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Solar-Enhanced Waste Stabilization Ponds: A Comparative Analysis of Reflector Shapes for Optimizing Urban Wastewater Treatment

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Abstract: The extensive land requirement is a primary barrier to the adoption of waste stabilization ponds (WSPs) in urban areas. Solar-Enhanced Waste Stabilization Ponds (SEWSPs) address this limitation by incorporating reflectors to intensify solar radiation, thereby enhancing pollutant removal efficiency and reducing land usage. This study assessed the performance of plane and parabolic reflectors in SEWSPs, hypothesizing that the parabolic reflector, due to its unique optical and geometric properties, would concentrate solar radiation more effectively than the plane reflector. Samples from the influent and effluent valves of a pilot-scale facultative SEWSP were analyzed for 5-day biochemical oxygen demand (BOD_5) and fecal coliform (FC), demonstrating that pollutant removal efficiency varied with temperature, which was influenced by reflector shape. Suitability of standard ANOVA for mean comparisons was assessed, and robust alternatives were considered. At a 5% significance level, the Games-Howell Q-test indicated that the parabolic reflector significantly improved BOD ($p = 0.024$) and FC ($p = 0.002$) removal over the control, while the plane reflector showed no significant enhancement. These findings suggest that concentrating solar radiation in WSPs could enhance treatment efficiency and reduce land demands, positioning SEWSPs as a viable wastewater treatment option for urban environments.

Keywords: BOD, faecal coliform, reflector, solar radiation, temperature, ANOVA

1. INTRODUCTION

Waste stabilization ponds (WSPs) are shallow, large basins surrounded by natural embankments where organic material in wastewater is broken down through natural biological processes [1], [2]. While WSPs use relatively simple technology, they support a complex ecological network, including algae, viruses, protozoa, rotifers, insects, crustaceans, and fungi, all of which contribute to organic waste stabilization and reduction of pathogen levels in the effluent [3]. This engineered system leverages the natural synergy between algae and bacteria to process wastewater efficiently. When optimally designed, WSPs produce high-quality effluent, rich in nutrients and suitable for irrigation without requiring costly chemical disinfection [4]–[6]. These systems are widely adopted by both municipal and industrial sectors. However, the requirement for large tracts of land limits the feasibility of WSPs in densely populated urban areas [7].

Extensive research has focused on enhancing the operational efficiency of waste stabilization ponds (WSPs) while minimizing their spatial footprint. Strategies to optimize WSPs include several innovative techniques, such as implementing recirculating stabilization ponds in series [8], step-feed approaches [9], hybridizing with attached growth systems [10], and using natural zeolite to enhance the irrigation potential of WSP effluent [11]. Improvements also encompass precise calculation of design parameters for optimal performance [12]–[16]. Additional studies examine the impact of deeper pond configurations and modified surface areas on treatment efficacy [17]–[20], including tapered pond surfaces [17]. Among these land-saving innovations, Solar Enhanced Waste Stabilization Ponds (SEWSPs) have garnered notable interest. SEWSP technology integrates a tilted reflector to concentrate sunlight onto the wastewater surface, producing a "solar image" that amplifies the energy available for treatment processes, thereby increasing the efficiency of stabilization [21]–[26].

The efficiency of stabilization in waste ponds hinges largely on microbial processes within the system, with bacteria and algae playing key roles [27], [28]. Three main environmental factors influence these microbial communities: temperature, sunlight, and mixing. Temperature has an exponential effect on bacterial activity [29], [30]; light intensity directly impacts algal concentration [34]; and mixing aids in the distribution of oxygen and non-motile algae throughout the pond's depth [32]. Mixing in WSPs occurs through two mechanisms: wind and thermal mixing. Without wind, thermal stratification issues can be mitigated by introducing additional heat, thereby enhancing the pond’s capacity [33]. The reflectors in Solar Enhanced WSPs (SEWSPs) serve dual functions to support this natural microbial symbiosis: they directly increase water temperature, enhancing bacterial action and promoting thermal mixing, and indirectly boost algal photosynthesis, which raises pond pH and dissolved oxygen levels due to rapid photosynthetic activity [31].

