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SAFE DRINKING WATER FROM CONTAMINATED SOURCES WITH SODIS TECHNIQUE

Fahadi Bakaki[1], Pius Mbuya Nina[1, 2], Zawadi Lukuni Rosette[1], and Adam Yusuf Muhammad Munir[1],

[1]Department of Environmental Science & Management, International University of East Africa, P.O Box35502 Kampala.
[2]College of Natural Science, Department of Biology, Makerere University, P.O Box7062 Kampala

ABSTRACT: *Background: Solar water Disinfection (SODIS) is a low cost, simple and environmentally friendly household water treatment method that can be adopted as a strategy for reducing diarrheal prevalence among children under 5 years in areas that lack access to safe drinking water. Both field and laboratory studies have shown the efficacy of the SODIS method to deactivate waterborne pathogens. Methods: A descriptive cross-sectional study was conducted in Kiwempe urban slum, Kampala. A total of 12 (24 replicates) water samples were collected from four springs with three samples (6 replicates) from each spring at intervals of one week. One replicate for each source was preserved following the standard methods for examination of water and wastewater (APHA, 2012) and the (WHO, 2004) guidelines for drinking water sampling while the second replicate was exposed following the standard SODIS procedures (EAWANG) and later analyzed for total coliform and E.coli using the chromogenic medium technique. Results: The overall spring bacterial counts for T.coliform and E.coli were between (6.43 - 514.57) cfu/ml and (2.63 - 8.03) cfu/ml respectively while turbidity ranged between 0.32 & 0.35 NTU. The paired mean differences for T.coliform and E.coli across all sites were not statistically significant. Statistical significance was only observed for E.coli between site1 and 2 (0.02). SODIS significantly reduced T.coliform by 99.65% and E.coli by 99.999%. Conclusion: The SODIS treatment significantly reduced total coliforms and completely deactivated E.coli in all spring water samples. Therefore, SODIS method should be adopted by households as a low-cost water treatment method to reduce diarrheal prevalence among children under 5year in Kiwempe urban slum, Kampala, central Uganda.*

KEYWORDS: Under-Five Children, Diarrheal Prevalence, SODIS, Kiwempe Urban Slum, Uganda.

INTRODUCTION

According to the WHO (2018), 1.6 million people die every year due to diarrhea from waterborne diseases of which the majorities (525000) are children under 5yrs, and 1.1 billion people do not have access to an acceptable source of drinking water (WHO, 2004; 2007). In sub Saharan Africa where safe water coverage is less than 50%, about 319 million people lack access to improved water sources, diarrheal disease remains one of the leading causes of mortality and morbidity (WHO/UNICEF, 2015). A water and sanitation report (2013) by the UN habitat estimated over 60% of African urban dwellers are in slums and most African cites, water and sanitation infrastructure and services are unable to keep the pace, projecting population doubling in the next 20years observing that the growth rates pose strong challenges for water and sanitation provision. According to water and sanitation study (2012), under – five mortality rates in Uganda due to water and sanitation diseases stood at 650 per 1,000 by 2013.

Government efforts recommend promotion of household safe storage and water treatment among others as reduction initiative (MWE, 2012). 90% of the water borne diseases can be prevented through simple modification to the environment and increasing access to clean drinking water through promotion of appropriate point-of-use interventions within households (WHO/UNICEF, Water for Life, 2005).Water can be treated at household level by either physical or chemical disinfection (Bamutanze, 2014). The physical methods include boiling, heating (fuel and solar), settling, filtering, exposure to UV radiation in sunlight [SODIS] and UV disinfection with lamps (ibid). However, SODIS technology has gained popularity in Haiti, Indonesia, Sri Lanka, India, Cameroon, Vietnam and Kenya because of its potential to reduce diarrheal diseases incidence (Tamas&Mosler, 2009).

Solar water Disinfection (SODIS) is a low cost, simple and environmentally friendly household water treatment method that can be adopted as a strategy for reducing diarrheal prevalence among children under 5 years in areas that lack access to safe drinking water (Eawag). Both field and laboratory studies have shown the efficacy of the SODIS method to deactivate waterborne pathogens.

MATERIALS AND METHODS

Study Area

The urban slum is located in Kansanga division, Makindye municipality, Kampala district. The slum is divided into four zones; Sankara, Kigundu, Mutesasila and Kiwempe. There is high pressure exerted on springs for drinking and domestic water hence four springs were purposively selected from, one from each zone. These springs were located at; site1 (32.60546772, 0.27826779), site2 (32.60793233, 0.28063555), site3 (32.60348724, 0.28270223) and site4 (32.60599041, 0.28270223).

Research Design

The researcher used an experimental descriptive cross-sectional research design with a quantitative approach. The researcher made use of specific numerical measures hence the research was objective. The researcher manipulated and directly controlled the independent variables. The researcher used the positivistic approach to deal with quantitative data, analyze data with the aim of testing the hypothesis and made conclusions based on the findings.

