ISSN No:-2456-2165

Prediction of Piggery Wastewater Nutrient Attenuation by Constructed Wetland in a Humid Environment

I. J. Udom[1], E. S. Udofia[2], S. A. Nta[1], G. A. Usoh[1], E. O. Sam[1]
[1]Department of Agricultural Engineering, Akwa Ibom State University, Ikot Akpaden
[2]Department of Mathematics, Akwa Ibom State University, Ikot Akpaden

Abstract:- A mathematical model for predicting the reduction of nitrogen and phosphorus concentrations in horizontal subsurface flow constructed wetlands was developed. The model considered the piggery wastewater input, storage, plant use and nutrient output to the environment is predominantly through nitrogen denitrification. Nutrient release from plant litter was not considered an influence on the constructed wetland because the young plants were picked for fodder and, contamination from rainfall and groundwater was considered insignificant. The adjustment and authentication of the model was carried out by separate data sets. Nutrient attenuation followed exponential trend during the period followed by stability contingent on the decay coefficient. Simulated parameters correlated highly with the observed values with R= 0.8940 for nitrogen and 0.9518 for phosphorus respectively. ME of 0.211 and 0.139, RMSE of 0.32 and 0.18, RE of 24 and 12%, model efficiencies of 64 and 37% and index of agreements of 0.6527 and 0.8676 for nitrogen and phosphorus respectively. The linear regression coefficients appear good for a natural system under environmental influences.

Keywords:- *Piggery Wastewater, Horizontal-Subsurface-Flow-Constructed-Wetlands, Pollution, Water Quality, Nutrients.*

I. INTRODUCTION

Pork is highly consumed and accounts for over 30% of world-wide meat demand (Modern technologies for raising pigs, 2015). In 2016, (Soare and Chiurciu, 2017), pork's per capita consumption was the highest in the world accounting for over 39% of meat consumed from all sources. Pig production is an important aspect of the livestock enterprise in Nigeria's agriculture (Uddin and Osasogie, 2016).

Nutrient pollution from large scale pig farms is the main concern in managing pig waste (Udom et al., 2018). Pig waste contains excessive nutrient that can negatively impact on land, water and aquatic environments (Mason, 2002); and breeds pathogens, bacteria and heavy metals which are harmful to human health (Wendee, 2017, Horton et al., 2009). Good waste control is inevitable to secure sustainable environmental quality (ECC, 1999; EPA, 2000). The best approach to managing waste is to recycle the waste or treat it before discharge to the surroundings instead of stockpiling them in drains and pond where it decomposes and becomes part of the soil as is the case in Nigeria (Kadurumba and Kadurumber. 2019, Ewuziem *et al.,* 2009) Nutrients (nitrogen and phosphorus) are the pollutants of concern in pig wastewater to safeguard infants' health and nutrient enrichment of water because oxidation of ammonium to nitrate take as much as 4.3 g for each gram of ammonium (Henze *et al.*, (1995).

Similarly, Phosphorus modifies freshwater plant and algae development (EPA, 2000) and substantially regulate downstream water quality (Wallace and Knight, 2006) and use (Gouriveau, (2009).

Satisfactory wastewater management in developing countries is impeded by financial requirement (Muga and Mihelcic, 2008), for construction, maintenance and upgrading and ignorance of cheap but effective and sustainable wastewater management due to the huge investments necessary to construct, maintain and improve wastewater treatment amenities, but it is also due to lack of information on developments in wastewater treatment technologies and the use of low cost wastewater treatment know-hows (Mburu *et al.,* 2012).

Treatment or constructed wetlands (CW) systems deliberately attenuate nutrients by receiving, retaining and processing nutrients by physico-chemical and biological paths (Abbasi et al., 2019; Nandakumar et al., 2019) as wastewater gradually passes through the wetland. The above paths account for an assortment of nutrient attenuation through disintegration, uptake and transformation of nitrogenous composites. There are qualitative evidences to show that the wastewater depuration efficiency of constructed wetlands but quantitative confirmations are required for ecological conditions and system design (Kadlec and Wallace 2009) necessary for appropriate design, operation, feedbacks and improvement of CW systems in different situations. CW design has evolved from input-output empirical relationships to complex relationships (Kadlec and Wallace, 2009) but, the problem of approximating the numerous parameter interactions involved in pollutant removal process justify the rising utilization of prediction models for the design of CW (Kadaverugu, 2016). A prediction model describes the physical processes and boundaries of a system using one or more governing equations. Prediction models define the connection among the model parameters and connect them with between the model components and link them together using precise mathematical balances (Jorgensen and Bendoricchio, (2001). FITOVERT (Giraldi et al., 2010), HYDRUS 2D/3D (Simunek et al. 2008), PHWAT (Brovelli et al. 2009) are examples of CW models with prediction capabilities for intermittently inundated soils and pollutant fate but they are not freely available. STELLA is a dynamic software program with wide application but is expensive for rural applications (Allen 2019).

In this paper, we develop a prediction model for piggery wastewater nutrient attenuation using a sub-surface horizontal flow CW. This study will be useful for CW development and application in pollution control.

II. MATERIALS AND METHOD

A. Study Area and Project Location

The location of the horizontal subsurface flow constructed wetland (HSSFCW) at the Obio Akpa campus of Akwa Ibom State University (AKSU) is highlighted in Figure 1. Obio Akpa is situated between longitudes 07º 3¨E and 07º 3¨E and latitude 04º 45¨N and 04º 55¨N.

