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1 **Evaluation of Solar Disinfection of *E. coli* Under Sub-Saharan Field Conditions Using a 25 Litre**
2 **Borosilicate Glass Batch Reactor Fitted with a Compound Parabolic Collector**

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9

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11 (CPC); point of use water treatment

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21

22

Abstract

23 The bacterial inactivation efficacy of a solar water disinfection (SODIS) reactor consisting of a 25L
24 borosilicate glass tube fitted with a compound parabolic collector (BGTR-CPC) was assessed under
25 equatorial weather conditions in Uganda. The SODIS BGTR-CPC was tested over a 17-month period
26 in Sub-Saharan conditions in Kampala, Uganda. The BGTR-CPC was filled with natural water from a
27 nearby protected well. A wild strain of *Escherichia coli* isolated from local natural water was added to
28 the reactor to give a starting population of between 10^5 and 10^7 CFU/100ml. This spiked water was
29 exposed to natural sunlight. Satisfactory bacterial inactivation (\log_{10} reduction values >6 units or
30 inactivation to below the limit of detection (<1 CFU/100ml.)) was observed for 11 of 13 experiments.
31 Rainfall and overcast/cloudy conditions were factors on both of the occasions when incomplete
32 inactivation was observed. In conclusion, the use of CPC SODIS technology is suitable for treating
33 drinking water both at household level and institutional level in Sub-Saharan and other similar tropical
34 climates if careful consideration of the cloud cover and rainfall is taken into account.

35

36

37 1. Introduction

38 In many parts of the world households rely on untreated drinking water leaving them at great risk from
39 waterborne disease. Solar disinfection (SODIS) is a point-of-use household water treatment which
40 can be used to treat drinking water in those parts of the world where suitable levels of sunshine are
41 available. SODIS usually involves exposing water in 1.5 to 2 L transparent bottles to sunlight for a
42 minimum of 6 hrs and has been found to be effective against a range of waterborne pathogens
43 including: *Salmonella typhimurium*; *Shigella dysenteriae*; *Escherichia coli* (*E. coli*); *Vibrio cholera* and
44 *Pseudomonas aeruginosa* (Berney *et al.*, 2006; Kehoe *et al.*, 2001; Smith *et al.*, 2000; McGuigan *et*
45 *al.*, 1998). However, one disadvantage of SODIS remains the small treatment volume and the labour
46 intensive nature of filling several bottles in order to treat an adequate volume. Other concerns relate
47 to the possible release of genotoxic photoproducts into the water after prolonged use of plastic
48 bottles. Despite experimental evidence to the contrary (Schmid *et al.*, 2008, Reed 2004, Ubomba-
49 Jaswa *et al.*, 2010), many people have remained unconvinced about the safety of plastic SODIS
50 bottles.

51 In addition to the practical restrictions mentioned earlier, in terms of solar collection, a major limitation
52 of standard SODIS bottles is that usually they are only illuminated on the upper side that faces the
53 sun. The bottles are often of irregular shape which makes it difficult for the sunlight to penetrate
54 inside. The material from which they are made is PET, which absorbs sunlight in the UV-B range, the
55 most damaging part of the available solar spectrum for microorganisms. Therefore, to improve the
56 disinfection efficiency, other materials should be desirable for these solar reactor systems.

57 Efforts to improve the disinfection of water using solar energy include; 1) maximising the received
58 solar energy dose, 2) enhancing the disinfection efficacy against resistant waterborne pathogens; 3)
59 increasing the output volume of treated water; 4) reducing user dependence (work effort) associated
60 with reactor systems; and 5) using cheap and robust materials for low-cost disinfection systems.

61 Research to develop low-cost solar reactors to enhance the efficacy of solar water disinfection has
62 been carried out in the last decade (McGuigan *et al.* 2012, Marques *et al.*, 2013). Some flow reactors
63 have focused on increasing the optical inactivation component of sunlight inactivation using solar
64 collectors and reflectors, while others have focused on increasing the thermal component of the solar

65 spectrum (Li *et al.* 2013). The most important criterion for good solar photo-reactor performance is the
66 increase of output volume of treated water within a given solar exposure. To address these objectives
67 one must take into account the collection of solar light (using either CPC solar mirrors or other low-
68 cost reflectors which increase the solar light collection) into the photo-reactor must be efficient for
69 large volumes of water. Therefore water turbidity is critical. If the water is sufficiently transparent
70 (turbidity < 10 NTU) the optical reactor path length (i.e. diameter of the photo-reactor cross-section)
71 can be increased up to 10 cm (Ubomba-Jaswa *et al.*, 2010, Marques *et al.*, 2013). If the water is not
72 very transparent, then the required reactor diameter must be reduced to a few cm and the large
73 volume requirement will be accomplished by connection of several photo-reactor modules.

74 There are limitations of solar disinfection when it is scaled-up through the use of large batch volumes
75 or continuous flow recirculation reactors (Ubomba-Jaswa *et al.*, 2010). Flow through systems have a
76 negative effect on inactivation of bacteria as at a given time point there needs to be maximum
77 exposure of bacteria to UV to ensure inactivation as compared to having bacteria exposed to several
78 sub-lethal doses over a long period of time. When the water containing bacteria remains static under
79 solar light it is constantly illuminated and hence the required uninterrupted UV dose is achieved and
80 complete inactivation to below the detection level takes place. With continuous flow systems, the
81 lethal dose will be deposited to the bacteria but in an intermittent manner and may not produce
82 complete inactivation (Ubomba-Jaswa, 2009). This statement has important implications for those
83 attempting to scale-up solar systems through the use of pumped, re-circulatory, continuous flow
84 reactors. If the operational parameters are set such that the microbial pathogens are repeatedly
85 exposed to sub-lethal doses of solar radiation followed by a period within which the cells have an
86 opportunity to recover or repair, complete inactivation may not be achieved.

