Nigerian Journal of Physics (NJP)
ISSN online: 3027-0936
ISSN print: 1595-0611
DOI: https://doi.org/10.62292/njp.v33(s).2024.263
Volume 33(S) 2024

Solar Disinfection of Drinking Water in Semi-Temperate Rural Community of Jos, Nigeria

*[1]Taddy, E. N., [1]Itodo, A. S., [1]Makama, E. K., [1]Durodola, O. M., [1]Yohanna, E. M. and [2]Gesa, F. N.

[1]Department of Physics, Faculty of Natural Sciences, University of Jos, Nigeria
[2]Department of Industrial Physics, Joseph Sarwuan Tarka University Makurdi, Nigeria

*Corresponding author's email: emmanueltaddy@yahoo.com

ABSTRACT

A significant number of the world's population lacks access to safe drinking water, relying mostly on wells and streams, which are usually contaminated with faeces and other pollutants, as sources of drinking water. This results in many diseases that plague these communities, predominantly in rural areas of developing countries where there is abundant solar radiation all year round. SODIS is a popular method of disinfecting water with remarkable success in many rural areas globally. This method was used in Maza community of Jos North Local Government area of Plateau state in the current study. 2-liter PET bottles, differently modified, were filled with water and placed on corrugated roofing sheets for direct exposure to solar radiation. Some of the bottles were modified by painting them white, white with insulation, half black, black with insulation, and plain with insulation. Delagoa test kits applied to contaminated SODIS bottle showed rapid decrease in the concentration of pathogen at about 40 ^{0}C. The Black painted Insulated modified bottle presented the highest maximum temperature of 62.0 ^{0}C, which occurred around 2 pm, while the least maximum temperature (53.0 ^{0}C) was obtained at the same time for the white modified bottle. Though the plain unmodified bottle showed the least temperature the value was higher than the ambient temperature of Maza. Contrasting the maximum SODIS temperature of the black modified bottle to the corresponding maximum value for the ambient temperature indicates a 29 ^{0}C (96.7 %) rise in temperature within 6 hours. SODIS modification, therefore, enhances the temperature of water by several degrees, and can, therefore, be deployed as an alternative means for households in Maza community to access safe drinking water.

Keywords:
SODIS,
UV light,
Microbial disinfection,
Pathogens,
PET bottles.

INTRODUCTION

Although good quality water is an integral part of life, it is sadly, not sufficient for human use in most parts of the world. For instance, out of the estimated global population of over 8 billion people (UN, 2022), 1.7 billion depend solely on faeces-contaminated drinking water (WHO 2023). This situation exposes people to a high risk of waterborne diseases like cholera, typhoid fever, diarrhea, amoebic and bacillary dysentery, etc., with dire consequences. According to WHO (2023), diarrhea is said to be responsible for about 505,000 deaths globally. Public water supplies in developing countries often fail to produce and distribute water that is safe for consumption. This, in many cases, has left the responsibility of access to safe drinking water in the hands of individual households. Majority of the affected people live in rural areas of developing countries where the scarcity of pipe-borne water abounds. In most situations, wells, rivers, and streams, which are usually contaminated, form the main source of drinking water. The prevalence of most diseases ravaging people in these rural communities are, therefore, attributed to their patronage of contaminated sources of drinking water. The treatment of drinking water at the point of use helps to mitigate the high incidences of diarrheal diseases and can have a significant positive impact on the socio-economic status of the household. This will not only improve productivity of the individuals resulting from good health but will ensure financial resources for medical care are saved. Additionally, school attendance of children in such community is improved, and their prospects enhanced.

To ameliorate these avoidable diseases, many water treatment methods like boiling, filtration, chlorination, iodine, pasteurization, flocculation, and ultraviolet (UV)-stabilizer have been suggested (Wang et al., 2016; Hindeyeh & Ali, 2010; Garcia-Gil et al., 2021). However, most of the suggested water treatment methods proved to be expensive for the rural-dwelling communities. Though health agencies in most developing countries have stepped up campaign for boiling of water for drinking, the process, however, requires the use of fossil fuels which can increase the risk of respiratory diseases due to exposure to smoke. More so, this is hardly practicable in places where firewood and other fossil fuels are scarce and expensive, and may aggravate deforestation where wood is readily available, leading to an environmental problem. Generally, the suitability of these different methods and the acceptance among the population is highly site-specific and depends on the socio-economic conditions of the users and his/her specific preferences.

