Environmental Management Tool for Treatment of Wastewater and Re-use in Aquaculture and Agriculture: The use of Wetlands and other Bio-systems in Treatment of Wastewater & re-use/recycling

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Abstract: *STELLA II v9.1.4 Modelling Software (1985-2010) was used to develop a fish pond model which is a good environmental health management tool. The problem studied was to reduce environmental pollution and encourage efficient re-use of used resources. The methods used in the study were quantitative by grabbing the wastewater samples three times a week seasonally in one year and data for model calibration was collected daily for a period of three months. Temperature, pH, and DO were measured "in situ" using portable Multi-parameter, HACH Model SENSION 156 (2001). Org-N, TKN,* NH_3*-N,* NO_3*-N, N-Sediments, Chl"a"/N-Planktons, N-Fishes and F-Coliforms were measured in laboratories by standard methods of water and wastewater treatment. The results obtained indicated that Ammonia-Nitrogen (*NH_3*-N) in fish pond receiving outlet from Horizontal Subsurface Flow Constructed Wetland (HSSFCW) reached an average of 3.3 mg/l* NH_3*-N more than 1.2 mg/l standard for re-use in agriculture and body threshold of 0.1 mg/l. N-Fishes was 21.1% higher than the Standards of 4-10% in animal tissues. The dominant routes of Nitrogen removal were sedimentation, accretion, decaying and denitrification resulting in 87.48% total N-removal at 95% confidence level. Sensitivity analysis of fish pond model gave the uptake rate of 0.3* d^{-1} NH_4*-N (*$R^2 = 0.71$*) and fish growth rate of 7.0* d^{-1} *(*$R^2 = 0.99$*) as the most important parameters. It is concluded to construct two further HSSFCWs to buffer N-nutrients. It is recommended to conduct another research to examine Nitrogen and toxic heavy metals in soils and yields from farms to safeguard human health and the environment.*

Key words: Environmental management tool, fish pond, wastewater treatment, re-use in agriculture and aquaculture

INTRODUCTION

About 90% of wastewater in cities and towns in developing countries is discharged untreated into water bodies (Senzia *et al.,* 2004; Steiner and Tibaijuka, 2010). Municipal, domestic and industrial wastewaters are point sources of pollutants that lead to excessive Nitrogen and Phosphorus nutrients, pathogens, suspended matter and heavy metals in the receiving water bodies (Steiner and Tibaijuka, 2010) Excessive nutrients concentration may cause health effects to the quality of receiving waters, aquifers, aquatic species and humans that can pollute both surface and ground waters.Excess nutrients in receiving water bodies cause eutrophication, siltation and oxygen depletion (Mayo and Bigambo, 2005). In drinking water, excess nutrients such as nitrogen can cause the blue-baby-syndrome (Methamoglobinemia) in infants and other water-related diseases. Climate change caused by wastewater-related emissions of global warming gases such as methane and nitrous oxide nitrogen compounds is estimated to rise by about 50% by the year 2020 (Steiner and Tibaijuka, 2010). Excess nutrients are accrued from domestic, municipal wastewater, urban run-off, agricultural, mining drainage and industrial discharges (Sekiranda and Kiwanuka, 1998). Excess nitrogen compounds in water can deplete oxygen due to nitrification, which can cause eutrophication in aquatic ecosystems. To solve some environmental pollution problems and water related diseases like Methaemoglobinaemia and other diseases, it is crucial to monitor nutrient levels in the environment. This paper deals with the development of an environmental management tool to answer the following questions among others:

(i) How to determine nitrogen nutrient in a fish pond receiving an outlet from HSSFCW to get quality outlet for re-use in agriculture and to model it using an environmental management tool?
(ii) What is happening with the water quality, if input inlet water gets worse or better?
(iii) Is the ammonia (NH_3-N) concentration acceptable to the fish or not toxic to them?

It is required that $[NH_3] < 0.025$ mg/l as an acceptable value which is not toxic to the fish.

(iv) What happens if the fish pond is bigger (2x) or smaller (1/2x) compared to the present volume?
(v) What can happen if the number of fish is reduced to half or doubled?

The main focus of this study is therefore, how to use the STELLA II v9.1.4 Model Software (1985-2010) to develop a good environmental health management tool for the purpose of maintaining environmental health. It is hypothesised that the fish pond receiving an outlet from HSSFCW can have about 1.2 mg/l ammonia-N for fish growth tolerance (WHO, 1989; FAO, 1997; TBS, 2005).

MATERIALS AND METHODS

The research methods included fieldwork, sampling of water samples from Mabogini Moshi-Kilimanjaro study area, laboratory work, statistical data analysis and ecological modelling. The laboratory experiments were conducted at Moshi Municipal Water and Sanitation Authority (MUWSA); Arusha Urban Water and Sanitation Authority (AUWSA); Ngurdoto De-fluoridation Laboratory Arusha; Ardhi University in Environmental Engineering; University of Dar es Salaam in the Department of Chemical and Mining Engineering, Botany and Zoology laboratories. Modelling work was done by using STELLA II v9.1.4 Model Software. Materials used during field work included white polyethylene plastic bottles of one litre each for carrying the small wastewater bottles to the laboratory for analysis within 24 hours time.

