PERFORMANCE OF A CONTINUOUS SOLAR WATER DISINFECTION SYSTEM IN ISIOLO COUNTY, KENYA

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ABSTRACT:

A continuous solar water disinfection system was designed, installed and tested in Isiolo town, Kenya. The system consisted of two flat plate solar collectors each having 2.34 m² gross area and photovoltaic pumping system. International Organization for Standardization (ISO) analytical procedures; ISO16649-3, ISO 6888-2, ISO 4833-1, ISO 9308-, ISO 10523:2017 ISO 7027: 2016, and ISO 7887: 2011 were used to determine the quality of disinfected and untreated water. The experimental design consisted of series collectors without heat exchanger, parallel collectors without heat exchanger and series arrangement of solar collectors with heat exchanger for preheating the cold incoming water using the exiting hot water. Total coliforms, total plate count, Staphylococcus aureus and Escherichia coli log10 counts in raw water were: 3.4, 3.8, 2.3 and 2.1 respectively. The mean Log10 reductions in total coliforms, Escherichia coli, Staphylococcus aureus and total plate counts were; 3.3, 1.9, 1.9 and 3.7 respectively in series arrangement with heat exchanger. Inactivation to < 1 CFU/ml was attained using series collector’s arrangement with heat exchanger between 12:00 and 14:00. Parallel collector arrangement induced water pasteurization that required recirculation and low flow rates to effectively initiate microbiological inactivation. Staphylococcus aureus required temperature greater than 48 °C to initiate inactivation. Series collector arrangement with heat exchanger produced 200 l of disinfected water per day. However, additional collectors and water recirculation are required to increase the volume of disinfected water.

Keywords: Flow rate, disinfection temperature, logarithmic reduction, solar radiation, water quality, total coliforms, Escherichia coli, Staphylococcus aureus.
1.0 INTRODUCTION

Access to adequate water is essential for drinking, food processing, sanitation and hygiene (Borde et al., 2016). Frequent cholera outbreaks in most rural areas of Kenya are water related (Ssemakalu et al., 2014). Heavy pollution of open surface water sources and limited water supply during drought have been implicated in incidences of water related diseases. Consequently, interventions such as rehydration therapy, the use of antibiotics, vaccination, the provision of chlorine tablets and hygiene sensitization drives have been used. The implementation of these interventions remains a challenge due to constraints associated with the cost, ease of use and technical know-how. These challenges can be addressed by solar water disinfection (Ssemakalu et al., 2014). Other water disinfection methods such as boiling and chlorination have been implicated in deforestation and production of toxic chemical compounds respectively. There is also negative cultural perception of chemical water treatment.

Solar energy technologies have been practised in ancient cultures for centuries, with established effectiveness on water treatment to destroy bacteria (Kean et al., 2014; McGuigan et al., 2012).

Solar water disinfection is one of the most practical and low-cost techniques to reduce pathogenic load in water at household level in low-income areas (Borde et al., 2016; Castro-Alferez et al., 2016). However, batch solar water disinfection (SODIS) systems are limited by the long water disinfection hours, low volume of water treated per batch and variation in disinfection time (Kean et al., 2014; Borde et al., 2016). As such continuous solar water disinfection systems have been established to be effective over the SODIS systems as they overcome the limitations of low volume and long water disinfection time of about 6 hours (Kean et al., 2014; McGuigan et al., 2012). Apart from water disinfection (pasteurization), continuous solar water treatment technologies have been used for desalination of water (Malato et al., 2016).

In water pasteurization, a continuous-flow gravity-fed system with flat reflectors in a simple solar oven heated incoming water to pasteurization temperature (70 °C) in seven minutes (Anthony et al., 2015). Total coliforms were reduced by 2 Log10 units in 20 minutes in a single pass continuous flow reactor at 0.12 kg s-1 flow rate (Gill and Price, 2010). This system recorded near complete disinfection. Similarly, 2 units log10 reduction of Escherichia coli in grey water by a 50 l continuous flow pilot scale reactor was reported by Pansonato et al. (2011). However, the disinfection effect was not sufficient to completely destroy Escherichia coli. Concentrating parabolic collectors (CPC) reflector of 1.89 concentration factor in a continuous single pass flow reactor, produced a reduction in residence time required for disinfection and a higher volume of disinfected water (Polo-lopez et al., 2011). Hot water at 70 °C and a flow rate of 0.0475 kg s-1 was produced per square meter of flat reactor for every kWh incident radiation with unreported units Log10 reduction of bacteria (El-Ghetany and El-Seesy, 2005). Thermosiphon solar water heating system with a single flat plate solar collector produced hot water at 80 °C and 0.06 kg s-1 flow rate per square meter of the flat plate solar collector for each kWh of incident solar energy with unreported unit Log10 reduction in tested bacteria (Bansal et al., 1988). El Ghetany and Dayem (2010) reported a single 2.34 m2 solar collector in a continuous solar water disinfection system operated at 0.0185 kg s-1 flow rate with an output of hot water at 60 °C. The disinfected water volume and temperature were affected by flow rate...
and solar radiation intensity (El Ghetany and Dayem, 2010). In Isiolo County Kenya, solar energy has been used to power borehole pumps and for drying of agricultural produce. However, the use in solar water treatment has only been practised in batch SODIS systems that are limited in volume.