One method of disinfecting drinking water commonly used in some parts of the world with reasonable success is solar disinfection (SODIS) (Martin-Dominguez et al., 2005; Mahvi, 2007). SODIS has been identified as a relatively cheap method of purifying water against pathogens, therefore providing potable drinking water, an essential component upon which living systems and the human body depend on (Adebiyi, et al., 2021). The method requires the use of only transparent Polyethylene Terephthalate (PET) bottles (or glass bottles) and sunlight. In its basic form, the bottles are usually filled with water and exposed to sunlight for at least 6 hours (Umar & Mohammed, 2023; Mcguigan et al., 1999, Teksoy & Eleren, 2017). The underlying principle is that heat and UV light act synergistically to kill the microbial contaminants within the water. Umar and Mohammed (2023) and Teksoy and Eleren (2017) have suggested that temperatures from 30 ^{0}C to about 60 ^{0}C can inactivate microbes within the water. In general, the higher the temperature the better the disinfection of the water. This, therefore, suggests that for optimum disinfection of water, the PET bottles require modification for the attainment of higher temperatures. Although SODIS has been found to reduce the number of pathogens in microbiologically contaminated water, the method does not improve the chemical properties of the water. The effectiveness of SODIS is confined to clean non-turbid water. As much as this may be a deficiency, the method leverages on the fact that the tastelessness of water is retained unlike in chemically treated water.

Fortunately, the communities lacking access to safe drinking water, mostly in developing countries are within the most favourable regions for SODIS. They are located basically around the equatorial regions (latitudes 35^{0}S and 35^{0}N) with 3000 hours of sunshine annually (Zerbini, 1999). The region considered to be the second most favourable lies between the equator and latitudes 15^{0}N and 15^{0}S having 2500 hours of sunshine annually (Mandell, 1995).

As simple and effective as SODIS is in the disinfection of drinking water, particularly for the rural populace, its utilization in Nigeria and Plateau State to be precise, has yet to be fully explored. This is without prejudice to the successful deployment of the method in other parts of the world. The utilization of SODIS does not only provide safe drinking water but also mitigate the prevalence of water-borne diseases like cholera, dysentery, diarrhea, etc. There is, therefore, the need to sensitize relevant authorities on the advantages of SODIS as a cheap and reliable means of water disinfection. In this study, SODIS is deployed to provide clean and safe means of drinking water in Maza village, a rural community of Plateau state, Nigeria.

The choice of Maza, a rocky terrain is informed by the fact that the open well, which is the only source of drinking water in the community is situated at the village clinic, farther from residential areas. The community, therefore, rely on the only stream that runs from the surrounding hills. More worrisome is that the river is jointly patronized by human and animals in the area. The rocky nature of the area makes the digging of wells very difficult and expensive. Therefore, to reduce the risk of water-borne diseases, SODIS remains a very viable alternative for the treatment of water safe for drinking.

MATERIALS AND METHODS

The Study Area

Maza village (9.956°N, 8.8583°E, and 1258m above sea level), is a rocky area, in Jos North of Plateau state, Nigeria. Figure 1 depicts the map of Plateau State and the study location. Although there are three overhead tanks in Maza for the storage of water from the only solar water borehole, the equipment was vandalized soon after installation and has remained so for many years. The only well in the community is situated at the village clinic, which is far from the residential areas. The major source of drinking water is the only stream that runs from the surrounding hilly area close to the village. The rocky nature of the area makes the digging of wells very difficult and expensive.

