RESEARCH ARTICLE

Decentralized solar-powered drinking water ozonation in Western Kenya: an evaluation of disinfection efficacy [version 1; peer review: 1 approved with reservations]

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Abstract

\textbf{Background:} Decentralized drinking water treatment methods generally apply membrane-based treatment approaches. Ozonation of drinking water, which previously has only been possible at large centralized facilities, can now be accomplished on a small-scale using microplasma technology. The efficacy of decentralized solar-powered ozonation for drinking water treatment is not known.

\textbf{Methods:} We established a 1,000L decentralized solar-powered water treatment system located in Kisumu County, Kenya. Highly contaminated surface water is pumped to the treatment system, which includes flocculation and filtration steps prior to ozonation. Turbidity, total coliform bacteria, and \textit{E. coli} were measured at various stages of water treatment, and bacterial log reduction values (LRVs) were calculated.

\textbf{Results:} Nine trials were conducted treating 1000L of water in three hours. Baseline turbidity and \textit{E. coli} concentrations were reduced from a median of 238 nephelometric turbidity units (NTU) and 2,752 most probable number/100mL, respectively, in surface water to 1.0 NTU and undetectable \textit{E. coli} per100mL in finished drinking water. The nine trials yielded a mean \textit{E. coli} LRV of 3.36 (2.71-4.00, 95\% CI).

\textbf{Conclusions:} Based on the observed reduction of \textit{E. coli}, the solar-powered system shows promise as a means for producing safe drinking water. Further research is needed to characterize limitations, scalability, economic viability, and community perspectives that could help determine the role for similar systems in other settings.
Keywords
Decentralized water treatment, drinking water treatment, ozonation, solar-powered water treatment, water quality, sustainable water treatment, microplasma technology

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Competing interests: S. Dorevitch, C. Hendrickson, and S-J. Park are employed by the University of Illinois. The University holds patents for the microplasma ozone generator technology used in the study. An institutional conflict of interest is declared. S-J Park holds patents for the microplasma ozone generator used in the study, and a stake in the company that manufactures the devices. He did not play a role in data generation, data analysis or developing the manuscript. D. Akello has a financial interest in Shemjen Engineering, Ltd., which designed and built the water treatment system. D. Akwiri works for Shemjen Engineering.

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Abbreviations
AC, Alternating current; CFU, colony forming units; DC, Direct current; Hz, Hertz; mL, Milliliters; L, Liter; LRV, Log reduction value; MPN, Most probable number; NTU, Nephelometric turbidity units; POU, Point of use; USEPA, United States Environmental Protection Agency; V, Volt; W, Watt; WHO, World Health Organization

Introduction
In 2017, an estimated 357 million cases of diarrhea occurred among children under the age of five years in low- and middle-sociodemographic index countries, resulting in approximately 222,457 deaths (IHME, 2020). Of those deaths, 93.5% are attributable to unsafe water, sanitation, and handwashing. Meeting Target 6.1 of the United Nations Sustainable Development Goals - universal and equitable access to safe and affordable drinking water by 2030 - should therefore substantially reduce the global burden of waterborne diarrheal disease in children. Meeting that target will require innovative and effective interventions, as an estimated 144 million people, more than half of whom live in Sub-Saharan Africa, collect drinking water directly from surface waters (UNICEF & World Health Organization, 2019).

The costs of constructing centralized drinking water treatment systems and water distribution systems, as well as the costs for operations and maintenance of such systems, are in the hundreds of millions of dollars (Plappally & Lienhard, 2013), far beyond the reach of many low- and middle-income countries. Point-of-use (POU) water treatment has been utilized as an alternative approach to centralized treatment in such settings. While certainly far less costly, the long-term adherence to POU water treatment is highly variable and often poor (Roma et al., 2014; Rosa & Clasen, 2017; Rothstein et al., 2015), perhaps in part due to challenges in adherence. High-quality intervention studies have not reported consistent reductions of diarrhea occurrence in children in association with POU water treatments (Clasen et al., 2015).

