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University of Ghana's Waste Stabilization Pond Efficiency

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Abstract:

Treatment of wastewater in the developing world is rarely practiced due to unavailability of treatment plants and high cost of treatment. Hugely polluted wastewater with high fecal coliform levels is a public health risk, increases cost of wastewater treatment, causes eutrophication, and ecosystems deterioration. There exist numerous studies on wastewater treatment but little or no studies examined the effect of waste stabilization pond (WSP) operating capacity on its efficiency. This study employed on-site and laboratory investigations to explore the University of Ghana's waste stabilization pond (WSP) efficiency, and the Onyease stream water quality after wastewater discharged into it. The Legon WSP system has a designed capacity of 8, 550 m^3, initially utilized 1, 300 m^3, and currently treats at 3,500 m^3/day. Though there exist works on WSPs in Ghana, no studies have examined the effect of WSP's operational variation on efficiency. Bi-monthly samples were taken from the influent, anaerobic, facultative, and two (2) maturation ponds in series and analysed in the laboratory. The study demonstrated the high efficiency of Legon's WSP in wastewater treatment and achieved over 94% removal of TSS, turbidity, BOD, and COD, and more than 96% reduction in NH_3-N and PO_4–P concentrations but maintained pH and temperature within Ghana's EPA standards. Microbiological analysis showed significant reductions in coliform counts and improved microbial water quality. Sludge assessment revealed efficient operation in the anaerobic pond (28.1%) and maturation pond 2 (27.1%), whereas the facultative pond (34.2%) and maturation pond 1 (33.9%) required desludging. More frequent desludging and expansion of the Legon WSP system to receive additional wastewater inflow are recommended in the short and long terms respectively. Overall, the WSP effectively enhanced water quality and ensured robust nutrient and microbial removal. Measures such as chlorination and ultraviolet (UV) treatment are recommended to improve the efficiency and meet the standard microbial limits of Legon's WSP.

Keywords — **pond efficiency, waste stabilization pond, wastewater, University of Ghana.**

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I. INTRODUCTION

Whereas global freshwater resources scarcity is a challenge and worsened by prevailing drought in semi-arid regions, increasing water scarcity is compounded by urbanization, climate change, and global population explosion [1]. Research shows that freshwater resources shortage is attributable to population rise, contamination of water due to anthropogenic activities, and weather fluctuation [2]. Unreliable access to safe water means that people in most rural communities are likely to use contaminated water for potable uses such as washing, drinking, and washing [3]. Though water scarcity affects all, children are the most affected by severe water scarcity since unprotected water use can lead to death of millions of young children [4]. Changes in the physio-chemical and microbial quality of water through anthropogenic activities remains a huge concern to health experts [5]. One primary surface water pollution source is inadequately treated wastewater discharge directly into waterbodies, sometimes without treatment [2]. Wastewater requires high standard of treatment before discharge to the environment or reuse [6], as untreated wastewater leads to ecosystem deterioration of water bodies such as rivers and lakes [7]. Untreated or partially treated wastewater also leads to widespread of communicable diseases such as dysentery, typhoid, cholera, and water-borne diseases, for instance, hepatitis [8]; [9].

Wastewater is any used and unwanted water from agricultural, commercial, domestic, and industrial activities, and surface runoff or stormwater [10]. Domestic wastewater is considered as used water in households, including water used for flushing toilets mixed with fecal matter and urine [11]. A study found no correlation between wastewater generation rate and wastewater treatment facilities availability, suggesting no corresponding increase in wastewater treatment facilities to match increasing wastewater generation [12]; [13]; [14]. Besides lack of sufficient wastewater treatment facilities, generated wastewater is often not well treated to prevent surface and groundwater pollution since inadequately treated wastewater is a public health threat and deteriorates ecosystems [15]. High content of pathogenic organisms is a matter of concern under inadequately treated wastewater [16]. Though nutrients (for instance, nitrates and phosphates) are useful to the growth of plants, high concentrations could promote algal growth and oxygen depletion in surface water, leading to eutrophication [17]; [18]. Eutrophication causes offensive odor in water, affects aesthetic values, and extinction of aquatic life, and therefore threatens biodiversity [19]; [17]. Well-documented studies show that wastewater with high microbial concentrations may be linked to with diseases such as typhoid fever, gastroenteritis, giardiasis, cholera, dysentery, and ringworm infections [20]; [21]. Developing countries are challenged in the ownership of conventional treatment facilities due to high cost in the design, construction, and maintenance. Besides, hard-to-come-by highly skilled personnel are required to operate these facilities. Waste stabilization ponds (WSPs) are therefore effective low-cost wastewater treatment alternatives.

