Nigerian Journal of Technology (NIJOTECH)
Vol. 42, No. 1, March, 2023, pp.55 - 63
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
https://doi.org/10.4314/njt.v42i1.7

EFFECT OF SUNLIGHT ON THREE STRATIFICATIONS OF WASTE WATER FROM A WASTE STABILIZATION POND

O. B. Ohazulike[1,*] and J. O. Ademiluyi[1]

[1]Department of Civil Engineering, University of Nigeria, Nsukka

*corresponding author (Phone Number: +234-706-265-8290. Email: oohazulike@gmail.com)

Article history: Received 15 November, 2022. Revised 01 January, 2023. Accepted 13 January, 2023

Abstract

Experimental studies on stratification were conducted on a waste stabilization pond system at the University of Nigeria, Nsukka, Nigeria. This was done to ascertain the effect of stratification due to sunlight on pond parameters. An experimental approach was adopted which involved pouring wastewater into a glass column apparatus and exposing to sunlight for 7, 14, and 21 days. The statues of 16 physicochemical and microbiological parameters were investigated in the three strata under consideration. Analysis of the samples collected at depths A, B and C, 30cm apart, starting from the top indicated different values of temperature, pH, and nutrients. Maximum values of temperature (32.9 ^{0}C), pH (7.9), turbidity (3.46 NTU), and iron (1.86 mg/l), were recorded at the top layer; while the concentration of conductivity (906 µS/cm), total dissolved solids (589 mg/l), BOD_5 (400mg/l), ammonia (290 mg/l), total coliform (126,000 cfu/100ml), and E. Coli (99,000 cfu/100ml) were highest at bottom layer. Conductivity, total dissolved solids, turbidity, iron, phosphorus and nitrates fell within World Health Organization (WHO) guidelines. A combination of sunlight with high pH and oxygen concentrations is needed for sunlight to have very significant effects. It is recommended that WSPs be designed with the consideration given to pond dimensions that will provide a wider surface area for sufficient sunlight and oxygen to be acquired.

Keywords: Sunlight stratification, Waste stabilization pond, Microcosm, E. Coli, Dissolved Oxygen, Biochemical Oxygen Demand, Chemical Oxygen Demand.

1.0 INTRODUCTION

Wastewater Stabilization Ponds (WSPs) are the simplest and most economical forms of waste water treatment especially in developing countries [1]. Due to their relatively shallow depths and high turbidity, a favorable condition is created for stratification to occur [2]. Stratification in wastewater stabilization ponds is a natural phenomenon that occurs yearly. Due to temperature changes in the summer periods, the top layers of WSP acquire more thermal energy from solar radiation which creates a temperature gradient between the top and bottom layers [3]. Although thermal stratification has been reported in several literatures, the performance of WSPs in response to the phenomenon still remains ambiguous. This may be because of the complexities involved when other factors such as wind, human activities, and type of wastewater are considered.

A number of authors have sought to explain the processes that influence pond performance. Some researches [4] focused on the impact of light on pathogenic organism as well as the mechanism of removal, while others [2, 5-7] studied the influence of thermal stratification on pond performance.

One pertinent reason to conduct these studies is to make available sufficient data to help in the choice, design and management of stabilization ponds. Another reason is to provide extensive insight on the environmental factors thatinfluence the performance ofWSPs. This paper is therefore aimed atinvestigating the variation of pond parameters at three stratifications due to sunlight intensity, which will provide information on the impact of sunlight on pond performance; to serveas basis for improvements in design,operation and maintenance practices on WSPs. The experimental approach adopted for this research seeks to simulate the daily conditions of a larger pond in a controlled manner so as to monitor the possibility of short term concentration of pond parameters due to exposure to sunlight.

2.0 MATERIALS AND METHODS

To properly simulate the natural conditions in which a WSP operates, a microcosm apparatus was constructed as shown in Figure 1. A cylindrical glass tube made of borosilicate with diameter 6cm and length 97cm was enclosed in a rectangular box measuring 98 x 20 x 20cm and with one side opened and placed firmly in the ground to hold the tube erect. The tube has three (3) outlet valves A, B and C (30cm apart) on its side for collecting wastewater from the column above it under the required conditions. The apparatus is then filled with wastewater collected from the University of Nigeria, Nsukka sewage pond. The exposure periods under consideration were 0 days, 7 days, 14 days and 21 days.

