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Evaluating the Optimal Removal of Pollution from Surface Water Within And Around Joseph Saewuan Tarka University Community

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Abstract
Surface water from five sources within Joseph Sarwuan Tarka University community environment were treated for pollutant removal on SODI platform made of corrugated sheet and exposed to direct sunlight in a non-shaded and non-cloudy day. Samples from each source were removed after 2 hrs, 4 hrs and 6 hrs of solar radiation to the laboratory for examination at Department of Water Resources Engineering of Ahmadu Bello University Zaria. The removal process was modeled and optimized for disinfection rate by completely randomized design (CRD). Root mean square linear model (RMS) Duncan multiple range test (MRT) method for LSD and t-test using various statistical analyses were employed. Coefficient of determination (R^2) adjusted R^2 (adj. R^2) and predicted R^2(Pred R^2) were utilizes for source of water and treatment time vs concentration of water quality parameters. Concentration of pH, Temp, Colour, Turbidity and TDS before SODIS treatment were above the maximum limit of NSDQW while Sulphate (360 mg/L) was below the maximum limit. Total coliform and Faecal coliform violated the maximum set limits although no health implication is attached to it. Total coliform was reduced from 95 x 10^2 (cfu/mL), 175 x 10^2 (cfu/mL), > 450 x 10^2 (cfu/mL),250 x 10^2 (cfu/mL),, 350 x 10^2 (cfu/mL),To 15 x 10^2 (cfu/mL), 21 x 10^2 (cfu/mL), , 150 x 10^2 (cfu/mL), And 45n x 10^2 (cfu/mL), While faecal coliform were reduce from 37 x 10^2 (cfu/mL), 55 x 10^2 (cfu/mL), 65 x 10^2 (cfu/mL), 40 x 10^2 (cfu/mL), 33 x 10^2 (cfu/mL), To 0 x 10^2 (cfu/mL), , 2 x 10^2 (cfu/mL), 3 x 10^2 (cfu/mL), And 2 x 10^2 (cfu/mL), In stream, River, Pond, Sand dam Lake/Stag respectively after treatment. The degree of variation among pollutant concentration and thr predictor were low except in Turbidity and Total hardness. Similarly, the regression coefficient for all quality parameters performed above average with exception of total hardness with just 17.10 % meaning that the data points fall very far away from the fitted line, SODIS therefore can remove the pollutants within 2 hrs based on the radiation from sum in the study area hence recommended for the rural dwellers that uses surface water from these sources

Keywords: *Surface water, Pollution, SODIS Technique, Optimal removal, Rural community*

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I. INTRODUCTION

Water plays a significant role as a carrier of microbes that causes diseases in humans; this role is often overlooked with diseases being vastly under-reported. A large number of human diseases are water-borne and can cause a variety of illnesses varying from slight discomfort to death (Stephanie *et al.,* 2012). It is estimated that 1.8 million people die each year from diarrhea diseases, eighty-eight percent of which are due to unsafe drinking water (WHO, 2004). 1.1 billion People (17 % of the global population) lack access to a safe drinking water and 2.6 billion people (42 % of global population) lack access to proper sanitation facilities (WHO/UNICEF, 2005). In Nigeria, 3 in 10 people still lack access to clean drinking water as reported by the National Bureau of Statistics (2006). Utsev and Aho (2012) also concluded that almost all the streams and well water in the three communities studied in Benue State were not safe for drinking due to high E-coli and coliform count, thus causing pathogenic diseases.

In most part of the rural communities in Nigeria, the surface waters are not safe for drinking as a result of high E-coli and coliform count (Wada *et al.,* 2021). A retrospective analysis of surveillance data collected between January 1st and November 19th, 2018 by Elimian *et al.* (2019) indicated that there were 43,996 cholera cases and 836 cholera deaths across 20 states in Nigeria during the outbreak period, with an attack rate (AR) of 127.43/100,000 population and a case fatality rate (CFR) of 1.90%.. Cholera outbreak and other water borne diseases were reported by Benue State Emergency Management Agency (BSEMA) in 2017 as a reoccurring

annual phenomenon in the rural communities and Flood Disaster Management (FDM)/Internal Displaced Persons (IDPs) Camps. In order to improve the living condition of the people, it is necessary to provide them innovations in technology that provide them with safe and clean drinking water.

Solar Water Disinfection (SODIS) is a very simple and environmentally friendly method of disinfecting polluted water (Clasen *et al.,* 2007; García-Gil *et al.,* 2021) . The technology or treatment method consists of exposing a bottle of biologically contaminated water to direct sunlight, allowing the UV component of the light to energize reactions in the water that kill or inactivate microorganisms. This renders the water biologically safe for drinking (Pierik, 2008). Therefore, using Solar Water Disinfection (SODIS) water is very economical (estimated costs of $0.63 per person per year) according to findings of Clasen *et al.,* (2007) and straight forward method in addition to this; it protects the health of the people from water-borne infections.

Joseph Salwuan Tarka University Makurdi (JOSTUM) is hosted by rural communities, the university has a water treatment plant for the immediate student and staff need but limited access to the surrounding host communities. They communities rely majorly on surface water bodies (Lake, Pond, Rivers, streams and Sand dam) for water supply. There have been reported cases of infringement of protest and paralysing of academic actives by the host communities at several times due to lack of access to safe drinking water which has motivated this study. The aim of this study is to scale the optimal performance of environmentally sustainable, low-cost SODIS technology for treatment of available surface water sources at household level for rural communities. The surface waters sampling is limited to rural communities surrounding the JOSTUM Benue State. Surface waters considered are limited to Streams, Ponds, Rivers, lakes and sand dams The findings from this study has established the rate of disinfection of surface water by duration of treatment (period of exposure) to maximum daily threshold of sunlight. It has also provided databanks for future study in alternative technologies for surface water disinfection.