87 In order to address these challenges, a 25L volume borosilicate glass tube reactor fitted with a
88 compound parabolic collector (BGTR-CPC) was developed by Ubomba-Jaswa and co-workers (2010)
89 for solar treating drinking water. The CPC works by redistributing the incident sunlight over the entire
90 outer surface of the reactor so that no portion of the reactor remains un-illuminated. While some
91 previous research has looked at the possibility of using CPC reactors for solar remediation of
92 microbiological contaminants in water (Duffy *et al.* 2004, Mcloughlan *et al.* 2004, Sciacca *et al.* 2011),
93 no research has been carried out on its efficacy under real field conditions in Sub-Saharan African

94 Tropical regions. The aim of this study was therefore to assess the efficacy of the BGTR-CPC over an
95 extended period of 17 months under local weather conditions in Uganda which is a tropical country
96 with two rainy and two dry seasons in the year. If this research proved successful it could be used as
97 proof of concept with wider geographical applications throughout Sub-Saharan Africa and the tropics
98 in other continents.

99

100 2. Methodology

101 2.1 Source of *E. coli*

102 In this study *E. coli* was used as the indicator micro-because of its widespread use as an indicator of
103 faecal pollution of water. *E. coli* UG-KST 001 was isolated from a protected well located in Kikonyi, a
104 heavily populated slum 2km away from Makerere University in Kampala, Uganda. Untreated water
105 sample (100 ml.) was filtered through 0.45- μ m pore-size and 47-mm-diameter Whatman cellulose
106 nitrate membrane filter (GN-6 Metrical Grid, Gelman Sciences Inc. USA). Filters were placed onto
107 Chromocult Agar (CCA) plates and pre-incubated at ambient temperature for 4 hrs to aid bacterial
108 resuscitation. The plates were then incubated at 37°C for 24 hrs. Presumptive *E. coli* colonies deep
109 blue in colour and were confirmed with Indole production, Methyl red (MR), Voges-Proskauer (V-P)
110 and Citrate tests (IMViC biochemical tests). Confirmed *E. coli* colonies were stabbed in Mueller-Hinton
111 and kept at room temperature for further experiments.

112

113 2.2 *E. coli* inoculum preparation

114 *E. coli* obtained from Mueller-Hinton agar was streaked onto Nutrient Agar and incubated at 37°C for
115 24 hrs. A single colony was then used to inoculate sterile nutrient broth (Conda Pronadisa 1340) and
116 was incubated at 37°C for 18 to 20 hrs. Cells were harvested by centrifugation at 8000xg for 10 min.
117 The pellet was resuspended in 5 ml. of quarter strength Ringers solution. Centrifugation and
118 resuspension steps were repeated three times to remove all traces of the growth medium. The cell
119 suspension was used to inoculate the reactor to give an initial concentration of *E. coli*. ranging from
120 10^5 - 10^7 CFU/100ml.

121 2.3 Water

122 In order to carry out the experiments under natural conditions and to avoid weakening of bacterial
123 cells due to unfavourable osmotic environmental conditions, unautoclaved natural well-water was
124 used (McGuigan *et al.*, 2012). Water was collected from the Kikonyi well near Makerere University in
125 Kampala on the day before the experiment and kept at ambient temperature overnight. The water was
126 analysed for *E. coli*, pH, temperature and total dissolved solids (TDS).

127 2.4 Solar enhanced Compound Parabollic Borosilicate Glass Tube Batch Reactor (BGTR-CPC)

128 The BGTR-CPC SODIS reactor previously described by Ubomba-Jaswa *et al.* (2010) was used in this
129 study. It was constructed by placing a glass tube at the linear focus of a compound parabolic collector
130 (CPC) positioned with the axis of the tube and CPC aligned along the North-South direction to receive
131 maximum solar radiation during the experiment. The borosilicate glass tube was fitted with an outlet
132 valve in the bottom (for taking samples during experiments, and for emptying the treated volume after
133 use) and a removable glass port at the top which facilitated filling the reactor. Untreated water was
134 poured into the unit through the top of the tank. Once the tank was filled with water, the top was
135 sealed using four Allen screws.

136 After the required exposure time, treated water was removed using the exit valve at the bottom. The
137 CPC collector was made of highly reflective anodised aluminium (specular reflectivity in the UV-A
138 spectrum is 92%). The glass tube had an internal diameter of 20 cm and an external diameter of
139 22cm. The concentration factor (CF) of the CPC was 1.0. The CPC collects both direct and diffuse
140 UV-A so the tube is homogeneously illuminated even on cloudy days. All experiments were performed
141 under natural solar radiation on a platform located at 0°20'15"N 32°33'51"E, the Makerere University,
142 Kampala Uganda. The CPC was mounted on a frame elevated at 20° from the horizontal. Although
143 the exposure is almost on the equator (Latitude 0°20'15"N) the elevation angle of the reactor was not
144 reduced because some inclination was required to facilitate maximal filling and ease of emptying the
145 reactor.

146 Experiments occurred on a monthly basis for a period of 17 months encompassing two dry and two
147 wet seasons. Typically one experiment was conducted in each month and tests started at 10:00 am
148 and finished at 5:00 pm local time. Samples were taken at hourly intervals.