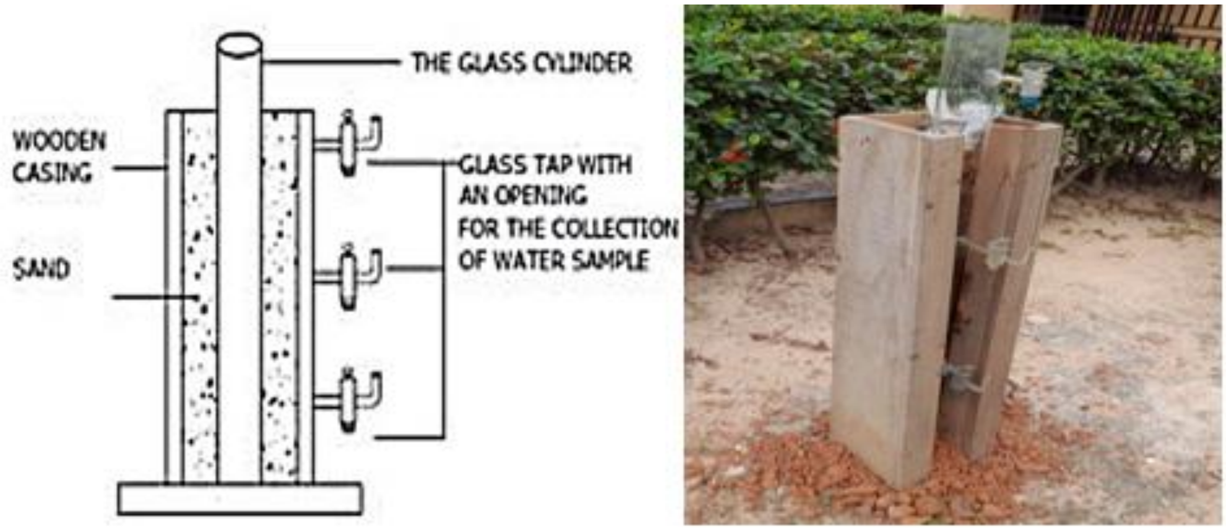

Figure 1: Schematic representation and picture of experimental setup

Waste water samples were collected after each detentionperiod at sunset from the outlet valves A, B and C of the apparatus representing depths of 30cm, 60cm and 90cm below the water surface. The valve for outlet A was opened to collect the top column; while those of B and C collected the middle and lower water columns respectively.

The experimental approach adopted for this research seeks to simulate the daily conditions of a large scale pond in a controlled manner using a microcosm so as to monitor the short term effect of sunlight on pond parameters. The reference WSP is located at university of Nigeria, Nsukka. Direct measurements, laboratory experiments and analytical methods were used to evaluate pond parameters. All laboratory experiments to determine the physico-chemical and biological characteristics were conducted according to standard methods as prescribed by the American Public Health Association [8]. The physicochemical and microbiological parameters investigated include: pH, Conductivity, Turbidity, Iron, Phosphate, Total Dissolved Solids, BOD, COD, Nitrate, Alkalinity, Hardness, Temperature, Total suspended solids, Nitrite, Dissolved Oxygen and Ammonia content, Coliform and E-Coli.

3.0 RESULTS

3.1. Effect of Stratification on Physical Characteristics

Temperature: The time variation and temperature gradient of waste water samples across the strata is shown in figure 2. Temperature of the system varied slightly with depth for each exposure period, the ambient temperature being 29.7^0C, 28^0C, 27.6^0C and 26.1^0C after each exposure period. For the unexposed sample, temperature was maintained at an average value of 38.1^0C. The temperatures at depths A, B and C for the first period of testing (7 days) were 31.3^0C, 32.9^0C and 31.9^0C respectively. For the second period of testing (14 days), temperatures at depths A, B and C dropped to 28.1^0C, 28.2^0C and 28.1^0C respectively. The final testing period (21 days) gave similar readings at depths A, B and C of 28.2^0C, 28.1^0C and 28.2^0C respectively.

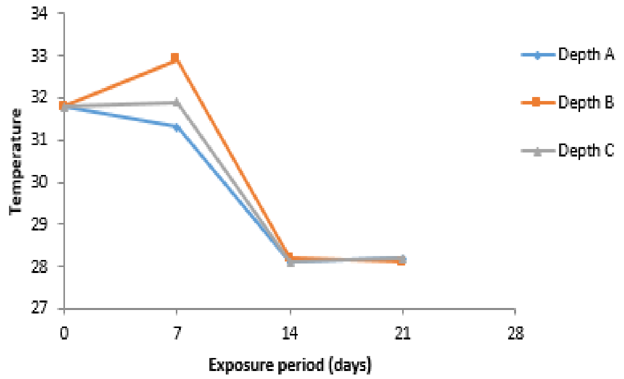

Figure 2: Variation of pond temperature with time

Conductivity: The time and depth variation of conductivity of the system are shown in Figures 3. Mean Conductivity for the unexposed samples was 1814µS. This value reduced to 878µS, 799µS and 698µS for depth A after the first, second and third exposure periods (7, 14, and 21 days) respectively. Similarly, conductivity reduced to 905µS, 789µS and 718µS for depth Bafter the first, second and third periods of exposure respectively. Also, conductivity reduced to 906µS, 819µS and 730µS for depth C after the first, second and third periods of exposure respectively. Alternatively, we can see that the conductivity increased with depth while reducing with detention period.