II. MATERIALS AND METHOD

The Study Area

Makurdi the Benue State capital lies has a population of about 292,664 people (NPC, 2006). The vegetation is mostly grasses but this has become disturbed due to land clearing for construction and other urbanization purposes. This practice over the years has exposed the top soil to erosive forces. The predominant soil is sandy loam soil (Hemba *et al.*, 2017). The relief of Makurdi is generally low and like most other cities in the lower Benue valley is drained by the Benue River and its numerous tributaries such as River Idye, Mu, Genabe, Kpege and Adeke . Other major and minor streams also contribute to the drainage of the town (Figure 1).The under lying parent material is sandstone over shale. The geologic logs of open wells and boreholes in Makurdi reveal a lot of sedimentary layers of fine sand which include coarse and single grained, poorly sorted sands and silts and/or sticky, plastic or gritty clays.

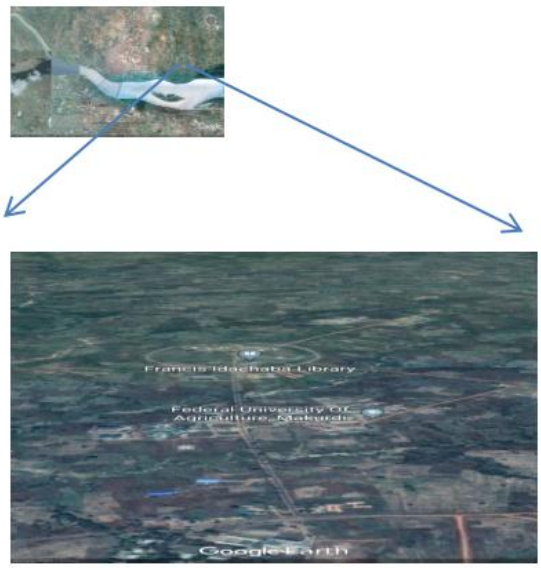

Figure 1: Google Earth Map of Makurdi showing the study area

Materials

The material selection for this study was guided in accordance with the World Health Organization (WHO) and Nigerian Standards for Drinking Water Quality (NSDWQ). The most essential material remains the PET bottles used for sampling as well as the SODIS experiment platform (SANDEC, 2002). Other materials

used were aluminum foil sheet, Thermometer, Labeling sticker, Sample Registration Form, Cooler, Ice packs, Alum, Filter, Funnel, Indelible ink, Bucket, SODIS platform, and SODIS logo.

Sample Collection

The samples were intended for physico chemical and microbial analysis so it was ensured that the sample collection was in compliance with recommended water quality standards by WHO and NSDWQ. This was to ensure that samples quality is not compromised during collection, storage, transportation and analysis. Samples were collected from the Stream, River, Ponds, Sand dam and Lake water sources sterile bottles made of transparent PET:

Analytical procedure

The Indirect method of sampling was used; five sterile sample bottles were used to collect the water from each source. To improve oxygen saturation, bottles were filled three quarters, shaken for 20 seconds (with cap on), then filled completely and recapped. Filled bottles are then exposed to solar radiation on a corrugated platform. This was done on a non-cloudy morning and sunny in the afternoon. After 2 hrs of exposure a sample of each water source were removed from the platform. This was repeated for 4hrs and 6hrs, while resting on a normal SODIS table in non-shaded conditions. Both treated and untreated samples were transported in a cooler packed with ice so as to maintain the temperature of the samples at between 2^{o}C and 8^{o}C to the National water research institute Kaduna for analysis.

Laboratory procedures

Standard laboratory procedures for physicochemical and bacteriological characteristics of various water samples as reported by several author (Abdul-Razak *et al.,* 2009; Maglangit *et al.,* 2014; Ewemoje *et al.,* 2014; Khan and Nath, 2014, Yurtseven *et al.,* 2016) were dully followed. The quality before treatment (Durat. 0 (0 hrs or no treatment)) and three other duration as Durat1 (2 hrs); Durat2 (4 hrs) and Durat3 (6 hrs).All the analysis were performed at the Department of Water Resources Engineering of Ahmadu Bello University Zaria. Physical test including turbidity and suspended solids were analysed according to the standard method. A HACH-HQ40d multi-model digital portable oxygen meter was used for the analysis of dissolved oxygen. Nitrates were measured with a HACH (Model DR3900) portable spectrophotometer. BOD5 analysis was performed in the laboratory, after careful transportation of the samples, with a manometric method in a HACH spectrophotometer. The chloride analysis was performed in a HACH spectrophotometer for chloride. The 15 variables were determined from field measurements.