Sampling, Sample Preservation and Laboratory Analysis

Sampling of water samples wasat Mabogini-Moshi Kilimanjaro Region, Northeastern Tanzania. Grab wastewater samples were collected with white polyethylene plastic bottles after rinsing three times with the same. The sample parameters were analyzed using the standard methods of the examination of water and wastewater analysis (APHA, 2005). These were then analysed in the laboratory were Nitrogen (Total Kjeldahl (TKN), Organic (Org-N), Ammonia (NH_3-N), Nitrate (NO_3-N), Chlorophyll "Chl a"/N-Planktos, Sediments (N-Sedim), Fish (N-Fish), and Faecal Coliforms). The samples were kept in a big cool box container with ice cubes at about 4^oC for preservation and carrying to Ardhi University at the Environmental Engineering Laboratory, Dar es Salaam for analysis. Sample bottles for "Chl a" were covered by an aluminum foil to prevent entrance of light. Temperature, pH and dissolved oxygen were measured ***"in situ***.

Modelling of Nitrogen nutrient in the Fish Pond

The conceptual diagram based on the Nitrogen cycle (Figure 1) was used to depict Nitrogen transformation or movement in the fish pond and how the parameters enter the equations 1 to 5. The outlet from the Horizontal Subsurface Flow Constructed Wetland (HSSFCW) is used for aquaculture farming and the outlet from the fish pond is used in paddy irrigation-agriculture.

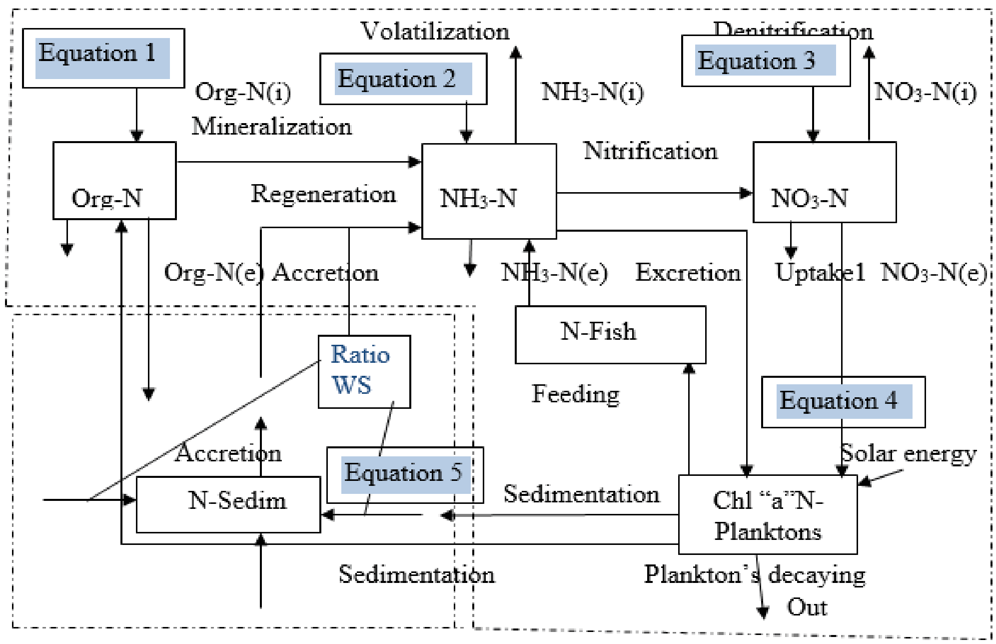

Figure 1: Conceptual diagram of Nitrogen nutrients in Fish Ponds (Irene, 2015)

Note:*The arrows show the flow of materials and processes in the ecosystem, the boxes indicate the six state variables and the dashed lines give the two sectors, the water and the sediment columns.(i)=influent at the inlet and (e)=effluent at the outlet. The mass balance equations1through 5 show how the parameters flow in the ecosystem.*

Therefore the requirements for re-use of the outlet is an essential part of planning and designing wastewater treatment facilities and recycling to conserve the scarce water in the ecosystem, reduce water borne diseases to ensure public health and to meet the 6th Millennium Development goal of Environmental Sustainability and the Second Tanzania National Strategy for Reduction of Poverty (NSGRP2) for Sustainable Development and "clean water for all by the year 2015" (Irene, 2007) as well as the Tanzania Development Vision by the year 2025.

Based on Figure 1 the equations for the mass balance of organic nitrogen (Org-N), ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), nitrogen in phyto-and zoo-planktons (Chl"a"N-Planktons) and nitrogen in the sediments (N-sedim) are given by equations (1) through (5), respectively. The modelling processes used Stella II (STELLA ® 9.1.4) computer software by utilizing the Fourth Order Runge-Kutta approximation incorporated in STELLA software. The forcing functions considered were temperature, pH and dissolved oxygen in the fish pond with solar natural energy.

