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RESEARCH ARTICLE

CHEMICAL CONTAMINANTS REDUCTION OF WASTEWATER USED FOR PERI-URBAN AGRICULTURE IN NORTHERN GHANA

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ABSTRACT

Wastewater irrigation can pose a variety of potential risks, excessive and often imbalanced addition of nutrients to the soil thus affecting crop production. Objective of the study was to reduce the level of chemical contaminants of wastewater used for peri-urban vegetable crop production by poor farmers in the Tamale Metropolis of Northern Ghana. Studied parameters included ammonia (NH_3), nitrate (NO_3^-), nitrite (NO_2^-) and phosphorus (P) and pH. Experimental setup was horizontal trickle sand filters combined with farm stabilization ponds with the working principle based on filtration theory. Results revealed the level of reduction of ammonia to be statistically significant in the wet season whiles both NO_3^-, and NO_2^-, recorded significant level of reduction in the dry season. Seasonal changes coupled with climatic variations were identified as factors which influenced the general response of chemical parameters to treatment. Ammonia levels ranged between 14.6 to 27.0 mg/l with 51.2% reduction level which was far above EPA Ghana recommendation. Levels of NO_3^- were lower than EPA Ghana standards, ranging from 0.293 to 3.80 mg/l with 49.4% reduction level. NO_2^- level ranged from 0.073 to 2.07 mg/l with 31% reduction level whiles phosphorus levels which ranged from 1.63 to 1.87 mg/l recorded insignificant reduction level.

INTRODUCTION

Every community produces both liquid and solid waste. The liquid portion called wastewater is essentially the water supply of the community after it has been fouled by a variety of uses (Tchobanoglous and Frank, 1995). It contains a variety of chemical substances from domestic and industrial sources including a number of potentially toxic elements. Even if toxic materials are not present in concentrations likely to affect humans, they might well be at phytotoxic levels, which would limit their agricultural use (FAO, 1992). Wastewater treatment according to Frans *et al.* (2006) implies the purification of a given wastewater until its characteristics achieve a certain objective, generally related to health, environmental, or economic matters. The world's population has been reported to continue to increase and at the same time water resources continue to dwindle and with global warming and other environmental threats, the situation will continue to deteriorate. Cities in developing countries, including Ghana, are also experiencing this unparalleled population growth. Rapidly increasing water supply and sanitation coverage generates large volumes of wastewater, which is often released untreated into the environment (streams, drains, etc.) (GSS, 2002). The need for year-round production of vegetables in or near urban areas makes irrigation necessary; hence, farmers in search of water for irrigation often rely on wastewater (Amoah, 2004). Aside microbiological hazards, the practice can pose a variety of potential risks, excessive and often imbalanced addition of nutrients to the soil. However, maintaining adequate levels of nutrients in wastewater according to Manzoor and Christopher (2010) is a challenging task because of the possible negative impacts of their excessive addition to the wastewater-irrigation soils. According to Helmer, and Hespano, (1997), contaminants in irrigation water may accumulate in the soil and after a period of years, render the soil unfit for agriculture. It also has the potential of affecting the acceptability of the agricultural product for sale or consumption. Treatment of wastewater for irrigation and other purposes is very expensive since much resource is required for the design and construction of treatment plants. In view of this, though water-quality management is reported to be a high priority and a major concern of developing country most governments do not have sufficient resources to treat wastewater (Manzoor and Christopher, 2010). This situation of rapid population growth coupled with scarcity of water and increase in the use of wastewater for irrigation of vegetables with its associated

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toxicity has call for frantic efforts to safeguard the risks posed by these chemical properties in the use of wastewater on both the farmer and the consumer in the Tamale Metropolis. Horizontal trickle sand filter combined with farm stabilization pond was design with the aim of reducing the level of chemical contaminants of wastewater used for vegetable crop production and to serve as a timely intervention to help avert the phenomenon of chemical effects with wastewater usage for poor peri-urban farmers.