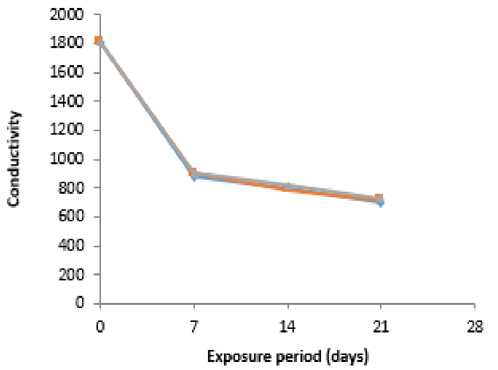

Figure 3: Conductivity variation with time

Total Dissolved Solids: TDS showed a linear decrease with time for each of the depths considered (Figure 4). TDS for the unexposed sample was 1179 mg/l, which reduced to 559mg/l, 589mg/l, and 589mg/l at depth A, depth B and depth C respectively for the first period of exposure (7 days). After the second period of exposure (14 days), TDS was 519mg/l, 513mg/l, and 532mg/l for depth A, depth B and depth C respectively. After the third exposure period (21 days), TDS was 419mg/l, 430mg/l and 438mg/l for depth A, depth B and depth C respectively.

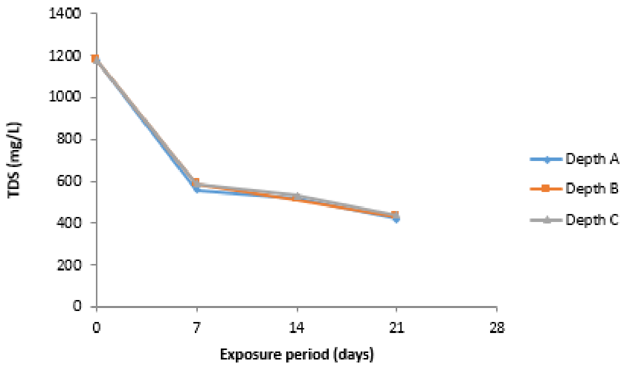

Figure 4: Variation of Total Dissolved Solids with time

Turbidity: The results for turbidity are shown in Figure 5. Turbidity reduced from 58 NTU to 34.6NTU, 33.5NTU and 33.5NTU for depth A, depth B and depth C respectively after the first exposure period. After the second exposure period, turbidity reduced to 20.5NTU, 20.0NTU and 18.3NTU for depth A, depth B and depth C respectively. Also, after the third exposure period, turbidity further reduced to 6.4NTU, 5.0NTU and 4.5NTU for depth A, depth B and depth C respectively. This indicates a linear decrease in turbidity as the duration of exposure increases.

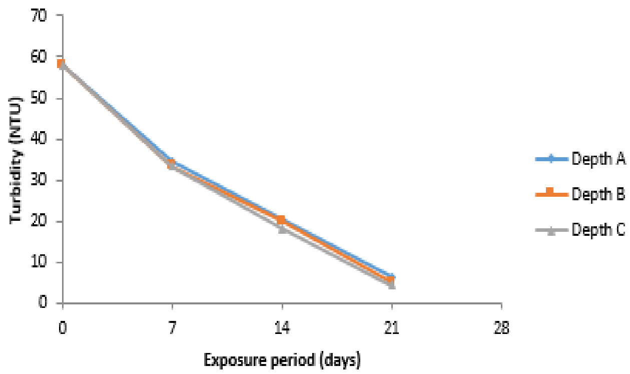

Figure 5: Variation of total Turbidity with time

Total Solids: The total solids obtained ranged between 464 mgl^{-1} and 1298 mgl^{-1} as shown in Figure 6. After the first exposure period (7 days), total solids reduced from 1298 mgl^{-1} to 648 mgl^{-1}, 667mgl^{-1}, and 679mgl^{-1} for depth A, depth B and depth C respectively. After the second exposure period (14 days), total solids were 567mgl^{-1}, 564mgl^{-1} and 588mgl^{-1} for depth A, depth B and depth C respectively. After the third exposure period (21 days), totals solids were 490mgl^{-1}, 484mgl^{-1} and 464mgl^{-1} for depth A, depth B and depth C respectively. Total solids reduced generally as the detention period increases.

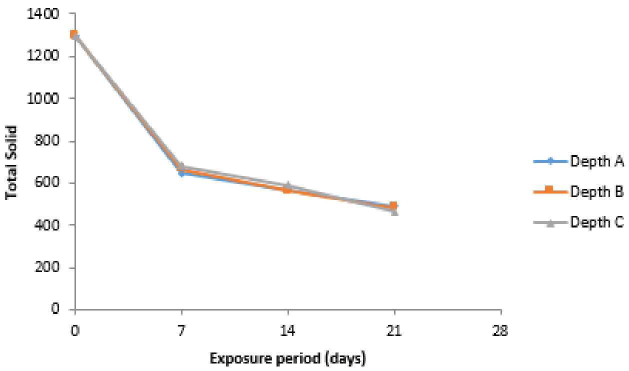

Figure 6: Variation of Total Solids with time

3.2 Effect of Stratification on Chemical Characteristics

Hydrogen Ion Concentration (pH): The pond pH values range from 7.16 to 7.90 and varied with depth for each exposure period (Figure 7). The pH value for the unexposed sample was 7.16. The pH value for depths A, B and C after 7 days of exposure was 7.47, 7.23 and 7.28 respectively. After the second exposure period (14 days), the pH at depths A, B and C was 7.9, 7.85 and 7.78 respectively. Also, after the third exposure period (21 days), the pH at depths A, B and C was 7.7, 7.65 and 7.5 respectively.