The objective of the present study was to establish the contamination levels on River Isiolo water and the performance of different arrangements of solar water disinfection systems (in parallel or in series and with or without a heat exchanger for recovery of heat from the hot water and using it to preheat the cold incoming water) in the inactivation of selected bacteria (total coliforms, Escherichia coli, Staphylococcus aureus, and total plate count) under varied time of the day and flow rates.

2.0. MATERIALS AND METHODS

2.1 STUDY Setting
The study was conducted in Isiolo County Kenya between 1st October and 30th November 2017 and solar radiation intensity variation during the experiments was 484 W m-2 – 1150 W m-2. Isiolo County is located within: 00°21′N 37°35′E / 0.350°N 37.583°E / 0.350; 37.583. The experimental system was set-up at Ewaso Nyiro North Development Authority (ENNDA) premises in Isiolo town.

2.2. SOURCE OF WATER
Surface water sourced from River Isiolo was used for disinfection experimental set-ups. The water was collected from the river in tanks and transported by pick-up motor vehicles to the ENNDA experimental site each day. Water was drawn from three sampling spots along River Isiolo and the portions mixed together. For each batch sourced, 1 liter sample of the untreated water was drawn for analysis. The sourced water was allowed to settle for 2 hours before decantation and pre-filtration through a cotton filter cloth into the raw water collection tank.

2.3. SAMPLE COLLECTION DURING EXPERIMENTATION
Samples were collected as described by American Public Health Association (APHA) 2012. The samples were refrigerated for 6 hours, then transported over 6 hours in ice packed cooler box to the laboratory for analysis. The analysis was done within 24 hours post sampling given the long distance of 285 km from experimental site in Isiolo to the University of Nairobi laboratory.

2.4. COMPONENTS OF THE CONTINUOUS SOLAR WATER DISINFECTION SYSTEM
A schematic diagram of the continuous solar water disinfection system is shown in Figure 1.
Two flat-plate solar collectors (Model ST 230, Bural Solar, Istanbul, Turkey), each having a collector area of 2.3 m² were used. The solar collectors incorporated full area copper absorption plates ultrasonically welded to copper circulation tubes, single block polyurethane insulation and tempered security glass cover. A shell-and-tube heat exchanger consisting of 25 cm diameter shell and 28 inner tubes each 2 cm in diameter and having a length of 1 m was used in the set-ups involving recovery of heat from the hot water to heat the incoming cold water. In addition, the photovoltaic pumping system consisted of; Solar panel (Model YL125P-17b6/7, Davis and Shirtliff, Nairobi, Kenya) with a power rating of 125 W and 17.9 V and SHURflo Diaphragm Pump (Model 2088-443-144, Davis and Shirtliff, Nairobi, Kenya), 3.5 GPM, 45 PSI pressure setting, 12 VDC voltage was used. The tanks for raw and disinfected water consisted of two 500 l galvanized steel tanks painted on the inside surface with crown two pack epoxy paint (EMERALD 14 E 53), to prevent corrosion. Six digital EE462 – Cable High-Temperature Sensors (China) were used to determine the temperatures of incoming cold water; water between the two collectors in series arrangement, hot water entering the heat exchanger from the collectors, water leaving the heat exchanger and entering the solar collector(s) and water at the point of discharge into the disinfected water tank.

### 2.5. DETERMINATION OF SOLAR RADIATION INTENSITY

A thermopile pyranometer (Model CM5-774035, Kipp and Zonen, Delft, Netherlands) with an output voltage of 6.09 x 10⁻³ mV/Wm⁻² for a resistance range of 10 Ohm was used for measuring the instantaneous value of the total solar radiation.
intensity (IT) incident on the collector surface. It was connected to a data logger that recorded the voltage and hence the corresponding solar radiation intensity.