MATERIALS AND METHODS

Study Area: The study area is Zayuri in the Tamale Metropolis of Northern Ghana and according to Obuobie *et al.*, (2006), it is 8 Km from the city center – Tamale and covers according to different sources in total about 7 - 12 hectares. The livelihood of Zagyuri farmers in the dry season revolves around the use of wastewater (grey and blackwater), a typical domestic untreated sewage effluent from the Kamina Military Barracks for vegetable crop irrigation. Cultivated vegetables in the study area include, "ayoyo'' (*Corchorus olitorius*), pepper (*Capsicum spp*), *Amarathus sp* and tomatoes (*Lycopersicum esculentum*).

Materials and Data Collection: The design included the use of eighteen drum shape containers with a diameter of 6.5 cm and a length of 8.5 cm, filter gauze and mosquito netting, sieving nets of various sizes and filter media of gravel. Cement and concrete blocks were used for construction of a stair case which connects the filter units to the stabilization ponds and the water source.

Laboratory Materials

- Measuring cylinder was used to measure the volumes of water sample to be tested.
- Pipette was also used to measure volumes of water samples for analyses.
- Conical flasks were used to keep water samples for preparation of chemical solution and reactions periods.
- Direct Reading Spectrophotometer 2800 was use to measure the levels of nitrate, nitrite and ammonia in the samples.
- YSI 556 Multi Probe System (MPS) was used for the pH determination.
- Both 25 ml and 10 ml cells were used for Spectrophotometer readings.

Data Collection: Water sampling was done at weekly (6 days) intervals for a period of sixteen (16) weeks that is eight (8) weeks for the rainy season and eight (8) weeks for the dry season. A total number of ten (10) water samples were taken for the weekly interval (having 160 water samples for the whole study).

Experimental Design: The experiment consists of three major treatments namely treatment one (T_1), treatment two (T_2), treatment three (T_3) and a main source as the control (MS).Treatment one consist of three 8.5 cm containers. Treatment two is made up of three 17 cm containers and treatment three is made of three 25.5 cm containers making up the filtering units. The system is made of nine (9) filtration tanks labelled 'T' which are of three different sets. The first set consist of one unit filter container, the second set consist of two unit filter containers joined together, and the third set is made of three unit filter containers also joined together. Each of the sets were filled with four different seizes of the filter media. Stabilization ponds were created to harvest the filtered water from the various treatment tanks. Wastewater from the Kamina Barracks sewage system is directed to the treatment tanks. Samples were taken from the pond to laboratory for quality analysis.

Methods

The following methods were used for the determination of the levels of the various parameters;

Ammonia (Nessler method)

1. Dilute 5 ml of each sample with distilled water up to the 25 ml.
1. 2 Add 1 ml of Roscheil salt to each sample.
2. Add another 1 ml of Nessler reagent to the solution.
3. Allow 1 minute reaction time before the spectrophotometer reading.
4. Zero the DR 2800 Spectrophotometer with the distilled water.

Nitrate

1. Crash 1tablet of nitrate1 and nitrate 2 into 10 ml of each of the sample consecutively.
2. Allow for 6 minutes reaction time before the spectrophotometer reading.
3. Zero the DR 2800 Spectrophotometer with the sample.

Nitrite (Colorimetric Method)

1. Measure 50 ml of the sample into a clean Erlenmeyer flask.
2. Add 2 ml of Gricess – Ilosvay's solution number 1.
3. Add 2 ml of Gricess – Ilosvay's solution number 2.
4. Swirl gently and allow the mixture to stand for 10 -15 minutes.
5. Transfer the sample into a Nesseler's tube and read the value of the nitrite.
6. Zero the DR 2800 Spectrophotometer with the sample before the reading.

Phosphorus (Spectrometric method)

1. Enter the programmed no 490 on the DR 2800 Spectrophotometer.
2. Fill the sample cells to 25 ml.
3. Add 1 phosvate 3 powder pillow.
4. Allow for 2 minutes reaction time.
5. Fill another 25ml cell of the sample as the blank to zero the DR 2800 Spectrophotometer.
6. Divide the recorded value by 3 to obtain the amount of Phosphorus in milligram per litter (mg/l).