Another type of alternative to centralized drinking water treatment is decentralized treatment (Peter-Varbanets et al., 2009). Such systems produce water, typically using membrane-based ultrafiltration with or without chlorination or ultraviolet disinfection. At decentralized treatment stations, community members can refill containers - generally approximately 20L – with treated water. Refill kiosks at decentralized systems have become local businesses in both urban and rural areas of Southeast Asia (Sima & Elimelech, 2013). In an evaluation of 10 decentralized membrane-based systems in rural healthcare facilities in rural Rwanda, the systems were found to consistently provide high-quality water without the need for technical expertise to operate (Huttinger et al., 2015). However, the use of those systems was limited to areas with robust access to water and electricity.

A strategy that has not be explored is to bring decentralized systems to areas without reliable access to electricity by deploying treatment systems that run solely on solar energy. New microplasma technology has made it possible to produce ozone using small, scalable units, with three times the efficiency of conventional dielectric barrier discharge or corona ozone reactors (Kim et al., 2017; Simek & Clupek, 2002). We recently evaluated that technology as a POU water treatment in Kisian, Kenya (Dorevitch et al., 2020). Ten families were asked to ozonate their household stored water in 20L containers for a two-hour period before using the water for drinking. Water quality was monitored weekly for eight weeks. The median (10th, 90th percentile) concentration of E. coli in household-stored water was 203.7 (7.9, 2,419.7) most probable number (MPN) per 100mL water. Household drinking water (which was meant to have been ozonated) had median E. coli concentrations of 11.4 (0.9, 369.7) MPN/100L. Thus, while E. coli levels decreased as a result of ozonation, they were generally above safe levels (i.e., zero), perhaps in part due to the high median turbidity of household-stored water of 48.6 nephelometric turbidity units (NTU). While solar-powered ozonation showed promise as a POU method, the deployment of the technology would be more efficient if several ozone generators simultaneously disinfected larger volumes of water over longer periods of time. The addition of turbidity reduction steps would be expected to increase the efficacy of the disinfection process.

The primary goals of this research are to: 1) describe a decentralized solar-powered drinking water treatment system using ozone disinfection, and 2) to evaluate the performance of that system in treating surface water.

Methods

Materials
Water treatment system. A schematic diagram (Figure 1) identifies key elements of the disinfection process. Approximately 5000L of river water were pumped from the River Nyando by a Pedrollo PKm100 1.1KW Pump. The raw water flowed through a PVC pipe and just before the settling tank, an inline dosing pump (22W Grundfos DDC 6-10 Dosing Pump (240V) injected the water with 935 gm of the flocculating agent alum (powder aluminum sulfate; Kurita Water Industries) from a 100L fiberglass tank. After suspended solids settled overnight, water was released from the settling tank and flowed by gravity to the balance tank through an outlet several cm above the bottom of the tank. Settled floc is removed via a clear-out valve below the outlet to the balance tank. Additional settling of solids took place in the balance tank. A 240V, 0.5 horsepower electric pump (Electric Filter (Pedrollo Linz Pump) moved water from the balance tank into a rapid glass filter containing Certikin glass media (3mm) and Jacobbi Activated carbon media chippings. Water was then pumped approximately 1.5 meters in elevation into the 1,000L PVC ozonation tank. The process of water filtration and filling of the ozonation tank took approximately 45 minutes. Following ozonation (described next), the water flows through the So-Safe Triple Multibody 10” Filter (8 bar) with an activated carbon and two sediment cartridges. After that step, the filtered water is considered to be “finished water.” A 5,000L tank collects rooftop harvested rainwater, so that if, during wet weather, cloud cover is too heavy to power the system (this has yet to occur), low-turbidity rainwater can be pumped directly into the ozonation tank. A utility housing (Figure 2) contained the filters, pumps, and ozone generators. Finished water was available to the public and water vendors at the on-site water kiosk (Figure 3).
Figure 1. Schematic diagram of the water treatment system.

Figure 2. Utility housing. Upper right: The large black tank on the right is the settling tank. Right: The white tank is the balance tank; Left: The white tank is the ozonation tank. Tubing carrying ozone to the diffusers (not visible) can be seen entering the tank. Yellow container in the foreground contains alum.