WSPs are simple in design, operation and maintenance are easy, and they require minimal technical know-how [22]. They also have low capital cost when compared to other wastewater treatment facilities, and treatment equipment is neither mechanized nor expensive [23]; [22]. Despite the merits of WSPs, the requirement for vast land with certain specific soil requirements may serve as breeding grounds for mosquitoes, and lack of effective control over the effluent quality are the demerits of WSPs [24]. About 90% of wastewater in the developing world is inappropriately disposed without treatment due to the absence of treatment plants and high cost of treatment [25]. However, 62% of Sub-Saharan Africa's urban population discharge wastewater directly to water bodies [8], while about 70%, on average, of high-income countries' generated wastewater is treated before disposal [26]. It is argued that untreated wastewater release into water bodies endangers aquatic life, increases sludge deposits, releases odour from anaerobic reactions in scum layer, and increases the cost of treatment [27]. A recent study in Jamestown, Accra, Ghana, recommended banana peels (*Musa spp*) use as a natural coagulant in wastewater treatment due to its organic nature and non-formation of disinfectant by-products [28]. WSPs are built to have long retention time for organic matter biodegradation, and removal of contaminants and pathogens. Besides, WSPs need minimal maintenance to effectively treat wastewater [29]. Further, WSPs are wastewater treatment technologies that require abaundant sunlight and high temperatures for effective treatment that meets the acceptable physical, chemical, and microbiological guidelines [9]. Though WSPs are neceassry for public health protection, they are rarely found in warm and sunligh-abundant countries such as Ghana.

WSPs are becoming widespread for wastewater treatment in abundant sunshine and high temperature areas, as treatment is achieved through natural biological processes. For instance, the most common treatment system in Ghana is WSP with a tricking filter and activated sludge, which are in almost all the regional capitals, Akosombo, Akuse, Kumasi, and University of Ghana. Remarkable performance is reported of the existing WSPs constructed across Ghana [30]. WSPs could be entirely relied upon if the process performance complies with the regulatory body's specifications represented as follows [31]: Failure = effluent concentration > effluent requirements. The Legon sewage treatment plant in Accra, Ghana, was constructed in 2012 to treat wastewater from the Achimota Hospital and some academic institutions around Legon. Effluent from the plant is released into the Onyease stream used to irrigate crops in surrounding farms, lettuce, cabbage, and gardens eggs inclusive. Untreated wastewater disposal happens partly due to the capital-intensive nature of conventional wastewater treatment systems in developing countries [32]; [33]. While wastewater treatment efficiency has significant impact on the environment, public health protection and communicable diseases transmission prevention are primary reasons for wastewater treatment before disposal [8]. However, WSP efficiency under continuous wastewater discharge for treatment can be compromised due to possible sludge build-up without desludging. Studies demonstrated that sludge accumulation in WSPs also affects treatment performance due to effective volume reduction, retention time reduction of pond, treatment efficiency, and eventual effluent quality [34]; [35].

Though past studies evaluated WSPs effectiveness in Ghana, little or no studies examined how ponds are affected by operational capacity variations. The Legon WSP operational capacity has gradually increased since its establishment. The plant's designed capacity is 8,550 m^3, initially utilized 1,330 m^3 capacity, but gradually increased over the years to a current treatment capacity of 3,500 m^3/day since 2022. There was therefore the need to ascertain the efficiency of Legon's WSP, determine the operational capacity variation on effect on its efficiency, and effluent quality discharged into the Onyease stream analyzed. Given the massive wastewater inflow from five (5) sources to the Onyease stream, the quality of final effluent from University of Ghana's WSP must meet Ghana's EPA recommended standards. This study therefore sought to provide baseline scientific data to influence decision-making in future wastewater treatment systems.

II. MATERIALS AND METHODS

The methodology aspect of this study is presented in this section.

A. The Study Area

The University of Ghana (UG), a premier tertiary institution located in the Greater Accra Region in Ghana, has an estimated population of 50,000 [36]. Founded as University College of Gold Coast by ordinance on August 11, 1948, UG provides higher education and research. The sewage treatment plant in Legon was built and operationalized in 2012 to safeguard environmental health and assist with the collection, and treatment of wastewater from the university community. Figure 1 is a map of the study community.

Figure 1: The study area map

Source:
https://earth.google.com/web/@5.66005571,0.18769131,79.53693111a,1689.43561362d,35y,84.84135762h,59.99056568t.

This study was conducted at a sewage treatment facility located in UG, Legon campus, near Onyease stream which flows along Legon Botanical Garden. The ponds receive wastewater from UG, Presbyterian Boys Senior High School, University of Professional Studies, Achimota Senior High School, and Achimota Hospital for treatment, and the effluent released to the Onyease stream. The Legon WSP has three (3) treatment units, and the institution's pumping stations received wastewater either by gravity or pumped to the treatment site. The primary treatment is a wide screen rectangular intake structure for the removal of non-biodegradable materials, into which effluent is directed from the pumping stations. Legon WSP is sited on a 58-hectare land inside Legon's Botanical Gardens, north of Accra, Ghana on 5°39'50.84" N and 0°11'29.87" E [37]. Out of the plant's 8,550 m^3 designed capacity, 1330 m^3 was initially utilized, and current treatment is at 3,500 m^3/day, representing 40.9% of the designed capacity. Table 1 shows the parameters for the anaerobic, facultative, and maturation ponds.