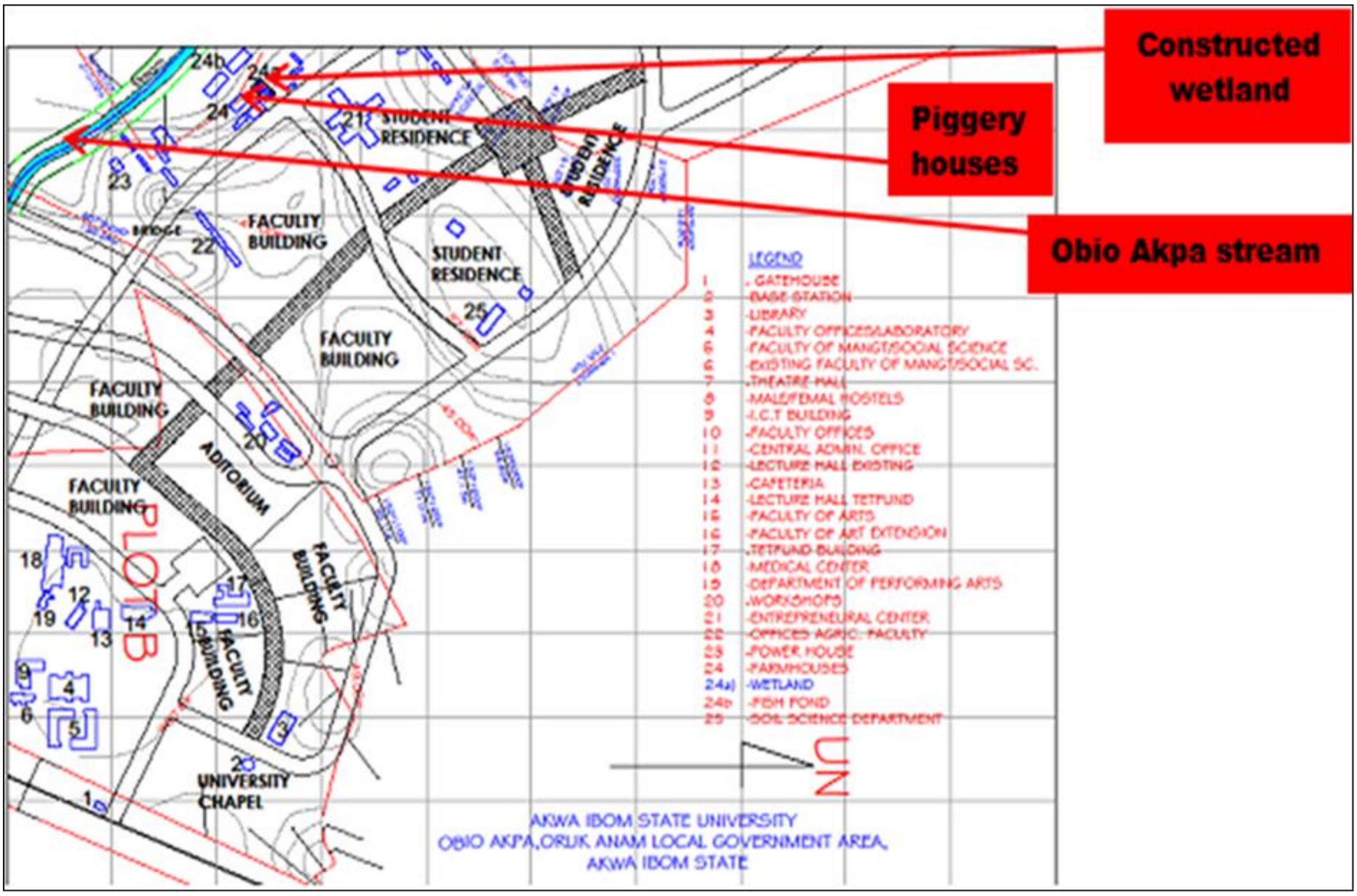

Fig 1 Location of Piggery and Constructed Wetlands.

Mean lowest and highest temperatures are between 18^{O}C -27^{O}C and 24^{O}C - 36^{O}C. A perennial stream is the main channel in the watershed with a population of over 150,000 people (NPC, 2006). Relative humidity ranges between 55-86% and average rainfall is between 2050 mm to 2450 mm. Estimated untreated wastewater volume of 9.46 m^3/day is released on the floodplain.

B. Experimental Setup

The study was carried out at the Akwa Ibom State University. A (7 m x 1.75 m x 0.60 m) concrete CW having three wetland cells were created. A 2.5 mm thick Texclear plastic liner covered the entire wetland floor. Both the wastewater inlet and outlet regions of the wetland basin were jam-packed up to 0.60 m depth with 30 mm crushed granite rock at a distance of one meter from each end. The wetland basins were packed to 0.60 m depth with sharp-sand and Pennisetum *clandestinum* (PC) was planted in two cells while the third cell was the control.

C. Sample Collection and Monitoring

The wetland was monitored after three month's stabilization. Wastewater samples were collected at the inlet before loading the CW and three days after at the outlet of the CW. The status of total nitrogen (TN) and total phosphorus (TP) were investigated (AOAC, 2007). Destructive and systematic sampling techniques were adopted for the plants and the soil respectively. Nutrient attenuation was calculated from the differences in wastewater concentrations before and after residence in the CW.