Figure 3. Sales kiosk. Jerry cans of water being prepared by kiosk staff for loading onto a water vendor’s cart. The black tank on the upper right is the settling tank.
Ozonation. Four portable microplasma ozone generators were used (Purelife 1000, EP Purification, Champaign, IL, USA). Each unit weighs 780 grams, and measures 5.4cm × 11.7cm × 18.4 cm, approximately the size of a book, and were maintained in the utility housing (Figure 4). The ozone unit has a miniature diaphragm air pump that draws ambient air at the rate of 2 liters per minute into the array of 250 µm scale (width) channels fabricated in a nanoporous Al₂O₃/aluminum chip (reaction volume of 1.9 µL/channel). In the microchannels, oxygen in ambient air (O₂) is converted to ozone (O₃) by a high frequency electric field applied across the top and bottom electrodes in the channel. The power consumption of the chip is 10–14 watts per hour. The unit has a built-in rechargeable battery of 7 amperes capacity to operate for 90 minutes if an external power failure were to occur. Each unit produces 0.2–0.35 gm of ozone per hour (depending on relative humidity); thus approximately overall 1 gram of ozone per hour was produced. The ozone/air mixture flowed from each ozone generator, through tubing and was released into the disinfection tank via an AS150 6-inch fine pore with ¼ inch barb ceramic aerator (diffuser) (Pentair Aquatic Eco-Systems, Apopka, FL, USA). Aerators were positioned at the bottom of the disinfection tank so that air/ozone bubbled up through the 1,000L water tank. A covered vent at the top of the disinfection tank released air/ozone to prevent pressure build-up within the tank. The ozone tubing was Teflon® and the ozonation tank was PVC because these are considered relatively resistant to oxidation by ozone.

Electrical supply and controls. Initially, the ozonation system and pumps were powered by 240V AC current from electrical outlets. Between Trial 5 and Trial 6, the solarization of the system was completed and from that point forward, the entire system operated exclusively on solar power. Two photovoltaic solar systems, each with its own modules (solar panels) were in place. To power the water treatment system, four roof-mounted 270W Polycrystalline Solar Modules (Yingli Solar) fed current to a Champion 200Ah 12V Sealed Solar Battery. An OPTI SC-PWM 60A 12/24V DC Charge Controller prevents the photovoltaic panels from overcharging battery. An Opti SP Effecto 2000 Hybrid Inverter (Input: 24VDC, Output: 230VAC/50Hz) was used to convert the stored voltage to AC to power pumps in the treatment system and the ozone generators. A separate solar-powered electrical system powered the Pedrollo PKm100 pump 1.1KW that moved water 164 meters from the River Nyando to the treatment system with an elevation gain of 5 meters and a dynamic head of 20 meters. Ten 200W Topray Solar Modules (Shenzhen Topray Solar Co) fed current through a Dayliff 1.5Kw SV2 Sunverter Solar Controller. A Lorentz Pv Disconnect Switch 1000VDC/40A, a C/W earth rod and lightening arrestor were also installed.

Procedures

Water sampling. Water samples were collected in 120mL IDEXX sampling bottles, which were autoclaved between rounds of sampling. Water samples were collected from a minimum of two sampling ports: river water before it entered the settling tank and from the ozonation tank at 0, 60, 120, 180 and 240 minutes. In three trials, water was also sampled between the balance tank and the sand filter, and again, between the activated carbon filter and the ozonation tank. Water samples were transported within 3–5 hours of collection in a cooler on ice to the Safe Water & AIDS Project (SWAP) laboratory in Kisumu, Kenya.

Water analysis. Turbidity was measured at the SWAP laboratory in Kisumu using the LaMotte 2020we (Chestertown, MD, USA) turbidity meter, which was calibrated daily up to 1,000 NTU. Concentrations of total coliform bacteria and E. coli were measured using the Colilert® (Laboratories, Westbrook, ME, USA) defined substrate culture method, which quantifies bacteria levels in units of MPN per 100mL. This method is approved by the US Environmental Protection Agency for drinking water testing purposes (USEPA, 2017). Surface water samples were generally, but not always, diluted with 25mL added to 75mL of distilled water and incubated for 24 hours at 35°C. Water samples collected elsewhere in the treatment process were not diluted. The upper limit of quantification of bacteria for undiluted water samples in 2,419.7 MPN/100mL; with the 25mL + 75mL dilution, the upper limit is 9,678.8 MPN/100mL. Generally, but not always, two separate laboratory technicians independently read the Colilert results (number of large and small positive wells).
Time and place of the trails. Data from all trials conducted once the system became operational in September 2019 through to April 2020 are reported here. The decentralized water treatment system was constructed at the site of a defunct water kiosk (0°10'19.7"S 34°55'21.6"E) that had been operated by SWAP in the town of Ahero, in Kisumu County, Kenya. The urban center of Ahero is located 22 km east of the city of Kisumu and has a population of 11,801 (Kenya National Bureau of Statistics, 2019). The River Nyando flows through the center of Ahero.