Table 1: University of Ghana's three (3) ponds' parameters

Features	Units	Anaerobic	Facultative	Maturation
Pond depth	m	5	2	1.5
Pond width	m	60	100	85
Retention time	days	40	80	75
Treatment units (No.)	N/A	5	7	5
Plant capacity	m^3	38	3	6

Source: University of Ghana waste treatment laboratory

1) University of Ghana's WSP Layout

The University of Ghana WSP consisted of three (3) parallel grit chambers, a distribution chamber, and a screen chamber. As depicted in Figure 2, the three (3) openings in the grit chambers streams with each stream having four (4) ponds – two (2) maturation ponds, one (1) facultative pond, and one (1) anaerobic pond.

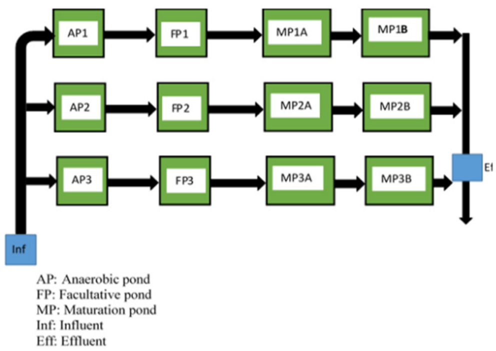

Figure 2: Schematic Layout of Legon WSP

Source: University of Ghana waste treatment laboratory

Upon entering the distribution chamber, the wastewater travelled via three (3) grit tubes each connected to different treatment streams. Each stream comprised an anaerobic pond, facultative pond, two (2) maturation ponds, and an outlet. The samples were influent (INF), anaerobic pond (AP), facultative pond 1 (FP1), maturation pond 1 (MP1), and maturation pond 2 (MP2). A Technician was present to monitor day-to-day performance of the treatment system. Earlier research and survey conducted were the basis for the analysis, methods, and tools selection. Assumptions were based on observation and interview of Technician who monitored the treatment system performance.

B. Sample Design

Purposive sampling was adopted for the analysis of wastewater samples at the Legon WSP. Parameters analysed in the influent and effluent were dissolved oxygen (DO), chemical oxygen demand (COD), five (5)-day biochemical oxygen (BOD_5), turbidity, temperature, pH, total dissolved solids (TDS), total suspended solids (TSS), NO_{3-} total phosphorus, NH_{3-} -N, colour, and conductivity. Wastewater influent samples of equal volumes were collected. Effluent samples from FP and maturation ponds were collected into a sterilized plastic bottle. While three (3) sampled points were analysed, duplicate samples were aseptically collected at each point into autoclaved glass bottles. Membrane filter (MF) technique enumerated the total and fecal coliforms present. To assess the total and fecal coliforms in the effluent, serial dilutions were done to reduce the bacterial load in the samples. The serially dilution (101 to 106) of samples was done using deionized water. A 100 ml prepared samples were filtered aseptically using filter membranes of 0.45 µm pore size, which were then placed on pads saturated with sterile m-Lauryl Sulphate broth. Inverted Petri dishes incubated at 37.0°C and 44.0°C between 16 – 18 hours were respectively analysed for total and fecal coliforms. The samples were collected from May to July after the covers of the sterilized bottles were opened to minimize chances of recontamination. The samples were then properly covered, labelled and transported in an ice chest to the laboratory. Parameters determined were temperature, pH, DO, conductivity, and TDS in-situ. Sampling was performed as per the Standard Methods for the Examination of Water and Wastewater provided in [38].

A total of 36 samples, each consisting of one (1) liter, were collected monthly for analysis from 12 different sampled points – one (1) sample was collected from the inlet, three (3) from the anaerobic pond, three (3) from the facultative, three (3) from MP 1, and three (3) from MP 2. Each pond performance was represented by an average figure calculated from the three (3) samples obtained. The sludge heights in the maturation and facultative ponds were determined using Echo Souder mounted at the base of a boat or the white towel method. The height of the sludge are various points of the pond was then determined.

C. Physico-Chemical Parameters Determination

The physicochemical assessment of samples was done on site with 1,500 ml plastic bottles, and some heavy metals were sampled into 750 ml plastic bottles. Wastewater parameters analysed included – temperature, DO, pH, turbidity, COD, TDS, TSS, nitrate, BOD_5, conductivity, NH_{3}-N, and total phosphorus. Table 2 summarises the wastewater parameters analysed, and the methods applied.

Table 2: Analysed wastewater parameters and methods applied.

Test	Parameters	Instrument/Method
Physico-chemical	Temperature, DO, pH, turbidity, COD, TSS, NO_{3-}, total phosphorus, NH_3-N, BOD_5, colour, and conductivity.	Online and laboratory monitoring devices, such as Nephelometric, among others.
Microbial	Total and faecal coliforms, and E. coli	Identification of media (Broth & Agar) microscopy and colony count.
Depth	Height of sludge	Echo Souder, Boat, White towel.

1) Potential of Hygrogen (p^H) and Temperature

The temperatures and pH of wastewater were determined using the Hach water meter (model HQ 40D). Deionized water was used to rinse the pH probe and dried with clean tissue. With the sensing edge submerged in the sample, the probe was inserted into the sample contained in a beaker. Both the temperature (°C) and pH were recorded when the meter stabilized.