Solar-Enhanced Waste Stabilization Ponds (SEWSPs) have shown high effectiveness in wastewater treatment, offering both operational and economic advantages. Studies highlight that integrating solar reflectors into SEWSPs significantly reduces land usage—by up to 75%—and cuts costs of conventional WSPs by approximately 50% [21], [22]. However, the plane reflector commonly used in SEWSPs has been criticized for its limited optical efficiency, as it simply reflects parallel rays without focusing them, which results in a lower-intensity solar image that shifts with the sun’s movement throughout the day [25], [35], [36]. Additionally, the fragility and maintenance costs of glass mirrors used as reflectors pose further challenges, suggesting a need for alternative shapes and materials to enhance SEWSP performance, especially in urban areas. Previous studies found that parabolic reflectors outperform plane reflectors and control setups in pollutant removal [26], yet some analyses in these studies relied on standard ANOVA without verifying its assumptions, which can yield inaccurate results when normality and homoscedasticity are violated [37]. To address these limitations, this study re-evaluated reflector shapes using robust analysis of variance methods, specifically to more accurately assess the treatment performance of plane versus parabolic reflectors in SEWSPs.

2. MATERIAL AND METHODS

2.1 Pond Design and Dimensions

This study utilized a pilot scaled 1:20 model of a conceptual prototype facultative waste stabilization pond (WSP), designed based on Froude number similarity principles. Table 1 outlines the necessary scaling ratios between the model and the prototype, along with associated flow characteristics. The pilot ponds were constructed from 2 mm metal sheets, which were precisely cut into rectangular sections and welded to achieve the desired pond volume. Each pond was equipped with an adjustable frame to mount the reflectors at specified angles.

Table 1. Model-prototype relationships based on Froude similarity law

Parameter	Unit	Dimension	Equation	Relationship	Prototype	Model
Length, L	m	L	L_r	$1/20$	20	1
Width, W	m	L	L_r	$1/20$	6	0.3
Depth, D	m	L	L_r	$1/20$	4	0.2
Surface Area, A	m^2	L^2	${L_r}^2$	$(1/20)^2$	120	0.3
Volume, V	m^3	L^3	${L_r}^3$	$(1/20)^3$	480	0.06
Ideal retention time, (V/Q)	hrs	T	${L_r}^{0.5}$	$(1/20)^{0.5}$	322	72
Influent rate, Q	m^3/d	L^3T^{-1}	${L_r}^{2.5}$	$(1/20)^{2.5}$	36	0.02
Avg. theoretical velocity (QD/V)	m/d	LT^{-1}	${L_r}^{0.5}$	$(1/20)^{0.5}$	2.98×10^{-1}	6.67×10^{-1}
Avg. Froude No. $F_r = \frac{v}{\sqrt{gR_h}}$	$-$	$-$	${L_r}^0$	1	8.42×10^{-7}	8.42×10^{-7}

2.2 Reflector Assembly and Design

The plane reflectors were created by cutting rectangular sections from 12 mm plywood, then covering the surface with reflective aluminum foil. For the parabolic reflector, an off-axis parabolic satellite dish was repurposed, lining its concave surface with reflective material. This "off-axis" or "offset" design places the dish's focal point below its aperture, away from the center, enabling focused convergence of reflected sunlight at a specific point below the dish. This unique feature makes it particularly suitable for use in SEWSP systems.

Technically, an off-axis parabolic dish represents a type of quadric surface known as an elliptic paraboloid. Standard off-axis dishes are nearly circular but are slightly taller than they are wide, with their outer edges aligned on a flat plane. The height and width are straightforward to measure, while the maximum depth can be determined by referencing the dish's top and bottom straight edges. For "shaped" off-axis dishes, these measurements can be obtained by placing the dish on a level surface and filling it with water to gauge depth. The solar reflection cast by an off-axis parabolic reflector onto the wastewater surface forms an elliptical pattern, which shifts in size as the sun's position changes throughout the day.