2.6. ANALYTICAL METHODS

Enumeration of *Escherichia coli*, *Staphylococcus aureus*, total plate count and total coliforms was done as described in ISO 16649-3, ISO 6888-2, ISO 4833-1 and ISO 9308-1 respectively. Water pH was determined as described in ISO 10523:2017 using HACH pH meter (Model E-08328 Crisson Instruments, South Africa). Turbidity was determined as described in ISO 7027: 2016, using turbidimeter HACH (Model 2100 Q01-2010 – USA). Electrical conductivity was determined as per ASTM-D1125-2014, (using HI 9033 Multi range conductivity meter, USA). Color was determined as described by ISO 7887: 2011 (Handheld colorimeter HI727 HANNA instruments, range 0 – 500 TCU).

2.7. DATA ANALYSIS

Analysis of variance (ANOVA) was done at 5 % level of significance to compare means of the logarithmic reduction in microbial counts in the disinfected water samples using statistical analysis software (SAS) version 9.0.

The least significant difference (LSD) was used to separate the means. Pearson correlation was used to establish the relationship among the quality characteristics of the sampled disinfected and raw water at 5 % and 1 % levels of significance.

3.0. RESULTS

3.1 RAW WATER QUALITY

The quality of river Isiolo water sampled on different days of the experiments from the three sampling spots is shown in Table 1.

Electrical conductivity significantly differed (p≤0.05) across the three raw water sampling spots. The pH, color, and electrical conductivity were within the acceptable limits of 6.5 -9.5, < 50 TCU (True color units) and 2500 µS/cm respectively (WHO, 2014; KS EAS 12, 2014). Turbidity had a significant positive relationship with electrical conductivity (r = 0.9). The Log10 unit count for *Escherichia coli*, total coliforms, total plate count and *Staphylococcus aureus* were 2.1, 3.4, 3.8 and 2.3 respectively. These values were >1 CFU/ml requirement for potable water.

### Table 1: Raw Water Quality

| Characteristic                              | S1       | S2       | S3       | MEAN | L.S.D | cv% |
|---------------------------------------------|----------|----------|----------|------|-------|-----|
| **PH**                                      | 7.2±0.7a | 7.6±0.7b | 7.38±0.35b | 7.36 | 0.19  | 0.8 |
| Color (TCU)                                 | 10.0±1a  | 9.2±0.21a| 13.3±1.56b | 10.85 | 2.9   | 8.4 |
| Turbidity (NTU)                             | 399.4±1.5a | 453.5±4.6b | 385±6.65a | 412.6 | 15.9  | 1.2 |
| Electrical conductivity (µS/cm)             | 286.5±1.9b | 310.9±1.7c | 250.9±1.9a | 282.8 | 5.86  | 0.7 |
| *Escherichia coli* (Log10 CFU/ml)           | 1.5±0.5a | 1.9±0.2b | 3.1±0.3c | 2.1   | 0.3   | 7.1 |
| Total coliforms (Log10 CFU/ml)              | 3.5±0.71b | 3.0±0.4a | 3.6±0.7a | 3.4   | 0.1   | 2.4 |
| Total Plate counts (Log10 CFU/ml)           | 3.9±0.6b | 3.4±0.1a | 4.1±0.5c | 3.8   | 0.6   | 3.0 |
| *Staphylococcus aureus* (Log10 CFU/ml)      | 1.9±0.2b | 2.5±0.3a | 2.6±0.4a | 2.3   | 0.3   | 7.9 |
1. Values are means of twenty determinations ± standard deviations.
2. Values with the same letters on the same row are not significantly different at 5% level of significance.
3. The letters S1, S2 and S3 are the three raw river Isiolo sampling points collected on different dates of the twenty-day experiments.

3.2. CHANGE IN SOLAR HEATED WATER TEMPERATURE WITH THE TIME OF THE DAY

The change in water temperature with time of the day for the three experimental arrangements is shown in Figure 2. Water temperatures for the three experimental set-ups had increased linearly from 08:00 at the onset of the experiments to a peak between 11:00 and 15:00. Beyond 15:00, the change in water temperature was small and tended to zero as the water exited the systems at a temperature just slightly above the water temperature in the reserve untreated water tank at 17.00.