$$\frac{dC_{Org-N}}{dt} = (1-p)At - rWC_{Org-N} \quad \ldots\ldots (1)$$

$$\frac{dC_{NH_3\text{-}N}}{dt} = \left(pNt + rM_{N\text{-}Sed}\right) - \left(n+v+rW\right) - rgcC_{Chl}\left(\frac{C_{NH_3\text{-}N}}{C_{NH_3\text{-}N} + C_{NO_3\text{-}N}}\right) \quad \ldots\ldots (2)$$

$$\frac{dC_{NO_3-N}}{dt} = \left(nC_{NH_3} - rWC_{NO_3}\right) - rgcC_{Chl}\left(\frac{C_{NO_3-N}}{C_{NO_3-N} + C_{NH_3-N}}\right) \quad \ldots\ldots (3)$$

$$\frac{dC_{Chl}}{dt} = rgC_{Chl} - (rW + s)C_{Chl} \quad \ldots\ldots (4)$$

$$\frac{dM_{N-Sed}}{dt} = scC_{Chl} - rM_{N-Sed} \quad \ldots\ldots (5)$$

Where: *dC* is change in concentration; *dt* is change of time; *p* is the proportion of nitrogen entering the fish pond with the outlet and the remainder entering as organic nitrogen; *At* is total nitrogen inflow (mg/l.d); *r* is remineralization rate of ammonia nitrogen in the pond/d; $M_{N\text{-}Sed}$is mass of nitrogen (mg/l) in the sediments; *n* is nitrification rate/d; *rg* is the planktons growth rate/d; *v* is volatilization rate of ammonia/d; *rW* is water exchange rate/d; *c* is nitrogen/chlorophyll ratio of phytoplankton; *Org-N* is organic nitrogen concentration dissolved in the fish pond water (mg/l); $C_{NH3\text{-}N}$is ammonia nitrogen concentration (mg/l); $C_{NO3\text{-}N}$is nitrate nitrogen concentration (mg/l); $C_{Chl}$is chlorophyll "a" concentration in fish pond; *s* is sedimentation and accretion rate of planktons per day.

The processes rate considered in the model were mineralization of organic nitrogen, volatilization of ammonia, nitrification of ammonia, denitrification of nitrate, assimilation of ammonium and nitrate, decay of planktons, accretion of organic nitrogen and regeneration of ammonium nitrogen from the sediments back to the water column.

Rate of mineralization (r_m),

Mineralization or ammonification is the release of ammonia-nitrogen from organic-nitrogen found in the residue or microbial tissue. Mineralization process of organic-nitrogen is the biological transformation of organically bound nitrogen to ammonia through degradation. Mineralization process depends on mineralization rate, temperature, oxygen, moisture, organic-nitrogen concentrations and ratio of carbon to nitrogen (C: N). Net mineralization occurs when C:N is less than 20:1, that is for every two parts of carbon, there should be one part of nitrogen. With this ratio, there is high nitrogen content for the needs of micro-organisms to convert excess organic nitrogen to ammonium (NH_4^+). On the other hand, if organic material has C:N greater than 20:1 (low nitrogen content) micro-organisms activity increases because of addition of carbon will not get enough nitrogen from the residue, hence leading to immobilization (loss of available nitrogen). After mineralization NH_4-N can be taken up by biomass, volatilized or nitrified. Mineralization was modeled using first-order kinetics equation (6) with respect to DiToro *et al.,* (DiToro *et al.,* 1975; DiToro and Matysik, 1980) and (Martin & Redd, 1997).

$$r_m = A_m x Org - N \quad \text{..........} \quad \textbf{(6)}$$

Where: r_m is mineralization rate constant of organic-nitrogen per day (d^{-1}) and A_m = 0.08 d^{-1} as adopted from [15] for model calibration in Ecological Modelling. This study was 0.15 for the Best Conceptual Model.

Ammonia Volatilization Rate in Fish Ponds

Volatilization is the loss of gaseous Ammonia to the Atmosphere. Volatilization rate of gaseous NH_3-N out of the wastewater surface depends on concentration of ammonia and the temperature and a high pH above 7.5, pond depth and wind velocity over the water surface (Thomas, 1982; Metcalf and Eddy, 1995; Martin and Reddy, 1997; Senzia, 1999). Ammonia in water exists as dissolved ammonia gas NH_3-N or ammonium ions (NH_4^+). The concentration of NH_3-N gas is temperature and pH dependent, (Emerson *et al*., 1975; Zimmo *et al.,* 2003; Epworth, 2004) equation (7).

$$NH_3 - N(g)conc = \frac{NH_3 - N}{1 + 10^{(10.5 - 0.032T - pH)}} \quad \text{..........} \quad (7)$$

Where: T is the wastewater temperature; (g) is gas and *conc* is concentration. The rate of ammonia volatilization is also influenced by an equilibrium-based mass transfer coefficient K_l(Stratton, 1968; Stratton, 1969) as in equation (8):

$$K_I = (0.0566/d).Exp[0.13(T - 20°C)] \quad \text{..........} \quad (8)$$

Where: K_1 is the ammonia-ammonium equilibrium constant; T is wastewater temperature (°C) and *d* is fish pond depth (0.8 m) of the wastewater column in the fish pond found to be (25°C) temperature.

The rate of nitrification (r_n)

The rate of nitrification (rn) which is facilitated by chemoautotrophic nitrifying bacteria depends on pH, temperature, ammonia and dissolved oxygen concentrations. Metcalf and Eddy, (1995) observe that the maximum rate of nitrification occurs between pH values of about 7.2 and 9.0 and this decreases with decreasing temperature and increases with increasing ammonia and dissolved oxygen. Nitrification was modelled by considering the first-order kinetics as presented by Kadlec and Knight (1996) in the relationships presented in equation (9).

$$r_n = \frac{U_n}{Y_n}\left(\frac{NH_4 - N}{Ks + NH_4 - N}\right)\cdot\left(\frac{DO}{K_sO_2 + DO}\right).C_T.C_{pH} \quad \textbf{(9)}$$

Where: r_n = nitrification rate, U_n = maximum *Nitrosomonas* growth rate per day, Yn = yield coefficient for *Nitrosomonas* bacteria in (mgVSS/mgN), K_s = Ammonia *Nitrosomonas* half saturation constant and ranges from 0.32 to 56 g/m^3, and a half rate saturation constant value of 6.8 g/m^3 is adopted from Nielsen *et al.* (1999) who dealt with simulation of nitrogen dynamics in ecological modelling. K_sO_2 = Oxygen *Nitrosomonas* half saturation constant (g/m^3), C_T is a temperature dependent factor; C_{PH} is *Nitrosomonas* growth-limiting factor for a given pH.

