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Nutrient Removal Efficiency of Activated Sludge Plants Treating Industrial and Municipal Wastewater in Ghana

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Abstract Discharge of untreated or poorly treated wastewater constitutes a major source of organic compounds to surface water posing serious threats to ecology and human health. The nutrient removal efficiency of three full-scale conventional activated sludge plants treating municipal and industrial wastewater in Ghana was investigated using standard methods. Industrial wastewater treatment plant had generally higher nitrogen removal efficiency (high as 75%) compared to municipal wastewater treatment plants (21%), with no significant differences in removal efficiency observed for phosphorus. However phosphorus removal efficiency was significantly higher (p-value = 0.005) in the wet season than dry season. A strong correlation between nutrient levels for the various plants was observed, with municipal wastewater plants recording generally higher levels. Effluent total nitrogen (TN) values ranged between 16.5 and 53.8mg/L and 29.4 and 71.5 mg/L for the wet and dry seasons respectively, with total phosphorus (TP) values also ranging between 3.23 and 6.57 mg/L and 6.3 and 15.8mg/L respectively. The effluent quality guideline value for nitrogen was missed by one of the municipal plants while all plants missed that of phosphorus. On the basis of these results, there is need for modifications to existing activated sludge plants in Ghana to improve their nutrient removal efficiency.

Keywords: *water pollution, nutrient removal, activated sludge process*

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1. Introduction

Water pollution remains a serious problem worldwide due to the threat posed to ecology and human health [1]. A major source of organic compounds, especially nitrogen and phosphorus, in surface waters is discharge of untreated or improperly treated wastewater from municipal and industrial sources [2]. Main sources of these nutrients in municipal and industrial wastewaters are fecal and waste materials, industrial and commercial uses, synthetic detergents and household cleaning products [3,4]. They constitute the most prominent macronutrients in aquatic systems which can act as limiting nutrients [5]. Soluble formsin which phosphorus occurs in wastewater can be categorized chemically into orthophosphate, condensed phosphate and organic phosphate, with nitrogen occurring mainly in organic and ammonium forms [3].

The presence of nitrogen and phosphorus in a wastewater discharge can be undesirable for several reasons [6,7]. Nitrogen as free ammonia is toxic to fish and many other aquatic organisms; as ammonium ion or ammonia it is an oxygen-consuming compound which will deplete the dissolved oxygen in receiving water; in all forms, nitrogen can be available as a nutrient to aquatic plants and consequently contribute to eutrophication; as the nitrate ion it is a potential public health hazard in water consumed by infants [3]. Thyroid dysfunction and formation of carcinogenic compounds have also been linked to nitrates in drinking water [8,9,10,11]. According to the World Health Organisation 2013 Updates on Sanitation and Drinking-water sources, Sub-Saharan African has one of the lowest drinking-water coverage with 24% depending on unimproved drinking water sources and 13% on surface water as at 2011 [12]. National statistics for Ghana indicate that 14% of the population depended on unimproved sources of drinking water at 2011 [13].

Additionally overall water demand in Africa is expected to more than double in the first half of 21st century, increasing water stress populations i.e. there is less than1000m^3/yr/capita available and hence more wastewater reuse [14,15]. About 25% of Africa’s population (about 200 million people) currently experience water stress [15]. Even in the absence of climate change, present population trends and patterns of water use indicate that more African countries will exceed the limits of their “economically usable, land-based water resources before 2025” [16]. Climate change profile of Ghana indicates a decline in total annual rainfall, with projections of 20.5% by 2080, early termination of rainfall and conversion of the current bi-modal regime to a unimodal one [13]. With a growth rate of 2.5% (Ghana Statistical Service 2012), Ghana eminently faces increasing wastewater reuse. Efficient wastewater treatment therefore is important to ensure safe reuse and maintenance of a healthy society [17,18].

Activated sludge process is the most commonly used technology for biological wastewater treatment [19,20,21]. The conventional activated sludge process consists of two stages; a biochemical stage (aeration tank) and a physical stage (secondary clarifier). In the aeration tank, organic carbon, ammonium and phosphate are removed from the wastewater by the activated sludge and in the sedimentation tank, quiescent conditions are provided for settling of microbial flocs produced during the aeration phase in the aeration tank [22]. This produces a clear supernatant (effluent), low in suspended solids and organic matter that can be discharged into receiving waters. Organic nitrogen in wastewaters in normally transformed through hydrolysis to ammonia (NH_3), which is then oxidized by *Nitrosomonas* to nitrite (NO_2) and eventually to nitrate (NO_3) by *Nitrobactor* in the nitrification process [23]. Several modifications in the forms of Contact Stabilization Activated Sludge (CSAS), Extended Aeration Activated Sludge (EAAS), and Sequencing Batch Reactors Activated Sludge (SBRAS) have been made to this process towards improving its nutrients removal efficiency [24,25].

