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Occurrence dynamics of nitrogen compounds in faecal sludge stabilisation ponds in the Tamale Metropolis, Ghana

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Faecal sludge, with richness in soil nutrients represents an important resource for enhancing soil productivity. In this study, the occurrence dynamics of nitrogen compounds NH_3, NO_2^- and NO_3^- in engineered waste stabilisation ponds in the Tamale metropolis was monitored for 5 months in the dry season. Four treatment ponds were divided into three units: Influent point, midpoint and effluent point for sampling purposes. Faecal sludge sampling was simultaneously carried out for each of the ponds at marked points and approximate depth of 30 to 50 cm using 500 ml sample collection bottles. Using the Nessler method and Powder Pillows NH_3, NO_3^- and NO_2^- levels were determined through direct reading with a DR 2800 Spectrophotometer. Mean concentrations of NH_3, NO_3^-, and NO_2^- were determined to be 42.65, 57.99 and 0.15 mg/l, respectively. The anaerobic pond on average, recorded the maximum concentration levels of all three compounds. The primary facultative pond recorded the average minimum concentration of NO_2^- while the maturation pond recorded the minimum for both NH_3 and NO_3. Variation in concentration of nitrogen compounds was statistically highly insignificant by ANOVA at 5% significance level, except NH_3. Average NH_3 concentrations in stabilisation ponds were observed to be higher than the allowable limit of EPA Ghana for effluent discharge or reuse for agriculture while NO_3^- was lower aside concentration in the anaerobic pond. The effluent should further be treated to reduce NH_3 concentration using different treatment options such as the filter beds or constructed wetland prior to reuse for agriculture.

Key words: Faecal sludge, stabilisation pond, nitrogen compounds, nitrification, denitrification.

INTRODUCTION

Management of faecal sludge in urban centres of most developing countries is generally characterised by indiscriminate disposal in the environment, notwithstanding the consequent health and environmental

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implications (Ingallinella et al., 2002). However, faecal sludge is rich in plant nutrients and organic matter constituents, which contribute to replenishing the humus layer, soil nutrient reservoir, and improvement of the soil structure. It thus represents an important resource for enhancing soil productivity on a sustainable basis (Koné et al., 2010). According to Kuffour (2010), treatment options for faecal sludge should allow for optimum recovery of nutrients to support agriculture. Over the years, stabilisation and settling ponds have been the significant faecal sludge treatment options in Ghana (Kuffour, 2010). Studies by Cofie et al. (2004) highlighted the potentials and acceptance of faecal sludge as a good source of fertiliser by farmers in the Tamale Metropolis.

Nitrogen compounds are essential nutrients for living organisms and undergo biogeochemical transformations in the environment as part of the nitrogen cycle (Lehnert et al., 2015). Plants and micro-organisms convert inorganic nitrogen to organic forms. In the environment, inorganic nitrogen occurs in a range of oxidation states as nitrate (NO_3^-), nitrite (NO_2^-), ammonium ion (NH_4^+) and molecular nitrogen (N_2) while organic nitrogen is found in proteins, amino acids, urea, living or dead organisms and decaying plant material (Wall, 2013). NH_3 is produced by the metabolism of proteins and other nitrogen-containing compounds. Mohiuddin and Khattar (2019) mentioned that glutamine is the primary source of ammonia (NH_3) in urine and also explained that the metabolic mechanism responsible for the regulation of NH_3 in the body causes the removal of nitrogen from peripheral tissues to the liver for its ultimate disposal as urea. Lentner et al. (1981) estimated that about 20% of faecal nitrogen is NH_3, biochemically degraded from proteins, peptides and amino acids. NO_3^- is an important pollutant which in excess serves as nutrient and stimulate the growth of algae responsible for algal blooms (Aniyikaiye et al., 2019) and other plants which decompose to increase biochemical oxygen demand (Okoh, 2010). NO_3^- in faecal sludge is attributed to possibly, the oxidation of nitrogenous waste products in human excreta (WHO, 2008). High NO_3^- concentrations in a treatment system primarily indicate a high level of oxygen available in the system and properly functioning nitrification (Krekeler, 2008).

The study determined the occurrence and concentration dynamics of nitrogen compounds in faecal sludge stabilisation ponds located at the landfill site of the Tamale Metropolis in Ghana.