III. RESULTS

Physical properties of water before and after SODIS Treatment

This session presents the summary of results for water sample analysis before the SODIS experiment and after the experiments. The results for the physical, chemical and biological analysis of the raw sample and SODIS treated water are as presented in Table 1. The pH of all the water samples from different sources were slightly acidic with exception of samples from river and Lake/Stag that were slightly alkaline in nature at no treatment and Durt1 of SODIS treatment. The mean value was 6.70 with and StDev of 0.33. Temperature staggered between 32.6 ^{o}C and 36.9 ^{o}C with an average of 32.82 ^{o}C with StDev of 4.74. Taste and odour are un-objectionable because they are function of individual. Colour was nearly uniform with sudden high values recorded after 2 hrs of SODIS treatment in pond and Sand dams accounting for 3.03 StDev, their mean value was 6.25 NTU. The lowest value in turbidity was 2.6 NTU in Lake/Stag water sample while the highest (658) was from sand dam, the mean value was 158.10 while the StDev was 329.06. TDS ranked closely in mean value of 88.16 mg/L with StDEv of 68.61

The Dissolved Oxygen of the water samples was lowest (0.1 mg/L) in river at treatment Durat.0 and highest (4.0 mg/L) in stream and sand dam at treatment Duration. 0, their mean value and StDev were 2.07 and 1.16 respectively. Biological Oxygen Demand from different sources varied slightly from 0.01 to 2.0 across the samples. Their mean and StDev were 0.77 and 0.65 respectively. Total Alkalinity was highest in Lake/Stag. Water sample (70 mg/L) and lowest (11 mg/L) in river, their mean value and StDev were 35.9 mg/L and 21.54 mg/L respectively. Total hardness (as $CaCO_3$) recorded the lowest (50.06) and highest value (161.28) in stream at no treatment (Durat.0) and treatment Durat.3 (6hrs), their mean value and StDev were 113.40 and 31.11 respectively.

Electrical Conductivity was lowest in River (40) and highest (443) in lake/Stagnant water occasioned by very high level of variation (StDev of 138.42) their mean value was 171.19. **Chloride Content** was just like electrical conductivity was lowest in River (4 mg/L) and highest (28.99 mg/L) in lake/Stagnant water occasioned by moderate variation (StDev of 8.69) their mean value was 13.04. In the same manner, **Sulphate (SO_4)** was lowest in River (235 mg/L) and highest (650 mg/L) in sand dam water occasioned by high level of

variation (StDev of 95.60) their mean value was 360.5 mg/L. Nitrate (NO_3) do not show significant variation among the samples, their StDev was 2.58 mg/L with a mean value of13.75 mg/L. the highest value (20) was recorded in pond while the lowest (10) was recorded in river.

Total Coliform (T. Coliform) was lowest in stream (15 x 10^2) and highest (>450 x 10^2) in river water acationed by very high variation (StDev of 99.39 x 10^2) their mean value was 169.55. In the same manner, Feacal Coliform (F.Coli) was lowest in stream (0) and highest (65 x 10^2) in river water acationed by oderate variation (StDev of 18.84) their mean value was 14.61.

Modeling and Optimization

The set of data from the field and laboratory were fitted to general linear regression model for modeling the efficacy of SODIS i.e water quality parameters vs source of water and duration of treatment by multiply analysis of variance (MANOVA) model using MINITAB software. The impute parameters were water quality parameters replicated into sources of water and treated at different level of treatment duration. The model assumed 8 hr maximum sun radiation (0.1 x 10^{-3} mW/cm^2) for the exposure period as reported by Nana-Obaayaa *et al.* (2023) for Nigeria. The key assumption here is that complete disinfection is only achieved if the SODIS is exposed on a threshold hour, i.e, at hours whose radiation intensity is higher than the disinfection threshold (Nwankwo and Attama, 2022).

Model development

In this section, three Feature Selection (FS) techniques; i) Copletely ramdomized BBD, ii) Duncan multiple range test method for LSD and iv) *t*-test using various statistical parameters i.e., coefficient of determination (R^2), adjusted R^2 (R^2 adj) and predicted R^2 (R^2 pred) were utilized to separate means and predict the variation in response of the fitted data of samples to the predictors. Two different independent process variables i.e. source of water and treatment time vs the dependent variable i.e source concentration of water quality parameters were optimized. Sequential experiments were carried out to develop the process. Each numerical water quality parameters were varied over 3 levels of treatment duration. The linear model generated was validated by conducting experiment on given optimal medium setting and statistical *t*-test using various statistical parameters in accordance with Tredennick *et al.* (2021)

Table 1. Quality chaeacteristics of water samples befor and after SODIS treatment