149

150 2.5 Enumeration of *E. coli*

151 Enumeration of *E. coli* was conducted using the standard plate count method for the first 3 hrs of each
152 experiment. Volumes of 0.1 ml. of the appropriately diluted sample were spread on chromocult agar
153 (CCA) plates in triplicate and incubated at 37°C for 24 hrs. For all samples taken after 3 hrs, 100ml.
154 water was filtered through 0.45 µm-pore-size and 47mm diameter Whatman cellulose nitrate
155 membrane filters (GN-6 Metricel Grid, Gelman Sciences Inc. USA. The filters were placed onto CCA
156 plates and incubated at 37°C for 24 hrs in a Paqualab 25 incubation kit. In both methods, deep blue
157 colonies were counted as *E. coli*. Control samples were kept in the dark until the end of the
158 experiment. The possibility of regrowth after treatment was also investigated by keeping part of the
159 last sample at room temperature under dark conditions for 24 hrs, 100ml. of sample was then filtered
160 and plated onto chromocult Agar at 37°C for 24 hrs. The numbers of typical colonies were counted to
161 calculate the number of *E. coli*/100ml. water.

162

163 In determining the log reduction values, numbers of *E. coli* were expressed as log₁₀ number of
164 organisms/100ml. water. The number of log reductions was determined by subtracting the log of the
165 number of cells remaining from the log of the initial number of cells. Inactivation curves were
166 constructed by plotting the number of *E. coli* as log₁₀ (N_t) against time. Where N_t = number of cells at
167 time t.

168

169 2.6 Measurement of environmental conditions

170 Solar UV irradiance was measured with a global UVA+B radiometer (Solartech, USA). The
171 temperature, pH and TDS of samples were measured using a calibrated pH/TDS meter (model HI
172 9813-6N, Hanna Instruments, S.L., Eibar, Spain).

173

174 Observations of weather conditions were recorded at each sampling. In this experiment, the
175 experimental day was described as sunny, intermittent sunny/cloudy or cloudy/overcast. A sunny day
176 was defined as zero cloud cover with strong sunshine for at least three quarters of the day and with

177 the remainder having not more than 1/4 cloud cover (2 octa) and no rain. We defined an intermittently
178 sunny/cloudy day as having between 1/4 and 1/4 cloud cover (2 octa – 4 octa) for more than 4 hrs.
179 We defined a cloudy/overcast day as having at least ½ cloud cover (4 octa) throughout the
180 experiment.

181

182 2.7 Data analysis

183 All samples were analysed in triplicate. Mean values and standard deviations were determined using
184 Excel. One-way analysis of variance (ANOVA, Origin v7.0300, OriginLab Corp., Northampton, USA)
185 was used to determine the significant differences between means.

186

187 3. Results

188 Uganda typically has two rainy and two dry seasons per calendar year, however, the timing of these is
189 no longer reliable due to the effects of climate change. For the period of this study April, May, August,
190 September, October, November and December were rainy (wet) months (rainy season) while
191 January, February, March, June and July were dry months (dry seasons). However, in between the
192 rainy or dry seasons some days could be sunny or cloudy rainy. Data were recorded on 13 occasions
193 over a 17 month period from May 2011 to September 2012. Data were not collected for the months of
194 June 2011, August 2011, October 2011 and October 2012.

195

196 3.1 Characteristics of untreated natural water

197 The characteristics of the untreated water used in all the experiments are described in Table 1. The
198 temperature and pH of the source water did not vary significantly ($p > 0.05$) for the duration of the
199 investigation. The temperature ranged from 22°C – 27°C and the pH from 6.0 – 7.7. The level of total
200 dissolved solids varied significantly ($p = 0.001$) with the season ranging from 26 – 63 mg l⁻¹ in the
201 rainy season and from 8 – 25 mg l⁻¹ in the dry season. The levels of *E. coli* in the untreated water also

202 varied from month to month and higher numbers were detected during the rainy season and
203 corresponded with higher levels of dissolved solids.

204

205 3.2 Response of *E. coli* to solar disinfection using the CPC

206 The response of *E. coli* to solar disinfection using the CPC was monitored over a 17 month period
207 from May 2011 to September 2012. None of the control samples, incubated in the absence of light,
208 showed any significant difference ($p>0.05$) in cell numbers from the starting inoculum size. This
209 implied that there was neither growth nor inactivation under dark storage. Furthermore, none of the
210 samples that were taken at the end of experiments and stored for 24 hrs in the dark showed any
211 significant change ($p>0.05$) in cell numbers indicating that there was no re-growth of *E. coli* after
212 treatment.

213 The results obtained on 13 occasions during this period are described in Figure 2 which shows the
214 starting population, final population after 7 hrs solar exposure and the \log_{10} -unit removal values (LRV)
215 for all experiments. It is evident from this figure that the starting bacterial inoculum varied between 10^5
216 and 10^7 CFU/100ml. Complete inactivation to below the detection limit (< 1 CFU/100ml) was achieved
217 for all 6 exposures conducted under strong sunlight conditions. If satisfactory disinfection is defined as
218 one which produces either a $LRV \geq 6.0$, as recommended by the US EPA (1987), or inactivation to
219 below the Ugandan National Bureau of Standards guidelines (UNBS 2008) for safe drinking water ($<$
220 1 CFU/100ml), then successful disinfection of the 25 litre batch volume was achieved in 11 of the 13
221 experimental investigations. Only experiments conducted in Sept 2011 ($LRV = 4.5$) and April 2012
222 ($LRV = 3.0$) failed to produce satisfactory disinfection levels. The former was conducted under
223 intermittently sunny/cloudy conditions and the latter under cloudy overcast skies, both exposures
224 experienced periods of rain or drizzle.