MATERIALS AND METHODS

Study area

This study was undertaken in the Tamale Metropolis waste stabilisation ponds near Gbalahi community in the Northern region of Ghana. Geographically, the stabilisation ponds are located between latitude 09°26'34.41"N to 09°26'41.90" N and longitude 000°45'24. 13" W to 000° 45'28.30" W. Figure 1 is the map of the study area and location of the faecal sludge stabilisation pond in the Metropolis. The region experiences one rainy season starting from April/May to September/October with a peak season in July/August with an average annual rainfall of 1,000 to 1,300 mm. The dry season is between the months of November and May. The region is one of the hottest in the country with an annual average temperature of 29 to 34°C. Annual average relative humidity is estimated at 47.0% while reference evapotranspiration (ETo) is reported above 600 mm/year (Armah et al., 2010; Abdul-Ganiyu, 2011).

The stabilisation ponds receive faecal sludge from cesspit emptier operators in the Metropolis and the ponds consist of two units, each of three ponds anaerobic, primary facultative, and secondary facultative ponds) in series connected to a single maturation pond.

Field data collection and analysis

Each of the four treatment ponds: Anaerobic (AN), Primary Facultative (PF), Secondary Facultative (SF) and Maturation (MT) were divided into three units: influent point (IP), midpoint (MP) and effluent point (EP) for sampling purposes. Faecal sludge sampling was simultaneously carried out for each of the ponds at marked points and approximate depth of 30 to 50 cm using 500 ml sample collection bottles. A total of 12 samples were collected per each sampling time and at 14 days interval for a period of 5 months (November 2013 to March 2014) in the dry season. Laboratory analyses were thus carried out on a total of 120 samples for the entire study. Using the Nessler Method and Powder Pillows NH_3, NO_3^- and NO_2^- levels were determined through direct reading using a DR 2800 Spectrophotometer. The data was analysed for variation in N compounds among stabilisation ponds by ANOVA performed at 5% level of significance. Minitab 16 was used for the ANOVA and multiple mean comparison while graphs were generated using Microsoft Excel 2016.

RESULTS AND DISCUSSION

Ammonia (NH_3) concentration in stabilisation ponds

The study results indicated that the AN pond recorded the highest NH_3 concentration of 142.53 mg/l at the IP, 114.71 mg/l at the MP, and 116.12 mg/l at the EP with the details presented in Figure 2. Volatilisation of NH_3 was noted to be the only likely nitrogen removal mechanism in AN pond. With a probability value (p-value) of 0.84 for the ANOVA at 5% significance level, the mean concentration of NH_3 was noted to be statistically insignificant. Ramadan and Ponce (2008) explained that in AN pond, organic nitrogen is hydrolysed to NH_3, so concentrations in AN pond effluent are generally higher.

NH_3 exhibited a slight variation in concentration in the PF pond with a maximum concentration of 35.41 mg/l at the IP, which slightly reduced to 34.28 mg/l at the MP and eventually increased to 34.96 mg/l at the EP (Figure 2).

A similar variation in the concentration of NH_3 was recorded in the SF pond and with ANOVA 5% significance level recording p-value of 0.74, and 0.99 for PF pond indicating no statistically significant variation within the various ponds. The evidence of NH_3 removal by volatilising in facultative ponds was noted in the study of