Throughout the day, the reflected solar image gradually shifts away from the ponds. This image reaches its largest size twice daily, with a minimum size occurring between these peaks—typically around 4:00 pm when the reflector tilt angle is set to 68°, equivalent to (90 - θ), where θ is the dish's offset angle. The reflectors' dimensions, positioning, and tilt angle were optimized to align with the maximum size and movement path of the solar image across the wastewater surface. Table 2 provides the geometric and optical specifications of the reflectors.

The second phase of the experiment involved three ponds (1 m ×0.3 m ×0.2 m) designated as Pond A (parabolic reflector), Pond B (plane reflector), and Pond C (control). Each reflector, with an equal surface area, was installed at a 68° tilt. Table 4 includes detailed specifications for each pond and reflector, while schematic and photographic representations of the setup are illustrated in Figures 2 and 3.

Table 2. Reflector geometry and optical characteristics

Properties	Off-axis parabolic reflector	Plane reflectors
Surface area	0.622 m^2	0.622 m^2
Aperture area	0.566 m^2	0.622 m^2
Focal length	0.46 m	Infinity
Offset angle	24°	-
Location of the focus measured from the aperture edges	0.83 m (from top edge) 0.46 m (from the bottom edge)	-

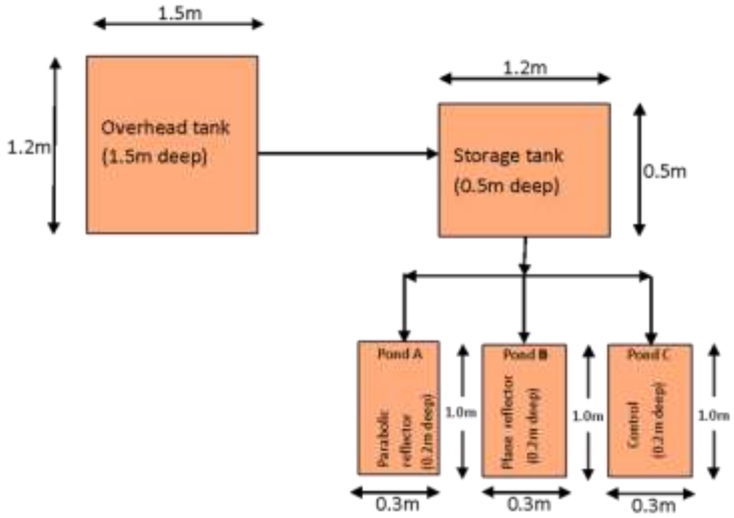

Figure 2. Illustration of experimental setup

Figure 3. Photographic diagram of experimental setup

Table 4. Functional details of ponds and reflectors

Experimental ponds	Size of pond (m)	Characteristics	Dimensions of reflector	Purpose
A	1 × 0.3 × 0.2	Off-axis parabolic reflector	Height (a)=0.89 m Width (b)=0.81 m depth (h)=0.08 m	Measure the effect of solar reflector
B	1 × 0.3 × 0.2	Plane rectangular reflector	Length = 0.40 m Width = 1.55 m	Measure the effect of solar reflector
C	1 × 0.3 × 0.2	No reflector	-	Control

2.3 Laboratory Analysis of Samples

Samples were taken from the effluent outlet valves and the common inlet valve of each pond, then labeled accordingly. Subsequent laboratory analyses were conducted to measure the concentrations of biochemical oxygen demand (BOD) and faecal coliform (FC). Additionally, the temperature, pH, and dissolved oxygen (DO) levels of the pond water were monitored. DO and temperature were recorded in situ at the sampling locations using a HI 9142 multi-parameter water testing meter. BOD measurements were also obtained in the laboratory using the same meter. All other tests were performed in the Sanitary Engineering Laboratory, Department of Civil Engineering, University of Nigeria, Nsukka, in accordance with Standard Methods [38].