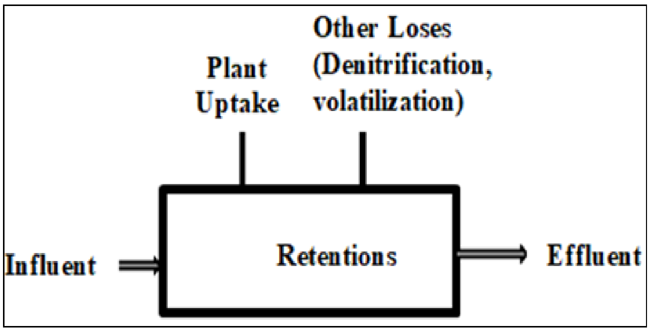

Fig 2 Theoretical Model of Nutrient Attenuation Process in CW

In Figure 2 the theoretical model of the nutrient attenuation pathways for conversion of organic matter to ammonia and phosphate and consequent transportation, retaining, use by plants and discharge (denitrification, volatilization, and burial) from the CW. The model divides the CW into three simple partitions: (1) wastewater pool (2) CW soil, and (3) CW plant. The CW water pool comprise pig excess flow, organic nitrogen and phosphorus deposit. Impact of pollutant input from the atmosphere is negligible in CW. The site for nitrification of ammonium nitrogen is in the aerobic part of the CW media and the water pool, while nitrate attenuation is restricted to the anaerobic region in the dynamic CW media and the root zone of CW macrophytes. Nitrogen is mainly lost to the atmosphere in conditions where the alkalinity is high (Reddy and Delaune, 2008). Ammonium ion oxidation in the water pool and oxidized media also produces nitrate.

Phosphorus attenuation derives from deposition of suspended organic matter residue but then does not result in gaseous losses. The physical routes of advection (inflow, outflow), deposition, resuspension, and dispersion is also applicable to phosphorus transportation and destiny in the CW. Biologically available inorganic phosphorus (typically orthophosphate) alone is easily reached by CW macrophytes. Phosphorus introduced to the CW from groundwater, sediment and runoff and breakdown of organic matter are the main sources of inorganic phosphorus in CW media and water pool. Apart from plant gathering, burial is nearly the single means for the attenuation of phosphorus in CW (Kadlec and Wallace, 2009).

D. Model Assumptions

Assumptions considered in the derivation of the first order equations to describe the rate of nutrient attenuation in the CW were:

- CW contains no initial nutrients. $N(0) = N_0$
- Nutrient introduction is periodical at the $f(t)$.
- Nutrient concentration at time $t > 0$ *is* $N(t)$
- Plant use, retention in CW media, biogeochemical process creates the nutrient attenuation avenues from the CW at the rate ρ proportional to the quantity present.
- Nitrogen supply rate to the CW from precipitation is insignificant.
- Supply to and from groundwater is zero..

E. Model Derivation

Equations derived based on the above assumptions were:

➢ *Nitrogen*

$$\frac{dN}{dt} = -\rho N(t) + f(t) \quad [2.1]$$

$N(0) = N_0$ Where,

N = nitrogen concentration (mg/l)

ρ = CW nitrogen removal rate (mgd^{-1})

$$\frac{dN}{dt} + \rho N(t) = f(t) \quad [2.2]$$

By using integrating factor,

$$I.F = P(t) = \rho$$

$$e^{\int P(t)dt} = e^{\int \rho dt} = e^{\rho t}$$

Multiplying both sides of (2.2) by the integrating factor, we have

$$e^{\rho t}(\frac{dN}{dt} + \rho N(t)) = e^{\rho t} f(t)$$

$$\frac{d}{dt}(Ne^{\rho t}) = e^{\rho t} f(t)$$

$$d(Ne^{\rho t}) = e^{\rho t} f(t)\mathrm{dt}$$

$$\int_0^t d(Ne^{\rho s}) = \int_0^t e^{\rho s} f(s)ds$$

$$N(t)e^{\rho t} - N_0 = \int_0^t e^{\rho s} f(s)ds$$

$$N(t)e^{\rho t} = N_0 + \int_0^t e^{\rho s} f(s)ds$$

Dividing through by $e^{\rho t}$

$$N(t) = N_0 e^{-\rho t} + e^{-\rho t}\int_0^t e^{\rho s} f(s)ds \quad [2.3]$$

Suppose $f(t) \equiv 0$, *where* $f(t)$ *is the influent*, then

$$N(t) = N_0 e^{-\rho t} \quad [2.4]$$

This is a first order differential equation with the initial condition (background concentration) $N(0) = N_0$

The quantity of N nutrient in the CW is represented by

$$N(t) = N_0 e^{-\rho t} + e^{-\rho t}\int_0^t e^{\rho s} f(s)ds, \ at \ t > 0 \quad [2.5]$$

This decay exponential function tells us that as $t \to \infty$ the quantity of $N(t)$ decreases to zero (0) but not rapidly because of the presence of the influent $f(t)$

