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ORIGINAL ARTICLE

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Effectiveness of Solar Disinfection (SODIS) in Improving the Microbial Quality of Well Water in Ago-Iwoye, Nigeria

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ABSTRACT

OBJECTIVES: To access safe drinking water remains a pressing challenge in many developing countries, where untreated groundwater serves as the primary household water source.

METHODOLOGY: This study assessed the effectiveness of solar disinfection (SODIS) in improving the quality of well water in Ago-Iwoye, Ogun State,Nigeria. Water samples were collected from five locations and subjected to physicochemical and bacteriological analysis before and after solar exposure.

RESULTS: Physicochemical results indicated that most parameters, including temperature (32.3 °C), turbidity (8.67 NTU), and biochemical oxygen demand (3.6 mg/L), exceeded World Health Organization (WHO) thresholds, suggesting compromised quality. Microbiological analysis revealed high baseline contamination, with microbial counts ranging from 50×10^4 to 80×10^4 cfu/mL. Following solar disinfection, counts were reduced to 15×10^4–30×10^4 cfu/mL, demonstrating a notable but incomplete reduction in microbial load. Morphological and biochemical characterization identified Pseudomonas spp. (38%), Klebsiella spp. (27%), Salmonella spp. (14%), Escherichia coli (11%), and Staphylococcus aureus (11%) as dominant isolates. Antimicrobial susceptibility testing revealed widespread resistance, particularly among Klebsiella and E. coli, while streptomycin and ampicillin remained the most effective drugs.

CONCLUSION: Although SODIS significantly reduced microbial contamination, post-treatment levels remained above WHO guidelines, indicating that the method alone is insufficient to make well water potable. Findings highlight the need for combined low-cost purification strategies and regular monitoring to safeguard public health in rural Nigerian communities.

KEYWORDS: Solar disinfection, Well water, Microbial quality, Antimicrobial resistance, Nigeria

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INTRODUCTION

Access to clean drinking water that is uncontaminated by dangerous chemicals and microbiological diseases is still a major global concern. According to WHO estimates, more than one-third of people in poor nations do not have access to safe drinking water, which adds to the high prevalence of waterborne illnesses. About 1.8 million deaths are attributed to diarrheal infections alone each year, with 90% of these deaths happening in children under five, especially in low- and middle-income nations.[1] This emphasizes the critical need for long-lasting and reasonably priced solutions that can raise household water safety.

Households usually have access to surface water from lakes, reservoirs, and rivers; atmospheric water from rain and dew; and groundwater from wells and boreholes. Sanitation methods, socioeconomic characteristics, and environmental circumstances also affect how good these sources are.[2] Water must be devoid of dangerous chemicals, disease-causing microbes, and an unpleasant taste or odour to be deemed drinkable.[3] However, untreated groundwater continues to be the principal source of domestic water supply in many parts of Nigeria, posing serious health dangers to people.

Large treatment facilities frequently use chemical coagulants like aluminium sulphate (alum) and other conventional water treatment techniques. Despite being efficient, these techniques

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have several disadvantages, including high expenses, the production of sludge, and health issues, such the connection between exposure to aluminium and neurological problems.[4] Centralised water treatment is frequently out of reach for households and rural communities in developing nations. Therefore, low-cost, ecologically friendly, and sustainable point-of-use (POU) water treatment technologies are becoming more and more popular. These include solar disinfection, heat-based techniques, chemical treatment, and physical filtering.[5]

Solar disinfection (SODIS) is a simple and inexpensive method that inactivates waterborne microorganisms by using solar light. When contaminated water is placed in glass or transparent polyethylene terephthalate (PET) bottles and exposed to direct sunlight for a number of hours, ultraviolet (UV) rays and thermal energy can interfere with microbial activity.[6] More than two million people utilize SODIS today in 31 countries, mostly in Asia, Africa, and Latin America.[7] It is especially well-suited for environments with limited resources due to its ease of use, cost, and low infrastructure needs.

Although South America and Asia have seen a large number of SODIS investigations.[8,9] Nigeria has produced very few published studies on the topic, despite the country's pervasive reliance on untreated groundwater. The primary supply of drinking and domestic water in Ago-Iwoye, a semi-urban village in Ogun State, is still well water. It is vital to assess how well SODIS works to enhance the microbiological quality of this water source. Public health strategies aiming at lowering waterborne illnesses in Nigeria and comparable settings should be informed by such evidence, which could also direct the actual implementation of household-level initiatives.