RESULTS AND DISCUSSIONS

Climatic Condition in the Tamale Metropolis and Wastewater Supply

The Tamale Metropolis experiences one rainy season starting from April/May to September/October with a peak season in

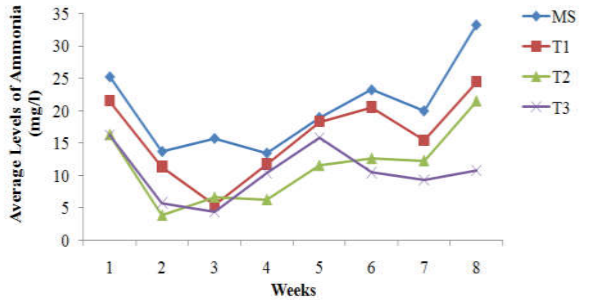

Fig. 1: Weekly Occurrence and Response of Ammonia to Treatment in the Wet Season

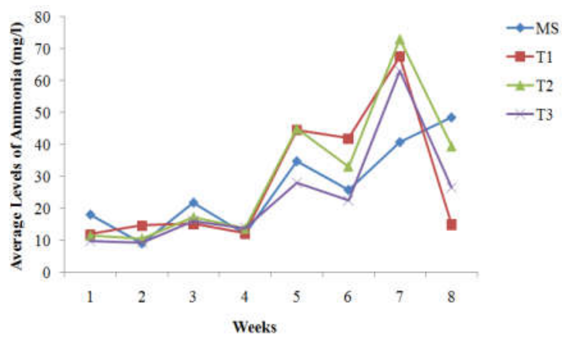

Fig. 2: Weekly Occurrences and Response of Ammonia to Treatment in the Dry Season