2) Total Dissolved Solids (TDS), Conductivity, and Turbidity

Both TDS and conductivity were determined using the Hach water meter (model HQ 40D). The conductivity probe was rinsed with deionized water and blotted dry. It was then inserted into the sample contained in a beaker, while the sensing edge was submerged. The conductivity and TDS were recorded in µS/cm and mg/L respectively when the display stabilized. Samples' turbidity was measured by HACH Turbidimeter (Model 2100AN) in Nephelometric Turbidity Unit (NTU). The samples were then poured into the sample tube until it reached the graduation mark and the parameters recorded when the display stabilized.

3) Dissolved Oxygen (DO) & Total Suspended Solids (TSS)

Dissolved oxygen (DO) was measured in mg/L using the Hach water meter (model HQ 40D) and the DO probe when the readings stabilized. The Photometric method and Hach spectrophotometer (Model DR 1900) were used to determine TSS. Samples in 500 ml were blended for two (2) minutes, poured into 600 ml beaker and stirred. 10 ml blended sample was then measured into a sample cell, and a second sample cell served as blank filled with deionized water to 10 ml mark and gently swirled to expel any available gas bubbles. An initial TSS reading of 0 mg/L was recorded when the blank was inserted into the spectrophotometer cell holder. Gently swirled to remove any trapped bubbles of gases, the prepared sample was placed in the cell holder and the reading recorded in mg/l TSS.

4) Total Phosphorus & Ammonium-nitrogen (NH_3-N)

PhosVer 3 with acid persulfate technique was used to determine phosphorus concentration. A simple (5 ml) was processed for 30 minutes using HACH DRB200 reactor. A spectrophotometer was then used to conduct colorimetric test on the sample to determine total phosphorus concentration. A sample (10 ml) of wastewater was pipetted into the sample cell to determine the parameter using Salicylate technique. Another sample cell (10 ml) was filled with deionized water to serve as blank. One (1) content of Ammonia Salicylate powder was introduced to each cell, stopped, and shook for the sample to dissolve completely. A three (3)-minute interval was allowed for the reaction to complete, and one (1) Ammonia Cyanurate reagent powder pillow reagent was added to each cell, stopped, and shaken to dissolve for 15 minutes to complete the reaction. Green coloration created after the reaction indicated the presence of of ammonia-nitrogen. Placed in spectrophotometer cell holder, the blank reading was then taken in 0.00 mg/L NH3-N, the sample inserted into the cell holder and the concentration recorded in mg/L.

5) Nitrate Concentration

Each sample nitrate concentration was determined using Cadmium Reduction Method and the Hach spectrophotometer (model DR 1900). A sample (15 ml) of wastewater measured into 25 ml measuring cylinder. NitraVer 6 reagent was emptied into the sample and shook vigorously for three (3) minutes. A two (2)-minute reaction time was allowed and 10 ml of prepared sample filled into a clean sample cell. One (1) NitriVer 3 nitrite reagent content was added to sample and swirled gently for 20 seconds. The prepared sample was added to the sample cell after 15 minutes until it reached the 10 ml level to serve as blank. The blank sample cell was put in the spectrophotometer cell holder and zeroed. Nitrate concentration (mg/L) was then determined by putting the prepared sample into the cell holder.

D. Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD)

The reactor digestion method – Standard Method for the Examination of Water and Wastewater – was used to calculate the chemical oxygen demand (COD) [38]. On the other hand, five (5)-day biochemical oxygen demand (BOD_5) of the samples measured during five (5) days of incubation at 20° C was analysed using Winkler's method and standard laboratory protocol [38].

E. Bacteriological Assessment

Bacteriological assessment of samples included total and fecal coliforms, and E. coli. However, the bacterial examination of samples was done using 300 ml sterilized bottles. The membrane filter (MF) technique enumerated total and fecal coliforms present in the samples. To facilitate discrete colonies formation, serial dilutions were used to reduce the bacterial load of samples. Samples collected were serially diluted (101 – 106) using deionized water. A 100 ml prepared samples were filtered aseptically using filter membranes of 0.45 µm pore size which were then placed on pads saturated with sterile m-Lauryl Sulphate broth. Inverted Petri dishes incubated at 37.0°C and 44.0°C between 18 – 24 hours were respectively analysed for total coliforms, E. coli, and fecal coliforms. The yellow colonies present were counted and expressed in CFU/100 ml.

F. Determination of Sludge Height

The height of sludge is determined by the sludge judge or white towel test, – labour-intensive and low-resolution technologies [34]. The sludge judge test used a transparent tube with both ends opened. The top end was covered after the tube was plunged into the pond's base to trap sludge in the tube. The tube was then withdrawn and the height of sludge that remained in the tube corresponded to the height of sludge in the pond [39]. A white towel is wrapped on a rod and dipped into the pond to form the white towel test [11]. Marks on the towel determined the sludge depth or height. These outlined procedures required time, are a danger to health, and the accuracy is subjective [39]. The height of sludge at each point was calculated by subtracting the depth of sludge from the actual pond depth for anaerobic, facultative, and maturation ponds. The percentages of sludge height at each point of each pond were determined, and the overall average height of sludge of all ponds calculated [34].