METHODOLOGY

This study was carried out in Ago-Iwoye, a town located in Ijebu North Local Governmental Area, Ogun State, Nigeria. Water samples from 10 different wells in the same location were collected using sterile sample bottles. Each sterile bottle was gently lowered into the well after having a strong thread attached to its neck. After observing that no more bubbles were emerging from the bottle, it was allowed to fall into the water and then raised. They cautiously took the bottle out of the well, making sure it did not touch the well's edges. Once the lids were carefully replaced, the sample was taken to the laboratory in an ice bath for immediate analysis.All constituted solid and liquid media were sterilized by autoclaving at 1210C for 15 minutes. Work workbench was disinfected with a swab. The inoculating wire loops were sterilized by heating over the bursen burner until red hot and allowed to cool before use.Salmonella Shigella agar (SSA), Mac Conckey agar (MA), Eosin Methylene Blue Agar (EMB), Nutrient Agar (NA), Peptone Water, and Normal Saline were the culture medium utilised. Every agar used in this investigation was made in compliance with the manufacturer's instructions.

Physicochemical parameters of the effluent water and contaminated soil samples: The pH meter Wag WT 3020 was used to measure the pH of the water samples. Prior to usage, the pH meter was calibrated using buffers 4, 7, and 9.[10] A mercury-bulb thermometer was used to measure each sample's temperature, which was noted at the time of collection and before the samples were sent to the lab. The WagWT3020 turbidimeter was used to measure each sample's colour and turbidity.

Isolation of Bacteria: Microorganisms were extracted from the sample using a pour plate method. On Salmonella Shigella agar, Eosin Methylene Blue agar, MacConkey, and Nutrient agar surfaces, 0.1 ml of each sample was plated. The plate was then incubated anaerobically at 370C for 24 to 48 hours. After that, they were streaked over a fresh plate that had all of the agar previously indicated until distinct colonies were formed. The distinct colonies were then maintained on a slant for further analysis.[11]

Total bacterial count: Using standard procedures, the pour plate technique was used to determine the overall bacterial count. The bacteria in the samples were counted using nutrient agar medium. Salmonella sp. was recovered on Salmonella-Shigella agar, whereas Staphylococcus aureus was isolated on mannitol salt agar. The coloured colonies were counted following a 24-hour incubation period at 370C.[12]

Total Coliform Count: Using a 3-3-3 regimen, the MPN index approach was used to determine this. When MacConkey broth was utilised, it produced gas and acid after 48 hours of incubation at 370C, indicating a successful outcome.[12]

To get the bacteria, 100 millilitres (mL) of water were run through a membrane filter. After that, the filter is put in an agar-filled petri dish to cultivate the bacteria for the entire night. The presence of bacteria is shown by the appearance of colonies on the filter paper, which can be counted.

Faecal Coliform Count: Using the pour plate method and Eosin Methylene Blue medium, the faecal coliform count was determined. Aerobacteraerogenes showed up as big pinkish mucoid colonies on Eosin Methylene Blue (EMB) agar, while E. coli strains showed up as greenish metallic sheen colonies, which were further supported by the organism's capacity to digest lactose at 44.50C.[13] The preferred technique for analysing faecal coliforms in water was membrane filtration. Samples of water were run through a membrane filter with a specific pore size (usually 0.45 micron). The water's microorganisms stayed on the filter's surface.

Parameters	Results
Temperature (0c)	32.33
Pressure (kpa)	159.33
Conduction (us/cm)	488.33
TDS (mg/l)	38.67
BOD (mg/l)	3.60
COD (mg/l)	49.30
Total hardness(mg/l)	13.15
Total Alkaline (mg/l)	16.33
Turbidity (NTU)	8.67
Ca (mg/l)	52.79
Mg (mg/l)	15.24
K (mg/l)	1.83
Fe (mg/l)	0.00
F (mg/l)	0.07
Nitrate (mg/l)	0.99
Nitrate (mg/l)	0.59

Key: TDS =Total Dissolved Solids, BOD =Biochemical Oxygen Demand, COD =Chemical Oxygen Demand, Ca =Calcium, Mg=Magnesium, K =Potassium, Fe =Iron

Table 1: Physicochemical properties of the wellwater samples under study

ISO	MCBD (cfu/ml)	MCAD (cfu/ml)
1SO1	50 X 104	15 X 104
ISO2	75 X 104	24 X 104
ISO3	55 X 104	20 X 104
ISO4	60 X 104	25 X 104
ISO5	80 X 104	30 X 104