The change in water temperature with time of the day was highest in series arrangement of the flat plate solar collectors coupled with a shell and tube heat exchanger. Change in water temperature with time of the day was least in parallel arrangement of the flat plate solar collectors. The highest change in water temperature in the parallel arrangement was 23.7 °C. Water temperature of above 65 °C was achieved by the series arrangement of the solar collectors with shell and tube heat exchanger between 11.00 and 15.00. Mean temperature change significantly differed (p≤0.05) across the three water disinfection systems.

![Figure 2: Change in water Temperature Vs Time of the Day](image-url)
3.3. DISINFECTION OF WATER USING PARALLEL SOLAR COLLECTORS’ ARRANGEMENT

The two flat-plate solar collectors were connected in parallel and the water circulated at a flow rate of 0.018 kg s⁻¹ without the heat exchanger.

Figure 3 shows the log₁₀ reduction in total plate counts, *Escherichia coli*, total coliforms and *Staphylococcus aureus* in the parallel solar collectors’ disinfection system.

![Figure 3: Log reduction in microbiological count vs time of the day in the parallel solar collectors’ disinfection system](image)

The mean log₁₀ reduction in total coliforms, *Escherichia coli*, *Staphylococcus aureus* and total plate counts in the water significantly differed (p≤0.05) across different times of the day. However, between 11:00 and 13:00 the mean log₁₀ reduction in the microbial load in the water did not differ significantly (p>0.05) for the analyzed microorganisms.

For complete disinfection, the expected log₁₀ reduction in *Escherichia coli*, total coliforms, total plate count and *Staphylococcus aureus* was 2.1, 3.4, 3.8 and 2.3 respectively. However, this was not achieved with the parallel arrangement of the solar collectors’ disinfection system. *Staphylococcus aureus* was not inactivated at 10:00 and 15:00 when the temperatures were below 48 °C.

3.4. LOG₁₀ DISINFECTION USING SERIES SOLAR COLLECTORS’ ARRANGEMENT WITH SHELL AND TUBE HEAT EXCHANGER

The two flat-plate solar collectors were installed in series coupled with the use of the shell and tube heat exchanger for heat recovery and water circulated at constant flow rate of 0.018 kg s⁻¹ between 09:00 and 16:00. Table 2 shows the log₁₀ reduction in microbial load in the test water.
Reduction of microbiological counts to below 1 CFU/100 ml was achieved between 12:00 and 14:00. About 200 l of disinfected water was produced within the three active disinfection hours between 11:00 and 14:00 at a flow rate of 0.018 Kg s⁻¹. The mean Log₁₀ reduction in total coliforms, Escherichia coli, Staphylococcus aureus and total plate counts were 3.3, 1.9, 1.9 and respectively. Despite the difference in temperature change with time of the day the Log₁₀ reduction in microbiological count did not significantly differ (p>0.05) for most parts of the day.

Log₁₀ reduction in microbiological counts had a significant positive relationship (p≤0.05) with the outlet water temperature; r = 0.799, 0.827, 0.848 and 0.798 for total coliforms, Escherichia coli, Staphylococcus aureus and total plate counts respectively.

### 3.5. LOG₁₀ DISINFECTION USING SERIES SOLAR COLLECTORS’ ARRANGEMENT WITHOUT SHELL AND TUBE HEAT EXCHANGER

The two flat-plate solar collectors were installed in series and water without circulated at constant flow rate of 0.016 kg s⁻¹ between 09:00 and 16:00. Table 3 shows the log₁₀ reduction in microbial load in the test water.

#### Table 2: Log₁₀ disinfection using series arrangement and Shell and tube heat exchanger

| Time of day | Escherichia coli | Total coliforms | Staphylococcus aureus | Total plate Counts |
|-------------|------------------|-----------------|-----------------------|-------------------|
| 10:00       | 1.8±0.01b       | 3.3±0.01b       | 1.5±0.01b             | 3.5±0.01b         |
| 11:00       | 1.9±0.01c       | 3.3±0.014b      | 1.6±0.0c              | 3.7±0.01c         |
| 12:00       | 2.1±0.0d        | 3.4±0.0d        | 2.3±0.0c              | 3.8±0.0c          |
| 13:00       | 2.1±0.0d        | 3.4±0.0d        | 2.3±0.0c              | 3.8±0.0c          |
| 14:00       | 2.1±0.0d        | 3.4±0.0cd       | 2.3±0.0c              | 3.8±0.0c          |
| 15:00       | 1.8±0.0d        | 3.3±0.0cd       | 1.6±0.0c              | 3.7±0.01c         |
| 16:00       | 1.5±0.01a       | 3.2±0.01bc      | 1.46±0.04b            | 3.4±0.0c          |