ource of water	Duration of treatment	pH	Temp	Colour	Turbidity	TDS	DO	BOD	Total Alkalinity	Total hardness (as	Electrical Conductivi ty	Cloride Content	Surphate (SO_4)	Nitrate (NO_3)	Total Coliform x 10^2	Feacal Coliform x 10^2
Stream	Durat. 0	6.7	23.6	5	41.7	51.6	1.7	0.2	22	50.1	102.1	6.0	465	17	95	37
Stream	Durat. 1	6.2	33.0	5	49.6	54.4	2.2	1.1	25	121.0	108.6	6.0	370	14	45	2
Stream	Durat. 2	6.8	35.8	5	40.5	52.6	1.1	0.2	30	121.0	115.0	6.9	265	13	15	0
Stream	Durat. 3	6.7	32.6	5	45.5	59.1	4.0	0.6	24	161.3	118.5	6.0	320	10	20	0
River	Durat. 0	7.2	23.7	5	24.2	20.7	0.1	0.1	15	131.0	41.1	6.5	235	14	175	55
River	Durat. 1	7.1	33.0	5	30.4	20.0	0.6	0.6	11	100.8	40.0	4.0	340	12	35	13
River	Durat. 2	6.7	35.5	5	23.3	21.0	0.4	0.4	15	80.6	41.5	5.5	290	10	25	4
River	Durat. 3	6.6	35.7	5	25.0	20.2	3.4	0.2	11	100.8	40.9	5.0	320	11.5	21	0
Pond	Durat. 0	6.4	23.4	5	20.2	112.2	3.0	1.6	56	101.2	206	17.5	275	20	>450	65
Pond	Durat. 1	6.4	34.1	5	8.7	133.1	0.9	0.2	63	141.2	242	17.5	325	16	315	10
Pond	Durat. 2	6.8	35.6	10	22.8	142.1	2.4	1.0	62	50.4	284.1	17.5	230	15	220	5
Pond	Durat. 3	6.6	37.0	5	30.6	144.1	3.6	2.6	55	151.2	297	19.0	300	13	150	2
Sand dam	Durat. 0	6.5	23.5	15	455	22.2	1.8	0.3	13	90.7	44.2	14.0	500	18	250	40
Sand dam	Durat. 1	6.2	33.9	5	1451	20.6	1.8	0.8	21	151.2	41.3	7.0	420	13	192	15
Sand dam	Durat. 2	6.8	35.9	15	638	57.6	1.4	0.2	20	131.0	43.8	5.5	410	11	45	8
Sand dam	Durat. 3	6.7	32.6	5	202	22.1	4.0	0.8	14	110.9	43.6	5.0	650	11.5	35	3
Lake/Stag.	Durat. 0	7.7	36.9	5	10.7	182.7	2.6	2.0	65	131.0	363	25.5	395	16	350	33
Lake/Stag	Durat. 1	6.6	37.0	5	20.6	194.8	0.7	0.3	62	90.7	389	28.5	420	15	175	5
Lake/Stag	Durat. 2	6.7	36.7	5	2.6	209.0	2.2	0.8	70	161.3	419	29.0	300	14	70	3
Lake/Stag	Durat. 3	6.6	36.9	5	19.5	223.0	3.4	1.4	64	90.7	443	29.0	380	11	63	2

Model output

The result for the model output is as presented in Table 2. From the percentage of variation in the response that is explained by the model was predicted at a; (R-Sq = 1.000) and at b; (α = 0.05) level of significant. The mean square value for pH, Temp, Colour, Turbidity, TDS, DO, BOD, Total Alkalinity, Total hardness, (as $CaCO_3$), Electrical Conductivity, Chloride Content, Sulphate (SO_4), Nitrate (NO_3), Total Coliform (T. Coli) and Faecal Coliform (F.Coli) were 0.116, 24.822, 10.197, 119676.129, 5202.858, 1.493,0 .464, 512.937, 1070.229, 21178.123, 83.693, 10097.105, 7.329, 11354.905, 389.568 respectively. That of the

intercept were 841.287, 20746.984, 682.264, 392605.310, 179806.359, 82.436, 13.493, 27849.070, 244958.220, 684395.618, 3782.213, 2418906.647, 3471.736. Turbidity was found to vary greatly among the water samples with S = 262.99 as compared to pH with just 0.253, however there were corresponding increase in turbidity with increasing temperature which is in agreement with the findings of Aduna *et al.* (2024).The analysis as can be seen from Table 2 showed that all the 15 parameter has R^2 above average with exception of Total Hardness (as CaCO3).)

The effect of SODIS process (duration of treatment) on the removal of pollution by water quality parameter

The effect of SODIS process (duration of treatment) on the removal of water quality parameter is as presented in Table 3 while Tables 4 presents the effect of the source of water on the removal of pollutants by SODIS and Table 5 present the analysis of the interaction between the effect of sites source of water and duration of treatment on the purification efficiency of SODIS. The analysis as can be seen from Table 2 showed Turbidity recorded the highest SED (168.63) and LSD (3.533 ^{a,b}) respectively. LSD was significant in all the parameters with Nitrate recording low (0.042) as compared with20.25 in T.coli. EC recorded 0.00 in F vr was highest in EC (464.17) against F p. (0.00) and lowest (2.10) against F.p (0.148) in colour. unity in Temp, Total alkalinity, Chloride and total coliform. Among the sources of surface water, only sample from there were no significant difference in all the water quality parameters with electrical conductivity leading by 403.5^{a}. the remaining samples Pond, River , Sand dam and Stream were significantly different to polluting parameters, highest values 282.5, 296.25 and 355.0 were noticed in SO_4 with 686.5 noticed in Turbidity.

In the case of effect of treatment duration on SODIS performance; there were no significance difference in all sample from all the water sources for all the water quality parameters. SO_4 recorded the highest values 71.121^{a} in SED and turbidity with 35.080^{a,b} LSD . Fvr was highest 65.54 in faecal coliform while Fp was highest (0.691) in total hardness, All water samples (Pond, River , Sand dam and Stream) were significant to polluting parameters at varying duration of treatment. However; SO_4 lead other pollutant by 374.000^{a}, 375.000^{a} , 299.000^{a}, and 394.000^{a} at 0, 2, 4, 8 hrs duration of treatment respectively.

