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NUMERICAL MODELING OF HORIZONTAL SUBSURFACE FLOW CONSTRUCTED WETLAND SYSTEM

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ABSTRACT

This is the first study looking at the wastewater treatment system created at Basrah University, Iraq. This study aims to investigate the effectiveness of horizontal subsurface flow (HSSF) constructed wetland (CW) system for treating municipal wastewater, and to understand the inner processes presented in the wetland to distinguish and define the function of each component of the treatment and to create wastewater treatment built using MATLAB programming language to represent the biochemical phenomena systems similar to the treatment system and implement them throughout Iraq. To do this, a mathematical model based on one dimensional constructed wetland model number 1 (CWM1) matrix and the optimum CWs operational parameters was occurring in the CWs. The CWM1 was used to simulate processes in horizontal subsurface flow (HSSF) constructed wetlands. Results of the simulation had a very good fit to measured NH_4-N as well as a good fit to measured chemical oxygen demand (COD) concentration after changing the values of the concentration autotrophic nitrifying bacteria (XA) and acetotrophic methanogenic bacteria (XAMB).

KEYWORDS: Constructed Wetland, Wetland treatment, Numerical modeling, Horizontal Subsurface Flow

1. INTRODUCTION

Constructed wetlands (CWs) are wastewater treatment techniques that take advantage of the physical, chemical, and biological operations occurring in soils to achieve better water quality. Treatment wetlands are engineered systems that use the same natural processes as CWs however under more controlled conditions (Hanna et al., 2015). CWs are very effective in removing organic and suspended solids though are not so effective at removing nitrogen.

The components that make up a wetland include water, substrate (media), plants, litter, worms, insect larvae, and microorganisms (Norio, and Wun, 2011). In comparison, CWs usually involve three main components; plants, microorganisms, and media (Cooper and Findlater, 1990). It is the interaction between these components that leads to the treatment and degradation of pollutants.

The function of plants in CWs is to remove pollutants from wastewater by accumulating them in the plant biomass and filtering the suspended solids that are present in wastewater. Furthermore, plants help to increase the dissolved oxygen through their rhizomes. Likewise, the roots of the plants play a vital role in transferring oxygen to the bulk volume of a CW, hence supporting microbial growth and aid in biological treatment (Brix, 1997). However, the effectiveness of plant uptake is determined by various factors including environmental factors, design considerations as well as the nature and number of pollutants present in wastewater. As for microorganisms, they play a role in the degradation and transformation of minerals, the activity of microorganisms is the main driving factor in wastewater treatment for CWs through their ability to break down organic matter under aerobic and anaerobic conditions (Chen et al. 2014). The main types of microorganisms present in wetland treatments include bacteria and fungi; they work by digesting, converting, and recycling chemical pollutants found in various wastewaters (Mueller et al., 2003). Finally, the media in CWs includes sand, gravel, rocks, slag from steelmaking and blast furnaces, and organic materials found below the root areas in CW subsurface flow systems. The media acts as a support for microorganisms, vegetation, the roots, and rhizomes, hence is a vital component in CWs. In addition, the media acts as a storage facility for certain pollutants and provides a large surface area for the bacteria to attach to the plant biomass. Furthermore, it also can act as a filter and adsorption media for the pollutants (Mueller et al., 2003). However, it should be noted that the media used in CWs could affect the wastewater interaction with the plants and microorganisms present. The main aim of this study to simulate the HSSF behavior using one dimensional model CWM1, and modification the CWM1 by considering the effect of flow in porous media and influence of the plants.

1.1. Types of Constructed Wetland Systems

According to the direction of water flow through the wetland basins, CWs can be classified into either subsurface flow wetlands or surface flow wetlands. In the former, the water flows underground through the porosity of the granular medium, whilst in the latter, water flows over the granular medium under atmospheric pressure (free surface flow) (Kadlec, and Wallace, 2008).

Subsurface flow CWs can further be subdivided into horizontal flow or vertical flow systems. In horizontal subsurface flow systems (HSSF), wastewater is maintained at a constant depth and flows horizontally below the surface of the granular medium. In comparison, in vertical subsurface flow systems (VSSF), wastewater is distributed over the surface of the wetland and trickles down through the granular medium (Brix, and Arias, 2005). CWs can include a combination of VSSF and HSSF to achieve a more effective treatment system. However, our study will focus on HSSF as shown in Figure 1.

1.2. Study of Constructed Wetland Behavior

CWs are sometimes referred to as 'black box' systems; this is due to the complex relationships between physical, chemical, and biological treatment processes. As a result of these complex interactions, previous designs have used empirical rules of hand or simple models of first-order decay to understand CWs (Vymazal, 2005). However, we believe that numerical models give the best understanding of the chemical and biological processes in CWs and the transformation and degradation that occurs. Numerical models must include a number of sub-models to describe all pertinent processes.