According to Downing, (1966), when pH $\geq$ 7.2, no significant inhibition occur in growth rate and thus C_{PH} = 1.0, but when pH < 7.2, the existence of free ammonia inhibits growth of nitrifying bacteria. Hence nitrification rate is corrected by introducing C_{pH} correcting factor equation (10). In this study, variation of pH was not significant because pH values varied from pH 7.44 ± 0.06 to 7.47 ± 0.09 seasonally. The average pH for the fish pond in this study was 7.46, thus C_PH= 1 means no significant growth inhibition.

If pH < 7.2, CpH = 1.-0.833 (7.2 – pH) ELSE (CpH = 1) ………….…...... **(10)**

Nitrification rate is also temperature-dependent according to (Davison, 1991, Hancke *et al.* 2007) of which an exponential function shown by equation (11) describes the temperature correction factor.

CT = exp. φ (T - T_o) ……………………………………………….……....….. **(11)**

Where: T_o is the reference temperature (15 °C) and φ is an empirical constant (0.098 °C). Maximum *Nitrosomonas* growth rate U_n of (1.0 d^{-1}) was found by calibration which was within the values in the literature of (0.33–2.21 d^{-1}) as presented by Jørgensen *et al.* (1991). This is because of varying forcing functions of temperature (23.52±1.4 to 25.70±0.6), oxygen levels (6.44±2.36 to 7.15±1.70) and pH (7.44±0.06 to 7.47±0.09). Very high *Nitrosomonas* growth rate can deplete all NH_4-N in the system which was not applicable for the measured data. This is because ammonia was twice (3.3 mg/l) higher (WHO, 2006; TSE, 2005) than the permissible limits of 1.2 mg/l which did not support the original hypothesis in this research. The yield coefficient (Yn) of *Nitrosomonas* bacteria found in the literature ranges between 0.03 and 0.13 (Charley *et al.*, 1980; Metcalf and Eddy Inc., 1991). The oxygen *Nitrosomonas* half saturation constant (K_sO_2) was assumed to be 1.3 mg/l according to Fritz *et al.* (1979) and Charley *et al.* (1980) because of the influence of temperature and mean oxygen levels of 6.79 ± 2.03 in fish pond. The *Nitrosomonas* half saturation constant value 3.0 mg/l was higher than the one specified in literature of (0.3 – 1.3 mg/l) given by Halling-Sorensen and Jørgensen (1993) and Senzia (2003) due to model calibration.

The rate of denitrification (r_{dn})

The denitrification rate depends on the amount of nitrate present and temperature in the ecosystem.

Denitrification rate (r_{dn}) in mgN/d was modelled by using suspended biomass in which the theory of Dawson and Murphy (1972) describe denitrification process to follow Arrhenius kinetics within the temperature range between 3 °C and 28 °C. In this study, the temperature ranged between 23.52±1.4 and 25.70±0.6°C, in the fish pond which was within the Arrhenius kinetics temperature range. Therefore, denitrification was modelled using the first-order Arrhenius kinetics equation (12).

$$r_{dn} = DR\ \theta^{(T-20)} NO_3 - N \quad \textbf{(12)}$$

The Arrhenius temperature coefficient θ varies from 1.02 to 1.09 and denitrification constant DR_{20} may vary from 0 to 1.0 as adopted from Bacca and Arnett (1976). The rate coefficient optimized from the model calibration gave θ = 1.08 and DR = 0.4 which were within the range of the Arrhenius temperature coefficient which describes the effect of temperature on denitrification.

The Rate of Ammonia and Nitrate Assimilation by Planktons in Fish Ponds

The principle in wastewater-loaded fish ponds is to add enough waste to provide enough food for the aquatic organisms which the fish eat. This should not lead to low dissolved oxygen levels which could risk fish survival according to Edwards (1990). The rate of ammonium assimilation and nitrate assimilation (rA) by planktons was modeled using Monod's kinetics, equations (13).

$$rA = \mu_{\max}\theta^{(T-20)}\left[\frac{NH_3 - N}{K_m + NH_3 - N}\right](Org\_N).P \quad \text{.............................. (13)}$$

Where: $\mu_{\max}$ is the maximum growth rate of the planktons; θ is the rate coefficient optimized. The model calibration used θ = 1.05and K_m is the equilibrium constant found to be 0.1 in this study. P is the preference factor for NH_3-N and NO_3-N. Usually, NH_3-N must be utilized and depleted in the fish pond water before NO_3-N is utilized for the plankton's cell synthesis (U.S.EPA, 1985; Metcalf and Eddy, 1995). This is because ammonium nitrogen requires less energy and time to assimilate than nitrate nitrogen (Dortch, 1990; Jørgensen, 1994; Jørgensen and Bendoricchio, 2001).