Assuming $f(t) \equiv 0,$,

Then the attenuation of the nitrogen will be fast. From experimental observation, we discover that the above statement and reason does not represent reality. Hence, we assume further that the introduction of nitrogen $f(t) = D$ into the CW is at a constant quantity over a period of time, and then the model equation becomes

$$\frac{dN}{dt} = -\rho N(t) + D \quad [2.6]$$

$$N(0) = N_0$$

$$\frac{dN}{dt} + \rho N(t) = D \quad [2.7]$$

$$N(0) = N_0$$

By still using the method of integrating factor to find the solution of the above problem,

$$I.F = e^{\int f dt} = e^{\rho t}$$

Multiplying both sides of Equation (2.7) by the integrating factor, we have

$$e^{\rho t}(\frac{dN}{dt} + \rho N(t)) = e^{\rho t} D$$

$$\frac{d}{dt}(Ne^{\rho t}) = e^{\rho t} D$$

$$d(Ne^{\rho t}) = e^{\rho t} D\mathrm{dt}$$

$$\int_0^t d(Ne^{\rho s}) = D\int_0^t e^{\rho s} ds$$

$$N(t)e^{\rho t} - N_0 = \frac{D}{\rho}[e^{\rho t} - e^0]$$

$$N(t)e^{\rho t} = N_0 + \frac{D}{\rho}[e^{\rho t} - 1]$$

Dividing through by $e^{\rho t}$

$$N(t) = N_0 e^{-\rho t} + \frac{D}{\rho}[1 - e^{-\rho t}] \quad (2.8)$$

The quantity of nitrogen that will remain in the system at $t > 0$ after a constant quantity D has been introduced into the system is represented by,

$$N(t) = N_0 e^{-\rho t} + \frac{D}{\rho}[1 - e^{-\rho t}] \quad (2.9)$$

This demonstrates that though the amount of nitrogen will decline in the CW, it will not be completely eradicated from the CW but, there will still be some background concentration within the CW. In practice, piggery wastewater is released into the CW at a given time period T. Presuming that the initial influent is at a time $= 0^+$, then the initial concentration is $N(0^+) = D$.

Such that,

$$\frac{dN}{dt} - \rho N(t), \quad 0 < t < T, that\ is, \quad t \in (0, T) \quad [2.10]$$

$$N(0^+) = D$$

Then solving this, we have,

$$N(t) = De^{-\rho t} \quad [2.11]$$

Which means that, the concentration before the second influent is,

$$N(T-) = De^{-\rho T} \quad [2.12]$$

The model for next influent, that is, $T \le t \le 2T$ is

$$\frac{dN}{dt} = -\rho N(t), \quad [2.13]$$

$$N(0^+) = N(T-) + D = D + De^{-\rho r},$$

$where,$

$r = t - T, t = T + r$

$T =$ loading interval (d)

$t =$ CW retention time (d)

Solving the above equation, we have

$$N(t) = (D + De^{-\rho T})e^{-\rho(t-T)} \quad [2.14]$$

$$N(2T-) = D(1 + e^{-\rho T})e^{-\rho T}$$

The concentration before the third influent is

$$N(2T-) = D(1 + e^{-\rho T})e^{-\rho T}$$

The model for next influent, that is, $2T \le t \le 3T$ is

$$\frac{dN}{dt} = -\rho N(t),$$

$$N(0^+) = N(2T-) + D \quad [2.15]$$

$$= D(1 + e^{-\rho T} + e^{-2\rho T}),$$

Where,

$$r = t - 2T$$

$$t = 2T + r$$

Solving, we have

$$N(t) \quad = \quad D(1 + e^{-\rho T} + e^{-2\rho T})e^{-\rho(t-2T)} \qquad [2.16]$$

The concentration before the 4th influent is

$$N(3T-) \quad = \quad D(1 + e^{-\rho T} + e^{-2\rho T})e^{-\rho T}$$

The general concentration before the nth influent is

$$N((n-1)T) = D\left(1 + e^{-\rho T} + e^{-2\rho T} + e^{-3\rho T} + \ldots + e^{-(n-1)\rho T}\right)e^{-\rho T} \; [2.17]$$

When making the nth influent,

$$N(nT+) = N\big((n-1)T\big) + D \qquad [2.18]$$

$$= D(1 + e^{-\rho T} + e^{-2\rho T} + e^{-3\rho T} + \ldots + e^{-(n-1)\rho T})$$

$$e^{-\rho T}N(nT+) = D(e^{-\rho T} + e^{-2\rho T} + e^{-3\rho T} + \ldots + e^{-(n-1)\rho T} + e^{-n\rho T})$$

$$N(nT+) - e^{-\rho T}N(nT+) = D(1 - e^{-\rho T})$$

$$(1 - e^{-\rho T})N(nT+) = D(1 - e^{-\rho T})$$

$$N(nT+) = \frac{D(1 - e^{-\rho T})}{1 - e^{-\rho T}}$$

$$\lim_{n \to \infty} N(nT+) = \frac{D}{1 - e^{-\rho T}} \qquad [2.19]$$

F. Summation of Nutrient Removal Sites

The above prediction model does divide nitrogen into the different partitions of the CW. To account for these partitions in the model, we assume further as below:

- The nitrogen supply rate into the CW from precipitation is insignificant,
- Rate of nitrogen consumption by CW macrophyte is δ_2,
- No loss to groundwater,
- Rate of nitrogen discharge (effluent) from the system is α,
- The rate of nitrogen supply into the CW is D
- The rate of retention of nitrogen in the CW water pool is δ_1
- The rate of retention of nitrogen in the CW media is ε
- The rate of denitrification of nitrogen in the CW is β

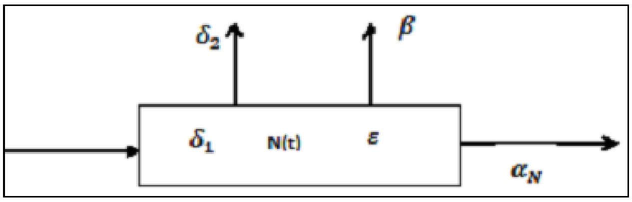

Fig 3 Nitrogen Sharing in Constructed CW

By applying the assumptions above, we get the resulting mass balance equation

$$\frac{dN}{dt} = D - \delta_2\,N(t) - \delta_1\,N(t) - \alpha\,N(t) - \beta N(t) - \varepsilon N(t) \qquad [2.20]$$