In Ghana, the activated sludge process has recently been employed, with a number of plants installed and used mainly for treatment of municipal and industrial wastewater [18]. Though several studies have been conducted on nutrient removal by activated sludge process in several countries, the same cannot be said for Ghana. The main goal of this research is to fill this knowledge gap by assessing the nutrient removal efficiency and final effluent concentrations obtained by conventional activated sludge treatment plants treating different types of wastewater. The values 50 mg/L for total nitrogen (TN) and 2.0mg/L for total phosphorus (TP) are currently in use by the Environmental Protection Agency of Ghana as effluent quality guidelines for discharge into natural water bodies. Besides the academic interest of this research, it will nonetheless contribute to progress in the field of environmental management.

2. Materials and Methods

2.1. Wastewater Treatment Plants

Three full-scale activated sludge wastewater treatment plants were used for this study. These plants are located at LaPalm Royal Hotel, Labadi Beach Hotel, and Nestle Ghana Ltd all in the Greater Accra Region of Ghana, with the LaPalm and Labadi plants treating only municipal wastewater while that of Nestle treats mainly industrial wastewater. All plants are operated on the basic design of the conventional activated sludge configuration consisting of aeration and sedimentation tanks (secondary clarifier).Nestle plant however has a balancing tank, two aeration tanks each with a capacity of $800m^3$ and scrapper on the secondary clarifier. Effluents from La Palm and Labadiplants are used for on-site landscaping while that of Nestle is discharged directly into the centralized municipal sewerage system.

2.2. Sampling

Sampling was carried out from May to July, 2013 and November to January, 2014 coinciding with the wet and dry seasons respectively in Ghana. Representative grab samples from the influent and effluent wastewater were collected during operation in appropriately labeled 100ml plastic bottles. Sample containers were three-quarters full to avoid septicity. Once collected, all samples were stored on ice, immediately transported to the laboratory and handled within three days after sampling.

2.3. Laboratory Analysis

Allsamples were centrifuged at 5000rpm for 5 minutes (Megafuge 3.0R) and the clear supernatants analyzed according to standard methods [26]. Briefly, nitrate determination was based on the principle of formation of 5-nitrosalicylic acid complex under highly acidic conditions [27]. 50µL of each sample was mixed with 200 µL of freshly prepared salicylic acid (0.2g salicylic acid / 4ml concentrated sulphuric acid) in a test-tube and shaken gently to dissolve the precipitate. The solution was allowed to stand for 20 minutes and then 4ml of 2N NaOH was carefully added and again properly shaken. The solution was then allowed to cool to room temperature and the NO_3 concentration in the sample determined at a wavelength of 410nm. Determination of ammonium was based on the formation of potassium iodide-amalgam. 5ml of appropriately diluted sample was mixed with 200 µl of potassium sodium tartrate solution and 200 µlNessler's reagents and thoroughly stirred. Samples were allowed to stand for five to eight minutes leaving a golden yellow coloration, and then measured photometrically at 425 nm with a UV/VIS spectrophotometer(SHIMADZU UV-2459). The limit of detection of NH_4 for this spectrophotometer is in the range of 0.1 to 5mg/l.Samples for TP analysis were first digested using a MARS Express CEM, by adding 100-200mg Oxisolv to 10ml of sample, heated to a temperature of 170°C within three minutes and maintained at that temperature for another three minutes. COD analysis was performed by adding the sample to standard vials (Merck-Spectroquant), shaken and placed in a thermoreactor (Merck TR 300) at a temperature of 148°C for 120mins, and measurements done with a photometer (MERCK, Spectroquant NOVA 60). TN and TOC were measured with DIMA-N connected to DIMA TOC 2000, at oxygen pressure of 1 bar and temperature of 330°C. The samples were transferred to the sample rag of DIMA TOC 2000 analyzer and subsequently programmed for the measurement. The signals generated from the samples were evaluated using the DIMA TOC 2000 program linked to the TOC analyzer (DimatecAnalysentechnik GmbH, 2013).