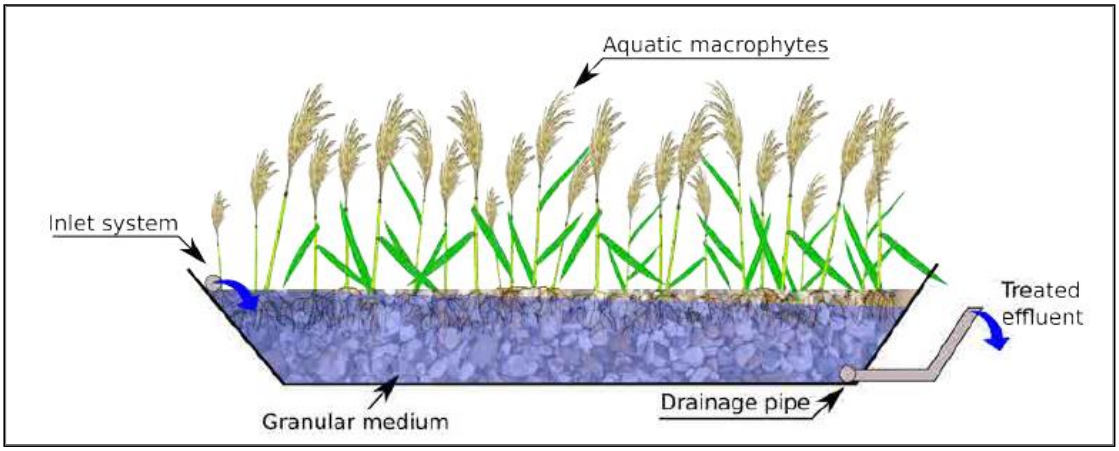

Fig. 1 Schematic Representation of an HSSF. (Roger, 2014).

Different models in subsurface flow CWs have been developed to describe different formulations for the reactions and bio-kinetic models; these include CWM1-RETRASO,

PHWHAT, HYDRUS CWMI, CW2D, and 5-FITOVERT. The main disadvantage of these models is that they are very expensive. In this study, we used CWM, which is based on a mathematical formulation introduced by the International Water Association (IWA) Activated Sludge Models (ASM), which include nitrogen and a fraction of organic substrate (Roger, 2014).

2. MODEL DEVELOPMENT

HSSF CWs are influenced by both external and internal factors. External factors include flow rate, wastewater composition, and temperature. On the other hand, internal factors include bacterial growth and development. Furthermore, the diversity and synchronicity of the physical, chemical, and biological processed involved of which some are yet to be understood, complicate the CWs even further. Hence, mechanistic models are being preferred over simple black box or first-order decay models (Kadlec, and Wallace, 2008).

2.1. Constructed Wetland Model No.1 (CWM1)

The CWM1 is a bio-kinetic model based on the ASM series and the anaerobic digestion model (ADM) for anaerobic processes, to describe the biochemical transformation and degradation of organic matter, nitrogen, and sulfur in subsurface flow CWs (Henze, 2000). The main aim of CWM1 is to predict effluent concentrations from either VSSF or HSSF CWs without predicting gaseous emissions. This model considers 17 processes, and 16 components (8 soluble and 8 particulate). CWM1 describes the effect of transformation due to microorganisms only. In this study, we modified the flow in porous media and the effect of plant and added to the CWM1 model, due to this modification the number of processes are become 18. In terms of notation and structure, CWM1 is described in a way similar to the ASMs, for example the ASMs concentration of dissolved components is referred to as Si, while the particulate components is referred to as Xi. It is significant to note that in addition to the biokinetic model, a number of other processes have to be thought about for the formulation of a full model for CWs, such as water flow in the porous media, the influence of vegetation, and the transport of particles like suspended matter to describe sorption and adsorption and the physical processes. The components of CWM1 and the effect of vegetation as well as the process kinetics and stoichiometry matrix of CWM1 are presented in Table 1 (Langergraber et al 2009, Rousseau, 2004). The definitions and units in each component of the CWM1 matrix are given in Table 2, and the process rates in CWM1 are shown in Table 3.

Table 1. Kinetic and schoichiometry matrix of CWM1.