G. Data Handling and Analysis

The analytical process was performed per the Standard Methods for Examination of Water and Wastewater provide in [38] unless otherwise stated. The means and standard deviations of all wastewater parameters under assessment were determined using Microsoft Excel (Version 2013).

III. RESULTS AND DISCUSSION

Waste stabilization pond's (WSP) efficiency plays a critical role in mitigating environmental and public health risks associated with wastewater discharge. When improperly treated, wastewater effluent can pollute water bodies and degrade ecosystems. The Legon WSP, designed to handle a capacity of 8,550 m³, has undergone gradual operational capacity adjustments since its inception. Initially operating at 1,330 m³ capacity, but progressively expanded treatment to 3,500 m³/day as of 2016. Table 3 provides the plant's performance data at 3,500 m³/day capacity in March 2016, and its compliance with Environmental Protection Agency (EPA) standards.

Table 3: WSP data at 3,500 m³/day capacity

Parameter	**Units**	**Influent**	**Effluent**	**EPA limit**
p^H	N/A	7.2	7.3	6 – 9
Temperature	°C	29.8	29.4	<3°C above ambient
Turbidity	NTU	475.2	17.8	75
TSS	mg/L	303.2	13.6	50
3BOD	mg/L	133.9	8.4	50
COD	mg/L	328.0	14.4	250
DO	mg/L	0.4	6.4	N/A
PO_4.N	mg/L	1.9	0.007	2.0
NH_3.N	mg/L	3.6	0.005	1.0
Fecal coliforms	CFU/ 100ml	2.1×10^8	4.3×10^3	10
Total coliforms	CFU/ 100ml	4.3×10^5	6.1×10^5	400
E. Coli	CFU/ 100ml	8.8×10^7	1.6×10^3	10

Key: N/A means Not Applicable; EPA means Environmental Protection Agency

Source: WSP Legon Plant Laboratory and EPA Ghana.

A. *Physico-Chemical Parameters*

Wastewater physico-chemical properties were measured across the treatment process from influent (INF) to final effluent (EF) in May, June, and July 2022. The analysis focused on pH, temperature, TSS, turbidity, BOD, COD, DO, PO4-P, and NH3-N. The percentage removal efficiency in wastewater treatment was calculated for each parameter, and the performance of wastewater treatment system was evaluated using equation (1) as follows [40]; [8]:

$$\% \text{ efficiency} = \frac{\text{Influent} - \text{Effluent}}{\text{Influent}} \times 100\ \% \quad ..\text{eq (1)}$$

1) Potential of Hygrogen (pH) and Temperature

p^H is a measure of how acidic or alkaline a solution is at a given temperature [41], a critical physico-chemical parameter for biotic ecosystems since plants and animals can survive only within a limited p^H rang – from slightly acidic to slightly alkaline [42]. A pH of wastewater for both influent and effluent (as shown in Table 3) was within Ghana's EPA and World Health Organization (WHO) permissible limits of 6 – 9 and 6.5 – 8.5 respectively throughout the treatment process in all three (3) months [30]; [43]. The influent pH was 7.2 and increased marginally across the treatment stages to 7.3 for the effluent, which indicated an effective buffering capacity of the treatment system. The slight p^H increase of 0.1 from influent to effluent could be due to wastewater dilution from rain between May and July [8]. Whereas the influent p^H was predominantly neutral, the effluent p^H was slightly alkaline, findings which agreed with an earlier study that found p^H of samples was slightly alkaline [43].

Temperature is necessary for the aquatic environment and contributes to regulating wastewater biological and physico-chemical parameters [44]. The influent temperature ranged between 29.4 °C and 29.6 °C but gradually decreased to between 28.1 °C and 28.3 °C as effluent, a reduction which aligned with Ghana's EPA standard for effluent discharge of less than 30°C and temperature difference maintenance within 3 °C above ambient levels [30]. This study results also agree with the observed 29°C temperature of water from Kpata River in LokoJa in Nigeria [44], and both findings were within WHO standard for drinking water. The decline in temperature might be attributed to the cooling effect of treatment ponds, especially during maturation.

2) DO and TSS

Dissolved oxygen is the oxygen concentration measured using Winkler's method or DO meter and is used to determine whether biological changes are due to anaerobic or aerobic organisms [45]. The DO concentration increased across the treatment stages from influent (0.37 – 0.5) mg/L to effluent (5.9 – 6.2) mg/L, an increase consistent with the oxygenation processes that occurred in the facultative and maturation ponds. Similar results were observed in Kpata river study in Nigeria where DO in water was 7.2 mg/L, indicating mild organic pollution [45], likely resulted from community excreta disposal. DO availability in the effluent reflects the system's ability to restore oxygen levels to meet discharge requirements. However, TSS levels showed significant reductions across the treatment process over the period, with influent levels ranging from (314.6 – 325.8) mg/L and effluent levels further reduced to 11.1 mg/L in June 2022. Another study recorded an overall decrease in TSS from February to April attributed to wastewater dilution from rain and runoff [8]. TSS removal efficiency was consistently high, ranging from 95.8% in May to 96.6% in June, which demonstrated effective sedimentation and filtration during treatment. Compared to the Ahinsan Estate study in Kumasi, Ghana, TSS removal efficiency which was 71.83% [30], TSS removal efficiency was significantly higher in this study. The TSS was calculated using the following formula [8]:

$$\text{TSS (mg/L)} = \frac{(\text{Wt. of filter + residue}) - (\text{Wt. of filter})\times 100}{\text{Sample volume (L)}} \quad \text{eq2}$$