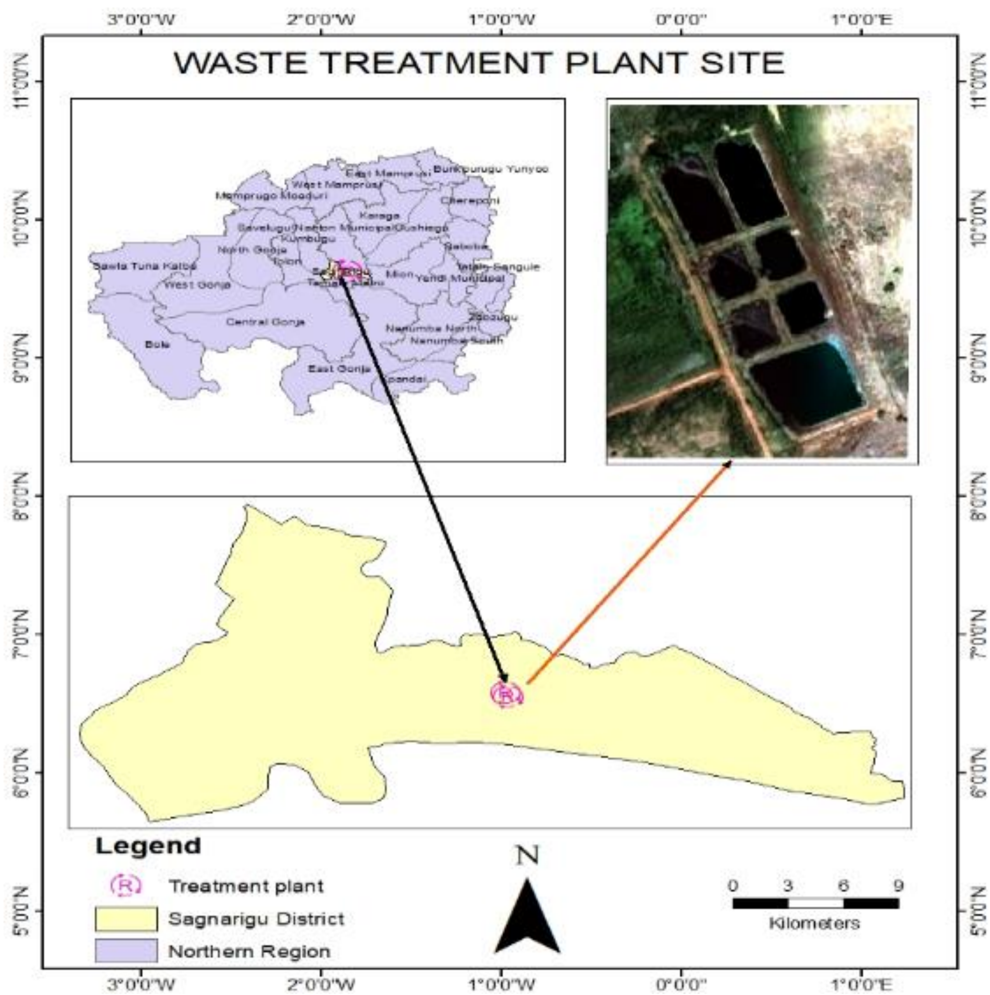


Figure 1. Map of study area.

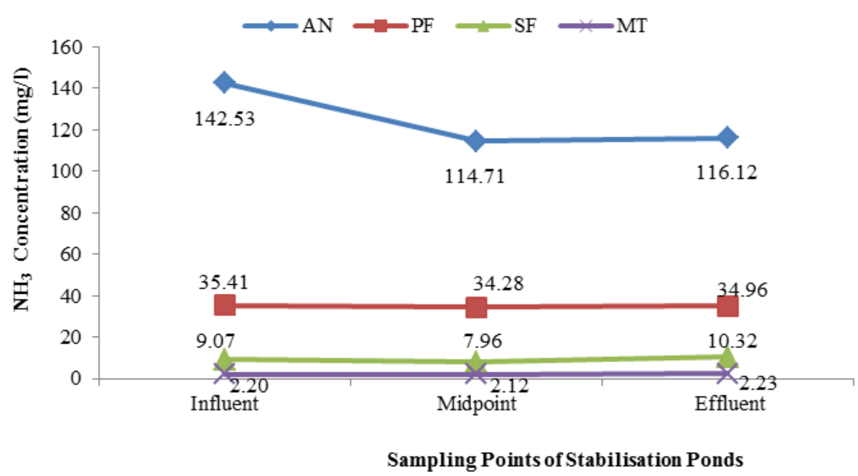


Figure 2. NH_3 concentration across sampling points in stabilisation ponds.