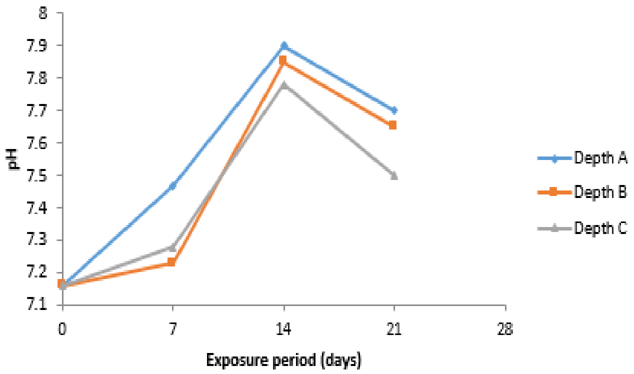

Figure 7: Variation of pH with time

Phosphate: The concentration of Phosphate in the pond water ranged from 0.9 mgl^{-1} to 13.2 mgl^{-1} (Figure 8). Phosphate concentration varied from 10.8 mgl^{-1} to 13.2mgl^{-1}, 11.6mgl^{-1} and 10.6mgl^{-1} for depth A, depth B and depth C respectively after the first exposure period (7 days). After the second exposure period (14 days), phosphate concentration was 11.4mgl^{-1}, 11.0 mgl^{-1} and 0.93mgl^{-1} for depth A, depth B and depth C respectively. Also, after the third exposure period (21 days), phosphate concentration was 10.2mgl^{-1}, 10.5mgl^{-1} and 0.9mgl^{-1} for depth A, depth B and depth C respectively. This also indicates a decrease in phosphate in the pond water as exposure period increased.

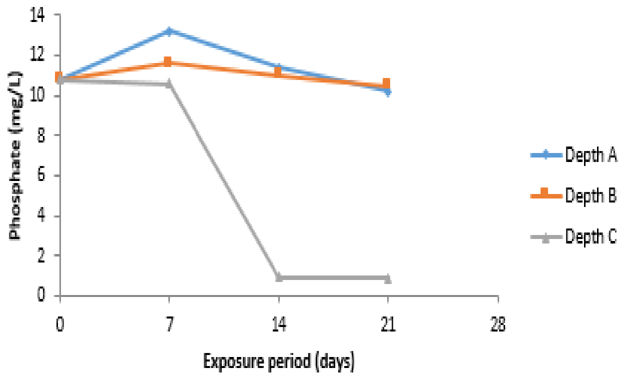

Figure 8: Variation of Phosphate with time

Biochemical Oxygen Demand (BOD): The BOD of the pond ranged from 360 mg/l to 400 mgl^{-1} (Figure 9). BOD of the unexposed pond water increased from 360 mgl^{-1} to 400 mgl^{-1} each for depth A, depth B and depth C respectively after 7 days exposure period. After the second exposure period (14 days), BOD was 370 mgl^{-1}, 390mgl^{-1} and 400mgl^{-1} for depth A, depth B and depth C respectively. By the end of the third exposure period (21 days), BOD was 400mgl^{-1} each for depth A, depth B and depth C respectively.

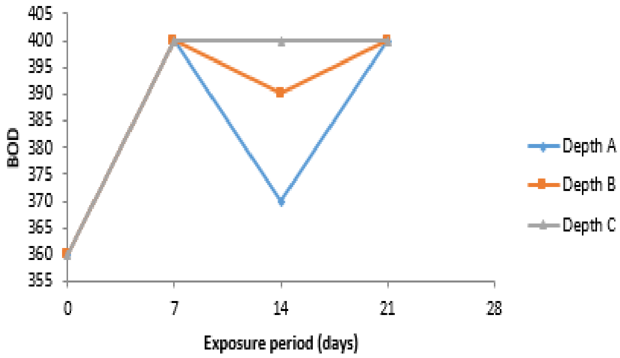

Figure 9: Variation of BOD with time

Chemical Oxygen Demand (COD): COD of the pond ranged between 390 mgl^{-1} and 400 mgl^{-1} (Figure 10). COD of the unexposed pond water increased slightly from 390 mgl^{-1} to 400 mgl^{-1} each for depth A, depth B and depth C respectively after the first exposure period (7 days). After the second exposure period(14 days), BOD was 400 mgl^{-1}, 398mgl^{-1} and 400mgl^{-1} for depth A, depth B and depth C respectively. By the end of the third exposure period (21 days), BOD was 400mg/l each for depth A, depth B and depth C respectively.