From Equation (2.15), we collect all the constants together

$$\frac{dN}{dt} \quad = \quad D - (\delta_2 + \delta_1 + \alpha + \beta + \varepsilon)N(t) \qquad [2.21]$$

$$Let \;\; \gamma \;=\; \delta_2 + \delta_1 + \alpha + \beta + \varepsilon$$

Then

$$\frac{dN}{dt} \quad = \quad D - \gamma N(t)$$

$$\frac{dN}{dt} + \gamma N(t) \quad = \quad D \qquad [2.22]$$

$$N(0) \quad = \quad N_0$$

Solving, we have the nitrogen removal model as,

$$N(t) \quad = \quad N_0 e^{-\gamma t} + \frac{D}{\gamma}[1 - e^{-\gamma t}] \qquad [2.23]$$

➢ *Phosphorus*

Phosphorus attenuation model was obtained on the same principles as nitrogen. The only difference the partitioning of phosphorus which excludes loss to the atmosphere as shown in the diagram below.

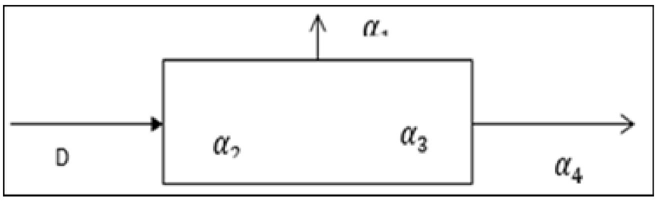

Fig 4 Phosphorus Partitioning in CW.

Based on the assumptions and the parameters above, the model equation becomes

$$\frac{dP}{dt} \;=\; D - kP; \;\; P(0) \;=\; P_0$$

$$\text{Where } k \;=\; \alpha_1 + \alpha_2 + \alpha_3 + \alpha_4$$

D = input phosphorus concentration (mg/l)

α_1 = CWplant use (mg/l)

α_2 = accumulation in CW media and sediment (mg/l)

α_3 = retention in wetland water pool (mg/l)

α_4 = discharged phosphorus concentration (mg/l)

Other variables are as defined for nitrogen.

Hence,

$$\frac{dP}{dt} + kP = D \quad [2.24]$$

$$P(0) = P_0$$

Solving, we have the phosphorus removal model as

$$P(t) = P_0 e^{-kt} + \frac{D}{k}[1 - e^{-kt}] \quad [2.25]$$

G. Model Solutions

Solutions to the first order equations concerning the nutrients attenuation in the CW were obtained by using MATLAB approach. Consequently, standardization of model constants and verification of the model were carried out using data obtained from the experiment. Finally, the model was validated by comparing field values with model predictions.

H. Evaluation of Model Performance

The model was evaluated statistically to indicate its performance. evaluated (Fox, 1981).

- *Bias or Mean Bias*

$$\mathrm{ME} = \frac{1}{N}\sum_{i=1}^{N}(P_i - O_i) \quad [2.26]$$

Where P and O are the predicted and observed values and N is the number of observations.

- *Root Mean Square Error (RMSE)*

It quantifies the dispersion between simulated and measured data.

$$\mathrm{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(P_i - O_i)^2} \quad [2.27]$$

- *Relative Error (RE):*

$$\mathrm{RE} = \frac{\mathrm{RMSE}}{\bar{y}} \times 100 \quad [2.28]$$

Where,

y is the mean of observed values.

- *Model Efficiency*

Model efficiency (EF) was calculated as:

$$\mathrm{EF} = \frac{\sum(O - \bar{O})^2 - \sum(P - \bar{P})^2}{\sum(O - \bar{O})^2} \quad [2.29]$$

Where,

O = observed values; $\bar{O}$ = mean observed values;

P = predicted values and, $\bar{P}$ = mean predicted values

- *Index of Agreement (IA):*

$$d = 1 - \frac{\sum_{i=1}^{N}(O_i - P_i)^2}{\sum_{i=1}^{N}(O'_i + P'_i)^2} \quad ,0 \le d \le 1 \quad [2.30]$$

Where $O'_i = |O_i - \bar{P}|$, $P'i = |Pi - \bar{P}|$, Oi is the observed value, Pi is the simulated value and $\bar{P}$ is the simulated mean. d = 1corresponds to a perfect match of predicted to observed data.

I. Model Calibration

Model calibration parameters for nitrogen and phosphorus removal respectively, are presented in Table 1

Table 1 Parameters for Calibration of Nitrogen and Phosphorus Removal.

Symbols	Description	N	P	Unit
N_0	Initial concentration of Nitrogen	6.00		mg/l
P_0	Initial concentration of Phosphorus		2.23	mg/l
t	Retention time	3	3	Days
ρ	Rate of Nutrient removal from the wetland system.	0.122	0.078	m^3/day
D	Input rate (mean)	29.2	11.52	m^3/day
T	Period time of introducing nutrient.	3	3	Days
δ_1	Nutrient retention in wetland water column	1.48		mg/l
δ_2	Plant Nutrient uptake	8.90		mg/l
β	Denitrification (52% of net N input)	15.2		mg/l
ε	Nutrient retention in wetland sediment	5.05		mg/l
α_N	Effluent rate or output	2.07		m^3/day
α_1	Plant uptake		2.08	mg/l
α_2	Nutrient retention in wetland sediment		2.87	mg/l
α_3	Retention in wetland water column		2.01	mg/l
α_4	Effluent rate		1.24	mg/l

To calibrate the model, field data collected within February – April, 2018 were used. The procedure was to adjust the model parameters and forcing within the boundaries of the uncertainties to get a model representation of the processes of interest that satisfies pre-agreed conditions.