The interactive effect (Table 5) was positive but no significant difference for all the quality parameters for Stag/Lake samples with SO_4 on the lead. However all other water samples were from the rest sources were significantly different

Table 2: Model output

S/No	Parameters		S	R-sq	**R-sq (Adj)**
1	pH	0.116	0.235136	73.74%	52.73%
2	Temperature	24.822	1.15738	96.46%	93.62%
3	Colour	10.197	2.74874	60.67%	29.21%
4	Turbidity	119676.129	262.999	69.31%	44.76%
5	Total desolve solids	5202.858	10.1554	98.95%	98.11%
6	Dissolved Oxygen	1.493	0.587282	87.43%	77.38%
7	Biological Oxygen Demend	0.464	0.571625	59.64%	27.36%
8	Total Alkalinity	512.937	2.77549	99.17%	98.51%
9	Total Hardness (as CaCO3),	1070.229	40.8990	17.10%	0.00%
10	Electrical conductivity	21178.123	13.0509	99.58%	99.24%
11	Cloride content	83.693	1.86501	97.78%	96.01%
12	NO_3	10097.105	1.16536	86.16%	75.09%
13	Sulphate	7.329	71.1206	72.53%	50.56%
14	Total Coliform x 10^2	11354.905	39.9485	92.09%	85.77%
15	Feacal Coliform x 10^2	389.568	4.26185	96.20%	93.16%

Table 3: Effect of Source of water on effectiveness of SODIS

	pH	**Temp**	**Colour**	**Turbidity**	**TDS**	**Dissolved Oxygen**	**Biological Oxygen Demand**	**Total Alkalinity**	**Total hardness (as $CaCO_3$)**	**Electrical Conductivity**	**Chloride Content**	**Sulphate (SO_4)**	**Nitrate (NO_3)**	**Total Coliform (T. Coli)**	**Faecal Coliform (F.Coli)**
Lake/Stag.	6.887 ^{a}	36.875 ^{a}	5.000 ^{a}	13.350 ^{a}	202.37 ^{a}	2.225^{a}	1.125^{a}	65.250^{a}	118.433^{a}	403.500^{a}	27.970^{a}	373.750^{a}	13.333^{a}	102.667^{a}	3.333^{a}
Pond	6.545	32.525	6.250	20.575	132.875	2.475	1.350	59.000	110.980	257.275	17.865	282.500	16.000	171.250	20.500
River	6.917	31.975	5.000	25.725	20.475	1.125	.325	13.000	103.320	40.875	5.250	296.250	11.875	64.000	18.000
Sand dam	6.513	31.475	10.000	686.500	30.625	2.250	.525	17.000	120.960	43.225	7.875	495.000	13.375	130.500	16.500
Stream	6.603	31.250	5.000	44.325	54.425	2.250	.525	25.250	113.315	111.050	6.225	355.000	13.500	43.750	9.750
S. E. D	0.150	0.00	0.158	168.63	6.551	0.00	0.390	0.00	0.00	0.00	1.318	45.601	0.747	0.00	3.013
L. S. D (0.05)	0.083 ^{a,b}	0.033 ^{a,b}	0.00 ^{a,b}	3.533 ^{a,b}	10.15	0.125 ^{a,b}	0.200	0.333 ^{a,b}	0.833 ^{a,b}	2.350	0.975	11.667 ^{a,b}	0.042 ^{a}	20.250	1.500
F vr.	3.25	22.49	2.10	4.04	184.73	2.87	2.29	232.95	0.23	464.17	88.21	4.05	3.99	14.18	2.80
F pr.	0.053	0.00	0.148	0.029	0.00	0.074	0.124	0.000	0.938	0.00	0.00	0.029	0.030	0.00	0.078

Table 4: Effect of Duration of Treatment on effectiveness of SODIS

	pH	Temp	Colour	Turbidity	TDS	Disolved Oxygen	Biological Oxygen Demand	Total Alkalinity	Total hardness (as $CaCO_3$)	Electrical Conductivity	Cloride Content	Surphate (SO_4)	Nitrate (NO_3)	Total Coliform (T. Coli)	Feacal Coliform (F.Coli)
Durat. 0	6.900[a]	26.220[a]	7.000[a]	110.360[a]	77.880[a]	1.840 [a]	0.840 [a]	34.200[a]	100.812[a]	151.280[a]	13.888[a]	374.000[a]	17.000[a]	174.000[a]	46.000[a]
Durat. 1	6.500[a]	34.200[a]	5.000[a]	312.060[a]	84.580[a]	1.240 [a]	0.600 [a]	36.400[a]	120.960[a]	164.180[a]	12.588[a]	375.000[a]	14.000[a]	152.400[a]	9.000[a]
Durat. 2	6.760[a]	35.900[a]	8.000[a]	145.440[a]	96.460[a]	1.500 [a]	0.520 [a]	39.400[a]	108.858[a]	180.680[a]	12.876[a]	299.000[a]	12.600[a]	75.000[a]	4.000[a]
Durat. 3	6.640[a]	34.960[a]	5.000[a]	64.520[a]	93.700[a]	3.680 [a]	1.120 [a]	33.600[a]	122.976[a]	188.600[a]	12.796[a]	394.000[a]	11.400[a]	57.800[a]	1.400[a]
S. E. D	0.235 a	1.157 a	2.748 a	263.3 a	10.155 a	0.587 [a]	0.572 a	2.775a	40.899a	13.051a	1.865a	71.121	1.165a	39.94	4.261
L. S. D (0.05)	0.120[a,b]	0.760[a,b]	1.000[a,b]	35.080[a,b]	2.760[a,b]	0.260[a,b]	0.080[a,b]	0.600[a,b]	2.000[a,b]	12.900[a,b]	0.080[a,b]	1.000[a,b]	1.200[a,b]	17.200[a,b]	5.000[a,b]
v.r.	1.35	64.98	1.81	0.89	1.42	19.2	1.36	4.17	0.50	0.309	2.20	1.75	15.62	14.18	65.54
F pr.	0.313	0.00	0.208	0.481	0.293	0.00	0.312	0.037	0.691	0.077	0.151	0.22	0.00	0.00	0.000