3) Turbidity

Turbidity levels in the influent ranged from 389.4 NTU – 486.5 NTU but reduced significantly to between 11.3 NTU and 18.7 NTU in the effluent. The highest turbidity removal efficiency of 97.1% was recorded in July 2022, an improvement that highlighted the treatment effectiveness in suspended and colloidal particles removal, thereby enhanced wastewater quality.

4) COD and BOD

COD is the amount of oxygen needed by microorganisms to oxidize organic and inorganic matter present in wastewater and calculated using the following formula [46]:

COD (mg/L) = 8 × (mL of titrant used in the sample – mL of titrant used in the blank) Eq (4). Therefore, the amount of oxygen consumed in oxidation is not only due to organic matter, but also inorganic matter to be oxidized [46]. While COD showed significant reductions in influent levels of (325.7 – 373) mg/L to effluent levels of (13.9 – 18.1) mg/L, the removal efficiency of COD was between 94.6% and 95.7%. This study's removal efficiency of COD was therefore aligned with Ahinsan WSP's removal efficiency of 95.2% [30]. A South Africa study had COD in effluent (82 – 200) mg/L far exceeded the country's wastewater discharge limit of 75 mg/L [22]. BOD is the quantity of oxygen required by microorganisms for the biological decomposition of dissolved solids and organic matter under anaerobic conditions [47]. BOD, however, reduced steadily in this study from influent levels of 142.3 – 161.7 mg/L to effluent levels of 6.3 – 8.2 mg/L over the three (3)-month period. The BOD removal efficiency was between 94.2% and 96.1%, which indicated highly efficient organic matter decomposition process. The BOD was determined using the following formula [48]:

$$\text{BOD} = \text{Initial DO} - \text{Final DO} \quad \text{……Eq (4)}$$

5) PO_4-P and NH_3-N Concentrations

The PO_4-P influent concentrations ranged from (2.1 – 2.6) mg/L but decreased significantly to effluent levels from (0.06 – 0.08) mg/L, which were within Ghana's EPA limit of 2.0 mg/L for effluent discharge

[30]. The highest removal efficiency (97.3%) was recorded in June 2022, a reduction attributed to nutrient uptake by algae in the facultative and maturation ponds. The NH_3-N concentration in the influent ranged from (3.9 – 4.2) mg/L, with effluent concentrations reduced to 0.03 mg/L, an effluent concentration well within EPA of Ghana's recommended limit of 1 mg/L [30]. The removal efficiencies were consistently high and ranged from 99.0% in May to 99.3% in July 2022, a high efficiency which indicated effective nitrification processes in the system.

B. **Microbiological parameters**

Wastewater microbiological quality over the period of May to July provided an account of fecal coliforms (FC), total coliforms (TC), and E. Coli across the treatment stages, including influent (INF), anaerobic pond (AP), facultative pond (FP), maturation ponds (MP1 and MP2), and final effluent (EF).

1) **Fecal Coliforms (FC)**

Fecal coliforms concentration in the influent (INF) was highest across all three (3) months and ranged from 2.5×10^8 CFU/100ml in May to 3.6×10^8 CFU/100ml in July. Progressive reductions were however observed as the wastewater passed through each treatment stage. Fecal coliform concentrations were then reduced to 3.4×10^3 CFU/100ml in May, 7.0×10^3 CFU/100ml in June, and 7.0×10^3 CFU/100ml in July at the EF stage, which represented a consistent removal efficiency of 99.9% for all months.

2) **Total Coliforms (TC)**

Influent total coliforms concentrations were consistently high and ranged from 4.7×10^8 CFU/100ml in May to 5.2×10^8 CFU/100ml in June. The treatment process effectively reduced these concentrations, with effluent concentrations of 1.5×10^5 CFU/100ml in May, 3.0×10^5 CFU/100ml in June, and 1.8×10^5 CFU/100ml in July. The overall removal efficiency was 99.9% in all three (3) months. Although the final effluent concentrations were higher than Ghana's EPA standard of 400 CFU/100ml [30], significant reductions were achieved throughout the treatment process.

3) **Escherichia coli (*E. coli*)**

Influent *E. coli* concentrations ranged from 7.4×10^7 CFU in May to 7.6×10^7 CFU/100 ml in July. Substantial reductions were observed as wastewater moved through the ponds, with effluent concentrations consistently reduced to 1.3×10^3 CFU/100ml in May, 1.5×10^3 CFU/100m in June, and 1.1×10^3 CFU/100ml in July, with an overall removal efficiency of 99.9% achieved over the treatment process.