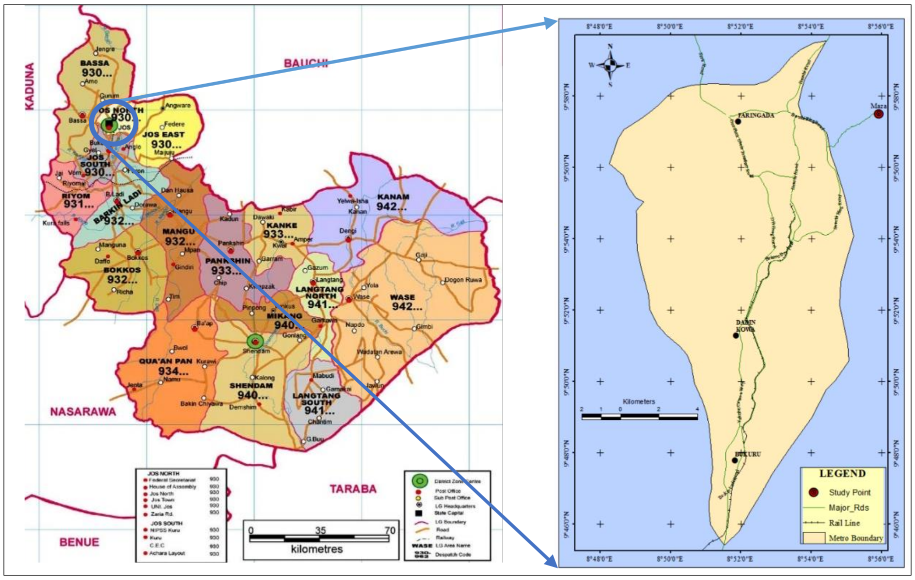

Figure 1: The map of Plateau state showing the study area, Maza to the right.

Materials

Different types of transparent plastic materials, which have been shown to be good transmitters of light in the UV-A and visible range of the solar spectrum, were used for the study. Plastic bottles are generally made of either Polyethylene terephthalate (PET) or Polyvinylchloride (PVC). Both materials contain additives like UV-stabilizer to increase their stability or to protect them and their content from oxidation and UV radiation. Other materials used include, thermometers, corrugated iron (or zinc) sheets, Delagoa test kit, and bottle supports. A Davis vantage PRO2 precision weather instrument was used to obtain the ambient temperature in Julián time for the study location.

Method

Daily weather information from google was used to pick a very sunny day with a forecasted clear sky, high temperature, low humidity and very low chance of precipitation was picked for the study. Two-litre transparent PET bottles, which are readily available in the market at very low cost, were used in the study. Each of the bottles was modified by coating its outer surface with a material or a combination of materials. Prior to the investigation, all labels were removed by immersing the bottles in soap solution and left for about two days for complete removal of adhesives. After removing all labels, the bottles were hand cleaned and thoroughly dried. A hole, enough to fit a thermometer, was then drilled on the cap of each bottle. The clean SODIS bottles were stratified into five different modifications of the back half of each: unmodified [Plain (*P*)], painted white (*W*), painted white with added insulation (*WI*), painted black (*B*), and painted black with added insulation (*BI*). A sample of water from the stream was also taken and subjected to a microbiological test using the Delagoa test kit.

Both the modified and unmodified bottles were each filled with water and placed on corrugated iron sheet at a height of 1m above ground. The iron sheet basically reflects sunlight on the bottles to increase the intensity of the radiation, causing the water to heat up faster, thereby increasing the temperature of the water in the PET bottles. The thermometer, fitted into each bottle, was used to determine hourly mean temperature changes in the water between 9 am and 5 pm on the day of the investigation daily. The process was repeated for five consecutive days for all classes of modification. The ambient temperature (*AT*) of Maza, used to contrast the water temperature in the SODIS bottles during the period of observation, was obtained using the vantage PRO2 weather instrument.

RESULTS AND DISCUSSION

Table 1 and Figure 2 present the microbiological screening result of water sample from the available stream in Maza for the period of five sunny days, which was obtained using Delagoa test kits. As seen in Figure 2, the response of pathogens in the water sample to solar radiation describes two distinct regimes. Firstly, a linear decrease of the number of pathogens in the water sample contained in a plain bottle is observed from 32.0 ^{0}C to about 37.0 ^{0}C, i.e., between 8 am and 9 am. The second regime depicts a gradual decay of pathogens with temperature and time of day from 9 am (37.0 ^{0}C), culminating in their complete removal at 40.0 ^{0}C, which is just before mid-day.