Table 5: Interaction Effect of source of water and Treatment time on effectiveness of SODIS

		pH	Temp	Colour	Turbidity	TDS	DO	BOD	Total Alkalinity	Total hardness (as $CaCO_3$)	Electrical Conductivity	Cloride Content	Surphate (SO_4)	Nitrate (NO_3)	Total Coliform (T. Coli)	Feacal Coliform (F.Coli)
Lake/Stag.	Durat. 0	7.710a	36.900a	5.000a	10.700a	182.700a	2.600a	.100a	65.000a	131.040a	363.000a	25.450a	395.000a	16.000a	95 a	37 a
Lake/Stag.	Durat. 1	6.550a	37.000a	5.000a	20.600a	194.800a	.700a	.600a	62.000a	90.720a	389.000a	28.450a	420.000a	15.000a	45 a	2 a
Lake/Stag.	Durat. 2	6.740a	36.700a	5.000a	2.600a	209.000a	2.200a	.400a	70.000a	161.250a	419.000a	28.990a	300.000a	14.000a	15 a	0 a
Lake/Stag.	Durat. 3	6.550a	36.900a	5.000a	19.500a	223.000a	3.400a	.200a	64.000a	90.720a	443.000a	28.990a	380.000a	11.000a	20 a	0 a
Pond	Durat. 0	6.400	23.400	5.000	20.200	112.200	3.000	.300	56.000	101.200	206.000	17.490	275.000	20.000	175	55
Pond	Durat. 1	6.380	34.100	5.000	8.700	133.100	.900	.800	63.000	141.120	242.000	17.490	325.000	16.000	35	13
Pond	Durat. 2	6.810	35.600	10.000	22.800	142.100	2.400	.200	62.000	50.400	284.100	17.490	230.000	15.000	25	4
Pond	Durat. 3	6.590	37.000	5.000	30.600	144.100	3.600	.800	55.000	151.200	297.000	18.990	300.000	13.000	21	0
River	Durat. 0	7.190	23.700	5.000	24.200	20.700	.100	.200	15.000	131.040	41.100	6.500	235.000	14.000	>450	65
River	Durat. 1	7.100	33.000	5.000	30.400	20.000	.600	1.100	11.000	100.800	40.000	4.000	340.000	12.000	315	10
River	Durat. 2	6.730	35.500	5.000	23.300	21.000	.400	.200	15.000	80.640	41.500	5.500	290.000	10.000	220	5
River	Durat. 3	6.650	35.700	5.000	25.000	20.200	3.400	.600	11.000	100.800	40.900	5.000	320.000	11.500	150	2
Sand dam	Durat. 0	6.480	23.500	15.000	455.000	22.200	1.800	.100	13.000	90.720	44.200	14.000	500.000	18.000	250	40
Sand dam	Durat. 1	6.150	33.900	5.000	1451.000	20.600	1.800	.600	21.000	151.200	41.300	7.000	420.000	13.000	192	15
Sand dam	Durat. 2	6.750	35.900	15.000	638.000	57.600	1.400	.400	20.000	131.040	43.800	5.500	410.000	11.000	45	8
Sand dam	Durat. 3	6.670	32.600	5.000	202.000	22.100	4.000	.200	14.000	110.880	43.600	5.000	650.000	11.500	35	3
Stream	Durat. 0	6.740	23.600	5.000	41.700	51.600	1.700	.300	22.000	50.060	102.100	6.000	465.000	17.000	350	33
Stream	Durat. 1	6.200	33.000	5.000	49.600	54.400	2.200	.800	25.000	120.960	108.600	6.000	370.000	14.000	175	5
Stream	Durat. 2	6.790	35.800	5.000	40.500	52.600	1.100	.200	30.000	120.960	115.000	6.900	265.000	13.000	70	3
Stream	Durat. 3	6.680	32.600	5.000	45.500	59.100	4.000	.800	24.000	161.280	118.500	6.000	320.000	10.000	63	2
	S. E. D	0.055	1.34	7.556	691.69	103.1	0.3449	0.3268	7.703	11673	170.0	3.478	5058	1.358	1596	18.16
	L. S. D (0.05)															
	v.r.	111.3	114.22	8.40	2.01	4.019	13.99	6.22	57.73	11.02	61.28	31.17	19.69	44.79	14.18	11.48
	F pr.	0.000	0.000	0.000	0.24	0.000	0.000	0.000	0.000	0.00	0.000	0.000	0.000	0.000	0.000	0.000

IV. DISSCUSSION

Concentration of water quality parameters in sampled surface water before and after SODIS

From the result of laboratory analysis of the mean concentration of surface water quality parameters (6.69, 32.82, 6.25, 158.10 and 88.16) for pH, Temp, Colour, Turbidity and TDS respectively before SODIS treatment found in the different surface water from the study area were above the maximum limit especially for colour (15 CTU) and Turbidity (5 NTU). There is no maximum limit set for pH and Temp however they are above reported values for hot dry climate of Nigeria as reported by Akpan *et al*, 2015; for temperature and presence of high levels of free CO_2 in the waters for pH according to (Ephraim and Ajayi, 2015). There is no health implication as regards this limit according to NSDWQ (NSDWQ, 2008). This was as a result of the anthropogenic activities contributing to water pollution. The chemical parameters; Total Alkalinity. Total hardness (as $CaCO_3$), Electrical Conductivity, Chloride Content and Nitrate (NO_3) were all below the maximum limit of NSDQW exception of Sulphate (SO_4) which recorded 360 mg/L as against the recommended limit of 100 mg/L although no health implication is attached to it by NSDWQ. The elevated SO_4 in surface water as opined by Ugbaja and Ephraim 2019 is primarily related to the types of minerals occurring in the watershed, acid rain and human factors. Two principal parameters violated the maximum allowable limit; these are the Total coliform and the Faecal coliform which were reduced from $37 \times 10^{2,} \cdot 55 \times 10^2$, 65×10^2, 40×10^2, 33×10^2 to 0×10^2 2×10^2 3×10^2 2×10^2 in Stream, River, Pond, Sand dam, Lake/stag, respectively after treatment. Thus been observed that the SODIS is a good treatment process considering that the initial concentration of biological parameters were observed in the water samples has been taken up in reasonable quantity by the process. In like manner concentration of physical and chemical parameters remaining in water after SODIS implies that a good percentage was removed although not below the maximum established threshold. It can be inferred that the health impact of urinary tract infections, bacteraemia, meningitis, diarrhea, (one of the main cause of morbidity and mortality among children), acute renal failure and haemolytic anaemia has been removed by SODIS which is supported by Chaúque and Rott (2021)