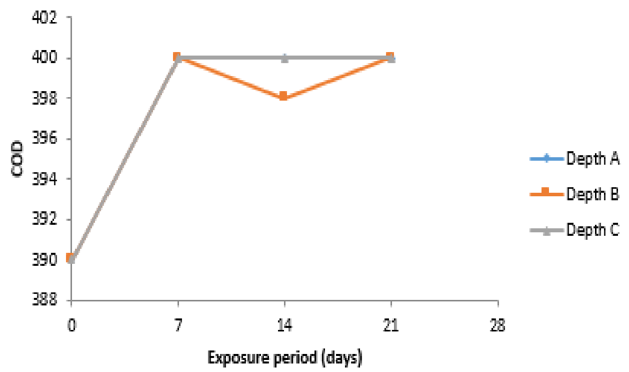

Figure 10: Variation of COD with time

Total Hardness: Hardness ranged from 150 to 220 mgl^{-1} (Figure 11). Hardness of the unexposed sample was 150 mgl^{-1}. After 7 days exposure period, total hardness foe column A and B was 210 mgl^{-1} each, while that of column C was 220 mg/l. After the second exposure period (14 days), total hardness was measured to be 220 mgl^{-1} each for columns A, B and C respectively. After the third exposure period (21 days), total hardness was measured to be 210 mgl^{-1}foe column A, 220$mgl^{-1}$for column B and 210$mgl^{-1}$for column C.

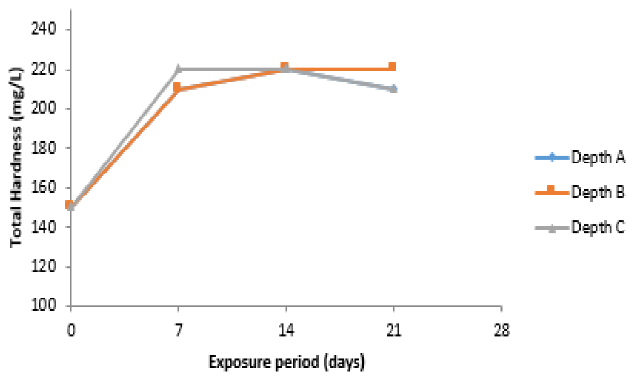

Figure 11: Variation of Total Hardness with time

Nitrates: The concentration of Nitrate in the pond water ranged from 3.4 mg/l to 12 mg/l (Figure 12). Nitrate concentration varied from 3.4 mgl^{-1} to 3.6mgl^{-1}, 3.4mgl^{-1} and 3.4mgl^{-1} for depth A, depth B and depth C respectively after the first (7 days) exposure period. After the second exposure period (14 days), Nitrate concentration was 10.6mgl^{-1}, 9.6 mgl^{-1} and 8.8mgl^{-1} for depth A, depth B and depth C respectively. Also, after the third exposure period (21 days), Nitrate concentration was 12mg/l, 10.7mg/l and 10.3 mg/l for depth A, depth B and depth C respectively. This indicates an increase in nitrates in the pond water as exposure period increased.

Ammonia: The concentration of Ammonia in the pond water ranged from 134 mg/l to 290 mg/l (Figure 13). Ammonia concentration for the unexposed sample was 145 mg/l. After 7 days of exposure, ammonia concentration was measured to be 134mg/l at depth A, 147mg/l at depth B and 212mg/l at C. Ammonia concentration after the second exposure period (14 days) was 197mg/l at depth A, 203 mg/l at depth B, and 236mg/l at C. After the third exposure period (21 days), Ammonia concentration was 259mg/l at depth A, 273mg/l at depth B, and 290 mg/l at depth C.

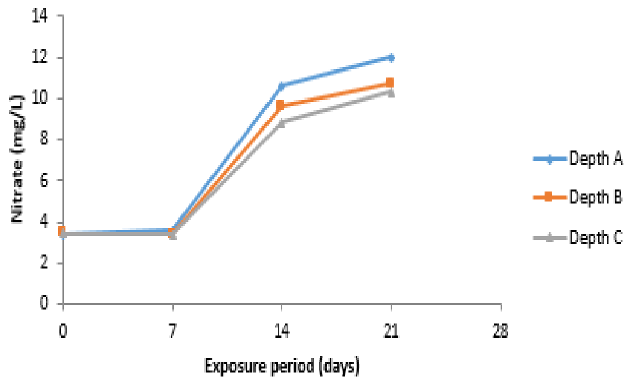

Figure 12: Variation of Nitrates with time

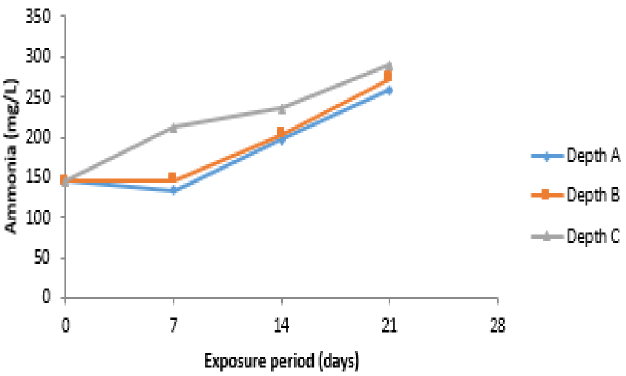

Figure 13: Variation of Ammonia with time

3.3 Effect of Stratification on Microbiological Characteristics

Total Coliform: Total coliform concentration in the pond water ranged from 60,000 cfu/100ml to 126,000 cfu/100ml (Figure 14). For the unexposed sample, total coliform was 68,000 cfu/100ml. After an exposure period of 7 days, total coliform at depth A was 93,130cfu/100ml, 110,000cfu/100ml at depth B and 116,800cfu/100ml at depth C. After the second exposure period of 14 days, total coliform was 108,400cfu/100ml at depth A, 106,000cfu/100ml at depth B and 126,000 at depth C. After the final exposure period (21 days), total coliform was 60,000 cfu/100ml at depth A, 84,000 cfu/100ml at depth B, and 92,000 cfu/100ml at depth C. The results show a higher concentration of total coliform with increasing depth.