The rate of decay of planktons (r_{dc})

The decay rate of the planktons $(r_{dc})$was modeled using first-order kinetics according to equation (14), (Buchan *et al.*, 2014; Hargreaves, 1998; Jamu and Piedrahita, 2002; Burford and Lorenzen, 2004):

$$r_{dc} = R_{decay}.N_{plankton} \quad \text{.. (14)}$$

Where: R_{decay} is decaying rate first-order constant (d^{-1}), assumed to be 0.006/d (Martin and Reddy, 1997) and found by model calibration in this study to be high (11.5 mg/l) due to high settling rate.

The rate of organic nitrogen accretion/settling in the sediments (r_a)

The rate of organic nitrogen accretion in the sediments depends on the concentration of organic nitrogen in the fish pond. The sediments and the planktons in the fish pond influence the rate of sedimentation by reducing the settling time of the organic-nitrogen. The rate of nitrogen accretion in the fish pond sediments was modelled using equation (15) according to first-order kinetics.

$$r_a = AC\_R(Org - N) \quad \text{.. (15)}$$

Where: r_a is the rate of nitrogen accretion in the sediments and the coefficient AC_R was found by calibrationto be 0.5 per day which is close

to who found settling rate of (0.8/d) of nitrogen in the fish pond sediments per day (Yohana, 2009).

The rate of nitrogen regeneration/re-mineralization to ammonia (r_r)
The nitrogen accumulated in the soil/aggregates/sediments due to decomposition and sedimentation process is ultimately regenerated back to ammonia (Jiménez-Montealerge *et al.*, 2002; YangYi *et al.*, 2000). The rate of regeneration (r_r) wasmodelled with respect to the first order kinetics equation (16).

$$r_r = R_{reg} . N_{aggreg} \qquad \textbf{(16)}$$

Where: R_{reg} is the regeneration rate of ammonia (d^{-1}) and N_{aggreg} is nitrogen in the aggregates of which R_{reg} was found by calibration to be 0.05/d higher than Pascal *et al*. (2005) who found 0.0001/d in Lake Victoria, Tanzania. The best fish pond model is presented in a diagram in Figure 2.

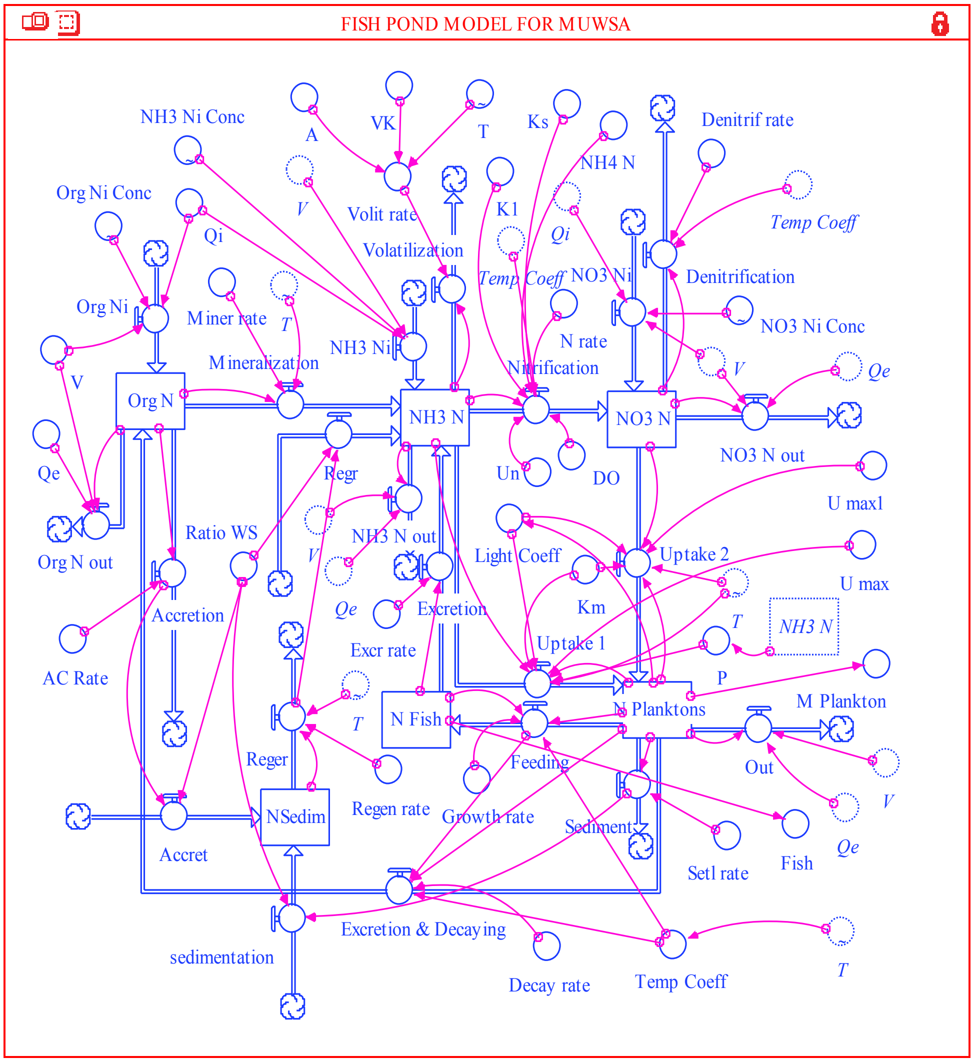

Figure 2: Conceptual Model of Fish Pond (Irene, 2015)

(Note that Table 1 in the Appendix No.1 gives the list of Parameters used in the Fish Pond Model, while Appendix II Show how the parameters enter into the equations).

