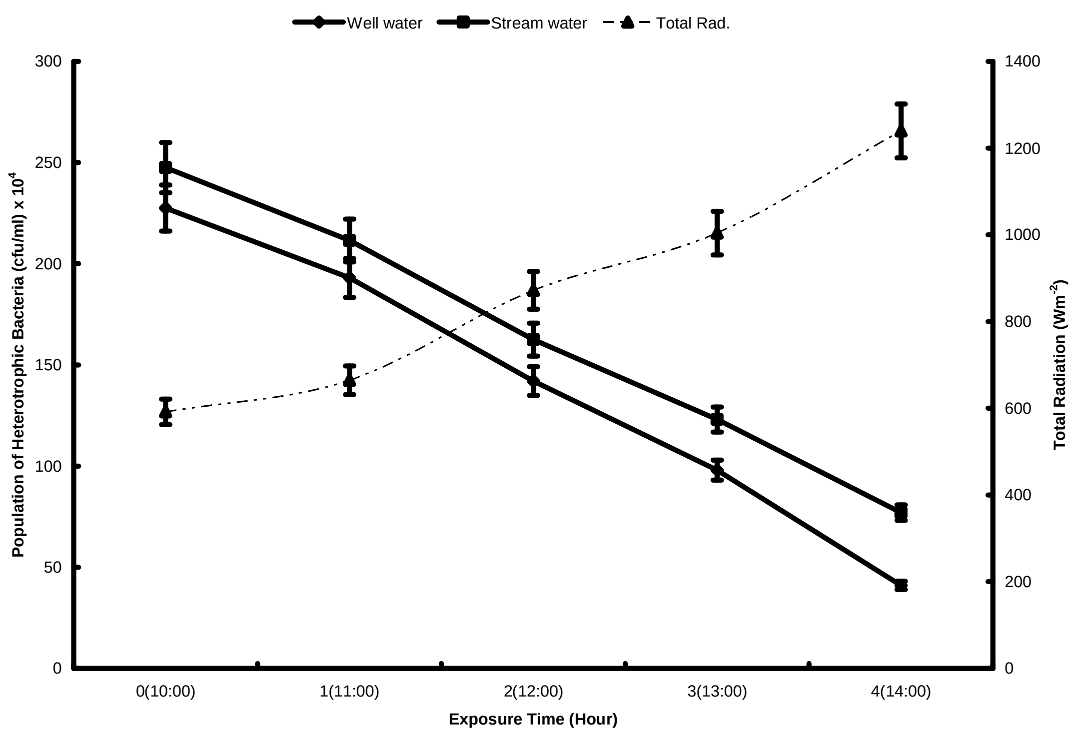

Figure 2: Mean Population of surviving bacteria in water samples during the exposure period.