Key: ISO; Isolation code, Cfu = Colony forming per unit, MCBD Microbial count before disinfection, MCAD Microbial count after disinfection

Table 2: Microbial count from the well water samples before and after SODIS

Identification of Isolates:Pure cultures of the isolates were identified based on their cultural, morphological, and physicochemical characteristics in accordance with the.[14]

Gram Staining: A sterile water drop was placed on a grease-free slide, and a sterile inoculating loop was used to select a bacterial colony drop in the centre of the sterile water drop. The drop was then spread to create a thin smear, allowed to air dry, and then heated and fixed by rapidly passing the slide's reverse side over a flame. After then, the smear was exposed to crystal violet stain for roughly 60 seconds. After rapidly draining the dye and washing it off with water, a drop of Lugol iodine was added to the slide. The iodine solution was drained off after 60 seconds, and water was then used to rinse the slide until it seemed to be clear of any strong stains. After flooding the slide with acetone (a decolorizer) for five seconds, the slide was blotted dry using filter paper to further decolorise it. The slide was coated with an oil drop and seen under a microscope. According to Willy et al. (2008), bacterial cells that were unable to preserve the crystal violet stain were classified as negative because they took up the counterstain and were pink in colour. Bacterial cells that maintained the purple colouration were recorded as positive.

Biochemical Test: The characterization of bacteria isolates is based on standard biochemical tests which are performed on the isolates to confirm pathogenic organisms in the soil and effluent water. Citrate test, indole test, motility test, catalase test, oxidative/fermentative test and utilization of carbon sources were performed.

Antimicrobial Susceptibility Test: The pathogenic isolates' susceptibility to different antibiotics was assessed using the disc diffusion method. After being moved into nutrient broth tubes, the isolated organisms were cultured for 18 to 24 hours at 37°C. The gram-negative antibiotics multidisc Tetracycline, Streptomycin, Oxacilin, Nalidixic acid, Amplicilin, and Erythromycin were aseptically placed at the centre of the plates using sterile forceps and incubated for 18 to 24 hours after the 18 to 24 hour-old culture isolate was inoculated onto the nutrient agar (NA) plates.[11]

RESULTS

Physicochemical Properties of Well Water

The physicochemical parameters of the sampled well water are presented in Table 1. The average temperature was 32.33 °C and pressure 159.33 kPa. Electrical conductivity (488.33 µS/cm), total dissolved solids (38.67 mg/L), biochemical oxygen demand (3.60 mg/L), chemical oxygen demand (49.30 mg/L), and turbidity (8.67 NTU) all fell within the World Health Organization (WHO) permissible limits for potable water. Concentrations of calcium (52.79 mg/L), magnesium (15.24 mg/L), and potassium (1.83 mg/L) were moderate, while iron was undetectable. Nitrate and fluoride levels were low (0.99 mg/L and 0.07 mg/L, respectively). Overall, these values suggest that the physicochemical quality of the well water was largely suitable for drinking, although elevated turbidity may indicate possible microbial contamination.

Microbial Load before and after Solar Disinfection

The microbial counts before sun disinfection (SODIS) varied from 50×10^4 to 80×10^4 cfu/mL, suggesting that all sites were highly contaminated. Counts dropped dramatically after SODIS treatment, ranged from 15×10^4 to 30×10^4 cfu/mL (Table:2). Although total eradication of bacterial contamination was not attained, this indicates that sun disinfection is successful in lowering bacterial contamination by about 60–70%.

Morphological and Biochemical Characterization

Thirty-seven bacterial isolates were identified across all water samples (Table 3). All isolates were rod-shaped and catalase-positive, with variations in colonial morphology. Probable

Sample code	Gram reaction	Cellular Morphology	Ox	Cit.	Ind.	Cat.	Colonial Morphology	Probable organism
WW1a	-	Rod	-	+	-	+	Pink, mucoid	*Klebsiella*
WW1b	-	Rod	-	+	-	+	Greyish white smooth colonies	*Salmonella*
WW1c	-	Rod	-	-	+	+	Cream mucoid Opaque colonies	*Escherichia coli*
WW2a	-	Rod	+	+	-	+	Large dark greenish blue colonies	*Pseudomonas spp*
WW2b	+	Rod	-	+	-	+	Golden yellow circular, convex and smooth colonies	*Staphylococcus aureus*
WW3a	-	Rod	+	+	-	+	Large dark greenish blue colonies	*Pseudomonas spp*
WW3b	-	Rod	-	+	-	+	Pink, mucoid	*Klebsiella*
WW3c	-	Rod	-	-	+	+	Cream mucoidOpaque colonies	*Escherichia coli*
WW4	+	Rod	-	+	-	+	Golden yellow circular, convex and smooth colonies	*Staphylococcus aureus*
	-	Rod	-	-	+	+	Cream mucoid Opaque colonies	*Escherichia coli*
	-	Rod	-	+	-	+	Greyish white smooth colonies	*Salmonella*
WW5	-	Rod	-	+	-	+	Pink, mucoid	*Klebsiella*