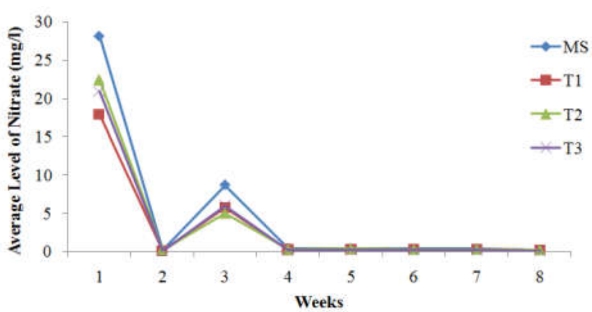

Fig. 3: Weekly Trend of Nitrate Levels in the Wet Season

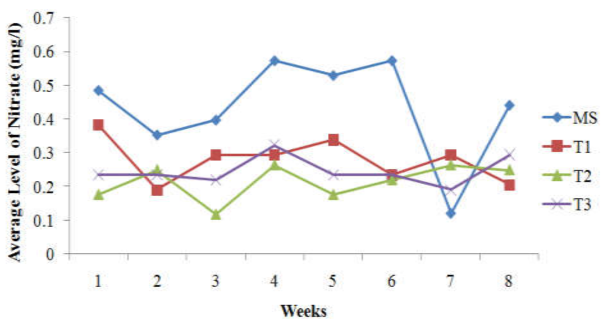

Fig. 4: Weekly Trend of Nitrate Levels in the Dry Season

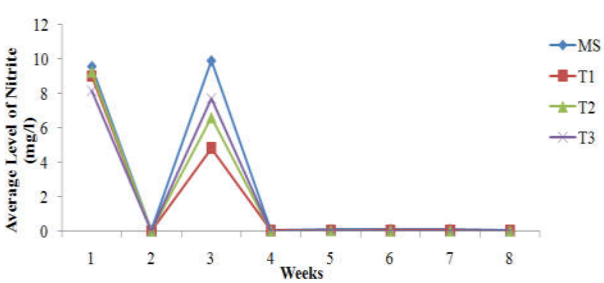

Fig. 5: Weekly Nitrite Levels in the Wet Season

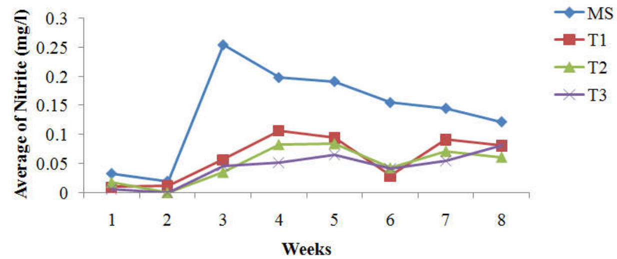

Fig. 6: Weekly Nitrite Levels in the Dry Season

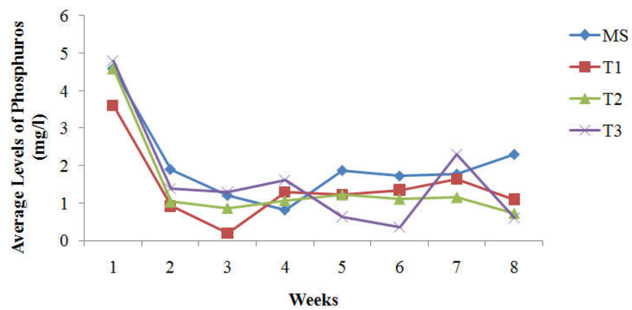

Fig. 7: Weekly Trend of Phosphorus in the Wet Season

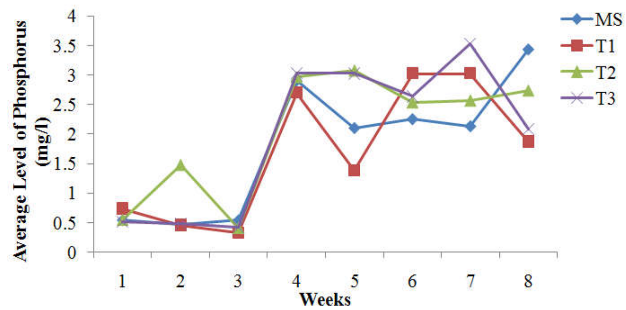

Fig. 8: Weekly Trend of Phosphorus in the Dry Season

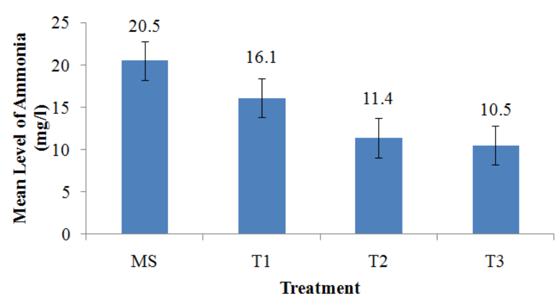

Fig. 9: Variation in Ammonia Levels

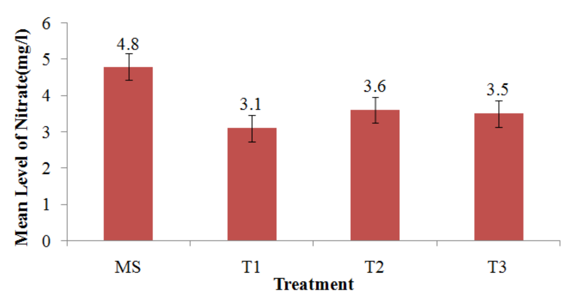

Fig. 10: Variation in Nitrate Levels

July/August. The mean annual rainfall is 1,100 mm within 95 days of intense rainfall. The dry season is usually from November to March. It is influenced by the dry North-Easterly (harmattan) winds while the rainy season is influenced by the moist South Westerly winds. The mean day temperatures range from 33°C to 39°C while mean night temperature range