The results, which show that temperatures above 37.0 ^{0}C can disinfect water, corroborate those reported by Anni, et al. (2022), who reported Solar disinfection as an appropriate water treatment method to inactivate faecal coliform in Finland. This may not be due to the temperature alone since temperatures of this value are believed to be ineffective in inactivating pathogens (Teksoy & Eleren, 2019). UV radiation and temperature must have acted synergistically to bring about this effect as reported in a similar study by Umar & Mohammed (2023). For optimum performance, water disinfection usually requires exposure to solar radiation during sunny day, or over an extended period of less sunshine. The attainment of optimum disinfection temperature may be difficult due to a range of prevailing climatic conditions of an area. The use of modified transparent SODIS bottles to maximize the period of solar exposure in Maza is, therefore, pertinent considering the low ambient temperature in the area (see Figure 2).

Table 1: Microbiological test for Pathogens in Water Sample contained in a Plain Bottle and the corresponding Bottle and Ambient Temperatures (^{0}C) averaged over five days in Maza

Time of Day	Pathogens (FC/100ML)	Temperature (^{0}C)	Ambient Temperature (^{0}C)
8	18200	32.0	20.4
9	2650	37.0	25.6
10	256	40.0	29.2
11	0	43.0	31.0
12		48.0	31.4
13		52.0	33.0
14		51.0	32.0
15		52.0	28.0
16		46.0	26.0

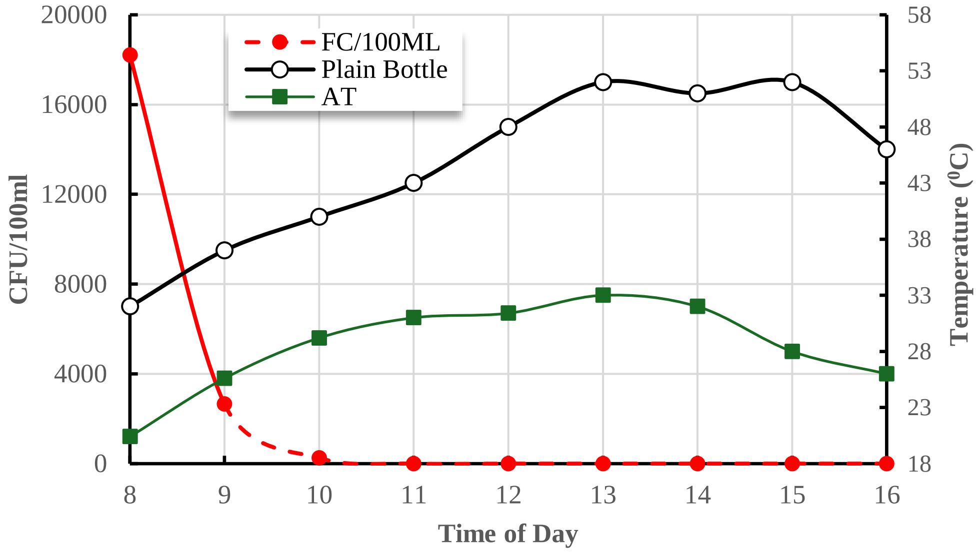

Figure 2: The microbiological screening test for water sample from the available stream in Maza, showing faecal coliform concentration, ambient temperature (*AT*), and plain bottle SODIS water temperature against time of day