Modeling

The standard deviation (S) for the various parameters measured in the units of the response variable and represents how far the data values fall from the fitted values. S is used to assess how well the model describes the response. The lower the value of S, the better the model describes the response. However, a low S value by itself does not indicate that the model meets the model assumptions. To verify the assumptions there is need to check the residual plots. From Table 2 the model has best prediction of S = 0.235 this result indicates that the standard deviation of the data points around the fitted values is 1.79. for pH followed by BOD and DO

while the worst prediction is for Turbidity 262.99 This result also indicates that the standard deviation of the data points around the fitted values is 262.99.

Model optimization

Optimization was done by testing the efficiency of SODIS at optimized conditions (duration of treatment). The model was optimized using the R-sq for predicting the responses by the pollutants. The R^2 is the percentage of variation in the response that is explained by the model. It is calculated as 1 minus the ratio of the error sum of squares (which is the variation that is not explained by model) to the total sum of squares (which is the total variation in the model). R^2 is used to determine how well the model fits the data. The higher the R^2 value, the better the model fits the data. R^2 is always between 0% and 100%.

A fitted line plot can be used to graphically illustrate different R^2 values. The plot illustrates a simple regression model that explains the % of the variation in the response. The more variation that is explained by the model the closer the data points fall to the fitted regression line. Theoretically, if a model could explain 100 % of the variation, the fitted values would always equal the observed values and all of the data points would fall on the fitted line this is illustrated as in the response of Turbidity to the model (Figure 2). Adjudging from the main effect plot for Turbidity, sand dam has higher mean effect than water from other sources while the best treatment duration came from 2 hr exposure period (Figure 3). This may not necessary mean that the longer the duration the better the performance but is a function of the sun radiation intensity.

However, even if R^2 is 100 %, the model does not necessarily predict new observations well. In view of the aforementions, all the quality parameters performed above average with exception of Total Hardness (as $CaCO_3$) with just 17,10 % meaning that the data points fall very far away from the fitted line (Figure 4)

Adjusted R^2 is the percentage of the variation in the response that is explained by the model, adjusted for the number of predictors in the model relative to the number of observations. Adjusted R^2 is calculated as 1 minus the ratio of the mean square error (MSE) to the mean square total (MS Total). The adjusted R^2 is used to compare compare models that have different numbers of predictors. R^2 always increases when you add a predictor to the model, even when there is no real improvement to the model. The adjusted R^2 value incorporates the number of predictors in the model to help you choose the correct model.