J. Model Validation

Input parameters for model simulation are shown in Table 2.

Table 2 Parameters for Model Simulation for Nitrogen and Phosphorus Attenuation.

Symbols	Description	N	P	Unit
N_0	Initial concentration of Nitrogen	6.06		mg/l
P_0	Initial concentration of Phosphorus		2.23	mg/l
t	Retention time	3	3	Days
ρ	Rate of Nutrient removal from the wetland system.	0.125	0.082	md^{-1}
D	Input rate (mean)	27.40	10.21	m^3/day
T	Period time of introducing nutrient.	3	3	Days
δ_1	Nutrient retention in wetland water column	1.28		mg/l
δ_2	Plant Nutrient uptake	8.76		mg/l
β	Denitrification (52% of net N input)	5.82		mg/l
ε	Nutrient retention in wetland sediment	5.65		mg/l
α_N	Effluent rate or output	1.28		m^3/day
α_1	Plant uptake		2.43	mg/l
α_2	Nutrient retention in wetland sediment		2.81	mg/l
α_3	Retention in wetland water column		1.71	mg/l
α_4	Effluent rate		0.96	mg/l

The simulation of the prediction model was effected by comparing the field data with the model prediction by plotting the simulated and field data against time after running a calibrated model with a new set of data (independent data set) with physical parameters and the derived functions to reflect new conditions and discover how well the model simulations fit the new data set.

III. RESULTS AND FINDINGS

➢ *Model simulation Results*

Simulations of nutrient attenuation in the CW were executed using the parameters shown in Table 2 to define the overall relations and connections that influence the attenuation of nitrogen and phosphorus in CW. The model simulations after introducing mathematical equations, parameters and initial conditions in the state variables are presented in Figures 5 and 6.

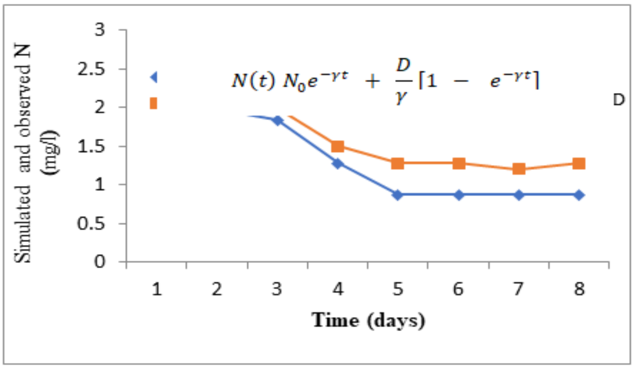

Fig 5 Simulated and Observed Nitrogen Attenuation in CW.

The relationship amongst the simulated and observed attenuation of nitrogen and phosphorus contaminants in the CW are presented in Figures 6 and 9 respectively. There was a high degree of relationship between the simulated and observed values.

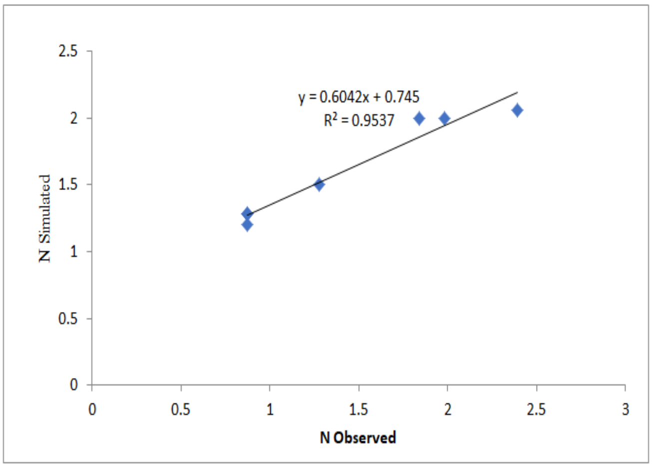

Fig 6 Correlation of Observed and Simulated Attenuation of Nitrogen in Constructed Wetland.

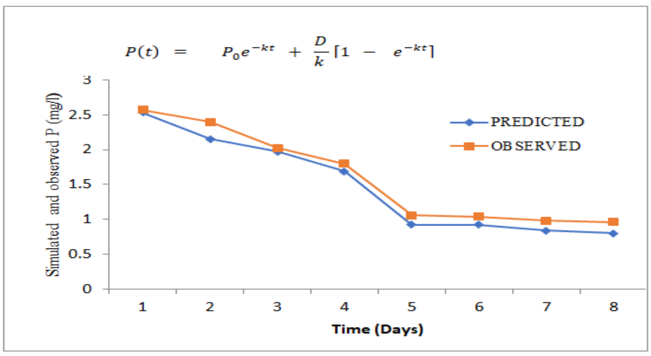

Fig 7 Simulated and Observed Variations for Phosphorus Removal in CW

The correlation between the simulated and observed attenuation of phosphorus in the CW is presented in Figure 9. There was high correlation among the simulated and observed values.