The temporal variations of temperature for the differently modified SODIS bottles and the ambient temperature of Maza are shown in Figure 3. From the figure, it can be seen that the SODIS water temperatures in both the modified and unmodified bottles are well above the ambient temperature (*AT*) of the study area. The Black painted plus Insulated (*BI*) modified bottle presents the highest maximum temperature of 62.0 ^{0}C, which occurred around 2 pm, while the least maximum temperature (53.0 ^{0}C) was obtained at the same time for the white modified bottle (*W*). The high temperature attained by the water in the black half-painted and insulated bottle aligns with the results of the studies carried out by Martin-Dominguez et al.(2005) and Teksoy & Eleren (2019). Though the plain unmodified (*P*) bottle showed the least temperature, the value is still higher than the ambient temperature of the study environment as stated earlier. Contrasting the maximum SODIS temperature of *BI* to the corresponding maximum value for the ambient temperature (*AT*) indicates a 96.7 % (29 ^{0}C) rise in temperature within 6

hours. Regardless of the method, it can be inferred that higher temperature connotes better disinfection rate.
SODIS modification, therefore, enhances the temperature of water by several degrees, and can, therefore, mitigate water contamination. The process enhances the disinfection of water within a short treatment period, and may, therefore provide alternative source of clean drinking water, free of contamination from faeces and other pollutants, for the Maza community.

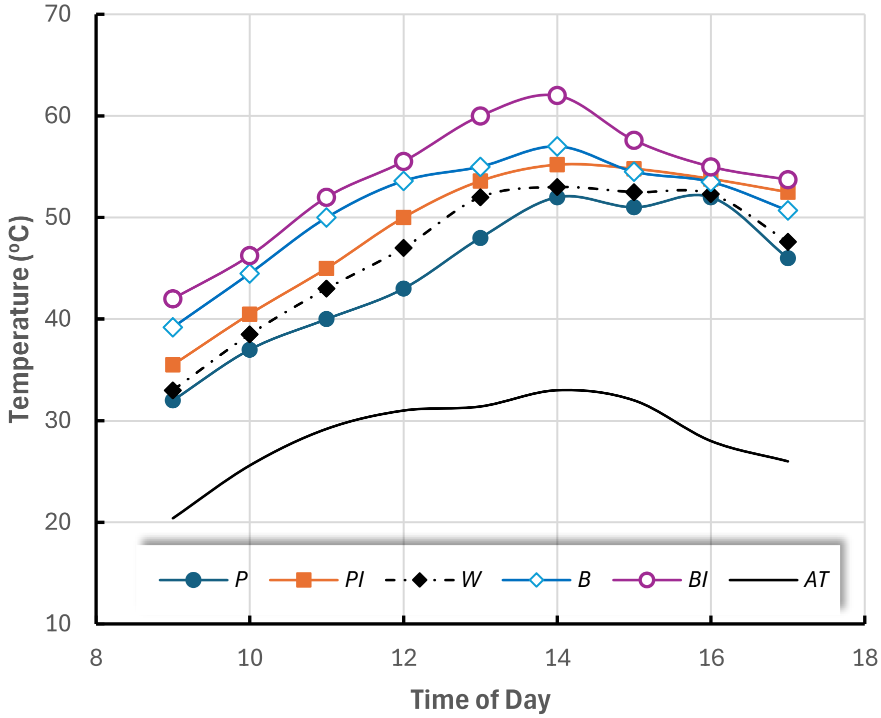

Figure 3: Variation of temperature for the different modifications of SODIS bottle and ambient temperature with time of day in Maza.
P = plain bottle, *PI* = plain bottle plus insulation, *W* = white-painted bottle, *B* = black-painted bottle, and *BI* = black-painted bottle plus insulation.

CONCLUSION

Safe drinking water is a pressing need in many parts of the developing world. Different methods have, therefore, been used to achieve this particularly, in rural communities where resources are scarce for conventional treatment methods. Chemical micropollutants in drinking water are considered as a minor problem in comparison to the possible risks of microbial contamination. The balance in exposure to chemical and microbial pollutants indicate that the contribution of drinking water to the total dietary exposure from most chemicals is very low (van Leeuwen, 2000). In an overall assessment of water treatments, benefits and risks are key parameters. In this study, different modifications were used for the PET bottles to enhance higher temperatures within short spells of time. SODIS is one such method that is not only cheap but a simple, and good method of water disinfection. However, the study could not claim the elimination of other microbial contaminants in the water since the Delagoa test was deployed only for faecal related pathogens. There is, therefore, no certainty that exposure to SODIS can alter the antibiotic susceptibility of a microbial pathogen. Consequently, the study recommends the use of SODIS in conjunction with other water purification methods to ensure potability.