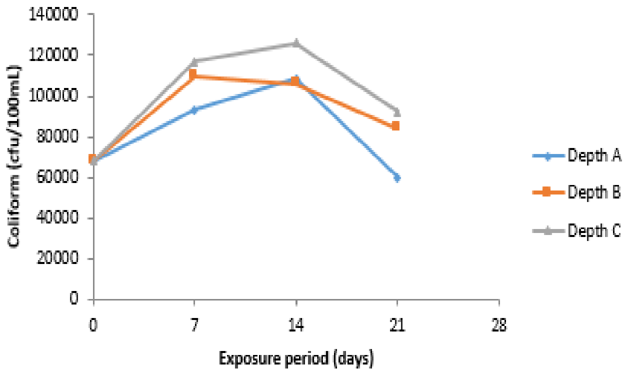

Figure 14: Variation of Total Coliform with time

4.0 DISCUSSION

4.1 Effect of Stratification on Physical Characteristics

The mean temperature of the system varied slightly with depth. However, over the period of exposure, mean temperature varied by 3^0C. Temperature increase or decrease can impact on microbial organism within the water body. Higher temperatures reduce the available oxygen which may be detrimental to aquatic life [9]. However, it also favors microbial growth. The drop in temperature with depth could be as a result of algal growth covering the surface of the microcosm [10], or the depth of the system, or a combination of both. The results also agree with the position of [11] that the pond temperature is about 2^0 to 3^0C colder than the temperature of the air in the warm period, the inverse occurring in the cold period. Temperature variation can also impact on parameters such as conductivity, hence salinity and total dissolved solids.

We can see that the conductivity of the pond water increased with depth while reducing with exposure period. The variations show a mean efficiency of 51%, 56% and 61% after the first, second and third periods of exposure respectively. Conductivity values fell below the NIS and WHO standards (1000 µS).The conductivity here has a relationship with the concentration of ionized substances present in the water sample. Cations and anions are formed when most of the inorganic substances dissolved in water. The values of conductivity depend on the nature, concentrations and strength of the various ions present in the water sample [12]. Therefore, the conductivity values obtained may indicate the quantity of dissolved mineral in the pond [13].

The stratification of Total Dissolved Solids (TDS) showed increment with depth, and decrement with increasing exposure period. The mean efficiency of treatment with respect to TDS removal was 58% after exposure. TDS values fell below the NIS standard of 500 mg/L The concentration of TDS influences the water balance aquatic organisms. For instance, an organism in a sample with a high solids concentration will tend to absorb the TDS species available as nutrients to support their metabolism and physiology, thereby reducing TDS [14, 15]. Consequently, this will affect the organisms' capacity to preserve proper cell density and maintain their place within the water column. They may then sink or float to an unfavorable depth, which may kill them off. This response is similar to the bioremediation technique of TDS removal in waste water [16].

Stratification shows a decrease in turbidity values with depth. The mean efficiency of removal due to exposure to sunlight was 41%, 66% and 91% after the first, second and third periods of exposure. This may be due to thermal stratification caused by sunlight intensity over the period under investigation. Similar research [17, 18] shows that turbidity was affected by temperature variations within the pond water and peaked mostly in the thermocline region. Turbidity reflects the amount of materials in suspension including inorganic and organic materials, algae, dissolved compounds and other micro-organisms. As a consequence, the reduction in turbidity may increase the quantity of sunlight penetrating the water, hence, increasing the rate of photosynthesis [18]. If the water is cloudy (turbid), sunlight tends to warms it more efficiently. This is due to the ability of suspended particles in the water to absorb the energy from sunlight, thereby warming up the surrounding water. The turbidity fell below the NIS standard (5 NTU).

The reduction in concentration of total suspended solids indicates that sunlight intensity has contributed to the decrease in the concentration of dissolve solids in the wastewater. The reduction shows a mean removal efficiency of 49%, 56%, and 63% after the first, second and third periods of exposure. However, the concentration of total solids was greater than the WHO guideline of 50mg/L for the protection of aquatic life. Total suspended solids impact on the clarity of water. Higher concentrations of solids reduce light penetration through the water column, thereby slowing down photosynthesis by aquatic plants [18]. Water temperature will rise slowly, thus affecting the available dissolved oxygen.