Independent laboratory analyses. Between Trials 4 and 5, the Water Resources Authority, and separately, the Kenya Bureau of Standards independently analyzed water samples and evaluated whether the finished water met World Health Organization (WHO) and Kenya’s Drinking Water Standards.

Data analysis. Turbidity, total coliform, and E. coli measures for each stage in the treatment process were analyzed for normality using the Kolmogorov-Smirnov test. Bacteria levels were not distributed normally and are summarized as the median and interquartile range (25th–75th percentile); turbidity at each stage of treatment were normally distributed and were summarized as mean and standard deviation. Log reduction values (LRV) of bacteria were calculated as log10(raw water concentration)-log10(ozonated water concentration). Data were analyzed using MS Excel and SAS version 9.4 (SAS Institute, Cary, N.C., USA).

Metals analysis. While the disinfection system was undergoing initial testing (before Trial 1 was conducted) aluminum, manganese and iron were tested. Finished water samples were analyzed using the HACH Model DR 3900 Laboratory Spectrophotometer. Reagents and methods used were HACH method 8012 for aluminum, Method 8034 for manganese, and FerroVer® for iron.

Results

Once the decentralized system was built and tested, nine trails were conducted to evaluate system performance. Table 1 describes water quality, as measured by bacteria concentration and turbidity, at each stage of testing. Neither the bacteria nor turbidity were measured at all steps in all trials. Nevertheless, it is clear that substantial reductions in E. coli, total coliforms, and turbidity occurred, mainly as a result of flocculation and filtration. Table 2 presents LRV for E. coli and total coliforms, showing a mean LRV reductions greater than 3.0. In Trial 2 the LRV was only 2.24, which was the maximum possible for that trial, given a raw water E. coli concentration (baseline) was 171 MPN/100mL.

Independent laboratory testing

The Kenya Bureau of Standards analyzed finished water from the decentralized system and reported that E. coli and coliform concentrations were reported as 0 colony forming units/100mL. The Water Resources Authority tested River Nyando water and found that turbidity was >1,000 NTU (WHO and Kenyan standard: <5 NTU). E. coli and coliform bacteria were “too numerous to count.” Finished water met WHO and Kenyan drinking water standards: turbidity was 4.5 NTU, and 0 CFU/100mL of E. coli and coliforms were detected.

Metals analysis of finished water (prior to Trial 1) showed concentrations of metals that were well within Kenyan Drinking

<table>
<thead>
<tr>
<th>Trials: Bact.</th>
<th>EC (MPN/100mL) Median (25th, 75th %iles)</th>
<th>TC (MPN/100mL) Median (25th, 75th %iles)</th>
<th>Trials: Turbidity (NTU) Mean (std. dev)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw water</td>
<td>6</td>
<td>2,752.6 (1,554.1, 9,682.8)</td>
<td>6,576.2 (2420.7, 9,682.8)</td>
</tr>
<tr>
<td>Post-flocculation</td>
<td>3</td>
<td>0.0 (0.0, 7.3)</td>
<td>50.6 (2.0, 58.6)</td>
</tr>
<tr>
<td>Post-filtration</td>
<td>3</td>
<td>0.0 (0.0, 10.7)</td>
<td>48.9 (4.1, 49.7)</td>
</tr>
<tr>
<td>Ozonation 0 minutes</td>
<td>8</td>
<td>0.0 (0.0, 0.0)</td>
<td>15.2 (7.9, 71.1)</td>
</tr>
<tr>
<td>Ozonation 60 minutes</td>
<td>9</td>
<td>0.0 (0.0, 0.0)</td>
<td>11.9 (5.1, 125.6)</td>
</tr>
<tr>
<td>Ozonation 120 minutes</td>
<td>9</td>
<td>0.0 (0.0, 0.0)</td>
<td>7.3 (0.0, 21.3)</td>
</tr>
<tr>
<td>Ozonation 180 minutes</td>
<td>9</td>
<td>0.0 (0.0, 0.0)</td>
<td>4.1 (0.0, 6.2)</td>
</tr>
<tr>
<td>Ozonation 240 minutes</td>
<td>6</td>
<td>0.0 (0.0, 0.0)</td>
<td>1.5 (0.0, 19.1)</td>
</tr>
</tbody>
</table>