2.4. Statistical Analysis

Microsoft Excel, 2013 was used to plot histograms for comparing results of various treatment plants. A single factor ANOVA was used to determine seasonal variations in treatment efficiencies. Correlation analysis was applied to determine relations between nutrient levels in the various treatment plants.

3. Results and Discussion

Treatment efficiency of industrial and municipal wastewater plants was compared for nutrient removal. Influent and effluent TN,NH_4-N,PO_4-P and TP values for dry and wet seasons were analyzed to determine removal efficiencies and seasonal variations in concentrations. Additionally, Total Organic Carbon (TOC)and Chemical Oxygen Demand (COD)were analyzed to determine their effects on nutrient removal efficiencies and the characteristics of the wastewater.

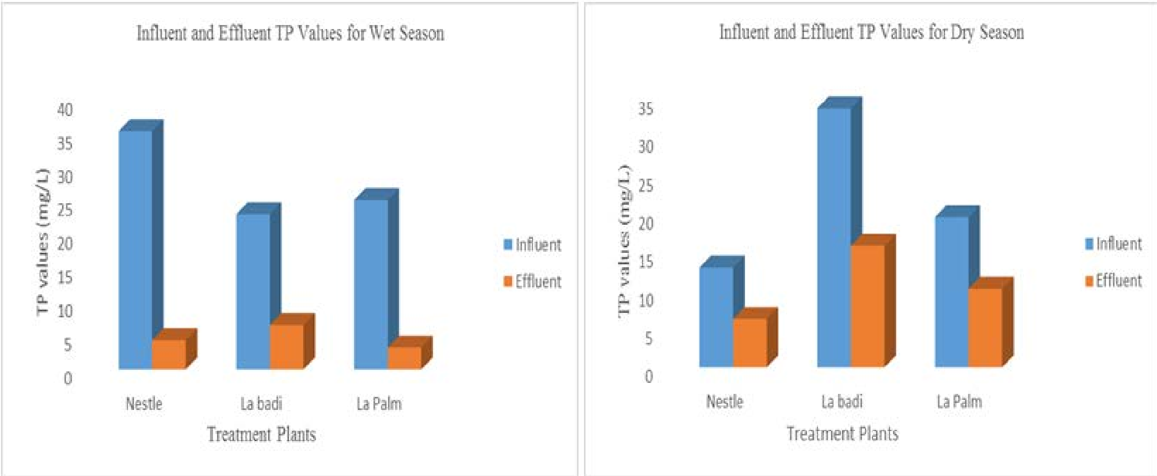

Figure 1. Showing Influent and Effluent TP Values for the Wet and Dry Seasons

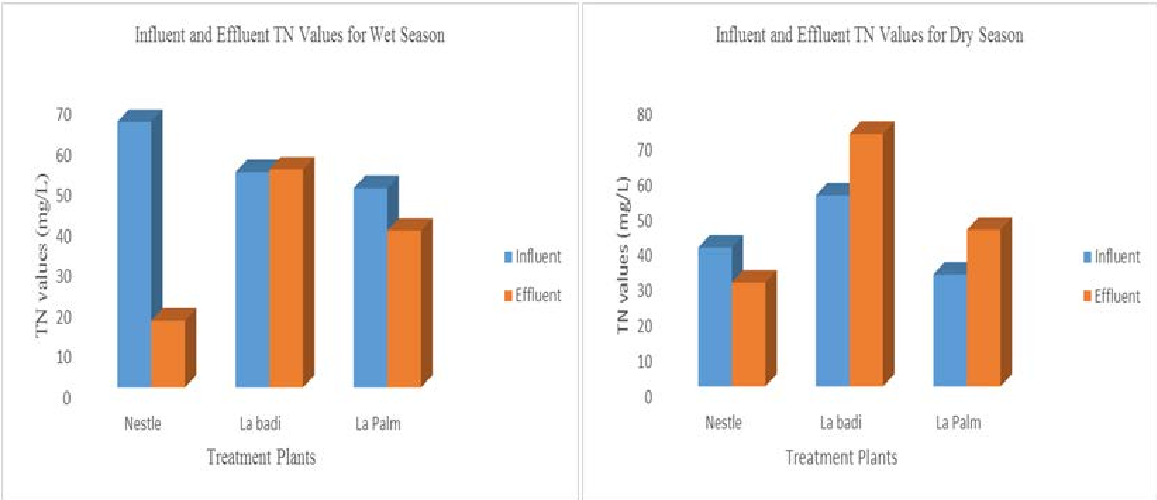

Figure 2. Showing Influent and Effluent TN Values for the Wet and Dry Seasons

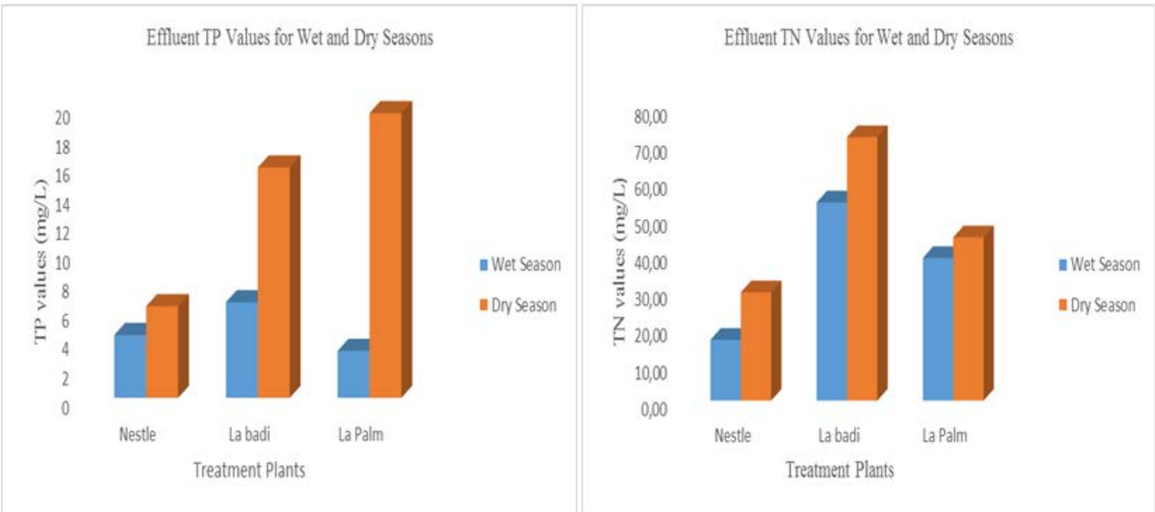

Figure 3. Comparing Effluent TP and TN Values for Wet and Dry Seasons

Industrial wastewater recorded effluent TN values of 16.5 and 29mg/L, and TP values of 4.3 and 6.3mg/L. For municipal wastewater, effluent TN values ranged 38 and 71mg/L with TP ranging from 3 to 15mg/L (Table 1 and Table 2). All plants recorded higher effluent TN and TP values for the dry season than the rainy season, with municipal wastewater