225

226 Representative data for Sunny (a), Intermittently Sunny/Cloudy (b) and completely Overcast/Cloudy (c
227 and d) months during the study period are presented in Figure 3. An absence of data at any time point
228 before the end of exposure (7 hrs) indicates the bacterial population is below the limit of detection (1

229 CFU/100ml.). In Sept 2012, complete inactivation was achieved within 7 hours. No colonies were
230 obtained from the samples taken after 7 hrs exposure indicating the population at this time was below
231 the limit of detection (1 CFU/100ml.). Satisfactory inactivation of the bacteria was achieved for the
232 sunny (a) and intermittently sunny/cloudy (b) conditions. LRVs of 7-log units are observed within 6
233 and 7 hrs for the Sept 2012 (sunny) and Aug 2012 (intermittently sunny/cloudy) conditions,
234 respectively.

235

236 In the case of the overcast/cloudy months while the inactivation of the bacteria was unsatisfactory in
237 April 2012, a satisfactory response in March 2012 was attributed to the higher levels of UV detected.
238 The April 2012 exposure was conducted under such rainy/overcast conditions that we suspected
239 complete inactivation would not be achieved during the 7 hrs duration of the experiment.
240 Consequently the experiment was extended to the following day and the results of this two-day
241 exposure are provided in Figure 4. Despite improved cloud and sunshine conditions on Day 2 full
242 inactivation was not achieved with final concentration remaining at 10^4 CFU/100ml. Figure 5 shows
243 the maximum water temperatures achieved in the BGTR-CPC reactor for each experiment.

244

245 4 Discussion

246 In the current study, *E. coli* was the organism of choice because it is widely used as a faecal indicator
247 and is known to be resistant to sunlight compared to other bacteria such as *Salmonella typhi*, *Shigella*
248 *flexneri* and *Pseudomonas aeruginosa* (Wegelin *et al.*, 1994). Since the control and t_0 concentrations
249 were not significantly different, the observed inactivation of *E. coli* in all the experiments was as a
250 result of SODIS treatment and there was no re-growth of *E. coli* after treatment in all experiments.

251

252 These experiments formed part of a larger research programme (The “Water is Life –Amazzi Bulamu”
253 project, see www.waterislife.ie) funded by the Irish government. Work commitments for the Uganda
254 based graduate researcher (RN) on other work-packages within this project resulted in the BGTR-
255 CPC experiments having to take place in the fourth week of each calendar month. Consequently

256 given the preparation time required for each experiment (one day to prepare the inoculum, one day to
257 conduct the exposure and 1 day to analyse the results), there was no possibility of waiting for optimal
258 weather conditions. Instead each experiment started on roughly the same day (\pm 1 day) of each
259 month, regardless of weather conditions. As shown above, season does not guarantee the daily
260 weather conditions or the number of hours (days) of exposure for full treatment. However, as one
261 might expect, the chances of experiencing a cloudy day are higher in a wet season than in a dry
262 season.

263
264 Compared to other enhanced SODIS technologies for example methacrylate and PET bottles, the
265 borosilicate glass reactor has the best transmission properties for the microbicidal UVA and UVB
266 (Ubomba-Jaswa *et al.*, 2010). A 2.5L borosilicate glass tube reactor of 2.5L volume was found to
267 achieve full inactivation of *E. coli* K-12 under both sunny and partially sunny in only 3 hrs exposure
268 (Ubomba-Jaswa *et al.*, 2010). However, in this current study the 25L borosilicate glass tube reactor
269 required 6-7 hrs on continuously sunny days to achieve complete inactivation of the bacteria. This
270 difference in exposure time of required to achieve complete inactivation of *E. coli* can be attributed to
271 a number of factors. The current research used a borosilicate glass tube reactor of 25L which is 10
272 times larger in terms of volume than that used by Ubomba-Jaswa *et al.* (2009). The diameter of the
273 current CPC tube used is 20cm and so solar radiation has a longer path-length to traverse than in the
274 smaller CPC tube of 5cm diameter that was used in Ubomba-Jaswa *et al.*(2009).

275 In this study, a wild strain of *E. coli* isolated from protected natural well water located in a heavily
276 populated slum was used. Ubomba-Jaswa *et al.*(2009) used a laboratory strain (*E. coli* K-12). Wild
277 strains of *E. coli* are known to be more resistant to treatment than laboratory strains like *E. coli* K-12
278 and therefore they are more suitable for testing treatment efficiencies than laboratory strains (Quek
279 and HU, 2008). Comparing the results reported here with the first testing of a CPC-25l methacrylate
280 reactor (Ubomba-Jaswa *et al.*, 2010), we observe similar treatment times to attain the detection limit
281 starting at similar initial concentrations of *E. coli*. Although in the former study the water was only well
282 water with no dissolved solids (maximum dissolved organic carbon in the water was 5 mg l⁻¹), very low
283 turbidity (1.5 NTU), and with spiked bacteria from the Spanish collection of cultures (Ubomba-Jaswa
284 *et al.*, 2010). These collection strains have been shown to be more sensitive to any disinfection

285 method than wild species isolated from real contaminated water sources (Agulló-Barceló *et al.*, 2013).
286 In the present study, the real contaminated water presents with a complex chemical matrix, a
287 moderate level of TDS and naturally occurring bacteria, as explained in the experimental section.