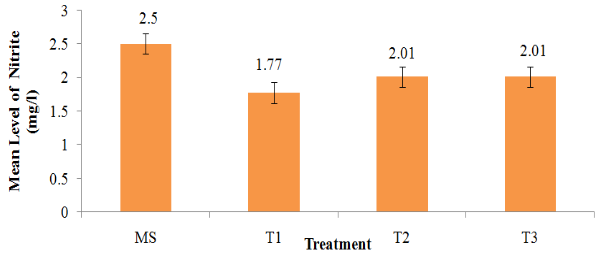

Fig. 11: Variation in Nitrite Levels

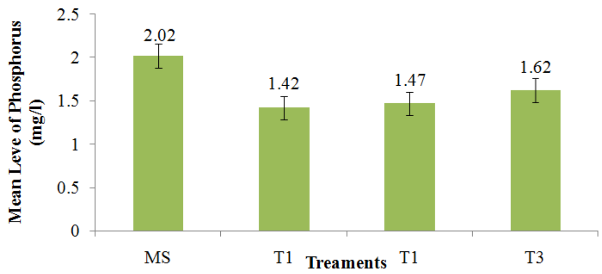

Fig. 12: Variation in Phosphorus Levels

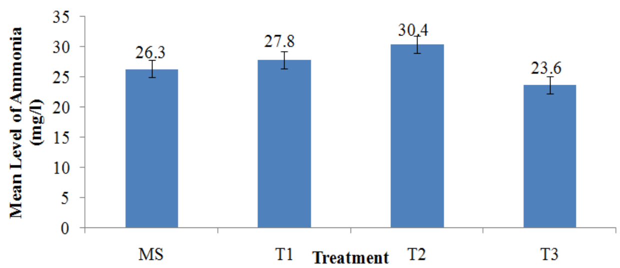

Fig.13: Variation in Ammonia Levels

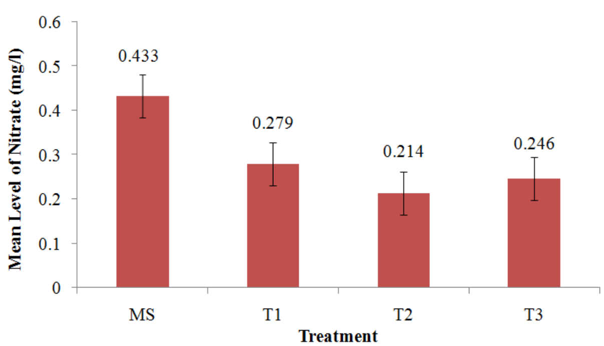

Fig. 14: Variation in Nitrate Levels

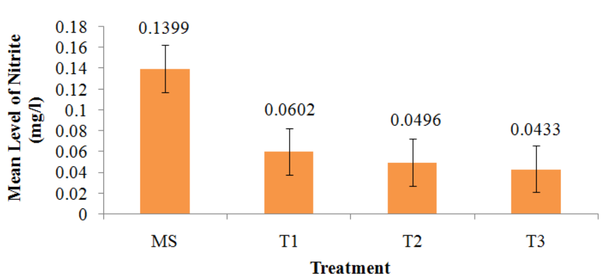

Fig. 15: Variation in Nitrite Levels

from 20°C to 22°C. The wet season relatively recorded larger volumes of water supply to the treatment system. During the dry season wastewater supply (MS) from the Kamina Barracks to the treatment system was highly irregular, thus little

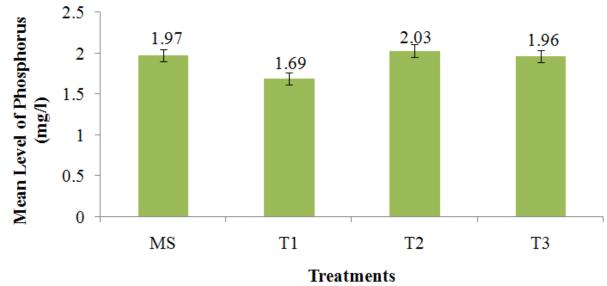

Fig.16: Variation in Phosphorus Levels

volumes of wastewater was observed for the main source during data collection whiles the stabilization ponds had weekly treated accumulated wastewater.