recording the highest values (Figure 3). Correlation analysis gave a very strong relation for TN and TP effluent values for both municipal and industrial wastewaters for both seasons. All plants exceeded the TP guideline value of 2.0mg/L with plants treating municipal waste recording the highest values of 6.6 and 15.8mg/L respectively for the dry and wet seasons. In addition, LabadiBeach Hotel treatment plant recorded effluent TN values of 53.8 and 71.5mg/L respectively for the wet and dry seasons, thereby exceeding the guideline discharge value of 50mg/L. Comparing influent and effluent values to determine removal efficiency of the various plants gave higher TN removal efficiency (75%) for industrial wastewater than municipal wastewater (25%) (Table 1 and Table 2, and Figure 2). The differences in removal efficiencies obtained by this study compared to results by other authors [24,28] who reported efficiencies between 68 and 80% could be a result of differences in characteristics of sewage [2]. Domestic wastewater is subject to wide variations in flow and load resulting in wide variations of influent nutrient ratios [29]. Influent TOC and COD values and TN/NH_4-N ratios of the various wastewaters confirmed variations in composition of the various wastewaters, with high TN/NH_4 ratio an indication of high inorganic nitrogen content. Seasonal changes in flow and loading of these wastewaters could therefore account for the variations in the ratios calculated and hence different removal efficiency observed.