RESULTS AND DISCUSSIONS

Results

The results from the laboratory gave a concentration mean of 3.33 mg/l twice the standards in this study. The fish pond results of organic nitrogen (Org-N), ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), nitrogen in the planktons (N Planktons), nitrogen in the fishes (N-Fish) and nitrogen in the sediments (N-Sedim) are shown in the calibrated and correlation graphs of the state variables in the fish pond model in Figures 3 through 8.

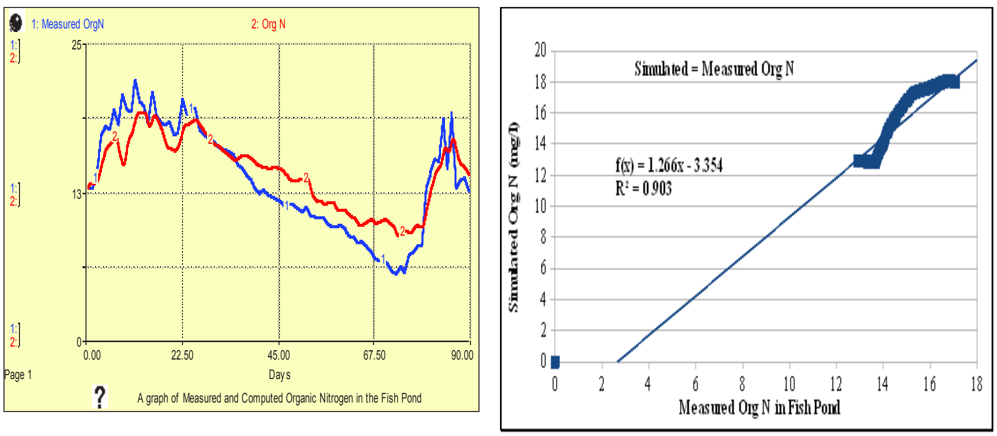

Figure 3: Correlation between Simulated and Measured Organic Nitrogen in Fish Pond

Correlation between the simulated and measured organic nitrogen are in good accordance $R^2 = 0.91$.

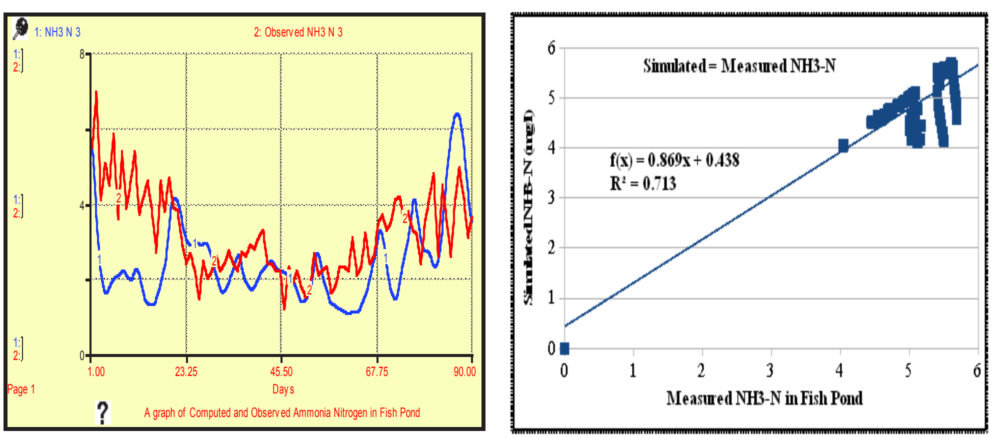

Fig. 4: Correlation between Simulated and Measured NH3-N in the Fish Pond

As in organic nitrogen, correlation between the simulated ammonia nitrogen was also very close to the observations (R2 = 0.71)

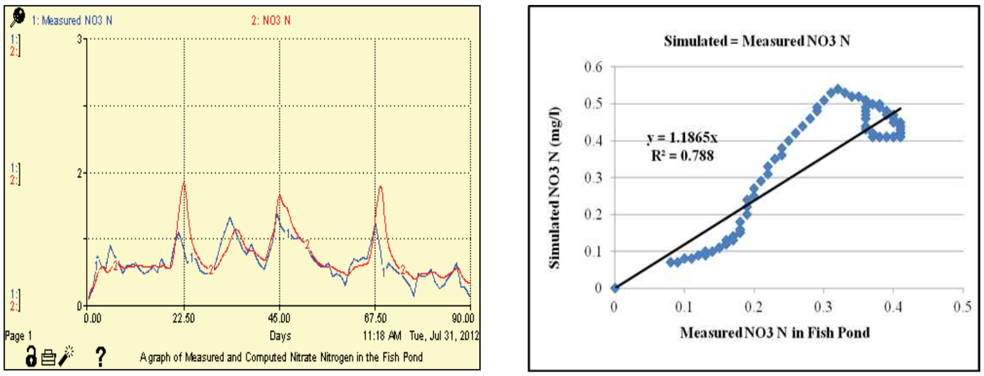

Figure 5: Correlation between Simulated and Measured NO_3-N in the Fish Pond

Correlation between the simulated nitrate nitrogen was also very close to the observations (R^2 = 0.79)