The removal efficiency of BOD is typically expressed as a percentage that quantifies the reduction in BOD from influent to effluent in a treatment process. The formula is given as:

$$\text{BOD (\%)} \quad = \frac{BOD_{influent} - BOD_{effluent}}{BOD_{influent}} \times 100 \qquad (1)$$

Where $BOD_{influent}$ is the initial BOD concentration (usually in mg/L) before treatment and $BOD_{effluent}$ is the BOD concentration after treatment.

The efficiency of FC removal was evaluated as log. reduction value (LRV). LRV quantifies the reduction in concentration on a logarithmic scale and is commonly used in water treatment to assess performance at removing pathogens. The formula for LRV is given as:

$$\text{LRV of FC} \quad = \log_{10}\left(\frac{FC\ concentraion\ in\ influent}{FC\ concentraion\ in\ influent}\right) \qquad (2)$$

In this context, a higher LRV indicates a greater reduction in the FC concentration, meaning the treatment process is more effective. For example, an LRV of 1 corresponds to a 90% reduction, an LRV of 2 corresponds to a 99% reduction, and an LRV of 3 corresponds to a 99.9% reduction. LRV is especially useful when contaminant concentrations vary widely or when very high removal efficiency needs to be quantified.

2.4 Statistical Methods for Comparing Means

Levene's test [39] is used to assess the homogeneity of variances (equal variances) across groups, which is an assumption in many statistical tests like ANOVA. Homogeneity of variances is important because it affects the robustness of these tests. Levene's test specifically tests if the variance among groups is similar, helping determine whether a test like standard ANOVA is appropriate or if a more robust method, like Welch's ANOVA, should be used. Furthermore, Levene's test doesn't assume that the data are normally distributed, making it suitable for many types of data. However, it's sensitive to outliers, which can sometimes affect results.

Modified Z-score test is a robust alternative to the standard Z-score, useful for detecting outliers in data that may be non-normal or have extreme skew. It is used to test suitability for data with potential outliers that may affect the mean. No strict distributional assumptions are required, making it robust. It uses the median and median absolute deviation (MAD) values with a modified Z-score outside ±3.0 are flagged as outliers.

Welch's test [40] was used to check for any statistically significant difference in the performances of the ponds in removing BOD and faecal coliform. Welch's ANOVA (or Welch's test) is a variation of the standard ANOVA designed to compare the means of three or more independent groups, particularly when assumptions of equal variances across groups are violated. It's a more robust approach than traditional ANOVA for handling datasets with heterogeneous variances, providing reliable results without requiring transformations or adjustments.

If Welch's test indicates a significant difference, post hoc tests can determine where the differences lie. Games-Howell test [41] is a common post hoc test used with Welch's ANOVA, as it also doesn't assume equal variances and is well-suited for unequal sample sizes. The study of Sauder and DeMars [42] found slightly higher power for the Games-Howell test when compared with other pairwise comparison procedures.

All comparison tests, including assumption tests, were computed with Real Statistics Using Excel (version: Rel 8.9.1, released on October 2, 2023).

3. RESULTS AND DISCUSSION

3.1 Laboratory Analysis of Samples

The influent wastewater characteristics were assessed weekly over the 5-month experimental period. Characteristics of wastewater used in the experiments are presented in Table 1. Parameters evaluated included BOD_5, fecal coliforms, suspended solids, total nitrogen, total ammonia, free ammonia, sulfide, pH, and dissolved oxygen. Notably, only pH conforms with the World Health Organization's (WHO) in effluent standard for discharged into inland surface waters. While BOD, fecal coliforms, and sulfide may necessitate additional treatment, such as a maturation pond, to meet discharge standards, the remaining requirements are not likely to cause difficulty to anaerobic and facultative ponds in series.