**Mean** | 1.9±0.1 | 3.3±1.2 | 1.9±0.4 | 3.7±0.4 |
**cv%** | 0.2     | 0.2     | 1.1     | 0.2     |
**L.S.D** | 0.01    | 0.02    | 0.04    | 0.01    |

1. Values are means of ten determinations in duplicate ± standard deviations.
2. Values with the same letters on the same column are not significantly different at 5% level of significance.

#### Table 3: Log₁₀ disinfection using series arrangement without shell and tube heat exchanger

| Time of day | Escherichia coli | Total coliforms | Staphylococcus aureus | Total plate Counts |
|-------------|------------------|-----------------|-----------------------|-------------------|
| 10:00       | 0.6±0.01b        | 1.4±0.01a       | 0.1±0.02a             | 1.7±0.03a         |
| 11:00       | 0.8±0.01c        | 1.4±0.02a       | 0.5±0.01b             | 2.1±0.01b         |
| 12:00       | 1.1±0.03d        | 2.3±0.01c       | 1.4±0.02d             | 2.7±0.03d         |
| 13:00       | 1.1±0.01d        | 2.5±0.03d       | 1.5±0.01d             | 2.9±0.01e         |
| 14:00       | 1.1±0.02d        | 2.5±0.02d       | 1.3±0.03d             | 2.9±0.04e         |
| 15:00       | 0.9±0.01c        | 2.2±0.01c       | 0.8±0.01c             | 2.4±0.03e         |
| 16:00       | 0.5±0.05a        | 1.9±0.01b       | 0.46±0.02b            | 2.2±0.02b         |
Reduction of microbiological counts to <1 CFU/100 ml was not achieved by this system. The mean Log10 reduction in total coliforms, *Escherichia coli*, *Staphylococcus aureus* and total plate counts were 2.03, 0.73, 0.89 and 2.42 respectively. The change in water temperature with time of the day in this system was slightly lower than system consisting of series arrangement of flat plate collectors with heat exchanger.

3.6. EFFECT OF FLOW RATE ON HOT WATER TEMPERATURE

The experiment was carried out between 11:00 and 14:00 when the average solar radiation was 800 – 1100 W m⁻² using series arrangement of the two flat-plate solar collectors without using the shell and tube heat exchanger. The flow rates were varied as shown in Figure 4

![Figure 4: Effect of flow rate on hot water temperature](image)

Flow rate and temperature of the disinfected water exhibited an exponential relationship \( y = 0.5293e^{-0.055x} \). Flow rate significantly influenced the temperature of the disinfected water \( r = 0.9738 \). Disinfection temperature was attained at flow rates below 0.02 kgs⁻¹. At flow rate of 0.142 kgs⁻¹ the change in water temperature was zero. At this flow rate water passed out unheated. Higher temperature of greater than 70 °C was attained at a flow rate of less than 0.005 kgs⁻¹ though exhibiting pulsating flow.

4.0. DISCUSSION

4.1. SUMMARY OF THE FINDINGS

The objective of the study was to establish the contamination levels on river Isiolo water, the performance of different arrangements of solar water disinfection systems in the inactivation of the selected bacteria under varied time of the day and flow rates. Water sourced from river Isiolo was contaminated with total coliforms, total plate count, *Staphylococcus*
Escherichia coli and Staphylococcus aureus to levels regarded as unsafe (WHO, 2014). Point of use disinfection is thus necessary. However, water pH, color, and electrical conductivity were within the acceptable limits of 6.5–9.5, < 50 TCU (True Color Units) and 2500 µS/cm respectively. The highest disinfection temperature of greater than 65 °C was attained using series arrangement of the flat plate collectors with heat exchanger. Inactivation of Escherichia coli, total coliforms, total plate counts, and Staphylococcus aureus to < 1 CFU/ml occurred between 12.00 and 14.00 at a flow rate of 0.018 kg s⁻¹ using the series arrangement of the flat plate solar collectors and the shell and tube heat exchanger.