Vendramelli et al. (2016). Similarly, NH_3 in the MT pond recorded mean concentration of 2.18 mg/l with p-value of 0.99, thus indicating statistically insignificant variation. Soares et al. (1996) found that, high degree of NH_3

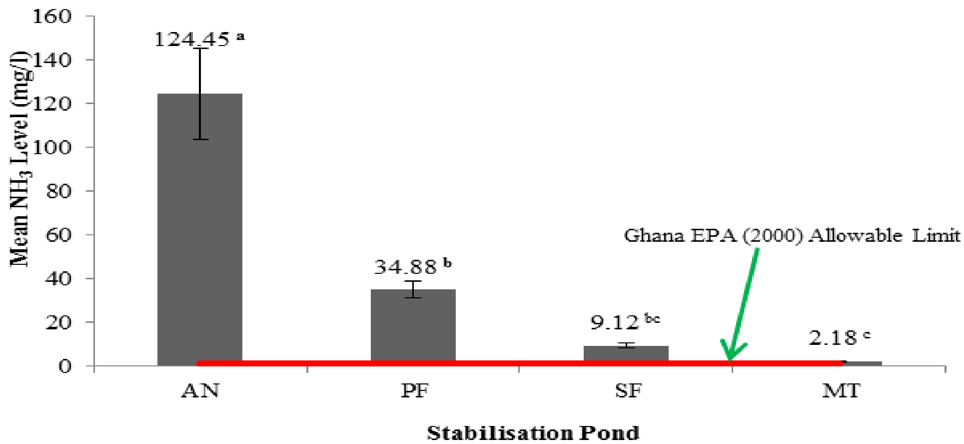


Figure 3. Average NH_3 concentration in stabilisation ponds**.** Data labels that do not share a letter (a, b or c) are significantly different.

removal commenced in the SF pond and subsequent MT pond due to improved aerobic conditions in shallow ponds.

The concentration rate of NH_3 indicated average maximum concentration of 124.45, 34.88, 9.12 and 2.18 mg/l in the AN, PF, SF and MT ponds, respectively as presented in Figure 3. Higher concentrations of NH_3 in the AN pond as well as the PF pond, could be an indication of high organic pollution (Deborah, 1996). Low NH_3 concentrations in the SF and the MT ponds could be attributed to losses via volatilisation which increases with increasing pH (Metcalf and Eddy, 1995; Deborah, 1996). Bastos et al. (2018) proved that algal nitrogen uptake and sedimentation of biologically incorporated organic nitrogen are the principal mechanisms responsible for NH_3 and total nitrogen removal in MT pond. In the study of Mayo (2013), mineralisation and NH_3 uptake by microorganisms accounted for 39.1 to 35.4% of the total nitrogen transformed for which NH_3 served as a source of nitrogen for cellular growth. Nitrification and denitrification also accounted for 31.3 and 26.2%, respectively of total nitrogen transformed in SF pond while in MT pond, NH_3 uptake accounted for 35.9%.

The results of ANOVA at 5% significance level showed that the variation of NH_3 concentrations among stabilisation ponds was statistically highly significant with p-value of <0.001. With least significant difference (LSD) of 29.93, NH_3 concentration in the AN pond was statistically different from the other ponds (Figure 3). All the NH_3 levels in the stabilisation ponds were above the allowable limit of 1 mg/l standard by Ghana EPA (2000) for effluent discharge or reuse for agriculture. High NH_3 levels in sludges may affect the performance of the treatment systems by posing biocidal effects to a range of microorganisms involved in the different biological treatment process and impair or suppress anaerobic degradation and/or algal growth (Montangero and Strauss, 2002; Koné and Peter, 2008; Liu et al., 2019). The effluent should thus further be treated to reduce NH_3 concentration using different treatment options such as the filter beds or constructed wetland prior to reuse for agriculture.

Nitrate (NO_3^-) concentration in stabilisation ponds

NO_3^- exhibited diverse degrees of occurrence within the stabilisation ponds. NO_3^- concentration steadily decreased from IP to EF at respective concentrations of 142.53 to 32.41 mg/l, 10.38 to 7.65 mg/l, and 11.76 to 9.03 mg/l for AN, PF and MT ponds, respectively. SF pond however, decreased from 11.88 mg/l to a minimum of 8.18 mg/l at MP and finally increased to 10.9 mg/l at the EP as presented in Figure 4. Results of ANOVA at 5% significance level for the variation in sampling point location presented no significant difference within the ponds with p-values of 0.24, 0.82, 0.65 and 0.81 for AN, PF, SF and MT ponds, respectively. The subsequent rise of NO_3^- concentration at the EP in SF pond can be attributed to oxidation of NO_2^- to NO_3^- in nitrification processes (Lenntech, 2014). NO_3^- concentrations in stabilisation ponds are largely influenced by nitrification and denitrification processes (Mayo and Hanai, 2014). Accordingly, the higher NO_3^- concentration might indicate a higher nitrification rate than denitrification at the various points within the stabilisation ponds and vice versa.