Key: WW1 to WW5= Well water1 to Well Water5, Cat. = Catalase test, Ind. =Indole test, Ox. =Oxidase test, Cit. =Citrate Utilization test, (+) = Positive, (-) = Negative

Table3: Morphological and biochemical characteristics of bacterial isolates from water sample.

ORGANISM	FREQUENCY	% Occurrence
E. coli	4	11%
Klebsiella	10	27%
Pseudomonas spp	14	38%
Salmonella	5	14%
Staphylococcus aureus	4	11%

Table 4:Frequency and Percentage Occurrence of Bacteria Isolates.

organisms included Klebsiella pneumoniae, Salmonella spp., Escherichia coli, Pseudomonas spp., and Staphylococcus aureus.

Frequency and Percentage Occurrence of Isolates

As shown in Table 4 and Figure 1, Pseudomonas spp. was the most frequently isolated organism (14 isolates; 38%), followed by Klebsiella spp. (10 isolates; 27%). Salmonella spp. accounted for 14%, while E. coli and S. aureus each contributed 11%. The dominance of Pseudomonas and Klebsiella suggests persistent environmental contamination and the presence of opportunistic pathogens in the water supply.

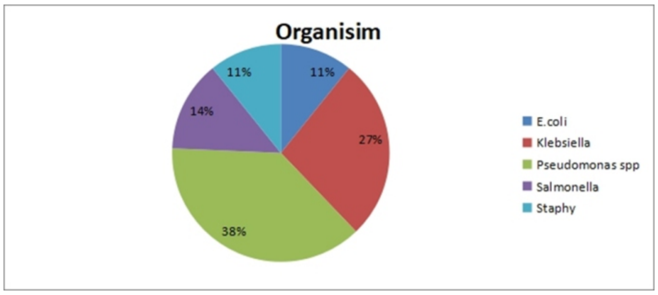

Fig 1: Percentage occurrence of bacteria isolates

Antimicrobial Susceptibility Profiles

The antimicrobial sensitivity test revealed widespread resistance among the isolates (Table .5). Notably, isolates WW1a (Klebsiella) and WW3c (E. coli) were resistant to all tested antibiotics, indicating multidrug resistance. Resistance to streptomycin and oxacillin was particularly common across isolates. Some isolates demonstrated sensitivity to tetracycline,

Sample Code	Organism	T	S	OX	NA	AP	E
WW1a	*Klebsiella*	R	R	R	R	R	R
WW1b	*Salmonella*	S	R	R	R	S	R
WW1c	*Escherichia coli*	S	R	S	R	R	S
WW2a	*Pseudomonas* spp	S	R	R	R	S	R
WW2b	*Staphylococcus aureus*	R	R	R	S	R	8
WW3a	*Pseudomonas* spp	S	R	S	S	R	R
WW3b	*Klebsiella*	R	S	R	S	R	S
WW3c	*Escherichia coli*	R	R	R	R	R	R
WW4a	*Escherichia coli*	R	R	S	R	R	R
WW4b	*Staphylococcus aureus*	S	S	R	S	R	R
WW4c	*Salmonella*	R	R	S	S	R	S
WW5a	*Klebsiella*	S	R	R	S	R	R
WW5b	*Escherichia coli*	R	S	R	S	S	R

Key: T= Tetracycline, S =Streptomycin, OX =Oxacillin, NA =Nalidixic acid, AP =Amplicilin, E =Erythromycin, R =Resistant.

Table 5: Antimicrobial Sensitivity Test

ampicillin, or erythromycin, though susceptibility was inconsistent across genera. The high rate of resistance underscores the potential public health risk of consuming untreated well water, even after partial microbial reduction through SODIS.