Table 1. Influent and Effluent Values for Dry Season

Parameter	Influent Values			Effluent Values		
NH_4-N (mg/l)	1.8	27.9	20.2	0.77	47.9	35.1
TN (mg/l)	39.3	54.1	31.7	29.4	71.5	44.3
PO_4-P (mg/l)	4.5	5.9	3.2	1.1	2.2	1.1
TP (mg/l)	13.0	33.7	19.6	6.3	15.8	10.3
TOC (mg/l)	391.1	198.6	113.1	13.9	71.1	21.2
COD (mg/l)	1220	660	392	76	276	66

Table 2. Influent and Effluent Values for Wet season

Parameter	Influent Values			Effluent Values		
NH_4-N (mg/l)	10.1	41.6	34.5	0.8	7.5	33.1
TN (mg/l)	65.6	53.2	49.2	16.5	53.8	38.7
PO_4-P (mg/l)	13.0	2.6	6.9	3.5	1.76	2.6
TP (mg/l)	35.2	22.9	25.0	4.3	6.6	3.2
TOC (mg/l)	555.6	151.1	44.8	11.4	84.2	17.5
COD (mg/l)	2388	360	208	134	34	26

TN and TP removal efficiency was significantly different for all plants for both seasons, with the dry season recording low removal efficiencies (48-53% for TP) as compared to the wet season (71-88% for TP) (Table 1 and Table 2, Figure 1 and Figure 2). A single factor ANOVA (alpha=0.05) on seasonal TP removal efficiency gave a P-value of 0.005 (F > F crit.), indicating significant differences. Varied effects of seasonal variations on nutrient removal efficiency have been reported by other studies. Reference [30] observed seasonal variations in TN removal with warmer seasons recording lower efficiencies than colder seasons in a full-scale municipal wastewater plant employing conventional activated sludge process. In addition, reference [31] concluded that a decline in water quality during summer droughts was as a result of high temperatures, long residence time and a reduction in the dilution capacity of point source effluents. Dilution effect due to rain water runoff should largely account for the comparably higher TN and TP removal efficiency for the wet season than the dry season. Reference [25] however reported higher efficiency of nutrient removal due to more impressive performance of activated sludge at warmer temperatures as a result of increase in microbial activity with temperature. The low removal efficiency observed in the dry season by this study seems contrary to the expected improvement in performance of the activated sludge process due to the well-established relation between temperature and microbial activity [2]. A possible explanation for this observation could be temperatures higher than the optimum range for the microorganisms resulting in reduced microbial activity.

Municipal wastewater treatment plants recorded higher TN values in the effluent than the influent in the dry season; thereby performing more as nutrient accumulators than removers (Table 1, Figure 2). High TN effluent levels could be due to either decrease in nitrification activity as a result of inhibition by other chemicals, or shock loading of ammonia. Previous research has shown that periods of nitrification failure coincide with increased phenol concentration in the wastewater produced by natural degradation of organic waste including benzene [32]. The low N removal could be attributable to the process being fully aerated, thereby not allowing for denitrification which is more effective at nitrogen removal. Correlations between fractions of nitrogen and phosphorus removed by biological mechanisms and influent COD/TN and COD/TP ratios have been reported by other studies [33]. This study however could not establish such a relation since significantly different seasonal removal efficiencies were recorded despite the similar COD/TN and COD/TPratios. Other factors besides COD/TNand COD/TPratios should account for the nutrient removal efficiency. Research conducted by [28] on nutrient removal efficiency of sequencing batch reactor found that ammonium-N and phosphate-P removal efficiencies were affected by sludge age. Increasing solids retention time (SRT) beyond 10 days resulted in a decrease in removal efficiency [25]. This could have accounted for the low removal efficiency for the dry season observed. Interference of nitrate as an oxidative agent has also been reported as a cause for low TP removal efficiency [34].

4. Conclusion and Recommendation

Nutrient removal efficiencies of three full-scale activated sludge plants treating industrial and municipal wastewaters were assessed for the dry and wet seasons in Ghana. Higher TN removal efficiency was recorded for industrial wastewater, with no differences in TP removal efficiencies among plants. Significant seasonal variations in removal efficiency were observed, irrespective of type of wastewater. The research also indicated that municipal wastewater effluents recorded higher nutrient levels. Since the effluent quality discharge guideline value for TP was missed by all plants for both seasons, it is recommended that modifications be made to currently existing conventional activated sludge wastewater treatment plants in Ghana.

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Statement of Competing Interests

The author has no competing interests.

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