The dynamics of NO_3^- resulted to an average maximum concentration of 67.06 mg/l in AN pond, which significantly reduced to 9.16 mg/l in the PF pond, 10.32 mg/l in the SF pond and 10.68 mg/l in the MT pond (Figure 5). Bansah and Suglo (2016) similarly recorded an appreciable reduction of NO_3^- from 2.39 to 0.4 mg/l in final effluent of typical waste stabilisation ponds in the Obuasi Municipality of Ghana. NO_3^- reduction from the

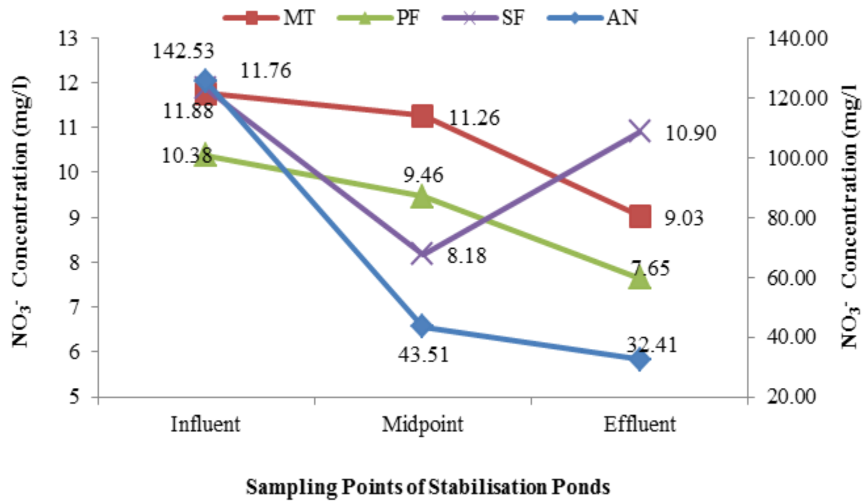
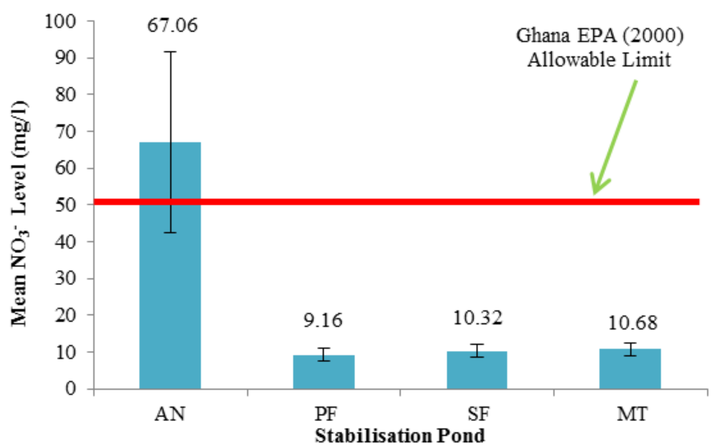


Figure 4. NO_3^- concentration in stabilisation ponds.



Figures 5. Average NO_3^- concentration in faecal sludge treatment ponds.

AN pond to the PF pond can be attributed to the biochemical reduction of NO_3^- to NO_2^-. NO_3^- may biochemically reduce to NO_2^- by denitrification processes, usually under anaerobic conditions (Deborah, 1996).

Statistically, variation of NO_3^- concentrations among stabilisation ponds were realised to be insignificant by ANOVA at 5% significance level with a p-value of 0.119. Aside NO_3^- concentration in the AN pond, all concentrations were below the Ghana EPA (2000) allowable limit of 50 mg/l for effluent discharge or reuse. According to Deborah (1996), NO_3^- concentrations above 5 mg/l usually indicates pollution by human waste, and in cases of extreme pollution, concentrations may reach 200 mg/l. Higher concentrations can, therefore, represent a significant health risk to humans when especially exposure levels are high.

Nitrite (NO_2^-) concentration in stabilisation ponds

Variation of NO_2^- concentration from the IP, MP and the EP for the various ponds is presented in Figure 6.