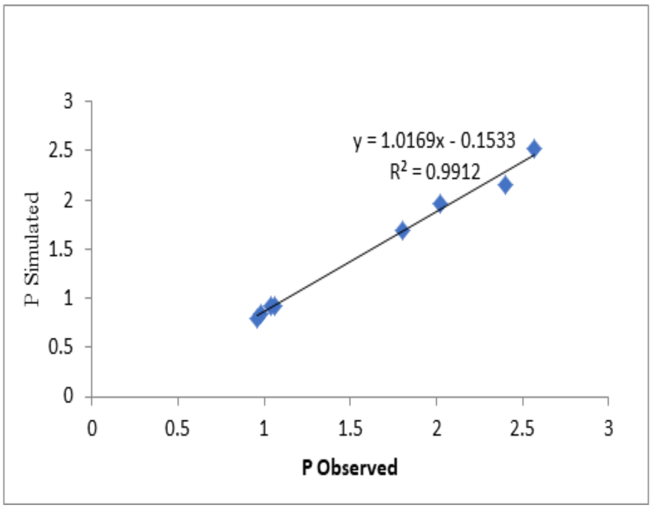

Fig 8 Correlation of Observed and Simulated Removal of Phosphorus in CW

IV. DISCUSSION ON FINDINGS

A. Process Model Assumptions and Development

In this model, nutrient discharge due to plant die-off was not considered to have an input into the wetland since the macrophytes are likely to be mowed fresh to feed the pigs. Nitrogen release to the atmosphere is primarily through denitrification of nitrogen. Contamination from rainfall and interchange with subsurface are insignificant matched with other processes.

In the research, nitrogen and phosphorus attenuation was exponential in the first three days of detention of the wastewater in the CW and thereafter the attenuation was constant at greater detention periods contingent on the decay constant. The CW design was centered on first order plug flow reaction that is characterized by decay response indicating a weakening in contaminant strength along the CW basin as long as the strength of the entering wastewater exceed that of the CW. This remark is compatible with that of Kadlec and Wallace (2009) for a number of CW. The relationship among the observed and simulated attenuation rates removal for N and P in Figures 6 and 8 indicated good agreement as presented by regression equations in Figures 6 for N (R = 0.9537) and Figure 8 for P (R = 0.9912) separately.

The linear regression coefficients are very good agreed that the CW was a natural system sited in the field, where unrestrained impelling influences might wane optimum efficiency according to Jørgensen and Bendoricchio**,** (2001).

B. Statistical Indicators of Model Performance

The statistical pointers of model performance are shown in Table 3.

Table 3 Statistical Pointers of Model Performance

Nutrient	R^2	R	Mean bias error (mm)	Root Mean Square Error (mm)	Relative Error (%)	Model efficiency (%)	Index of Agreement
Nitrogen	0.9537	0.9766	0.211	0.32	24	84	0.6527
Phosphorus	0.9912	0.9956	0.139	0.18	12	77	0.8676

The statistical pointers of simulation performance are summarized in Table 3. The rate of coefficient of determination (R^2, 0.9537, 0.9912) indication that a good relationship exists between observed and simulated values for both Nitrogen and Phosphorus separately. The proportion of mean bias error (MBE) is equivalent to 0.21 and 0.14 mm for both nitrogen and phosphorus separately. A positive rate of MBE shows excessive estimation and vice-versa. The mean root square errors are 0.32 and 0.18 mm for both nitrogen and phosphorus. The extent of root mean square error (RMSE) is a suitable parameter of model performance. In an ideal situation, the rate of relative error (RE) and the model efficiency (EF) will be 0% and 100%, separately. So the RE value of about 24 and 12 % and EF value of about 64 and 37 % obtained in this study show that the strength of model in predicting real life attenuation of the nutrients was good for nitrogen and reasonable for phosphorus. The limit of index of agreement (d) value is from 0 to 1. A higher value indicates a better agreement between the simulated and observed values. In this study, the value of d (0.6527 and 0.8676) indication a good performance of the model in attenuating the nutrients. However, much departure from the ideal value for the model may be owing to in-built assumptions in the model code, and also in the field data. For instance, the model adopts the steady-state situation but in reality, this may not be true (as the flux can vary with the change in moisture level and atmospheric demand). Overload of phosphorus in the wetland bed and /or low bed porousness of the parent material used for bed construction could prejudice phosphorus attenuation efficiency as observed by Karczmarczyk (2004).

C. Model Applications and Limitations

The models developed in this study are suitable for performance analysis of horizontal subsurface flow constructed wetlands getting secondary piggery wastewater. Their application requires information on inflow wastewater concentrations (mg/l) of organic nitrogen and phosphorus in the wetland and the inflow rate. The initial values of nitrogen and phosphorus in the soil and in the wastewater are also required (Udom, 2023).

REFERENCES

[1]. H. N. Abbasi, J. Xie, S.I. Hussain, X. Lu. "Nutrient removal in hybrid Constructed Wetlands: spatial-seasonal variation and the effect of vegetation". *Water Science and Technology*., vol.79 issue 10. pp 1985–1994, 2019

[2]. A. Karczmarczyk. "Phosphorus removal from domestic wastewater in horizontal subsurface flow constructed wetland after 8 years of operation – a case study" *Journal of Environmental Engineering and Landscape Management*, vol.12 issue 4. Pp 126-131, 2004.

[3]. Allen, H. Private communication. 2019. AOAC. "Official methods of analysis. Association of Official Analytical Chemists". Washington. 2007.

[4]. Brovelli, A., F. Malaguella, D.A. Bary. "Bioclogging in porous media: Model development and sensitivity to initial conditions". *Environmental Modelling and Software*. vol. 24 issue 5. pp 611-626, 2009.