Data Collection

Data were collected from primary and secondary sources. Primary data was obtained through direct observation at four different water sites, which are approximately less than 1km apart. Water samples were collected from the purposively selected springs from 22nd .Feb, 2019 to 8th.Mar. 2019. A total of 12 (24 replicates) water samples were collected from the four drinking water sources (all springs) and with three samples (6 replicates) from each water source at intervals of one week. The water samples were collected early in the morning (6am) in 1.5ltr PET bottles and immediately placed in a back bag so as to prevent multiplication of the

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microorganisms. The samples were then transported to the microbiology laboratory for bacteriological analysis. Secondary data on similar variables was acquired from the existing published literature regarding SODIS.

Laboratory Sample Testing

Laboratory experiments were also carried out to detect the E.coli and T. coliform load in water before and after Sodis treatment .One replicate was preserved following the Standard methods for Examination of water and wastewater (APHA, 2012) and the (WHO, 2004) guidelines for drinking water sampling while the second replicate was exposed following the standard SODIS procedures (EAWANG) and later both analyzed using the E.coli coliform chromogenic medium technique (LABORATORIOS CONDA, S.A.). The bacteriological parameters analyzed included; total coliforms and E. coli while the physicochemical parameter was turbidity.

Data Analysis

The descriptive statistics (mean, standard deviation, standard error of mean) of total coliform and E. coli counts were tabulated. Mean differences of the total coliform and E. coli counts across water sources before and after SODIS treatment were compared using one-way ANOVA (t) test. The data presentations and analysis were done by using Microsoft Excel 2007 and SPSS 21.0 statistical packages.

Mean intervals at 95% confidence level were calculated from the formula;

Mean ± Z X S.E, where; Z=1.96 (constant) and S.E- standard error of mean (Moore et al, 2013). Paired mean difference intervals were calculated from; MD ± S.E,

RESULTS

The results obtained in this study describe the microbiological quality of water before and after SODIS, and findings on cause of different levels of microbial load in the study sites.

Results for T.coliform before and after SODIS Treatment

Based on the sample data collected with a confidence level of 95%, the analysis results before SODIS treatment showed that all the sites contained large volumes of T.coliform except site1. Site1 had the lowest count of T.coliform which ranged between (1.34 - 4.00)cfu/ml compared to the rest of the sites. This was followed by site2 with the second lowest count which was in the range (95.77 - 110.23)cfu/ml. site3 was recorded with the highest number of T.coliform (251.37 - 1184.63)cfu/ml.

After SODIS treatment, the mean counts for T.coliform reduced significantly in all the sample sites. However, results showed that site2 had the lowest mean T.coliform of <1 in the range (0 - 0.97)cfu/ml while the mean count for sites 1,3and 4 ranged between (0 & 3)cfu/ml. The results obtained for T.coliform before and after SODIS treatment were as presented in the table below.

Table 1: T.coliform Results before and after SODIS Treatment

		MEAN ± SD	
SITE	**LOCATION**	**Before SODIS Treatment**	**After SODIS Treatment**
1	Sankara	1.34 - 4.00	0.96 - 2.96
2	Kigundu	95.77 - 110.23	0 - 0.97
3	Kiwempe	251.37 - 1184.63	0 - 2.96
4	Mutesasila	192.3 - 244.36	0 - 3.06

Results for E.coli before and after SODIS Treatment

Site1 had the lowest count for E.coli of <1 that ranged between (0 - 0.67)cfu/ml before SODIS treatment. In contrast, E. coli significantly reduced to 0cfu/ml after treatment with SODIS. The highest number of E.coli (5.80 - 12.86)cfu/ml was recorded in site2 which also reduced significantly to 0cfu/ml. The E.coli mean count for sites;3&4, was between (3.48 - 8.52)cfu/ml and (4.22 - 7.12)cuf/ml. These values reduced significantly to zero for all the three sites after SODIS treatment.

Table 2: E.coli Results before and after SODIS treatment

		MEAN ± SD	
SITE	**LOCATION**	**Before SODIS Treatment**	**After SODIS Treatment**
1	Sankara	0 - 0.67	0
2	Kigundu	5.80 - 12.86	0
3	Kiwempe	3.48 - 8.52	0
4	Mutesasila	4.22 - 7.12	0

A Comparison of Results for T.coliform across sites before SODIS Treatment

Comparing Kiwempe with (Sankara, Kigundu and Mutesasila), the paired mean difference was between (384.82 & 1045.84) cfu/ml, (284.49 & 945.51) cfu/ml and (169.16 & 830.18) cfu/ml with levels of marginal significance of 0.06, 0.1 and 0.17, respectively which showed no significant difference. However, the level of marginal significance between Kiwempe and Sankara (0.06) was so close to 0.05 level.