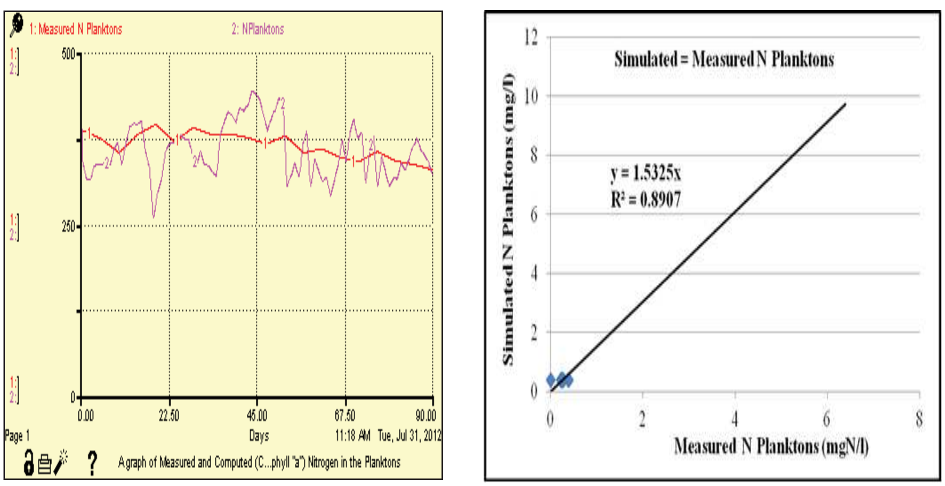

Figure 6: Correlation between Simulated and Measured N-Planktons in the Fish Pond

Like in nitrate nitrogen, correlation between the simulated nitrogen in the planktons was found in a very good accordance with observed results (R^2 = 0.89). Planktons here refers to the bacteria population, phytoplanktons and the zooplanktons which dwell in the water and sediment columns in the fish pond as the micro-organisms which help in the decay and decomposition of the organic matter.

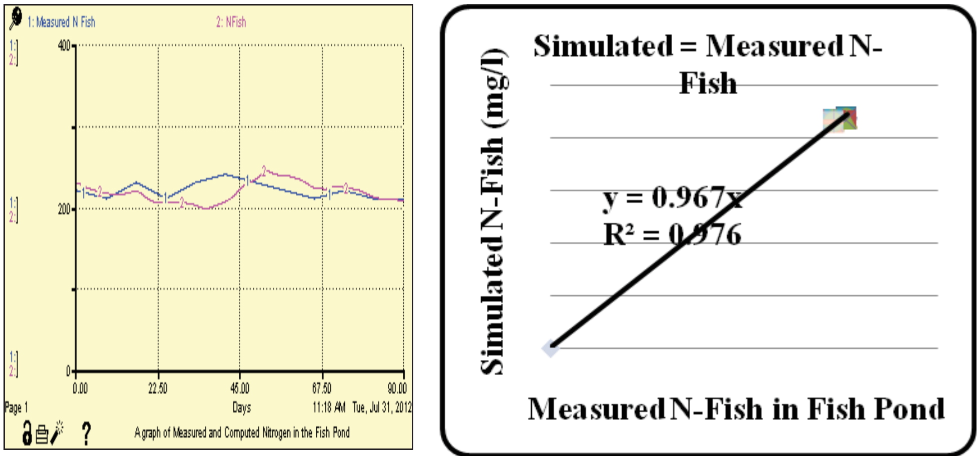

Figure 7: Correlation between Simulated and Measured N-Fish in the Fish Pond

Correlation between the simulated and observed nitrogen in the fishes was not so significant with (R^2 = 0.976).

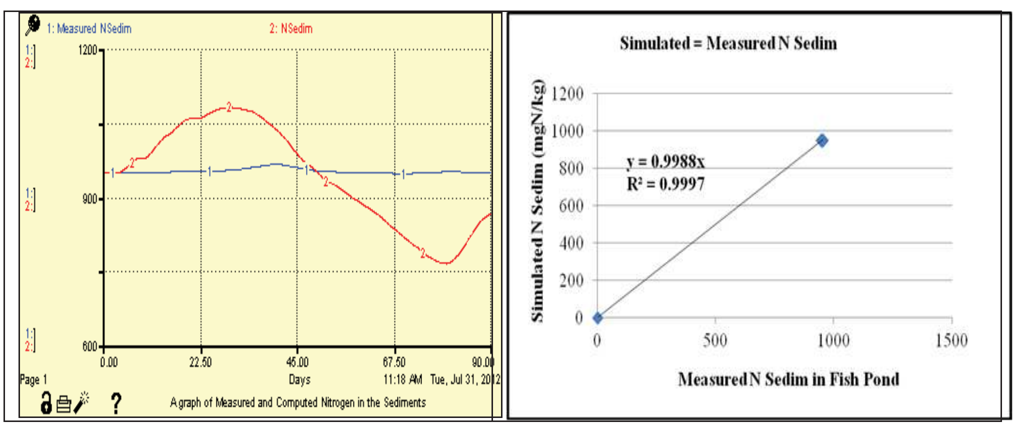

Fig. 8: Correlation between Simulated and Measured N-Sedim in the Fish Pond

As in organic nitrogen, correlation between the simulated and observed nitrogen in the sediments was in good accordance with the regression analysis of R^2 = 0.99 in the fish pond ecosystems.