H. **Legon WSP Sludge Height**

The height of sludge, wastewater depth, and sludge percentages of the four (4) ponds in the Legon WSP, namely the AP, FP, MP 1, and MP 2 were observed. Observations were recorded over three (3) months (May, June, and July) and the operational efficiency of ponds assessed to determine the need for desludging based on sludge percentage thresholds. Operational performance key indicator is sludge percentage and was calculated using the following formula [49]:

$$\text{Sludge percentage} = (\text{Sludge height}/\text{Water depth})\ (\text{m}) \times 100. \quad \text{eq (5)}$$

The recommended sludge threshold for effective pond operation is 33.33%, beyond which desludging is necessary to prevent reduced treatment efficiency [50]. The anaerobic pond exhibited an average sludge height of 1.1 m, with slight monthly variations ranging from 1.08 m in May to 1.13 m in July. However, wastewater depth decreased marginally from 3.92 m in May to 3.87 m in July, averaging 3.9 m over the study period. Consequently, the sludge percentage for the AP was 28.1%, which was well below the operational threshold of 33.33%, an indication that the pond was functioning efficiently, and there was no immediate need for desludging.

The FP sludge height varied from 0.49 m in May to 0.52 m in June, averaging 0.51 m over the study period. Wastewater depth, however, fluctuated slightly between 1.51 m in May and 1.48 m in June, with an average depth of 1.49 m. The resulting sludge percentage for FP was 34.2%, which exceeded the recommended threshold, suggesting that the FP slightly exceeded its operational limit and required desludging to restore treatment capacity and efficiency. The MP 1 recorded an average sludge height of 0.38 m, with a slight increase from 0.37 m in June to 0.4 m in July. The wastewater depth was relatively stable, and ranged from 1.1 m to 1.13 m, with an overall average of 1.12 m. The calculated sludge percentage was 33.9%, marginally above the threshold, which indicated that though the pond was still operational, it could soon require desludging to maintain its effectiveness.

The MP 2 maintained a consistently low sludge height from – from 0.3 m in May to 0.34 m in July – with an average of 0.32 m. The wastewater depth showed slight variation of 1.16 m to 1.2 m, with an overall average of 1.18 m. The sludge percentage for MP 2 was 27.1%, well below the recommended threshold, demonstrated that the MP 2 operated efficiently and needed no immediate desludging. Consequently, therefore, though AP and MP 2 operated within the threshold of 33.33% and so required no desludging, FP and MP 1 operated marginally above threshold and would need to be desludged to maintain their effectiveness. Given that both AP and MP 2 operations were close to the threshold while FP and MP 1 exceeded it, more frequent desluding is advised in the short term. It is therefore recommended that Legon's WSP system be expanded to accommodate extra wastewater inflow in the long term.

IV. FURTHER DISCUSSION

The findings of Legon WSP study provided crucial insight into its performance and aligned with broader literature on wastewater treatment in similar systems. The efficiency of the WSP system in physicochemical and microbiological pollutants removal demonstrated its effectiveness, though some variations existed when compared to findings from other studies. The influent and effluent pH levels remained within the EPA standard range of 6 – 9 throughout the study period, with only marginal increment from influent to effluent. This study result was aligned with findings from other WSP studies that reported well-functioning stabilization ponds exhibit effective buffering capacity due to microbial activities and the presence of carbonate species [51]. Another study in Obuasi reported a significant pH increase along the treatment line of the WSP [52]. Similar pH stabilization was also observed attributable to biological processes such as nitrification and photosynthesis [53]. The slight temperature reduction from influent to effluent also aligned with EPA's guidelines of Ghana and temperature difference maintenance within 3°C above ambient levels [30].

This finding was consistent with observations on other tropical WSP systems, where the cooling effect of evaporation and exposure to ambient temperatures in maturation ponds were reported to stabilize effluent temperatures [11]. Another study on WSP in Akosombo, Ghana, recorded an insignificant temperature reduction from influent (29.12°C) to final effluent (28.93°C) [54]. The total suspended solids (TSS) removal efficiency in this study ranged from 95.8% to 96.6%, demonstrating excellent sedimentation and filtration processes in the treatment system. This study finding therefore aligned closely with those of an Indian study where TSS removal efficiencies of over 90% were attributed to sedimentation and microbial activity [55]. Another study in Kumasi found a mean removal efficiency for TSS as 90.53% [56]. However, the influent TSS levels in Legon WSP ranged from 314.6 mg/L – 325.8 mg/L were slightly higher than reported in temperate regions where influent TSS rarely exceeded 200 mg/L [57]. The difference might be due to variations in wastewater composition and pretreatment methods between regions.

Turbidity removal efficiency reached 97.1% in this study, which confirmed Legon's WSP effectiveness in suspended and colloidal particles reduction, a finding consistent with earlier WSPs studies that achieved high turbidity reductions through natural settling and microbial flocculation [58]. However, the influent turbidity observed from 389.4 NTU – 486.5 NTU was higher than recorded in similar studies conducted in South America, where lower values were attributed to upstream pretreatment facilities [59]. Organic matter removal was highly efficient as indicated by BOD and COD reductions – BOD removal efficiency ranged from 94.2% to 96.1% while COD efficiency reached 94.6%. These results are comparable to WSPs performance in other tropical settings, which documented BOD removal efficiency exceeding 90% [60]. The low effluent BOD and COD observed in this study suggested effective organic matter decomposition, largely facilitated by aerobic and anaerobic microbial activities.