4.2 Effect of Stratification on Chemical Characteristics

It is seen that the pH of the system responds to the available sunlight reaching the various depths. During exposure to sunlight, there is an increase in photosynthetic activity. Consequent to the photosyntheticactivities of the pond algae, the dissolved oxygen concentration varies diurnally. The pond pH follows this variation since at maximum algal activity, the reaction of carbonate and bicarbonate ions provide more CO_2 for the algae, thereby leaving excess hydroxyl ions which results in the rise of pH beyond 9 which kills off faecal bacteria. The increase in pH value with increasing exposure to sunlight shows an agreement with [19]. Most anaerobic bacteria are sensitive to pH values less than 6.2 [10]. The increase in pH value from 7.16 to 7.90 may be as a result of increased algal activity in the microcosm as algaeconsumed CO_2 during photosynthesis. The increase in pH value may also indicatea high ammoniaconcentration in the sample [20]. [21] also reported similar findings. The pH value in the stratified microcosm waswithin the permissible range of NIS and WHO (6.5–8.5).

Phosphorus is a major nutrient contributing to the eutrophication of ponds and lakes. The high levels of phosphate in the pond water could be due to poor agricultural practices from the hinterland, as well as domestic and municipal waste. Stratification results show that sunlight was effective in reducing the concentration of phosphates by 91.6% after a total period of 21 days. However, this result falls below the NIS and WHO guidelines of 5mg/L. This reduction makes the effluent suitable for irrigation purposes.

The increase in $BOD_5$and COD of the pond water is an indication of the low levels of dissolved oxygen. The removal efficiency of BOD_5 mostly depends on the environment and type of oxidation pond [19, 22]. [2] suggests that this occurrence may be as a result of digestion previously sedimented matter and anaerobic re-dissolution. The NIS standard for BOD stipulates 3 mg/l which shows that the pond water has a relatively high BOD. This implies that the amount of oxygen that aerobic bacteria in the pond water require to break down biodegradable organic matter is high [10]. It also indicates a high count of microbial organisms. Similar studies show that BOD was reduced up to 76% [10]. However, it must be noted that larger surface areas of exposure were involved. It can therefore be inferred that the small surface area of the pond water is insufficient to acquire heat from sunlight and oxygen from the atmosphere. This makes it difficult for atmospheric oxygen to be dissolved.

The concentration of Nitrate in the pond water showed a slight decrease from the top to bottom layer for the first and second periods of exposure. However, the concentration increased as the exposure period increased. Although the efficiency of removal was less that reported in [23], the quantities of nitrate in the pond water were below NIS standards (50 mg/l). The implication of this is that eutrophication is less likely since the amounts of nitrates present in the pond water is low. This also may affect nitrification, as well as regulate overall nitrogen metabolism since sunlight drives transpiration and mass flow of nitrogen required for plant growth.

The concentration of Ammonia in the pond water ranged from 134 mg/l to 290 mg/l. The concentration of ammonia increased with depth after each exposure period. This indicates that sunlight was most effective in ammonia reduction at the top column. The concentration of ammonia is dependent on the amounts of nitrates and nitrites present in the pond water [24]. High amounts of nitrates or nitrites may increase the concentration of ammonia when the get charged. Nitrogen atoms when released could bond easily with readily available hydrogen atoms to for ammonia.

4.3 Effect of Stratification on Microbiological Characteristics

Total coliform (TC) concentration in the pond water increased with depth. The concentration of TC was considerably higher than WHO limits (1000cfu/100mL) for wastewater. There is obviously a minimal impact of sunlight in reducing total coliform due to a high depth to width ratio of the apparatus. [21, 25] suggests that the reduction in colonies is dependent on temperature, pH, nutrients, dissolved oxygen concentration and intensity of light. From a public health standpoint, the pathogens present in treated wastewater must be taken into consideration. Problematic pathogens have been known to cause various ailments including typhoid fever, dysentery, gastroenteritis and cholera [20, 23].

5.0 CONCLUSION

Thefindings in this workshowedthat the response of physicochemical and microbiological characteristics to sunlight is not as simple as previously envisaged. The physicochemical characteristics (e.g. Temperature, pH and Nutrients) showed varying degrees of concentration in response sunlight intensity.

The efficiency of the system to reduce faecal coliforms also showed some promise. However, it is obvious that only sunlight alone cannot effectively reduce total coliforms in the WSP. A combination of sunlight, high pH level and oxygen concentration is needed for sunlight to have very significant effects as other researches [25] have shown.

Since only sunlight cannot effectively reduce total coliforms, it is recommended that the design of WSPs should consider pond dimensions that will provide a widersurface area for sufficient sunlight and oxygen to be acquired.

REFERENCES

[1] Kadri, et al., "Overview of Waste Stabilization ponds in Developing Countries" in book: Cost-efficient Wastewater Treatment technologies: Natural Systems. Springer Nature Switzerland, 2021.

[2] Ukpong, E. C., Agunwamba, J. C., and Egbuniwe, N. "Stratification in waste stabilization ponds I: Effects on pond parameters". *Nigerian Journal of Technology*, Vol. 25(2); 2006, pp24-25.

[3] Sengupta, P. "Potential health impacts of hard water". *International Journal of preventive medicine.* Vol. 4(8), 2013, pp866.