DISCUSSIONS

Three important parameters which make the system to run out its activities in the model include the observed or measured state variables, calibrated parameters and the forcing functions. The calibrated parameters include the processes or rates which are represented by mathematical equations that runs the system and the forcing functions being the external variables to the system as narrated in Table 1 in the Appendix. Six observed state variables were measured in this fish pond model which included organic nitrogen (Org-N), ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), nitrogen in the planktons (N-Planktons), nitrogen in the fishes (N-Fish) and nitrogen in the sediments (N-Sedim).

In the evaluation of the fish pond, the most important observed and simulated parameters were ammonia nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), and nitrogen in the fishes (N-Fish). Their nitrogen mass balances were about 2.20% with the standard deviations of ±0.004 N-Fish, ±0.0 NH_4^+-N, ±0.24 NH_3-N and ±0.12 NO_3-N respectively. The dominant routes were found to be mineralization rate average 4.49±0.37, uptake of ammonia 9.29±0.11, decay rate 7.88±0.93, accretion rate 11.74±0.13, settling rate 13.00±1.32 and regeneration rate 84.91±4.45.

To look how good the observations were in accordance with the simulated values, correlation coefficient (R^2) was computed. The results revealed that simulated Org-N Fig. 3 was found to be in a very good accordance with the observed value of R^2 = 0.903. Simulated and observed NH_3-N Figure 4, gave a significant value of R^2 = 0.71, and in Figure 5, NO_3-N gave R^2 = 0.79. The simulated and observed correlation of nitrogen in the planktons was also found significant with R^2 = 0.89 and was very significant in the sediments with the value of R^2 = 0.99 almost R^2 = 1. However, correlation of the simulated and observed nitrogen in the fish was not significant with a value of R^2 = 0.39. This was expected because we should not to have high nitrogen in the fish which are used as food. It may be dangerous to human health especially the children.

In testing the model parameters to find out if they comply with the values in other literatures, the rate processes of mineralization, nitrification, volatilization, uptake/assimilation, and maximum growth of *Nitrosomonas* micro-organisms, fishes growth/feeding, excretion, settling/sedimentation, decaying, regeneration and accretion were examined. Mineralization rate in this fish pond model was found (0.15 d^{-1}), very close to the literature values found out by Jiménez-Montealerge (2001) as well as Jørgensenand Brian, (2011). Also nitrification rate calibrated value of (0.55 d^{-1}) was found to be within the values observed in other literature (Prats and Lavador, 1994) in addition to Jørgensenand Brian, (2011). Denitrification rate value of (0.4 d^{-1}) lies within the literatures values as found out by (Hargreaves, 1998; Gross *et al*., 2000). Growth rate in this study was found to be 0.058 d^{-1} lower than the values found by other researchers such as (Schroeder *et al.,* 1991; Jørgensen and Bendoricchio, 2001; Piedrahita, 2001; Burford and Lorenzen, 2004). Growth or feeding rate was low because of high nitrogen settling in the sediments. As it was for growth rate, excretion rate was 0.065 d^{-1} lower than the literature ranges due to low feeding rate (Jørgensen and Bendoricchio, 2001). Different from growth and excretion rates, decay rate was found to be very high (11.5 d^{-1}) because of high settling rate (Jiménez-Montealerge, 2001). The calibrated regeneration rate in this study was found to be 0.04 d^{-1} that is lower than the literature ranges because of low growth and excretion rates (Jiménez-Montealerge *et al.,* 2002). On the other hand, accretion rate value of 0.5 d^{-1} was higher than the literature ranges due to high organic nitrogen loading in the fish pond as reported by Kadlec and Wallace, (2009). The maximum growth rate value of the *Nitrosomonas* micro-organisms in the fish pond was 1.157d^{-1} for the uptake of ammonium and 1.195 d^{-1} for the uptake of nitrates for their energy. These values were well in accordance with the literature ranges of 0.34 to 1.25 d^{-1} as were also found by Farrara and Hermann (1980) as well Halling-Sorensen and Jørgensen (1993).

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The main focus of this study was how to determine nitrogen transformation in the fish pond that receives an outlet from a horizontal flow constructed wetland for re-use in agriculture and to develop the modelling to obtain a good environmental management tool for these ecosystems. It was hypothesized that the fish pond receiving effluent from HSSFCW can have about 1.2 mg/l Ammonia-N for fish growth tolerance (WHO, 1989; FAO, 1997). The results gave a mean ammonia nitrogen concentration of 3.33±0.012 mg/l that was more than twice higher than the standards of 1.2 mg/l, which did not support the original hypothesis. This was due to an overloading of the HSSFCW and hence the fish pond. From the ecological model developed, the most important state variables of ammonia nitrogen, nitrate nitrogen and nitrogen in the fishes were in accordance with the health standards and hence not detrimental to human life and the environment. A good ecological model as an environmental management tool was developed for the fish ponds.

Recommendations

(i) Further research is important to polish the outlet and remove overloading by adding at least one HSSFCW unit downstream before re-using it for aquaculture/agriculture and ultimate discharge to the receiving water bodies.

(ii) This developed ecological model for the fish ponds can be used by others to evaluate and monitor the fish ecosystems.
(iii) Develop capacity building to water managers, farmers and the community at large for environmental pollution control, wastewater treatment and re-use to safeguard the health of the end-users.
(iv) Study the quality of soils and agricultural products to monitor heavy metals and pathogens.

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