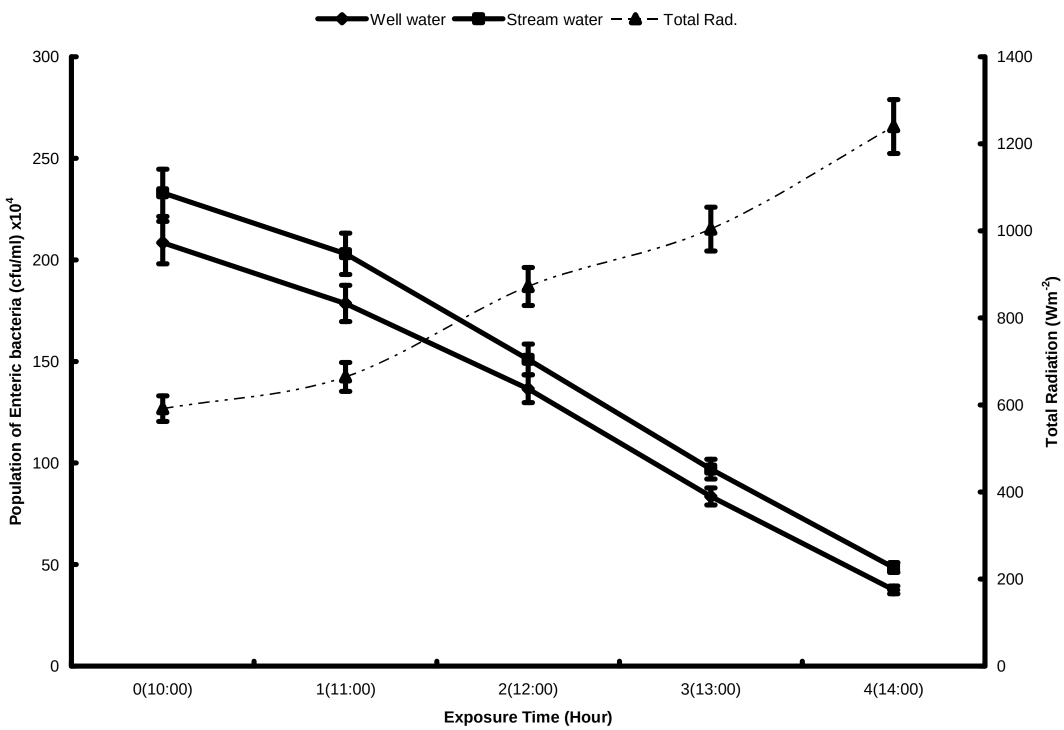

Figure 3: Mean population of enteric bacteria in the water during the exposure

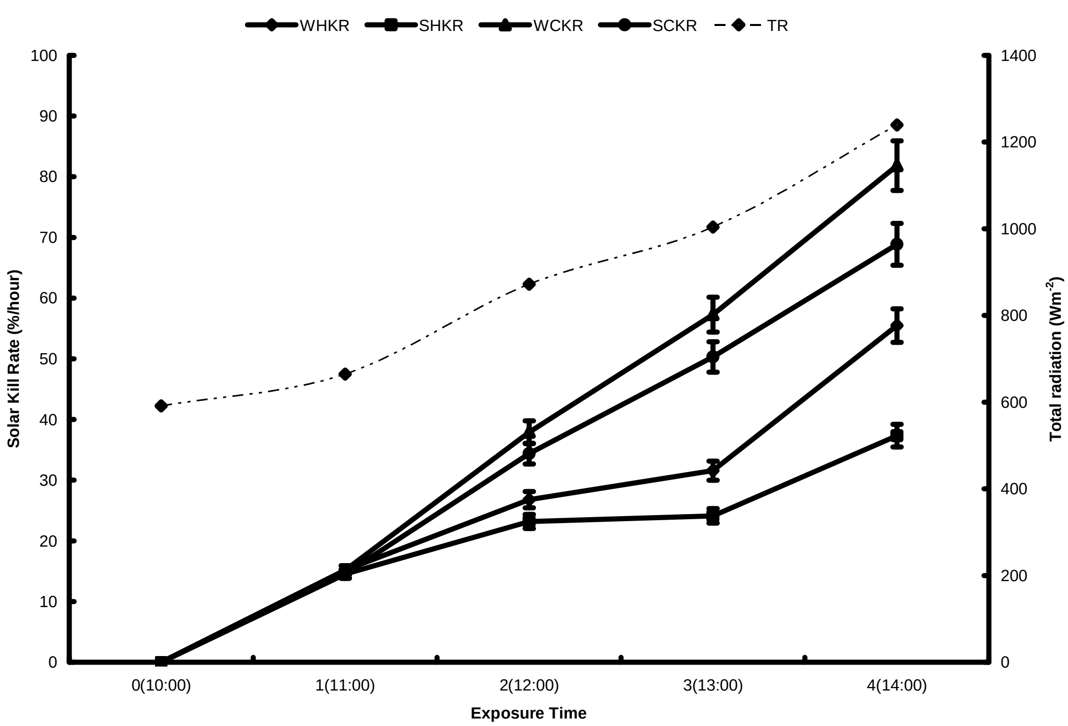

Figure 4: Variations in rate of Solar killing of heterotrophic bacteria during the exposure period.
WHKR: Hourly solar kill rate (well water) WCKR: Cumulative solar kill rate (well water)
SHKR: Hourly solar kill rate (stream water) SCKR: Cumulative solar kill rate (stream water)

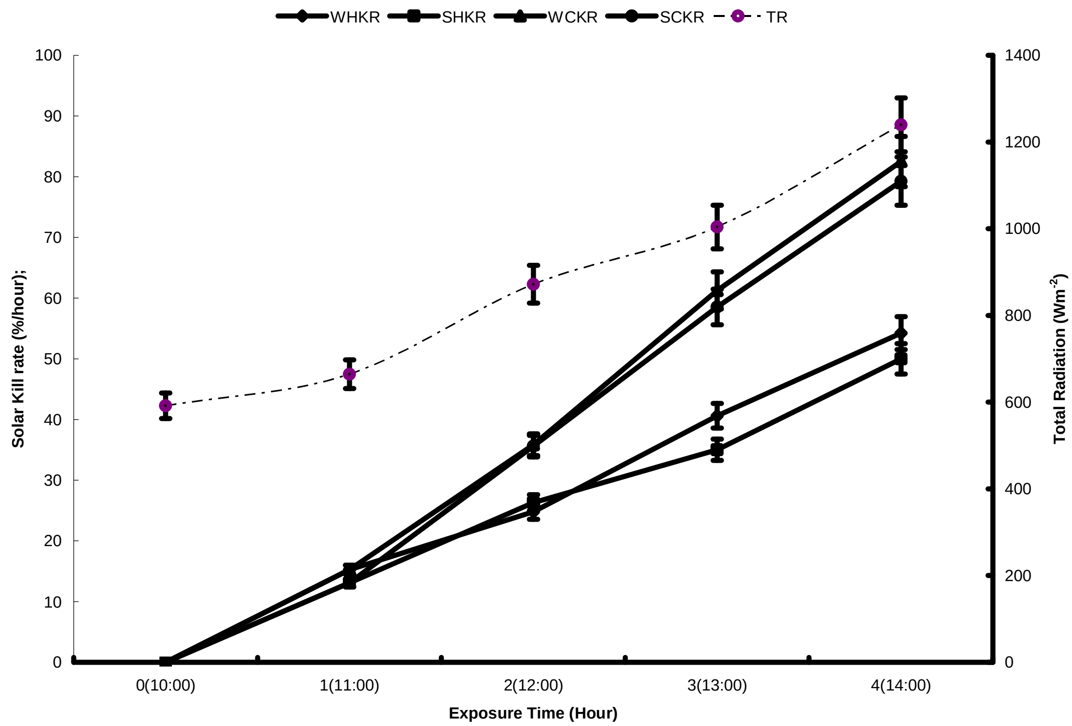

Figure 5: Variations in rate of Solar killing of coliform bacteria during the exposure period.

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