The paired mean difference between Sankara and Kigundu was between (-430.84 & 230.18) while for Sankara and Mutesasila was between (-546.18 & 114.84), both were not statistically significant at 0.59 and 0.76 P-value, respectively. Similarly, there was no significant mean difference between Kigundu and Mutesasila ($p = 0.43$).

In general, the paired mean differences for T.coliform before exposure among all the sites were not statistically significant for $P=0.05$

Table 3: Results for T.coliform Comparison across sites before SODIS Treatment

Site		Paired mean Difference (1-J)	Sig
Kiwempe	- Sankara	384.82 - 1045.84	0.06
	- Kigundu	284.49 - 945.51	0.1
	- Mutesasila	169.16 - 830.18	0.17
Sankara	- Kigundu	-430.84 - 230.18	0.59
	- Mutesasila	-546.18 - 114.84	0.76
Kigundu	- Mutesasila	-445.84 - 215.18	0.43

A Comparison of Results for E.coli across sites before SODIS Treatment

A multiple compulsion test was run to obtain the paired mean difference intervals and significance levels for E.coli between study sites as illustrated in the table below;

Table 4: Results for Comparison of E.coli across sites before SODIS Treatment

Sites		Paired mean Difference (1-J)	Sig
Kiwempe	- Sankara	2.43 - 8.91	0.12
	-Kigundu	-0.09 - 0.09	0.33
	-Mutesasila	-2.91 - 3.57	0.92
Sankara	- Kigundu	-12.24 - 5.76	0.02
	-Mutesasila	-8.57 - 2.09	0.14
Kigundu	- Mutesasila	0.43 - 6.91	0.29

Comparing Kiwempe with Sankara, Kigundu and Mutesasila, the mean difference was between (2.43 & 8.91), (-0.09 & 0.093) and (-2.91 & 3.57) cfu/ml respectively. The mean difference for Sankara and Kigundu ranged between (-12.24 and -5.76)cfu/ml while for Sankara and Mutesasila, MD was in the range (-8.57 and -2.01)cfu/ml. The negative signs imply that the means for Kigundu and Mutesasila were higher than for Sankara.

The mean difference between Sankara and Kigundu (0.02 cfu/ml) was statistically significant while for the rest of the site's compulsions, the MDs were not significant since their P-values were above 0.05.

A Comparison of Results for T.coliform across sites after SODIS Treatment

A compulsion test between all the sites for T.coliform after SODIS treatment showed no significant differences with the highest significance level (1) observed between (Kiwempe and Sankara) while the lowest (0.43) was observed between (Kigundu and Mutesasila), which were all above 0.05 hence the mean differences were not significant as illustrated in Table 5.

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Table 5: Results for T.coliform Comparison across sites after SODIS Treatment

Sites		Paired mean Difference (1-J)	Sig
Kiwempe	- Sankara	-1.20 - 1.20	1
	-Kigundu	-0.53 - 1.87	0.59
	-Mutesasila	-1.53 - 0.87	0.79
Sankara	-Kigundu	-0.53 - 1.87	0.59
	-Mutesasila	-1.53 - 0.87	0.79
Kigundu	- Mutesasila	-2.20 - 0.20	0.43

The results further showed that the MD between Kiwempe and Kigundu (-0.53 - 1.87)cfu/ml was the same as for Sankara and Kigundu with p - value 0.59 while the MD for compulsion between Kiwempe and Mutesasila (-1.53 - 0.87)cfu/ml was also the same as for Sankara and Mutesasila with a p - value 0.79.

Overall Results for T.coliform and E.coli before and after SODIS Treatment

Analysis of water samples before SODIS treatment showed that all sites contained E.coli and T.coliform. However, T.coliform recorded be higher values than E.coli in all the study sites throughout the study period. After SODIS treatment, No E.coli was recorded and T.coliform reduced significantly.

With a 95% confidence interval, the average mean for all the samples before SODIS treatment ranged between (6.43 and 514.57)cfu/ml for T.coliform and (2.63 and 8.03)cfu/ml for E.coli. However, the mean for E.coli count was lower than T.coliform.

After SODIS treatment, the mean count for T.coliform ranged between 0.17 and 1.66cfu/ml which was significantly lower than before SODIS treatment. The results obtained for T.coliform and E.coli were as presented in the table below;

Table 6: Overall Results for *T.coliform & E.coli* before and after SODIS Treatment

	MEAN ± SD	
Exeriments	***T. coliform* (cfu/ml)**	***E.coli* (cfu/ml)**
Before SODIS Treatment	6.43 - 514.57	2.63 - 8.03
After SODIS Treatment	0.17 - 1.66	0

Turbidity

Turbidity was analyzed once for all the samples; before SODIS treatment. This is because it has a profound effect on U.V penetration. Hence there was no relevance of analyzing turbidity after SODIS treatment.