Hydrogen sulfide, primarily generated by the anaerobic reduction of sulfate by sulfate-reducing bacteria like Desulfovibrio, serves as the main potential source of odor. However, trace levels of sulfide can be beneficial, as it binds with heavy metals to form insoluble metal sulfides that precipitate out of the water column. Additionally, small concentrations of sulfide (10–12 mg/L) are advantageous, as they are highly toxic to Vibrio cholerae, the causative agent of cholera [43].

Wastewater pH is also known to play a significant role in odor inhibition. In well-designed anaerobic ponds, with typical pH values around 7.5, most sulfide exists in the form of the odorless bisulfide ion. Odor arises only from the release of hydrogen sulfide gas, which diffuses to achieve a partial pressure in the air above the pond, in equilibrium with its concentration in the water (according to Henry's law). For further details on the impact of pH on the equilibrium between hydrogen sulfide, bisulfide, and sulfide, refer to Sawyer et al. [44].

3.2 Suitability of BOD Data to ANOVA Test

Table 2 presents descriptive statistics and the Shapiro-Wilk test of normality for the BOD values recorded across the three pond types. Normality and equal variance are part of the assumptions implicit in many statistical tests like ANOVA. Figure 4 shows the dot plot, box plot, and Q-Q plot for the control, plane reflector, and parabolic reflector ponds. Notably, the Q-Q plots exhibit S-shaped curves, with most points deviating from the 45-degree reference line, indicating a lack of fit to a normal distribution. The S-shaped pattern in the Q-Q plots suggests that the distributions are skewed or have heavier tails than a normal distribution. This visual assessment is further corroborated by the Shapiro-Wilk test results, which confirm that BOD values across all ponds are not normally distributed ($p<0.05$)—an important consideration for selecting appropriate statistical tests for comparing the pond's BOD removal efficiencies. Even though Levene's test is not significant at 95% level, it is significant at 90% level ($p=0.091$), raising questions about the suitability of ANOVA for comparing the group means of the pond's efficiencies.

The dot plot reveals that the parabolic reflector pond has the widest spread and variability, followed by the plane reflector pond, and then the control pond. No outliers are visible in the dot plot, which is consistent with the box plot findings, where no points fall outside the whiskers, indicating an absence of outliers. The absence of outliers in all three datasets is further confirmed by the modified z-scores, which show no significant outliers across the datasets.

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Table 1. Characteristics of wastewater used in experiment

Parameter	Influent values	Discharge standard
BOD (mg/l)	288	30
Faecal Coliform (per 100 ml)	3×10^6	$<1\times10^3$
Suspended solids (mg/l)	256	100
Total Nitrogen (mg/l)	31	100
Total Ammonia (mg N/l)	35	50
Free Ammonia (mg N/l)	6.1	5
Sulphide (mg/l)	9.0	2
pH	8.8	5.5 – 9.0

Table 2. (a) Descriptive statistics and (b) Shapiro-Wilk test

(a) Descriptive statistics

	Control	Plane	Parabolic
Mean	26.388	36.714	40.872
Standard Error	3.161	3.949	4.324
Median	32.033	43.301	46.62
Standard Deviation	17.600	21.989	24.077
Sample Variance	309.775	483.525	579.694
Kurtosis	-1.495	-1.582	-1.324
Skewness	-0.039	-0.162	-0.317
Range	55.177	66.725	75.163
Maximum	55.286	68.307	76.763
Minimum	0.110	1.583	1.600
Sum	818.024	1138.123	1267.033
Count	31	31	31

(b) Shapiro-Wilk test

	Control	Plane	Parabolic
W-stat	0.912	0.898	0.913
p-value	0.015	0.007	0.016
alpha	0.05	0.05	0.05
normal	No	No	No

Table 3. (a) Descriptive statistics, (b) Shapiro-Wilk test, and (c) Levene's test for FC efficiency