288 A lower efficiency on the solar disinfection for real contaminated waters as compared with ideal
289 conditions of distilled water and well water spiked with culture strain collection bacteria was also
290 reported with a similar design CPC-25l-solar reactor in a recent study carried out at PSA in Southern
291 Spain (Bichai *et al.*, 2012). The authors assessed the efficiency of solar disinfection to reduce
292 microbial contamination in solar-treated real wastewater effluents from a municipal wastewater
293 treatment plant which was subsequently used for irrigation of horticultural crops. They reported solar
294 disinfection results of 20 litres of real wastewater effluents with *E. coli* bacterial decrease from
295 concentrations of $>10^3$ - 10^4 CFU/ml to <2 CFU/ml. (detection limit of that study) within 4 hrs of solar
296 exposure using the same reactor under clear sunny conditions in the South of Spain. They reported
297 that the required exposure times for disinfecting similar levels of *E. coli* in distilled water (1h), well
298 water (1.5h) and simulated effluents of wastewater (3h) were shorter than for real contaminated
299 wastewaters (4h) (Bichai *et al.*, 2012). It should be noted that complete inactivation was achieved
300 even when high starting inoculum sizes of the order of 10^7 CFU/100ml. were used. Such starting
301 populations would be consistent with wastewater treatment (Kitis 2004).

302 Despite the fact that the synergistic effect of temperature and UVA has been reported to play a key
303 role in SODIS inactivation of bacteria (Kehoe *et al.*, 2001, Ubomba-Jaswa *et al.* 2010) this was not
304 observed in the current study. The main reason for this is that the thermal inertia associated with the
305 large volume of water is such that water temperature increased slowly during solar exposures
306 compared with those reported for smaller volumes of up to 2.5L. None of the current experiments in
307 achieved maximum water temperatures near the 45°C that has been reported necessary for a
308 synergistic effect (Joyce *et al.* 1996). However, since the irradiated collector surface of the 25L CPC
309 is ~2 times that of the 2.5L CPC reactor used by Ubomba-Jaswa *et al.* (2010), a 25L CPC would
310 require nearly 5 times longer continuous solar exposure to attain 45°C from 20°C compared to the time
311 required for the smaller volume reactor. Consequently, given the disparity between volume and
312 illuminated area, it is not surprising that the maximum water temperature achieved at any point in the
313 studies was only 38°C (December 2011) for the 25L reactor.

314

315 Total dissolved solids (TDS) have also been reported to have an effect on bacterial inactivation for
316 several SODIS enhancement reactors (Kehoe *et al.*, 2001). Curtis *et al.* (1992) suggested that natural
317 organic matter may facilitate faster solar disinfection as it acts as photo-sensitizer. Ubomba-Jaswa *et*
318 *al.* (2009) also noted that the higher the turbidity, the higher the maximum water temperature attained
319 since the organic matter absorbs heat (Kehoe *et al.*, 2001). On the other hand, increased turbidity
320 reduces solar light penetration (Joyce *et al.*, 1996, Kehoe *et al.*, 2001) which is very important in
321 treating microbes in water. Therefore, the advantage of increased temperature as a result of
322 increased turbidity to facilitate increased synergistic effect between UVA and temperature to
323 inactivate bacteria is thus not enough to compensate for the reduction of solar penetration through
324 turbid water (Kehoe *et al.*, 2001).

325 Conclusion:

326 Complete and satisfactory bacterial inactivation was achieved using the 25L BGTR-CPC SODIS
327 reactor under conditions of strong continuous sunlight or of intermittently sunny/cloudy conditions.
328 However, completely overcast conditions accompanied by periods of rainfall may result in incomplete
329 inactivation (LRV = 3.0) even after 2 days exposure. The exposure time required to obtain fully treated
330 water (safe drinking water) with use of the CPC does not depend on seasons but on daily weather
331 conditions. The use of CPC SODIS reactor technology is suitable for treating drinking water both at
332 household level and institutional level in Sub-Saharan Africa and other similar tropical climates if
333 careful consideration of the cloud cover and rainfall is taken into account.

334

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346

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- 424 28. World Health Organization. 2011. Evaluating household water treatment options: health-
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426

427 Table 1. Physico-chemical and microbial quality of untreated natural water collected from Kikonyi
 428 protected well.

429

Exposure Date (MM/YY)	<i>E. coli</i> conc. CFU/100ml	Temp. (°C)	pH	Total Dissolved Solids (mg l⁻¹)	Season (Rainy/Dry)
05/11	136 ± 11	23.0	7.6	32	Rainy
07/11	117 ± 5	23.5	6.3	19	Dry
09/11	174 ± 30	25.0	6.8	40	Rainy
11/11	11 ± 2	23.0	6.8	47	Rainy
12/11	>300	23.8	6.0	55	Rainy
01/12	136 ± 14	27.0	6.4	12	Dry
02/12	190 ± 23	23.0	7.3	10	Dry
03/12	56 ± 15	22.1	5.8	21	Dry
04/12	230 ± 23	25.0	6.0	37	Rainy
06/12	91 ± 13	22.0	7.6	25	Dry
07/12	126 ± 6	22.0	6.0	8	Dry
08/12	>300	23.0	6.9	63	Rainy
09/12	105 ± 5	23.0	7.7	26	Rainy

430

431

432 **Figure Captions:**

433

434 Figure 1. The 25L volume borosilicate glass tube reactor fitted with a compound parabolic collector
435 (BGTR-CPC) of concentration factor CF=1.

436

437 Figure 2. Summary of the bacterial inactivation efficacy of the BGTR-CPC over the study period.

438

439 Figure 3. A comparison of bacterial inactivation (-) and incident UVA+B (-) for a representative sample
440 of Sunny (a), Intermittently Sunny/Cloudy (b) and completely Overcast/Cloudy (c and d) months
441 during the study period. An absence of data at any time point indicates the bacterial population is
442 below the limit of detection (1 CFU/100ml.)