The sample results showed that turbidity ranged between (0.32 & 0.35) NTU across all the sites which was in the recommendable standard range for SODIS method. The lowest turbidity range was observed in site1 which ranged between (0.31 - 0.34) NTU while the highest was observed in site3 in the range (0.31 - 0.38) NTU. Turbidity results for site2 and4 were in the range (0.30 - 0.37) NTU and (0.33 - 0.37) NTU respectively.

All the study sites had E. coli and *T. coliform* above the World Health Organization (WHO, 1993) guideline value of 0 (non-detectable). The presence and variations of the total coliforms and E. coli counts among the selected water sources were related to the bacterial contamination risks posed to the various water sources. Lukubye (2017) and Kabagambe et al.(2005) urged that the proximity of the water sources to human and animal faecal sources as well as landfills plays a significant role in total coliform and E. coli contamination of the water sources. The nearer the pit latrines and landfills are to the water sources, the higher the level of bacterial contamination and vice versa. Moreover, the latrines and septic systems in the present study were located in <10m from sites;2, 3 &4 which might have contributed significantly to the bacterial contamination of the sources. Contrary, no pit latrine, septic or dumpsite was located within 10m near site1 and this could explain the low levels of contamination at this site.

The present study discovered a significant reduction of Total coliform and complete deactivation of E.coli after 6hours of SODIS treatment. T.coliform count reduced significantly by 99.65% (2-3log) from the initial counts but the range (0 - 3.06cfu/ml) was more than 10 CFU/100ml as required by WHO standards of <10 in every 100ml (WHO, 1993). The results are however in disagreement with Bamutaze (2013); Burgess (2004), who recorded <1cfu/ml of T.coliform in all the samples after 6hours of SODIS treatment. The detection of some T.coliform after SODIS treatment may be attributed to factors associated with irradiation intensity, water temperature and re-growth (Dübendorf, 2016). For this particular study, the average temperature was 29.3 °C (partly cloudy days). However, research by EAWAG and Dübendorf (2016) recommend more than 40°C temperature for 99.999% T.coliform reduction. According to EAWAG, a warmer temperature speeds up the process but bacteria, viruses, giardia and cryptosporidium are killed by UV-A radiation even when water is cooler and this means that there is need to extend the exposure time to more than 6hrs for this particular study.

Swistock (2016) argues that the presence T.coliform indicate existence of a contamination pathway between the source of bacteria (animal waste or septic system) and the water supply which disease- causing bacteria may use to enter the water supply rather than a possible cause of an illness. Dübendorf (2002) also argues that the total count of bacteria is not an adequate parameter for the assessment of SODIS efficiency, as harmless organisms, such as environmental bacteria or Algae which present no threat to human health may grow during sunlight exposure of a SODIS bottle. Hence no risk/ low risk of illness (diarrheal) is posed to the population consuming SODIS water as various studies have shown that the rest of the coliform bacteria are harmless except the rare strain of E.coli 0157:H7 (New York department of Health, 2018)

On the other hand, E.coli was reduced to below detection level as required by WHO, EPA and UNBS drinking water guidelines which recommend zero E.coli detection in drinking water (WHO, 2014; EPA & UNBS) and this suggests the vulnerability of E.coli to UV radiation. Findings concur with results obtained under laboratory and field conditions by Bamutaze, (2013); Burgess (2002); and EAWAG, (2011), who recorded complete E.coli deactivation.

Previous study by Bitew et al (2018) in Dabat, northwest Ethiopia showed a 57.9% reduction in the risk of fecal contamination of drinking water and a 40% reduction in diarrheal episodes. Other trials at the University of Uppsala and Christian medical college in India recorded a 40% reduction in diarrheal diseases among children in Tamil, India. In 2002 and 2003, the Swiss Tropical Institute recorded a 70% reduced risk of diarrheal illnesses among children in Bolivia.

CONCLUSION

Overall, SODIS treatment significantly reduced total coliform to 3.6cfu/ml, above 10cfu/100ml required by WHO as the acceptable standards for springs and well drinking water. In contrast, E.coli reduced to zero making SODIS a good fit for water disinfection where communities lack access to clean piped water. Hence, SODIS can work perfectly well and may be adopted as a strategy to reduce water-related illnesses in Uganda and other sub-Saharan countries with adequate sunshine when administered at 6hours minimum on sunny days, following the right procedures and can completely deactivate E.coli plus the consequential diarrheal illnesses.

However, as also stated by Bamutaze (2013) there is need for experimental repetition during rainy seasons. As discussed earlier, there is also need for a study with larger sample to be able to validate some uncertain findings i.e., incomplete deactivation of total coliform.

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