(a) Descriptive statistics

	Control	Plane	Parabolic
Mean	1.382	1.654	2.289
Standard Error	0.151	0.199	0.207
Median	1.321	1.897	2.406
Standard Deviation	0.841	1.105	1.154
Sample Variance	0.707	1.222	1.333
Kurtosis	-0.929	-1.396	-0.982
Skewness	0.272	0.110	-0.395
Range	2.879	3.358	3.720
Maximum	2.974	3.469	3.869
Minimum	0.094	0.112	0.149
Sum	42.842	51.268	70.957
Count	31	31	31

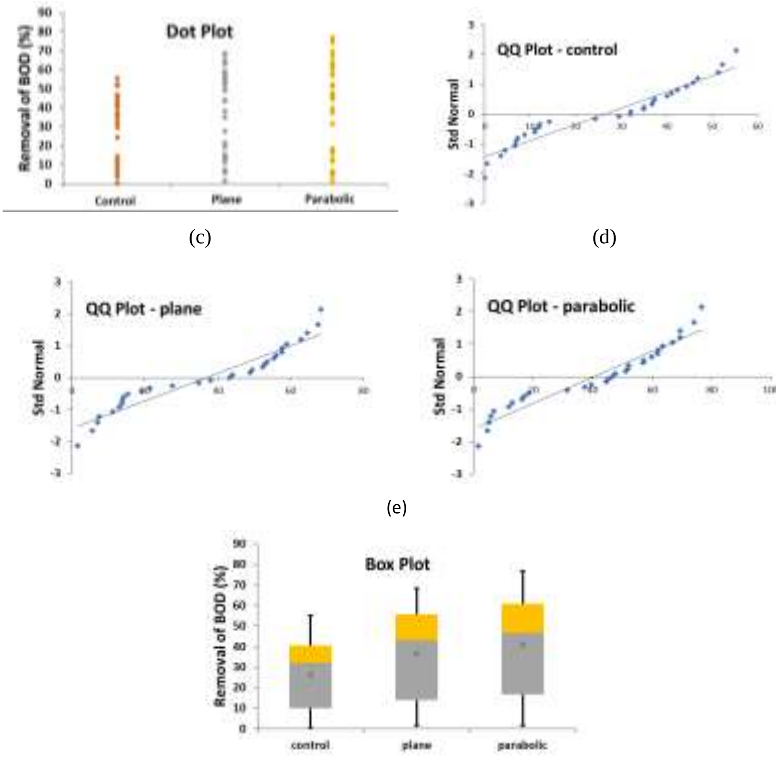
(b) Shapiro-Wilk Test

	Control	Plane	Parabolic
W-stat	0.955	0.92	0.936
p-value	0.216	0.024	0.065
alpha	0.050	0.05	0.050
normal	Yes	No	Yes

3.3 Laboratory Analysis of Samples Suitability of Log. Reduction Values of Faecal Coliform Data to ANOVA Test

Table 3 presents descriptive statistics and the Shapiro-Wilk test of normality for the log. reduction values (LRV) of faecal coliform recorded across the three pond types. Figure 5 shows the dot plot, box plot, and Q-Q plot for the control, plane reflector, and parabolic reflector ponds. Notably, the Q-Q plots exhibit S-shaped curves, suggesting lack of normality, although that of the control pond is not very profound. However, the Shapiro-Wilk test results show that the hypothesis of normal distribution could not be rejected for control (p=0.251) and parabolic reflector (p=0.154) at 95% level of significance. Whether ANOVA or other robust methods for comparing group means is employed depends on normality and homogeneity of variance. Even though Levene's p-value was not significant (p=0.053), it was close, raising concern about the suitability of standard ANOVA for comparing the group means the LRV of FC.