443

444 Figure 4. Bacterial inactivation (-) and incident UVA+B (-) over two consecutive days within a
445 completely cloudy/overcast period in April 2012.

446

447 Figure 5. Maximum water temperature achieved in CPC during each exposure.

448

449 Figure 1

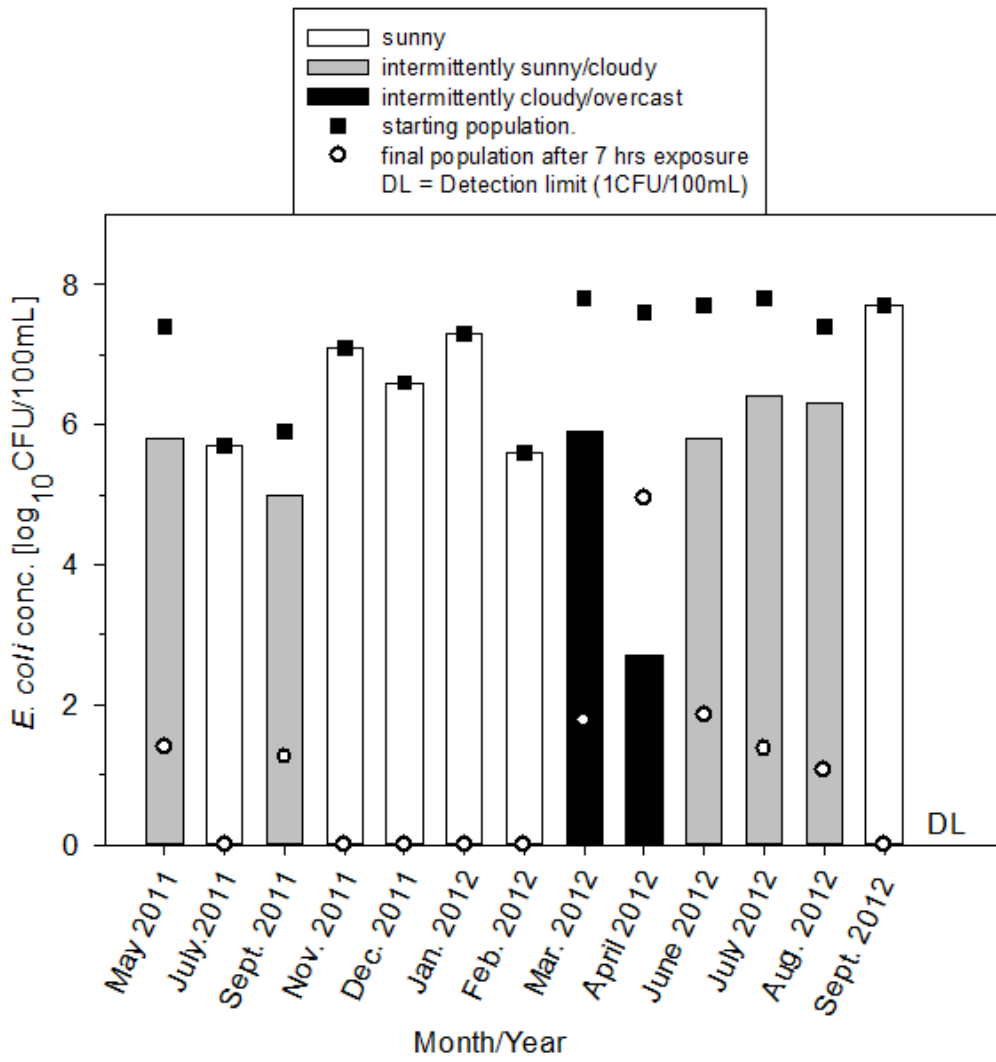


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452 Figure 2

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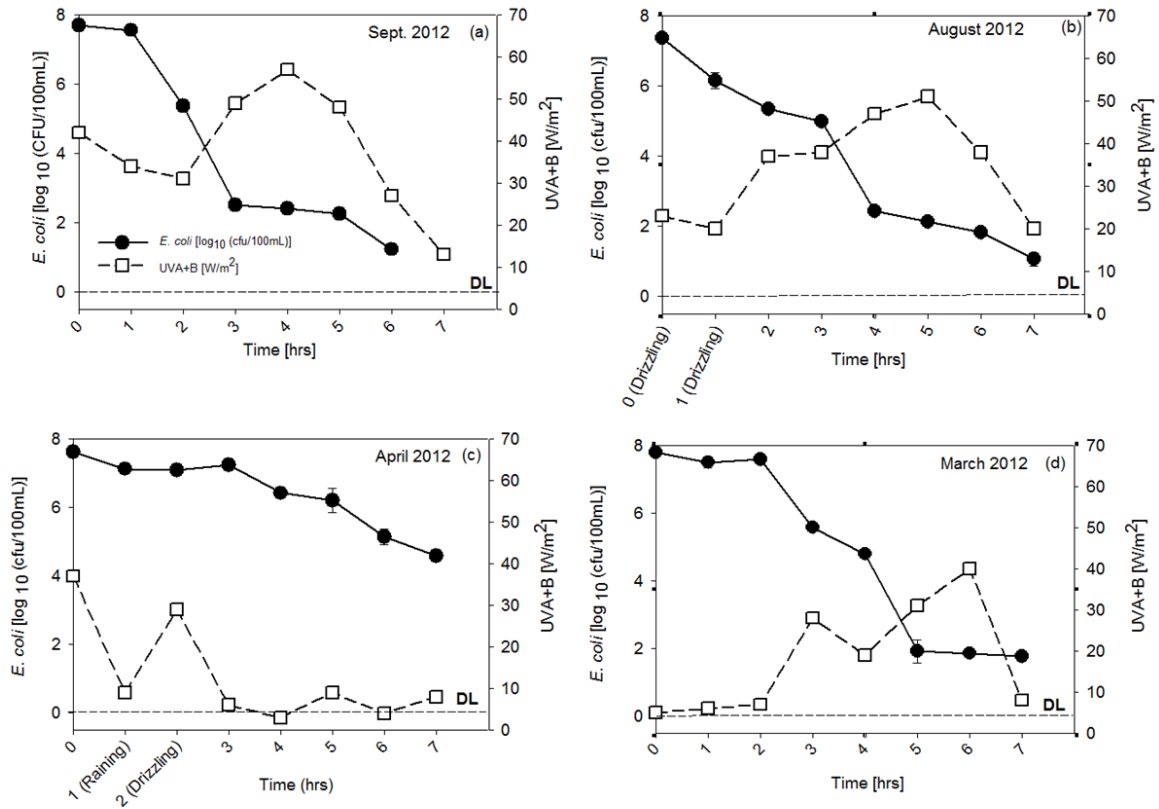