[5]. ECC. "Effluent Management Guidelines for Intensive Piggeries in Australia" Australian and New Zealand Environment and Conservation Council, 1999.

[6]. EPA."Constructed Wetlands Treatment of Municipal Wastewaters". United States Environmental Protection Agency, 2000.

[7]. EPA. 2000. "Alternative Systems for Piggery Effluent Treatment". Available: http://www.epa.sa.gov.au/.

[8]. J. E. Ewuziem, A.C. Nwosu, E.C.C. Amaechi, A. O. Aniebo and P. O. Anyaebu. "Piggery waste management and profitability of pig farming in Imo State, Nigeria". *Nigerian Agricultural Journal vol 4 issues 1-2 pp 42 – 53,* 2009.

[9]. D. Giraldi D, M. de Michieli Vitturi, R. Iannelli. "Fitovert: a dynamic numerical model of subsurface vertical flow constructed wetlands".*Environmental Modeling Software* vol. 25 issue 5 pp. 633–640, 2010.

[10]. F. Gouriveau. "Constructed farm wetland designed for remediation of Farmyard runoff: an evaluation of their water treatment efficiency, ecological value, costs and benefits". PhD Thesis – University of Edinburg, 2009.

[11]. Henze, M., P. Harremoes, J.L.C Jansen., and E. Arvin. "Wastewater Treatment: Biological and Chemical Processes". Springer, Verlag, Berlin, Germany, 1995.

[12]. R. A. Horton, S. Wing, S.W. Marshall, K.A. Brownchery. "Malodour as trigger of stress and negative mood in neighbours of hog operations". *American Journal of Public Health* vol. *99 issue 3 pp 610-615*, 2009.

[13]. S. E. Jørgensen, and G. Bendoricchio**. "**Fundamentals of ecological modelling". Elsevier.

[14]. R. H. Kadlec ., S.D. Wallace. "Treatment Wetlands". 2nd Edition; CRC Press Boca, Raton FL, USA. 2009.

[15]. C. Kadurumba, M.E. Kadurumber. Piggery waste management practices and environmental implications on Human health in Rivers State, Nigeria. International Journal of Agric. and rural development. 22(1): 4161– 4166), 2019

[16]. R. Kadaverugu. "Modeling of subsurface horizontal flow constructed Wetlands using OpenFOAM_Mode". *Earth Syst. Environ*. vol. 2 pp. 55-65, 2016.

[17]. C. Mason. "Biology of Freshwater Pollution". Fourth Edition. Pearson Educational Ltd, Edinburg Gate, Harlow, Essex, Uk. 2002.

[18]. "Modern technologies for raising pigs" 2015. Available at:https://gazetadeagricultura.info/animale/porcine/17466-tehnologii-moderne-pentru-cresterea-porcilor. html.

[19]. H. F. Muga, R. Mihelcic. "Sustainability of wastewater treatment technologies". *Journal of Environmental Management* vol. 88 issue 3 pp. 437- 447, 2008.

[20]. Mburu N., R.D.L Rousseau., J. J. A. van-Bruggen and P.N.L Lens. "Potential of Cyperus Payrus Macrophyte for wastewater treatment: A review". 12th International Conference on Wetland systems for water pollution. Central Venice (Italy) 4th – 9th October, 2012.

[21]. S. Nandakumar, H. Pipil, S. Ray, A. K. Haritash. 2019. Removal of phosphorous and nitrogen from wastewater in Brachiaria-based constructed wetland. Chemosphere. vol. 233 pp. 216-222, 2019.

[22]. NPC. National Population Commission, Abuja, Nigeria, 2006.

[23]. K. A. Reddy, R. D. Delaune. "Biogeochemistry of Wetlands: Science and Applications". CRC Press. Boca Raton, FL., 2008.

[24]. E. Soare, and I. Chiurciu. "Study on the pork market worldwide". *Management, Economic Engineering in Agriculture and Rural Development*. 17(4): 321-326, 2017.

[25]. S. J. Simunek, M. Th. Van Genuchten, M. Sejna. 2010. "Developments and applications of the HYDRUS and STANMOD software packages and related codes". *Vadoze Zone Journal* vol. 7 pp. 587-600, 2010.

[26]. I. O. Uddin and D.I. Osasogie. "Constraints of pig production in Nigeria: A case study of Edo central Agricultural Zone of Edo State". *Asian Research Journal of Agriculture* vol. 2 issu 4 pp 1-7, 2016.

[27]. I. J. Udom. "Partitioning nutrients cycling in a constructed subsurface wetland treating piggery wastewater for pollution control". *Arid Zone Journal of Engineering, Technology & Environment* vol. 19 issue 3 pp 17-29, 2023.

[28]. I. J. Udom, C. C. Mbajiorgu, E. O. Oboho. **"**Development and Evaluation of a Constructed Pilot-Scale Horizontal Subsurface Flow Wetland Treating Piggery Wastewater for Pollution Control. *Ain Shams Engineering Journal* vol. 9 pp. 3179–3185, 2018.

[29]. S. D. Wallace, and R.L. Knight. "Small-scale constructed wetland treatment systems: Feasibility, design criteria, and O & M requirements". Final report, Project 01-CTS. Water Environment Research Foundation (WERF). Alexandria. Virginia. 2006.

[30]. S. Wendee. "Intensive livestock operations, health and quality of life among Eastern Carolina residents". *Environmental Health Perspectives* vol. 108 issue 3 pp 233-238, 2017.