Ammonia (NH_3)

According to Deborah, (1996) unpolluted waters contain small amount of ammonia and ammonia compounds, usually <0.1 mg/l as nitrogen. Total ammonia concentrations measured in surface waters are typically less than 0.2 mg/l N but may reach 2 - 3 mg/l N. Higher concentrations could be an indication of organic pollution such as from domestic sewage, industrial waste and fertilizer run-off. Ammonia is, therefore, a useful indicator of organic pollution. By definition, ammonia is a chemical consisting of one atom of nitrogen and three atoms of hydrogen and designated in chemical notation as NH_3. Ammonia is extremely soluble in water and is frequently used as a water solution called aqua ammonia. Ammonia chemically combines with water to form ammonium hydroxide (Properties of ammonia available at http://www.osha.gov/SLTC/etools/ammonia_refrigeration/ammonia/index.htm, 2011).

Substantial losses of ammonia can occur via volatilization with increasing pH. Anhydrous Ammonia gas is considerably lighter than air and will rise in dry air. However, because of ammonias' tremendous affinity for water, it reacts immediately with the humidity in the air and may remain close to the ground (Deborah, 1996). Ammonium hydroxide is a weak base that is partially ionized in water according to the equilibrium NH_3 + H_20 [NH_4OH] $NH4^{+}$ + OH. The dissociation constant, K_b, is 1.774 x 10^5 at 25°C (pKb is 4.751) and increases slightly with increasing temperature (Weast *et al.*, 1988). Ammonium salts such as chloride, nitrate, and sulphate are strongly dissociated and very soluble in water (Weast *et al*,. 1988); therefore, changes in pH will not normally result in the formation of ammonium precipitates (Ammonia Chemical and Physical Information. Available http//www.atsdr.cdc.gov/ToxProfiles/tp126-c4.pdf, 2011).

Effect of Treatment on Ammonia Levels

Ammonia in the wet season recorded a decrease in level for a two week period. The overall levels of ammonia (NH_3) for week two, three, four and five were quite lower than the other weeks. It can also be observed from Figure 1 that treatment effect seems best at higher levels of ammonia. It can also be observed from Figure 2 that the average levels of ammonia in the dry season were relatively high. The level of ammonia in the control (MS) of week four, five, six and seven were higher than that of the treatments (T_1, T_2, and T_3). This could be

Table 1: Reduction Levels of Chemical Contaminants

	Parameters							
	Ammonia		Nitrate		Nitrite		Phosphorus	
Treatment	mg/l	%	mg/l	%	mg/l	%	mg/l	%
MS	20.5	100	0.433	100	0.1399	100	2.02	100
T_1	16.1	78.5	0.297	68.8	0.0602	43	1.42	70
T_2	11.4	55.6	0.241	49.4	0.0496	35.5	1.47	73
T_3	10.5	51.2	0.246	56.8	0.0433	31	1.62	80

Table 2: Grand Means and EPA Ghana Standard Guidelines/Limits

Chemical Parameters/Limits	Grand Mean Levels Wet Season (mg/l)	Dry Season (mg/l)	EPA Ghana Standard (mg/l)
Ammonia	14.60	27.00	1.00
Nitrate	3.80	0.29	50.00
Nitrite	2.07	0.07	_
Phosphorus	1.63	1.87	2.00

attributed to relatively higher concentration of ammonia in the weekly accumulated volumes of water in the stabilization ponds to that of the main source (MS). This observation can also be an attribution of ammonia being highly volatile under different environmental conditions and therefore being volatile at a faster rate in the control (MS) than that of the treatment (T_1, T_2, and T_3).

Nitrate NO_3^-(mg/l)

According to Helmer, and Hespano (1997), the most widely used water quality standard for nitrate (NO_3^-) is the 50 mg/l limit adopted by World Health Organisatin (WHO) as a precautionary level to safeguard babies from the risks of contracting methaemoglobinaemia (WHO, 1993). Most national authorities regard the 50 mg /l concentration as a realistic target in relation to eutrophication. According to Tuikolongahau (2008), under normal conditions, both nitrites (except the ammonium salt) and nitrates are stable compounds. However, at higher temperatures they decompose, and may be explosive at extreme conditions (high temperature and pressure). Nitrate and nitrite compounds are very soluble in water and quite mobile in the aquatic environment. WHO has recommended a molecular absorption spectrometric method for the determination of nitrate in potable water, raw and wastewaters (ISO, 1984). According to ISO (1984) the limit of detection lies within the range of 0.005–0.01 mg /l.