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457 Figure 3



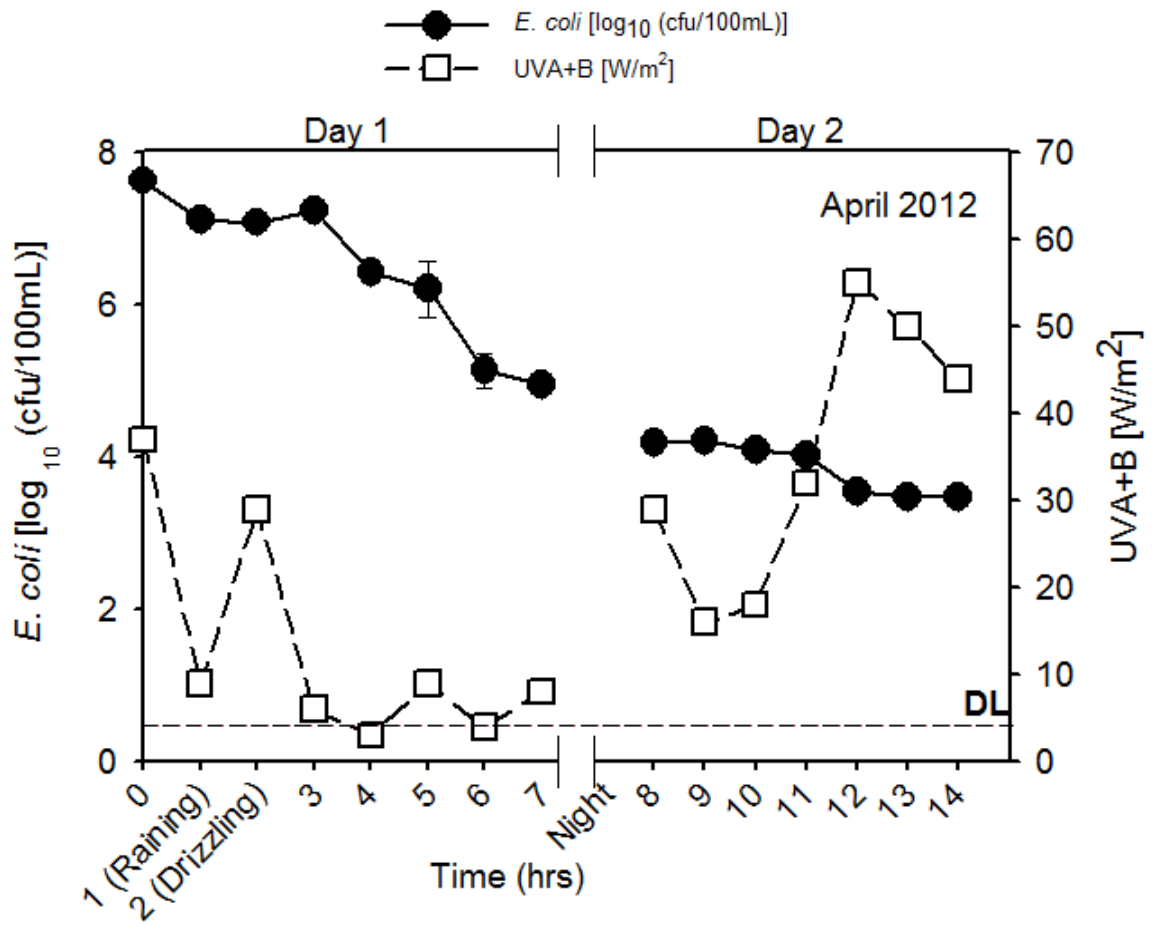
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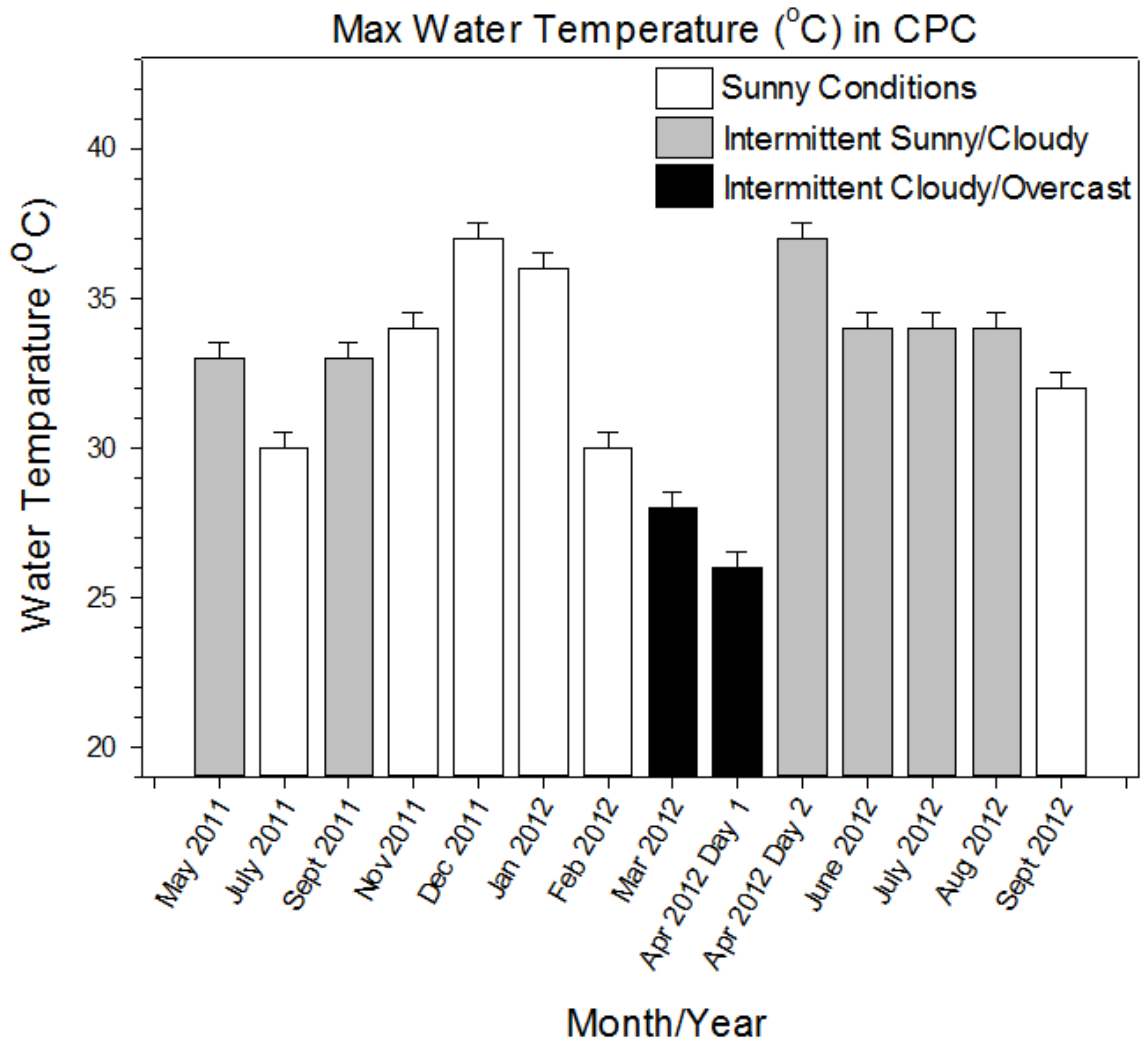
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462 Figure 4