EC: E. coli; TC: Total coliforms; MPN, mean probable number; NTU, nephelometric turbidity units.
Ozonation is that, unlike chlorination, it does not leave a residual level of a disinfectant in treated water. For that reason, education about safe water storage, such as the use of improved vessel containers with tap, lid and narrow neck, will be important when providing disinfected drinking water from the Ahero system. Ozonation of bromide can produce bromates (von Gunten, 2003; Yang et al., 2019), which are possible carcinogens (IARC, 1999). For that reason, ozonation of groundwater should be done only after ensuring that bromide is not present. It should be noted that very large reductions in turbidity and fecal indicator bacteria took place prior to ozonation. Thus, other disinfection methods could be implemented at that point. However, because we have demonstrated significant reduction in viral indicators using ozone, and because the taste of the finished water has been found to be very good by users, we intend to continue using ozone as the disinfection method (Dorevitch et al., 2020). The generation of electricity and ozone on-site also opens the door to the possibility of treating wastewater on-site as well.

Water Standards: aluminum: 0.01mg/L, iron 0.005 mg/L, and manganese 0.7 mg/L.

Discussion

The use of solar energy for drinking water treatment has been promoted, in part because regions of the world with little access to safe drinking water tend to be in equatorial regions, where sunlight is plentiful (Chu et al., 2019; Pichel et al., 2019). To the best of our knowledge, this is the first report of a decentralized drinking water treatment system that uses ozone disinfection. The water treatment system was able to consistently process extremely turbid water with high levels of fecal indicator bacteria, and to produce 1,000 L of water with turbidity levels and E. coli levels that met WHO drinking water guideline values (WHO, 2017). WHO’s Technology Non-Specific Harmonized Testing Protocol established performance standards for POU methods (World Health Organization, 2014). The evaluation process should assess performance with “pre-treatment” concentration of bacteria of 100,000/100mL and turbidity is set at 40±10 NTU. In our ‘real-world’ setting, the water sample dilution method resulted in a maximal measurable bacterial concentration of 9,682.8. Thus, the observed LRVs likely underestimate actual LRVs. The extremely high pre-treatment water turbidity exceeded by a wide margin WHO test protocol requirements. Nevertheless, the treatment system was successful in meeting the final turbidity goal of <1 NTU in four of the nine trials and <5 NTU in all trials.

Ozone disinfection has been largely limited to Europe and North America, in part because of the high costs of constructing and powering centralized ozone generation on a large scale (Loeb et al., 2012; Mundy et al., 2018). A disadvantage of the role of all-solar decentralized ozonation systems in the global effort toward achieving UN Sustainable Development Goal target 6.1 (safe and accessible drinking water for all by 2030) remains to be determined. Membrane filtration methods have been the focus of decentralized water treatment studies (Francis et al., 2016; Huttinger et al., 2015; Sima et al., 2012). Before systems, such as the one we described, could be widely deployed, research will be needed to determine the relative effectiveness, costs, impacts on health, and community acceptance of the ozonation and membrane filtration. By operating the system on solar power, this approach does not release particulate matter, carbon monoxide, and other air pollutants. This addresses concerns that arise when water treatment and air quality are not considered jointly (Clasen & Smith, 2019).