In the AN pond, a maximum NO_2^- concentration of 0.71 mg/l at the IP reduced to 0.10 mg/l at MP, and 0.12 mg/l at EP. The remaining ponds recorded a marginal increase from the IP to the EP at respective concentrations of 0.06 to 0.17 mg/l, 0.03 to 0.20 mg/l and 0.02 to 0.01 mg/l for PF, SF and MT ponds. Variation of the NO_2^- concentration was determined to be statistically insignificant with p-values of 0.318, 0.740, 0.645 and 0.343 for AN, PF, SF and MT ponds, respectively.

An average NO_2^- concentration of 0.31, 0.13, 0.14, and 0.01 mg/l were recorded for AN, PF, SF and MT ponds, respectively. The general dynamics of NO_2^- in the

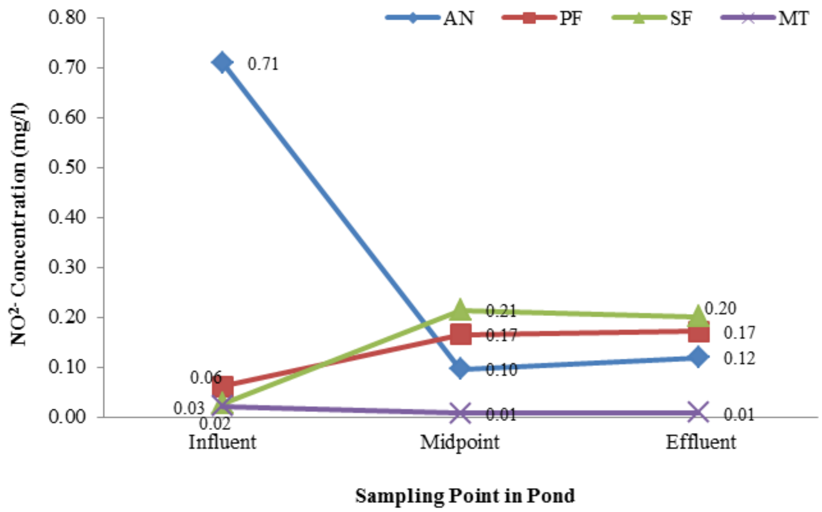


Figure 6. NO_2^- concentration in stabilisation ponds.

stabilisation ponds are mainly influenced by nitrification of ammonium (NH_4^+) to NO_2^- which produces NO_3^- as the final product. However, under favourable conditions, NO_3^- may be denitrified to form NO_2^- and N_2, with the involvement of bacterial species such as *Pseudomonas, Micrococcus, Achromobacter,* and *Bacillus* (USEPA, 2011).

Gad and Abdalla (2017) similarly observed an appreciable increase in NO_2^- and NO_3^- level from anaerobic to facultative ponds due to potential nitrification while further decreased in MT was attributed to denitrification and directly uptake by algal biomass.

The significance of sedimentation as a permanent or primary route for nitrogen removal in stabilisation ponds is highlighted by different authors (Senzia, 1999; Mkama, 2005; Mayo, 2013; Irene et al., 2014). Mayo (2013) found 73.7% of total nitrogen removal by sedimentation while denitrification accounted for over 90% in SF and MT ponds. The role of denitrification as a dominant mechanism for nitrogen removal in MT pond has also been reported by Mtweve (1999).

The acceptable limit of NO_2^- for effluent discharge is not defined by Ghana EPA. NO_2^- concentration are usually found to be very low, of about 0.001 mg/l, and rarely higher than 1 mg/l NO_2^-N thus high concentrations are often associated with unsatisfactory microbiological quality (Deborah, 1996).

Conclusion

Occurrence of nitrogen compounds was observed to vary in the faecal sludge stabilisation ponds. The AN pond on average, recorded the maximum concentration of all the compounds monitored and with the PF pond recording the average minimum concentration of NO_2^-. MT pond however recorded the minimum concentrations for both NH_3 and NO_3^-. Biochemical activities occurring within the ponds were noted to have very little effect on the variation of nitrogen compound concentrations. Average NH_3 concentration in stabilisation ponds was observed to be higher than the allowable limit of EPA Ghana for effluent discharge or reuse for agriculture while NO_3^- was lower, aside concentration in the AN pond. The effluent should thus further be treated to reduce NH_3 concentration using different treatment options such as the filter beds or constructed wetland prior to reuse for agriculture.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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