Nitrate Occurrence and Behaviour

The weekly trend for nitrate in the wet season recorded highest for week one and three and uniform low levels for the other weeks. The response to treatment though not statistically significant, but was quite positive with some level of reduction for the treatments. The situation for the dry season was different from that of the wet season. The response to treatment was statistically significant with f-probability of 0.001. Apart from week one and three of the wet season, nitrate levels for the dry season were relatively higher. This reason may be due to variation in stability and solubility by virtue of different environmental conditions like temperature, relative humidity among others for the respective seasons. From Figure 3 and 4 it is clear that Figure 3 followed a uniform pattern and this may be attributed to equal volumes of dilution from rain water aiding uniform solubility for the wet season.

Nitrite NO_2^-(mg/l)

Nitrite recorded significant level of reduction only in the dry season. Deborah (1996), indicated that nitrite concentrations in freshwaters are usually very low, 0.001 mg/l. NO_2^-N, and rarely higher than 1 mg/l NO_2^-N. High nitrite concentrations are generally indicative of industrial effluents and are often associated with unsatisfactory microbiological quality of water. According to Tuikolongahau (2008) in nature, nitrates are readily converted to nitrites and vice versa. Nitrite is a conjugate base of weak acid HNO_2; p*K*a = 3.4. It is highly soluble in water and mobile in the environment (WHO, 2007). Under normal conditions, both nitrites (except the ammonium salt) and nitrates are stable compounds. Generally, the presence of chlorides, some metals and organic material destabilize both nitrates and nitrites. Nitrites oxidize slowly to nitrates when exposed to air (Williams, 2001). Unlike ammonia, nitrites do not evaporate and remain in water until they are taken up by plants or consumed by microorganisms (Hill 1996; Bockman *et al,*. 1999). Chemical and biological processes can further reduce nitrite to various compounds or oxidize it to nitrate (ICAIR Life Systems Inc., 1987).

Nitrite Occurrence and Behaviour

Both nitrate and nitrite showed similar characteristics by virtue of occurrence and responds to treatment. Week one and three of wet season recorded the highest level and a uniform low level for the other weeks. The level of reduction was statistically significant with f-probability of 0.002 in the dry season. The reason may be due to the difference in microbial activities and stability for the various seasons, with the highest stability in the dry season. The similarities in behaviour may be attributed to their chemical composition (being ionic with negative charges) and the readiness of one converting to the other in nature as stated by Tuikolongahau (2008). Figure 5 and 6 depicts weekly mean nitrite levels with respect to treatment. The uniform pattern of Figure 5 can also be ascribe to equal volumes of dilution from rainwater coupled with uniformity of dilution of nitrite in the wet season.

Phosphorus P (mg/l)

According to Sotirakou *et al*. (1999), phosphorus (P) occurs in natural waters and in wastewaters almost solely as phosphates. These phosphates include organic phosphate, polyphosphate (particulate P) and orthophosphate (inorganic P). Critical levels of phosphorus in water above which eutrophication is likely to be triggered, are approximately 0.03 mg/l of dissolved phosphorus and 0.1 mg/l of total phosphorus. The discharge of raw or treated wastewater, agricultural drainage, or certain industrial wastes that contain phosphates to a surface water body may result in a highly eutrophic state, in which the growth of photosynthetic aquatic micro and macro organisms are stimulated to nuisance levels. Phosphates are typically present in raw wastewaters at concentrations near 10 mg/l as P. During wastewater treatment, about 10 - 30% of the phosphates in raw wastewater is utilized during microbial cell synthesis and energy transport. Additional removal is required to achieve low effluent concentration levels from the wastewater treatment process. Effluent limits usually range from 0.12 mg/l as P, with many established at 1.0 mg/l (Just what do Nitrate and Phosphate do? Available at http:// www.freedrinkingwater.com/water_quality/quality1/1-what-nitrate-and-phosphate-do.htm, 2011).