[4] Ansa, E. D. O., Andoh, A. H., Nienu, P., Banu, R., Akrong, M., Acheampong, M., and Adiyiah, J. " Sunlight Inactivation of Faecal Coliforms in Domestic Wastewater", *Desalination and Water Treatement*, 2015, DOI: 10.1080/19443994.2015.1063010.

[5] Aneke, P. N. and Ademiluyi, J. O. "Effect of Sunlight on the Different Strata of Lake Water" *International Journal of New Technology and Research (IJNTR)*, 7(1), 2021, pp16-25.

[6] Kellener, E., and Pires, E. C. "The influence of thermal stratification on the hydraulic behaviour of waste water stabilization ponds". *Water Science and Technololgy*, Vol. 45(1), 2002, pp.41-48.

[7] Klemetson, S. L. (1983). "Solar Heating of Wastewater Stabilization Ponds". *Colorado Water Resources research Institute*, 1983.

[8] APHA. "Standard Methods for the Examination of water and wastewater", 23rd Edition D. C., *American Public Health Association.* 2017.

[9] Droste, R. L., and Gehr, R. L. "Theory and Practice of Water and Wastewater Treatment", *John Wiley & Sons, Hoboken, NJ, USA*, 2018.

[10] Desye, B., Belete, B., Alemseged, E., Angaw, Y. and Gebrezgi, Z. "Evaluation of Wastewater Stabilization Pond Efficieny and its Effluent Water Quality: A Case study of Kito Furdisa Campus, Jimma University, Ethiopia". *The Scientific World Journal.* 2022, pp1-9.

[11] Mara, D. "Natural Sewage Treatment in the UK: Selection Guidelines", *Journal of the Chartered Institution of Water and Environment Management*, 18(4), 2004, pp.230-234.

[12] Velauthamurthy, K. "Some quality parameters of ground well water in the Jaffna peninsula", *Department of Chemistry, University of Jaffna, Sri Lanka.*B. Sci. Thesis, 2001.

[13] Ganeshalingam, S., Jeyadevan, J. P., and Kuganathan, N. "Physicochemical Analysis of Pond Water Samples from Selected Areas I Valukkai Aru Drainage channel, Jaffna, Sri Lanka", *Water Research and Development*, vol. 2(1&2); 2012, pp12-23.

[14] Khan, S., Shamshad, I., Waqas, M., Nawab, J., and Ming, L. "Remediating Industrial wastewater containing potentially toxic elements with four freshwater algae", *Ecological Engineering*, 102, 2017, pp536-541. https://doi.org?10.1080/09593330.2017.1415983.

[16] Pinto, P. X., Al-Abed, S. R., Balz, D. A., Butler, B. A., Landy, R. B., and Smith, S. J. "Bemch-scale and pilot-scale treatment technologies for the removal of total dissolved solids from coal mine water: A review". *Mine Water Environment*, 35, 2016. Pp.94-112. https://doi.org/10.1007?s10230-015-0351-7

[17] Elci, S. "Effect of thermal stratification and mixing on reservoir water quality" *Limnology*, vol(9); 2008, 99.135-142. DOI: 10.1007/s10201-008-0240-x

[18] Ma, J., Wu, S., Shekhar, S., and Sahu, K. "Determination of Physiocochemical Parameters and Levels of Heavy Metals in Food Waste Waster with Environmental Effects" *Bioinorg Chem Appli.* 2020. DOI: 10.1155/2020/8886093

[19] Mara, D., and Pearson, H. "Design Manual for Waste Stabilization Ponds in Mediterranean Countries", Lagoon Technology International, Leeds, England, 1998.

[20] Butler, E., Hung, Y., Suleiman Al Ahmad, T. M., Yeh, R. Y., Liu, L. H. and Fu, Y. P. "Oxidation ponf for municipal wastewater

treatment", *Applied Water Science,* vol. 7(1), 2017, pp.31-51.

[21] Engdaw, F. "Physioco-chemical parameters and bacteriological qualities of water samples from wastewater treatment pond, university of gonder, Ethiopia", *International Journal of Pharmaceutical and Health Care Research*, vol.2, 2014, pp. 192-197.

[22] Yeh, T. Y., Pan, C. T., Ke, T. Y., and Kuo, T. W. " Organic matter and nitrogen removal within field-scale constructed wetlands: reduction performance and microbial identification studies". *Water Environmental Research* , vol.82(1), 2010, pp.27-33.

[23] Beyene, H. and Redaie, G. "Assessment of waster stabilization ponds for the treatment of hospital wastewater: the case of Hawassa University Referral Hospital", *World Applied Science Journal,* vol. 15(1), 2011, pp. 142-150.

[24] Nye, J. "Addressing the Chanllenge of Removing Ammonia from Wastewater"\ Waterworld" 2010, https://waterworld.com/home/article/16194158/addressing-the-challenge-of-removing-ammonia-from-wastewater Accessed 29/10/2022

[25] Maiga, Y., Denyigba, K., Wethe, J. and Quattara, A. S. "Sunlight inactivation of *Escheirichia coli* in waste stabilization microcosms in a sahelian region". *Journal of photochemistry abd photobiology.* Vol. 96(2) 2009, 113-119