(a) (b)

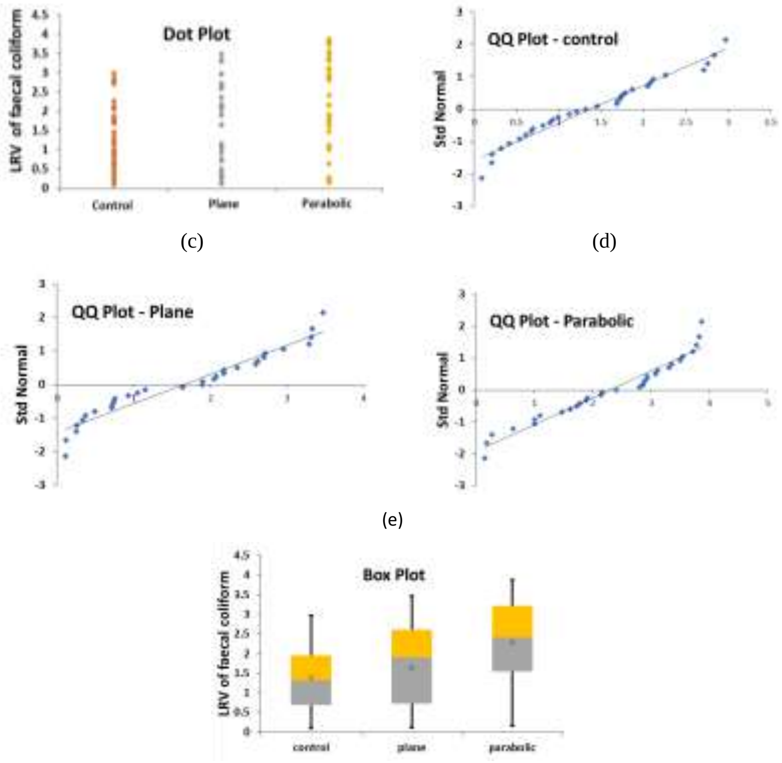


(c) (d)

(e)

Figure 4. Analysis of BOD data: (a) Dot plot, (b) QQ plot for control, (c) QQ plot for plane reflector pond, (d) QQ plot for parabolic reflector pond, (e) Box plot

(a) (b)



(c) (d)

(e)

Figure 5. Analysis of LRV of faecal data: (a) Dot plot, (b) QQ plot for control, (c) QQ plot for plane reflector pond, (d) QQ plot for parabolic reflector pond, (e) Box plot

The dot plot reveals that the parabolic reflector pond has the widest spread and variability, followed by the plane reflector pond, and then the control pond. No outliers are visible in the dot plot, which is consistent with the box plot findings, where no points fall outside the whiskers, indicating an absence of outliers. The absence of outliers in all three datasets is further confirmed by the modified z-scores, which show no significant outliers across the datasets.

3.4 Effect of reflector on BOD removal efficiency

The pond performances at removing BOD varied depending on the reflector used. The parabolic reflector pond recorded the highest BOD removal efficiencies, followed by the plane reflector pond, then the control. The results of the Welch test shows that there is a significant difference among the BOD efficiencies recorded from the ponds (p=0.019). Games-Howell post hoc test presented in Table 4 was used to identify precisely which ponds' BOD efficiencies differ significantly. It can be seen that it was the means of the control and parabolic reflector pond that differ significantly (p=0.024). No significant difference exists between the means of control and plane reflector pond (p=0.112) as well as between the plane and the parabolic reflector ponds (p=0.759).

The primary mechanisms behind BOD removal are sedimentation and oxidation of organic compounds into settleable new cells. These processes are enhanced at elevated temperature. It is worthy of note that the performance of the ponds depended on their ability to focus radiation from the sun, which raises pond water temperature. The parabolic reflector pond, plane reflector pond, and the control recorded an average temperature of 32.9 oC, 29.4 oC, and 28.6 oC, respectively. The higher average temperature recorded in pond A (parabolic reflector) is the most critical effect parabolic reflector had over the plane reflector. This is because virtually all wastewater treatment processes are temperature dependent [33]. WSPs perform according to their water temperatures. Their water temperatures, in turn, depended on the amount of solar radiation energy received by the ponds. Ponds total radiation energy includes the portion received from the sun and the portion provided by the reflectors. Pond A (parabolic reflector) kept its reflected solar image on the wastewater longer than pond B (Plane reflector), resulting in higher water temperature in pond A. On the average, pond A's water temperature is 3.5 oC higher than that of pond B. For this reason, pond A recorded better BOD removal efficiencies. However, temperature affected pH and DO negatively.