4.2. LEVEL OF CONTAMINATION OF RIVER ISIIOLO WATER

The prevailing environmental conditions did not adversely influence the discharge of ionic minerals into the river bed. The dissolved minerals were therefore in levels that did not significantly influence the shift in water pH and electrical conductivity to unacceptable levels (Begum et al., 2009; Reza and Singh 2010). However, River Isiolo water was polluted by suspended matter and silt to levels that made the water highly turbid (Ashraf et al., 2011; Bada et al., 2017; Ferreira et al., 2017). The turbid water is not appealing for direct use in drinking or in food processing. As such decantation and prefiltration treatment of the water was done to prevent the blockage of the solar collector’s tubes as well as reduce the flow and heat resistance (McGuigan et al., 2012).

Escherichia coli, total coliforms, Staphylococcus aureus and total plate counts indicated the extent of pollution of River Isiolo (Oludairo et al., 2015; Muhammad et al., 2017). The contamination levels exceeded 1 CFU/ml recommended for standard drinking water (Mahananda et al., 2010; Manhokwe et al., 2013). Point of use disinfection of River Isiolo water is necessary hence the need for appropriate water disinfection methods. The contamination levels were greater than 2 Log10 and therefore sufficient for the experimental activities (Ubomba-Jaswa et al., 2010; McGuigan et al., 2012).

4.3. LOG REDUCTION OF MICRO-ORGANISMS IN SERIES SOLAR COLLECTOR’S ARRANGEMENT WITH HEAT EXCHANGER

Complete inactivation of Escherichia coli and Staphylococcus aureus was attained at temperatures exceeding 65 °C. At this temperature the bacterial cell structure is susceptible to heat allowing the denaturation of cell proteins and stoppage of the cell metabolic activities (Birzer et al., 2014). Pathogenic inactivation occurs at temperatures exceeding 60 °C (Pansonato et al., 2011, Birzer et al., 2014). Reduction in Escherichia coli by 2 units Log10 has been attained with similar solar water disinfection systems (Gill and Price, 2010; Pansonato et al., 2011). However, the final counts were not reported to establish whether the inactivation was complete. Despite the inactivation of Escherichia coli to <1CFU/ml, the Log10 reduction is a function of the initial microbial load and as such the present study did not investigate this phenomenon with counts that require greater than 3 Log10 unit inactivation effect. In reference to the target River Isiolo water usage, the system was considered effective to provide safe drinking and food process water.

Total coliforms are more heat-resistant and reduction to <1CFU/ml was only attained at about 70°C disinfection temperature (Anthony et al., 2015). Attainment of a temperature of 70 °C required an average solar radiation of 700 W m⁻² at a flow rate of 0.018 kg s⁻¹. The volume of disinfected water flowing out of this system was slightly lower than that from the solar oven box reported by Anthony et al. (2015). Total coliforms Log10 reduction of >2 has been attained in other solar disinfection systems (Caslake
et al., 2004). In other studies, 2 Log10 units reductions were reported (Ubomba-Jaswa et al., 2010; Gill and Price, 2010). Water disinfection is thus a complex function of initial microbial load, temperature and exposure time influenced by collector surface area, flow rate and solar radiation intensity. However, this phenomenon requires further investigation in controlled systems. Inactivation of total plate counts to < 1CFU/ml was not achievable even at a temperature of 70 °C. This require the increase of collectors heating surface area and/or reduction of water flow rate.

5.0. CONCLUSION

River Isiolo water is contaminated with total coliforms, Escherichia coli, total plate counts and Staphylococcus aureus hence the need for point of use disinfection. In addition, the suspended matter and silt arising from the pollution of the water requires prefiltration and decantation prior to disinfection. The average solar radiation intensity of 800 W m-2 that was found in Isiolo is sufficient for use in solar water disinfection. Inactivation of Escherichia coli, total coliforms, total plate count and Staphylococcus aureus to < 1 CFU/ml cannot be attained using parallel arrangement disinfection system under the conditions encountered in the present study. Increased effectiveness of the parallel arrangement of solar collectors requires increased heating surface area, reduced flow rate of < 0.018Kg s-1 and recirculation of the heated water to increase exposure time. Series arrangement with shell and tube heat exchanger system is effective in inactivation of Escherichia coli, total coliforms, total plate count and Staphylococcus aureus to < 1 CFU/ml between 12:00 and 14:00. Water disinfected before and after this time requires recirculation at low flow rates. The initiation time for water disinfection is 10:00.

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DATA AVAILABILITY STATEMENT

Data used to support the findings of this study are included within the article.

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