The cost of materials and construction was approximately $24,000, though several tanks and kiosk structures were available at the defunct site when work began. Though in the trials reported here we treated 1,000L per day, two treatment cycles per day can be run, doubling output to 2,000 L with only a marginal increase in cost (primarily the time of the system operator and the cost of alum). The ozonation units are modular, and with several ozonation tanks, each linked to larger ozone generators, the cost per cubic meter of water produced can be decreased substantially. By assembling ozone generators and other system elements in Kenya, costs would decrease further. If future sites like this are developed, systems can be simplified, bringing down costs. Two modifications we intend to make are the elimination of the “balance tank” and directing ozone exhaust from the disinfection tank back to the settling tank for water pre-treatment.

The findings of this research are subject to several limitations. The number of trials was relatively small, and they took place over a six-month period. It is possible that system performance will decrease over longer time periods. The dilution of raw water samples was 25mL in 75mL of distilled water, and dilution was only done in the first four trials, limiting the

<p>| <strong>Table 2. Log removal values (LRV) of E. coli and total coliforms, by trial.</strong> |</p>
<table>
<thead>
<tr>
<th><strong>Trial</strong></th>
<th><strong>E. coli LRV</strong></th>
<th><strong>Total coliform LRV</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><em>3.99</em></td>
<td><em>1.81</em></td>
</tr>
<tr>
<td>2</td>
<td><em>2.24</em></td>
<td><em>1.81</em></td>
</tr>
<tr>
<td>3</td>
<td><em>3.49</em></td>
<td><em>3.19</em></td>
</tr>
<tr>
<td>4</td>
<td><em>3.99</em></td>
<td><em>3.99</em></td>
</tr>
<tr>
<td>5</td>
<td><em>3.38</em></td>
<td><em>2.77</em></td>
</tr>
<tr>
<td>6</td>
<td><em>3.38</em></td>
<td><em>2.68</em></td>
</tr>
<tr>
<td>7</td>
<td><em>3.38</em></td>
<td><em>3.38</em></td>
</tr>
<tr>
<td>8</td>
<td><em>3.19</em></td>
<td><em>3.38</em></td>
</tr>
<tr>
<td>9</td>
<td><em>3.19</em></td>
<td><em>3.38</em></td>
</tr>
</tbody>
</table>

Mean (standard deviation) 3.36 (0.55) 3.02 (0.77)

* No baseline sample was taken in Trial 5. No LRV could be determined without a baseline.

** Of the 5000L pumped into the system for Trial 6, 1000L of it was disinfected in Trial 6 and 1000L of it was disinfected the next day in Trial 7. Similarly, Trial 9 was conducted the day after Trial 8 using the same water in the settling tank.
upper limit of bacterial quantification. As a result, the reported LRVs likely under-estimate actual system performance. The research did include measures of ozone concentration in the disinfection process, though this has been measured during laboratory trials (Dorevitch et al., 2020). This research did not address community perspectives. However, the earlier work of POU ozonation (without turbidity reduction) found the taste of the water – but not the cloudiness of the water – to be acceptable.

Conclusion

Based on the substantial reduction in enteric bacteria and turbidity, we conclude that a solar-powered decentralized water system with microplasma ozone generating units can effectively treat highly contaminated surface waters. We believe this approach has several favorable features: 1) it is entirely solar-powered, 2) it is scalable; 3) it is effective in treating highly turbid water, 4) it is relatively simple to operate with training, and 5) the capital costs are small compared to those of a centralized treatment system. Further research will be needed to optimize this approach and characterize its limits.

Data availability

Underlying data


Data are available under the terms of the Creative Commons Zero “No rights reserved” data waiver (CC0 1.0 Public domain dedication).

References


Clasen T, Smith KR: Let the “A” in WASH Stand for Air: Integrating Research and Interventions to Improve Household Air Pollution (HAP) and Water, Sanitation and Hygiene (WaSH) in Low-Income Settings. Environ Health Perspect. 2019; 127(2): 25001. Published Abstract | Publisher Full Text


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Geremew Sahilu
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In general the research shows the application of solar powered decentralized water treatment utilizing ozone. However, the method is not clearly presented since there are no clear dimensions except volumes. This makes it difficult to replicate. Pre-ozone treatments have already achieved the requirement for E. coli and turbidity hence it is not clear what the effect of ozone treatment is. Moreover general information such as specific cost of treatment per cubic meter is not presented to compare it with other methods.

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
No

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Partly

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: My area of research is water supply, water treatment, sanitation, urban
drainage in general water supply and sanitation thematic areas.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.