Dissolved oxygen (DO) concentration increased significantly from influent to effluent, reaching 6.2 mg/L, result that agrees with findings from environmental monitoring studies in Tanzania, where DO concentration in effluents rose due to photosynthetic activity in facultative and maturation ponds [51]. Elevated DO concentrations in the effluent were crucial to prevent eutrophication when discharged into water bodies. PO4-P and NH3-N removal were also highly efficient – PO_4-P and NH_3-N removal efficiencies were 96.7% and 99.0% respectively. These findings collaborate a study result that found that nutrient removal in WSPs is primarily driven by microbial uptake, sedimentation, and chemical precipitation [61]. However, the Legon WSP showed higher nutrient removal efficiency compared to studies in arid regions, where limited microbial activity and lower retention times often reduced efficiency [24].

Microbial removal efficiency achieved for fecal and total coliforms, and *E. coli* was over 99%, a removal efficiency found in research carried out at Akosombo WSP where the overall system removal efficiency of 99.8%, 99.9%, and 99.99% for total, fecal and E. coli respectively [52]. In another study, however, fecal coliform removal efficiency was more than 92%, achieved using horizontal subsurface flow constructed wetland for domestic wastewater treatment [62]. These significant removal efficiencies might be attributable to optimal use of solar radiations in facultative and maturation ponds for the inactivation and destruction of total and fecal coliforms [63]; [64]. Though 100% microbial removal was not achieved in the Legon WSP effluent, it did not cause adverse public health risks. However, the waterborne pathogens of the enteric bacteria category are likely to be found when total and fecal coliforms are present. The concentration of E. coli (1.0×10^3 CFU/100 ml) in the effluent exceeded the recommended EPA acceptable limit of 10 CFU/100 ml. The results are comparable to findings of another study where the E. coli concentration of the final effluent often remained slightly above the regulatory thresholds [60]. This study discussion therefore concluded that though the Legon WSP system was effective, additional disinfection measures, such as chlorination or ultraviolet (UV) treatment, are recommended to meet stricter microbial standards.

V. CONCLUSION AND RECOMMENDATION

A. Introduction

Most wastewater generated in the developing world is disposed of without treatment due largely to limited treatment technologies and the high cost of treatment. Developing countries' water bodies receive about 90% of untreated wastewater generated because conventional wastewater treatment systems are capital-intensive and therefore unaffordable. Using WSPs to treat wastewater reduces the effect of partially treated wastewater on aquatic life and human health. Though there exist past studies on the subject, little or no studies examined the effect of WSP operating capacity on its efficiency. This study was therefore conducted in the Legon WSP which has a designed capacity of 8,550 m^3, initially operated at 1,330 m^3 capacity, and currently treats 3,500 m^3/day, to ascertain its efficiency, capacity variation effect on efficiency, and effluent quality discharged into the Onyease stream.

B. Conclusion

This study findings demonstrated Legon's WSP highly efficient wastewater treatment to meet Ghana's EPA standards. The Legon WSP system consistently exhibited significant reductions in key physicochemical parameters, including TSS, turbidity, BOD, and COD over a three (3)-month study period May – July 2022, with removal efficiencies exceeding 94%. Notably, NH_3-N and PO_4-P concentrations were reduced by over 96%, highlighting the system's effective nutrient removal capacity. Both pH and temperature values remained within the EPA recommended limits, underscoring the stability and robustness of the treatment process. Though the effluent failed to meet EPA standards, microbiological analysis revealed a significant reduction in coliform counts, including total coliforms and fecal coliforms, across the treatment stages, demonstrating the WSP's ability to improve microbial water quality and reduce health risks associated with pathogenic contamination. Sludge height and percentage assessments across the four (4) ponds in the Legon WSP showed varying operational efficiencies. While the anaerobic pond (28.1%) and maturation pond 2 (27.1%) recorded sludge percentages below the 33.33% threshold, which indicated efficient system operation with no immediate need to desludge, the facultative pond (34.2%) and maturation pond 1 (33.9%) exceeded the threshold, suggesting these two (2) ponds required immediate desludging. While more frequent desludging is advised in the short term, the expansion of Legon's WSP in the long term is recommended to enable receipt of additional wastewater inflow.

C. Recommendations

Based on the study conducted to assess Legon's WSP wastewater treatment effectiveness and the results thereof, the following recommendations were made:

(a) To further improve Legon's WSP efficiency to meet standard microbial limits, additional measures such as chlorination and ultraviolet (UV) treatment should be introduced;
(b) The WSP system be expanded in the long term to receive additional wastewater load inflow and prevent efficiency reduction;
(c) Additional investigations should be conducted to ascertain the:
   (i) Self-purification ability of the Onyease stream;
   (ii) Health implications associated with the pond's fish if used for human consumption; and
   (iii) Public health of residents in communities around the Onyease stream who use the effluent for agricultural and other activities.

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