Table 4. Games-Howell Q-test on BOD removal efficiency

Group 1	Group 2	Mean	Std err	Q-stat	df	Q-crit	p-value
Control	**Plane**	10.326	3.577	2.887	57.254	3.403	0.112
Control	**Parabola**	14.484	3.788	3.824	54.941	3.407	0.024
Plane	**Parabola**	4.158	4.141	1.004	59.513	3.400	0.759

Table 5. Games-Howell Q-test on LRV of faecal coliform

Group 1	Group 2	Mean	Std err	Q-stat	df	Q-crit	p-value
Control	**Plane**	0.272	0.176	1.541	56.003	3.405	0.524
Control	**Parabola**	0.907	0.181	5.001	54.836	3.407	0.002
Plane	**Parabola**	0.635	0.203	3.129	59.888	3.399	0.077

3.5 Effect of reflector on BOD removal efficiency

The pond performances at removing faecal coliform (FC) varied depending on the reflector used. The parabolic reflector pond recorded the highest FC removal efficiencies, followed by the plane reflector pond, then the control. The results of the Welch test shows that there is a significant difference among the LRVs recorded from the ponds (p=0.004). Games-Howell post hoc test presented in Table 5 was used to identify precisely the ponds whose LRVs differ significantly. It can be seen that it was only the means of the control and parabolic reflector pond that differ significantly (p=0.024). The superior performance of the parabolic pond could as well be explained by higher UV dose and temperature. No significant difference exists between the means of control and plane reflector pond (p=0.524). Also, the difference between plane and parabolic ponds was not statistically significant (p = 0.077), even though there was a trend toward significance. This suggests that while the observed effect may be noteworthy, it does not meet the conventional threshold for statistical significance. Further investigation with larger sample sizes may be warranted to explore this trend.

Faecal coliform is the most important consideration if effluents are to be reused for irrigation pond A (parabolic reflector) performed outstandingly well. Its removal efficiency is mediated by pH-temperature-DO relationship. The average pH recorded in pond A, B, C are 8.92, 8.99, and 8.74 respectively; those of DO are 5.9mg/l, 6.8 mg/l, and 6.0 mg/l respectively. While reduced DO in pond A could be explained by increased temperature and increased bacteria action, the pH-temperature dynamics of the ponds could not be explained by the existing theories within the context of the tested parameters. High pH occurs when algae use up CO2 for photosynthesis. Sunlight is the primary driver of photosynthesis, and higher radiation as provided by parabolic reflector should mean more algal activities, using more CO2. If CO2 is taken up faster than bacterial respiration can supply, the concentration of CO2 drops, causing a dissociation of the bicarbonate ion to form CO2 and alkaline hydroxyl [2]. These processes raise pH levels in facultative ponds. Nevertheless, increased solar radiation in pond A, which is known to increase photosynthesis action and algae concentration, did not necessarily translate to higher pH. One plausible explanation is that lethal combination of high UV, temperature and other adverse climatic conditions affected algae growth hence pH negatively.

4. CONCLUSIONS

Experimental results across various wastewater treatment parameters indicated that the parabolic reflector provides superior pollutant removal at a comparatively low cost. The parabolic reflector's design, which focuses and transfers heat directly into the pond, proved to be highly effective at elevating water temperatures. Findings revealed that this reflector setup can raise pond temperatures by an average of

3.5°C more than a plane reflector. The addition of solar heat significantly enhances pond performance by increasing thermal mixing and raising overall temperatures, which allows for more efficient use of the pond's full volume. Although further assessment is needed to determine the technical and economic feasibility of implementing parabolic reflectors in full-scale ponds, it is clear that this design holds promising potential for SEWSP applications.

5. ACKNOWLEDGMENTS

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