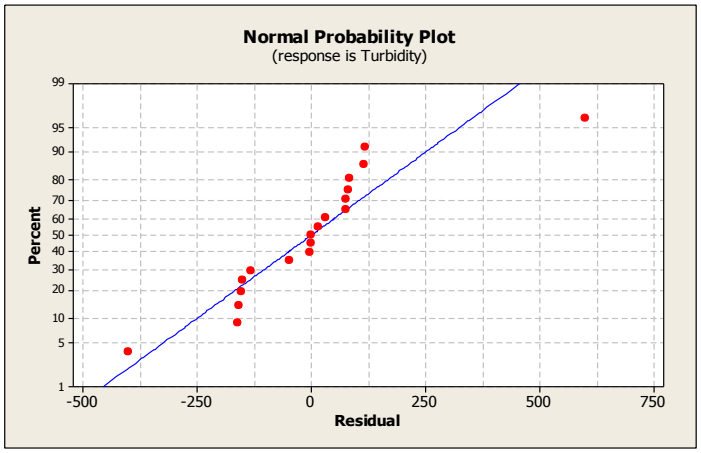

Figure 2: Normal Probability Plot for response of Turbidity to the Model

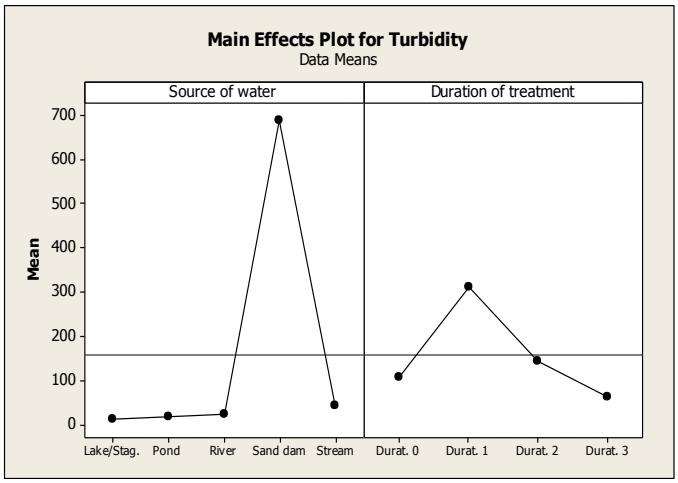

Figure 3: Response of Turbidity to SODIS Treatment

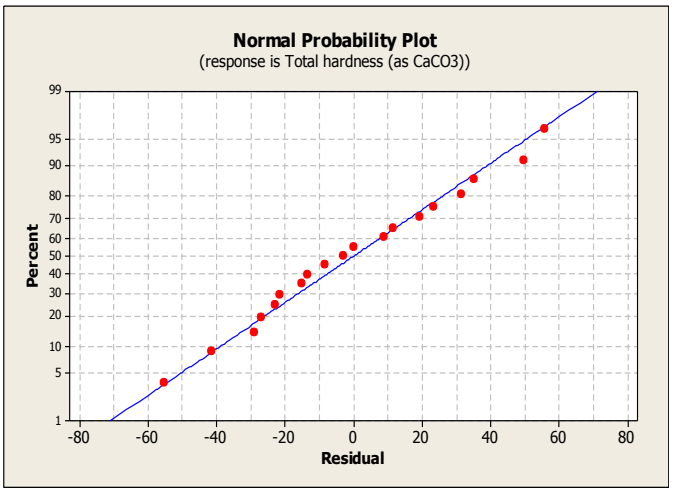

Figure 4: Response of Total Hardness (as $CaCO_3$) to SODIS Treatment

Effect of Source of water on effectiveness of SODIS

Effects of source of water on the uptake of metals by plant as shown in Table 6 using the Duncan method, all the parameters showed significant difference in means for Lake/Stag water sample with colour being highest with LSD of 0.00 and closely followed by Temp with 0.033 while Total coliform been lowest with LSD of 20.25 and closely followed by EC with 12.66 based on effect of source of water.

However, water samples from pond, river, stream and sand dam were highest in source effect by Turbidity and SO_4, the SED, LSD and F .pr values for Turbidity were 168.63, 3.533 ^{a,b} and 0.029 while that of SO_4, were 45.601, 11.667 and 0.029 respectively which implies that there's no significant difference in the effects of water source on the removal of pollution by these parameters.

Effect of Duration of Treatment on Effectiveness of SODIS

All the investigated water quality parameters were observed to be significantly different in means by all treatment duration, this is because the treatment duration might have received similar sun radiation at each period, the SED, LSD, and F .pr value were highest in Turbidity 263.3 a, 35.080^{a,b} and 0.481 respectively which implies that there's significant difference in the effects of treatment duration on the removal of pollution by SODID. The SODIS process therefore has similar ability in concentration of pollutants from water.

Interaction Effect of source of water and Treatment time on effectiveness of SODIS

Effects of the interactions between **source of water and Treatment time as** shown in Table 8 observed that reduction in concentration of parameters by SODIS are significantly different in means between Lake/Stag water sample and all treatment duration and not significantly different in means for the interaction of between Pond, Stream River Sand dam and treatment duration 0;1;2 and 3. This is because duration of treatment have similar abilities of reducing concentration of pollutants in Late/Stag. water than in other water sources.

The interaction between all the Plants pond river stream and sand dam for all the polluting parameters were not significantly different in means. This was because these water sources effect have similar abilities of pollutant contamination, also the SED, LSD and F .pr were gotten to be 0.01648, 0.01668 and 0.01668 which implies that there is no significant difference in the effects of interaction of water source and duration of treatment for removal of contamination

V. Conclusion

Surface water is a great and dependable source of water to rural dwellers in developing countries. However the quality of surface water has been threatened by contamination by anthropogenic and natural activities. SODIS has proven to be effective at reducing waterborne diseases incidence associated with microbiologically contaminated water in developing communities around the world. Although the technology is simple and appropriate method of reducing pollution level of surface water which is expected to significantly expand the number of users with access to SODIS. In this study, surface water has been reported to be polluted as the concentrations of key water quality parameters were above the maximum limit set by NDWQS. A methodology/model for estimating SODIS performance based on the source of water and duration of treatment has been presented. This study has shown that duration of treatment has effectively reduced the concentration of turbidity and other water quality parameters to levels suitable for SODIS treatment. This may appreciably increase the number of people who can practice SODIS as a means of accessing clean water for sanitation

purposes, and with some improvement, for drinking purposes. Future work should address the viability of this technology with different types of bentonite and at the field scale, as well as the effectiveness of bentonite and NaCl combinations at reducing microbiological content in water

VI. Recommendation

This study has contributed to knowledge by; providing a base line data on the pollution level of surface water sources and efficacy of SODIS as function of duration of exposure and radiation intensity in Makurdi. Developing a linear regression model for predicting the concentration of polluting parameters for surface water at different locations and has established optimum duration of exposure of 2 hrs on maximum threshold of sun radiation

Based on the findings from this study, the following has been recommended; SODIS should not be performed on cloudy days, better disinfection can be achieved with even 2 hrs of exposure at maximum sun radiation threshold in Makurdi

Standardized PET bottle based on family demand be made available in the Market for rural dwellers

Advocacy and social awareness is needed to sensitized the rural community an the effectiveness of the SODIS Technology

Further research be carried out on potentials of other packaging materials locally available other that PET bottles for application of SODIS

Further research be carried out on potentials of other platform materials locally available other that corrugated sheet for application of SODIS

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