Phosphorus Occurrence and Behaviour

The treatment of phosphorus recorded no significant level of reduction for both seasons. However, there were some weekly variations in levels in responds to treatment. Week one of the wet season recorded the highest level with a uniform decrease in week three and a slight increase in week four for all the treatments and the control. The behaviour for week five, six and seven can be described as irregular. Week eight observe a uniform decrease in levels for all the treatment and a rise for the control (MS). This observation is represented in Figure 7. The situation for the dry season is opposite to that of the wet season. Figure 8 clearly indicates that phosphorus recorded the lowest levels for week one, two and three followed by a greater rise from week three to four for all the treatments and the control. The observation for week five, six and seven can also be described as irregular. Week eight recorded a decrease in levels for treatment (T_1) one and three (T_3) and an increase for the control (MS) and treatment two (T_2). The major factor which alters the behaviour of phosphorus in wastewater treatment system is the activities of micro-organisms. According to Sotirakou *et al*. (1999), there are certain microorganisms capable of storing phosphorus (in the form of polyphosphates), metabolize it for energy reduction and cell synthesis, resulting in the removal of phosphorus from wastewater treatment system through activated sludge. Thus, the overall behaviour and variation of phosphorus levels may be attributed to the different rate of microbial activities at the various seasons in both the filtering units and the stabilization pond.

TREATMENT PERFORMANCE OF CHEMICAL PARAMETERS

Analysis of Variance (ANOVA) for the Wet Season

The results from ANOVA showed that the level of reduction was statistically significant for only ammonia in the wet season with f-probability of 0.006. The significant difference occurred between the MS and T_2 and T_3 but not T_1. However, phosphorus, nitrate and nitrite also recorded some level of reduction but not statistically significant.

Analysis of Variance (ANOVA) for the Dry Season

The level of reduction for both nitrate and nitrite were statistically significant with f-probability of 0.001 and 0.002 respectively for the dry season. The difference occurred between the control (MS) and the treatments. Ammonia and phosphorus also recorded variation in levels but was not statistically significant.

Treatment Efficacy on Reduction of Chemical Contaminants

It can be deduced from Table 1 that ammonia level was reduced best to a minimum of 51.2% by treatment three (T_3) in the wet season. The level of nitrate was reduced to a minimum of 49.4% by treatment two (T_2) whiles nitrite on the other hand, was best reduced by treatment three (T_3) to a minimum of 31% in the dry season. It can therefore be ascertained that treatment two (T_2) and three (T_3) had the best of treatment efficiency by virtue of level of reduction. Though phosphorus recorded no statistically significant level of reduction, treatment in the wet season it was relatively better than that of the dry season with 70% minimum level of reduction.

Allowable Limits of Chemical Contaminants

It is evidently clear from Table 2 that the level of ammonia contained in the wastewater is above the range of EPA Ghana guideline whiles nitrate on the other hand is far below the acceptable limit. The acceptable limit of nitrite though not yet define by EPA Ghana, recorded a wide range of reduction from the wet season to the dry season. Phosphorus levels are also below the EPA Ghana standard.

CONCLUSIONS

Based on the Environmental Protection Agency Guidelines of Ghana (2003), the level of ammonia in the wastewater is too high for irrigation purposes. The level of nitrate is lower and therefore safe for agricultural purposes. The wider difference between seasonal nitrite levels is a signal of potential health risk at the study site. Phosphorus levels though below standard, stand the chance of exceeding the limits since levels are closer to the EPA standards thus posing future risk. The study revealed that, with the exception of ammonia, all other parameters have relatively higher levels in the wet season as compared to that of the dry season. The study realised that the treatment of ammonia, nitrate and nitrite by the horizontal trickle sand filter combine with stabilization ponds varied seasonally. The design also had significant impact on level of reduction and behaviour of the chemical parameters of wastewater in the study area. Treatment two (T_2) and three (T_3) of the system have similar capability with respect to reduction of level of chemical parameters, however treatment three (T_3) emerged the best in reduction of the parameters.

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