DISCUSSION

This study evaluated how well water in Ago Iwoye, Nigeria, that is frequently used for drinking and household uses was affected by solar disinfection (SODIS). Bacterial isolates were tested for antibiotic susceptibility in addition to physicochemical and bacteriological tests.

The physicochemical analysis showed that, except for turbidity (8.67 NTU), which exceeded the suggested maximum of 5 NTU (WHO, 2006), most indicators were within the WHO-permitted limits for drinking water. Increased turbidity is problematic because it might conceal bacteria from UV light and decrease light penetration during solar disinfection, which would impair SODIS efficiency. However, indicators such as total dissolved solids (38.67 mg/L) and total hardness (13.15 mg/L) were well below WHO standards, indicating that the water's chemical quality alone would not render it unfit for human consumption. However, in line with findings by Clarke et al., (2004), elevated chemical oxygen demand (49.30 mg/L) and biochemical oxygen demand (3.60 mg/L) indicate organic pollution, which may also promote microbial development.

A microbiological examination, with counts ranging from 50 × 10^4 to 80 × 10^4 cfu/mL, verified severe bacterial contamination before treatment. Following solar disinfection, microbial loads decreased by roughly 60–70%; nevertheless, levels were still significantly higher than the WHO recommendation of 1 × 10^2 cfu/mL. Even though these decreases show that SODIS dramatically reduces the microbial burden, the treated water was still unsafe to consume due to microbiological concerns.[6] and[16] reported that Escherichia coli and other intestinal bacteria may survive extended exposure to sunlight, especially in turbid or organically enriched water. This is consistent with their findings.

The most common organism identified by the bacteriological profile was Pseudomonas spp., which was followed by Salmonella spp., Escherichia coli, Staphylococcus aureus, and Klebsiella pneumoniae. Serious public health issues are raised by the high frequency of opportunistic bacteria like Klebsiella and Pseudomonas, which are a reflection of ongoing environmental contamination. Antimicrobial susceptibility tests also revealed concerning resistance trends. Salmonella and Pseudomonas isolates exhibited varying sensitivity to antibiotics, whereas isolates of Klebsiella and E. coli exhibited multidrug resistance and were resistant to all tested drugs.The least active drugs were notably tetracycline and nalidixic acid, which is in accordance with general resistance patterns linked to their lengthy history of careless usage.[17,18] These results are consistent with those of [19] and [20], who also reported multidrug-resistant Klebsiella and E. coli from water sources in Nigeria.

CONCLUSION

This study shows that although sun disinfection (SODIS) significantly lowers the microbial loads in well water, it does not completely remove contamination to WHO-recommended levels that are safe for human consumption. The poor quality of untreated groundwater was further highlighted by physicochemical examination, which showed that indicators like turbidity and biochemical oxygen demand surpassed suggested norms. Enteric pathogens were detected by bacteriological examination; the most common isolates were Pseudomonas species, Klebsiella species, and Escherichia coli. Antimicrobial susceptibility testing alarmingly showed that multiple isolates were multi-drug resistant, with E. coli and Klebsiella demonstrating resistance to almost all tested drugs.

Despite being a low-cost, low-maintenance, and community-friendly intervention, our results imply that SODIS shouldn't be utilized as a stand-alone technique for water purification in high-risk environments. Instead, it might be used as a supplementary strategy to enhance microbiological safety in conjunction with filtration or chemical treatment. Multidrug-resistant bacteria's continued presence in water sources further emphasises how urgently regular monitoring, more stringent environmental laws, and community-based education campaigns about safe water management are needed. Expanding sustainable point-of-use purification techniques is still a public health priority for communities that mostly rely on untreated groundwater in order to lessen the prevalence of waterborne illnesses in Nigeria.

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CONFLICT OF INTEREST
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AUTHORS CONTRIBUTIONS

EHO: Conception, Design of the work, Data collection, and Drafting, Reviewed, Final approval, Agreement to be accountable.

CVU: Conception, Design of the work, Acquistion, Data Analysis, and Drafting, Reviewed, Final approval, Agreement to be accountable.

WKA: Conception, Design of the work, Interpretation of data for the work, and Drafting, Reviewed, Final approval, Agreement to be accountable.

AOJ: Conception, Design of the work, Data collection, and Drafting, Reviewed, Final approval, Agreement to be accountable

AHA: Conception, Design of the work, Acquistion, Data Analysis, Data collection and Drafting, Reviewed, Final approval, Agreement to be accountable.

DATA SHARING POLICY
The data that support the findings of this study are available from the corresponding author upon reasonable request.

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