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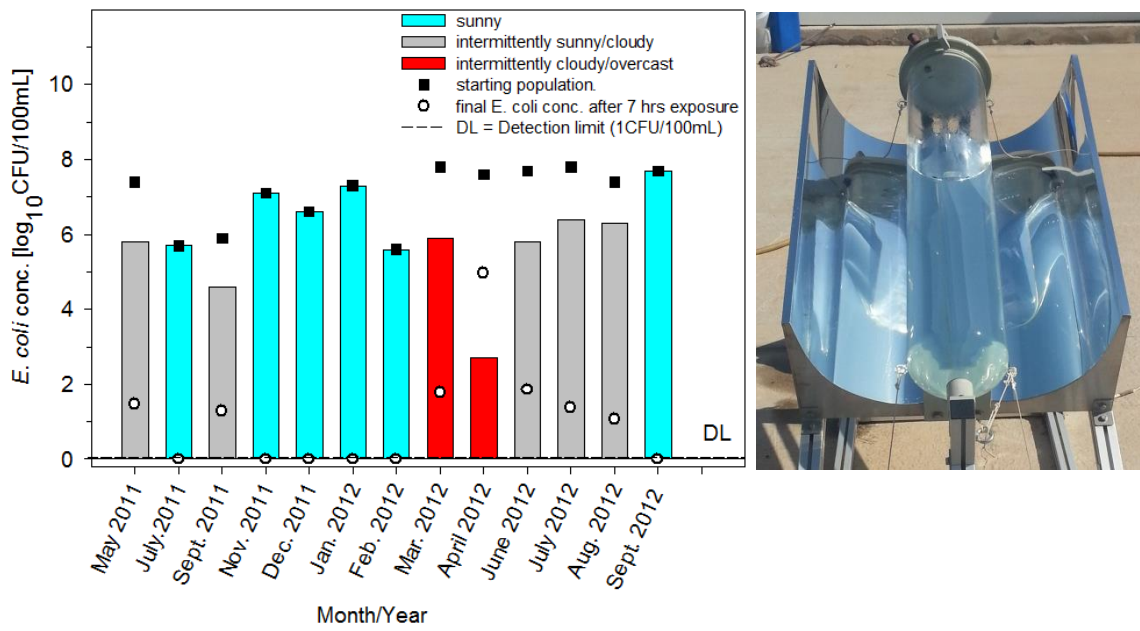
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468 **Graphical Abstract**



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