REFERENCES

Adebiyi, K. S., Emoresele, E., and Ogbonnaya, M. J. (2021). Antimicrobial efficacy of solar disinfection of selected drinking well water in Benin City, Nigeria. *Open Journal of Bioscience Research (OJBR)*, 2(1), 16-25. http://dx.doi.org/10.52417/j.ojbr.v2i1.207

Anni, J., Gaurav S., Manuel, A. M., Miguel A. M., Riku, V. and Irina, L. (2022). Solar disinfection – An appropriate water treatment method to inactivate faecal bacteria in cold climates. *Science of the Total Environment* 827 (2022) 154086. http://dx.doi.org/10.1016/j.scitotenv.2022.154086

McGuigan, K.G., Conroy, R.M., Mosler, H.J., du Preez, M., Ubomba-Jaswa, E., FernandezIbanez, P., (2012).

Solar water disinfection (SODIS): a review from bench-top to roof-top. J. Hazardous Materials 235, 29–46. https://doi.org/10.1016/j.jhazmat.2012.07.053

McGuigan, K.G., Joyce, T.M., Conroy, R.M., Gillespie, J.B., Elmore-Meegan, M., (1998). Solar disinfection of drinking water contained in transparent plastic bottles: characterizing the bacterial inactivation process. *J. Appl. Microbiol*. 84 (6), 1138–1148

Garcia-Gil, A., Garcia-Munoz, R.A., Mcguigan, K.G., & Marugan, J., (2021), Solar water disinfection to produce safe drinking water: A review of parameters, enhancements, and modelling approaches to make SODIS faster and safer, *Molecules*, 26, 1-26.

Hindiyeh, M., & Ali, A., (2010), Investigating the efficiency of solar energy system for drinking water disinfection, *Desalination*, 259, 208-2015.

Mandell, G.L. (1995), Principles and practice of infectious diseases, Fourth Edition, Churchill Livingstone.

Martin-Dominguez, A., Alarcon-Herrera, M.T., Martin-Dominguez, I.R., & Gonzalez-Herrera, A. (2005), Efficiency in the disinfection of water for human consumption in rural communities using solar radiation, *Solar Energy*, 78, 31-40.

Marvi, A.H., (2007), Feasibility of solar energy in disinfection of drinking water in Iran, American-Eurasian J. Agric & Environ. Sci., 2(4): 407-410.

Mcguigan, K., Joyce, T.M., & Conroy, R.M., (1999), Solar disinfection: use of sunlight to decontaminate drinking water in developing countries, *Journal of Medical Microbiology*, 48, 785-787.

Teksoy, A., & Eleren, S.C. (2019), Drinking water disinfection by solar radiation, *Environment and Ecology Research*, 5(5), 400-408.

Umar, A.M. & Muhammed, K., (2023), Household water purification using solar water disinfection (SODIS) in Gombe metropolis, Gombe state, Nigeria, *BSTR*, 11(1), 5-9.

UN (2022), Population, https://www.un.org/en/global-issues/population Accessed July, 2024.

Wang, Y., Jin, Y., Huang, Q., Zhu, L., Vivar, M., Qin, L., Sun, Y., Cui, Y., & Cui., L., (2016), Photovoltaic and disinfection performance study of a hybrid photovoltaic-solar water disinfection system, *Energy*, 106, 757-764.

WHO (2023), Drinking water, https://www.who.int/news-room/fact-sheets/detail/drinking-water Accessed July, 2024.

Zerbini, C., (1999), Kostengunstige und effective methode zur verbesserung der wasser-qualitat: Wirkung von UV-Licht kombiniert mit erhohter wassertemperatur auf die viabilitat der Giardia lambila zysten und der crystosporidium parvum Oozysten, Thesis, Swiss tropical institute.