j		1	2	3	4	5	6	7	8	9
Process	component expressed as	Hydrolysis	Aerobic growth of XH on SF	Anoxic growth of XH on SF	Aerobic growth of XH on SA	Anoxic growth of XH on SA	Lysis of XH	Aerobic growth of XA on SNH	Lysis of XA	Decomposition
	1		$1-\frac{1}{Yh}$		$1-\frac{1}{Yh}$			$-\frac{4.75-Y_A}{Y_A}$		
O2	SO									
COD	SF	$1-f_{HYD,SI}$	$-\frac{1}{Y_H}$	$-\frac{1}{Y_H}$			$f_{BM,SF}$		$f_{BM,SF}$	
COD	SA				$-\frac{1}{Y_H}$	$-\frac{1}{Y_H}$				
COD	SI	$f_{HYD,SI}$								
N	SNH	v_{5-1}	v_{5-2}	v_{5-3}	v_{5-4}	v_{5-5}	v_{5-6}	$-i_{N,BM}-\frac{1}{Y_A}$	v_{5-8}	
N	SNO			$\frac{1-Y_H}{2.86Y_H}$		$\frac{1-Y_H}{2.86Y_H}$		$\frac{1}{Y_A}$		
S	SSO4									
S	SH2S									
COD	XS	-1					$V_{9,1YSIS}$		$V_{9,1YSIS}$	
COD	XI						$f_{BMXI.}$		$f_{BMXI.}$	
COD	XH		1	1	1	1	-1			
COD	XA							1	-1	
COD	XFB									
COD	XAMB									
COD	XASRB									
COD	XSOB									
COD	XC						fp		fp	-1

10	Growth of XFB		$-\frac{1}{Y_{FB}}$	$\frac{1-Y_{FB}}{Y_{FB}}$		v_{5-9}								1				
11	Lysis of XFB		$f_{BM,SF}$			v_{5-10}				$V_{9,IYSIS}$	$f_{BMXI,}$			-1				fp
12	Growth of XAMB			$\frac{-1}{Y_{AMB}}$		v_{5-11}									1			
13	Lysis of XAMB		$f_{BM,SF}$			v_{5-12}				$V_{9,IYSIS}$	$f_{BMXI,}$				-1			fp
14	Growth of XASRB			$\frac{-1}{Y_{ASRB}}$		v_{5-13}		$-\frac{1-Y_{ASRB}}{2.Y_{ABRB}}$	$\frac{1-Y_{ASRB}}{2.Y_{ABRB}}$							1		
15	Lysis of XASRB		$f_{BM,SF}$			v_{5-14}				$V_{9,IYSIS}$	$f_{BMXI,}$					-1		fp
16	Aerobic growth of XSOB	$-\frac{2-Y_{SOB}}{Y_{SOB}}$				v_{5-15}		$\frac{1}{Y_{SOB}}$	$\frac{-1}{Y_{SOB}}$								1	
17	Anoxic growth of XSOB					v_{5-16}	$-\frac{1-Y_{SOB}}{0.875Y_{SOB}}$	$\frac{1}{Y_{SOB}}$	$\frac{-1}{Y_{SOB}}$								1	

2.2. Processes in CWM1

The processes in CWM1 can be described using Monod kinetics. The basic principle for Monod kinetics can be shown using equation 1 (Monod, 1994).

$$\mu = \mu_{max} \frac{S}{K_S + S} \qquad (1)$$

Where μ is a specific rate of growth, S is the concentration of substrate and Ks is half saturated coefficient.

Table 2. Definitions of 1D-CWM1 model component (Langergraber et al 2009, Rousseau, 2004).

Component Number	Component Symbol	Definition
1	SO	Dissolved oxygen, mg/l as O_2
2	SF	Fermentable, readily biodegradable soluble, mg/l as COD
3	SA	Fermentation products as acetate, mg/l as COD
4	SI	Inert soluble, mg/l as COD
5	SNH	Ammonium and ammonia nitrogen, mg/l as N
6	SNO	Nitrate and nitrite nitrogen, mg/l as N
7	SSO_4	Sulphate Sulphur, mg/l as S
8	SH_2S	Dihydrogen sulphide Sulphur, mg/l as S
9	XS	Slowly biodegradable particulate, mg/l as COD
10	XI	Inert particulate, mg/l as COD
11	XH	Heterotrophic bacteria, mg/l as COD
12	XA	Autotrophic nitrifying bacteria, mg/l as COD
13	XFB	Fermenting bacteria, mg/l as COD
14	XAMB	Acetotrophic methanogenic bacteria, mg/l as COD
15	XASRB	Acetotrophic sulphate reducing bacteria, mg/l as COD
16	XSOB	Sulphide oxidising bacteria, mg/l as COD
17	XC	Plant uptake, mg/l as COD

Table 3. Processes rates in CWM1 matrix (Langergraber et al 2009, Rousseau, 2004).

	Process	**Process rate ρ_j**
1	Hydrolysis	$k_h \left[\frac{X_s/(X_h + X_{FB})}{X_s + (X_s/(X_h + X_{FB}))}\right] * (X_H + \eta_h * X_{FB})$
2	Aerobic growth of X_H on S_F	$\mu_h * \left[\frac{X_F}{K_{SF} + S_F}\right] * \left[\frac{X_F}{K_F + S_A}\right] * \left[\frac{X_o}{K_{OH} + S_o}\right] * \left[\frac{X_{NH}}{K_{NHH} + S_{NH}}\right] * \left[\frac{X_{H2SH}}{K_{H2SH} + S_{H2s*}}\right] * X_H$
3	Anoxic growth of X_H on S_F	$\eta_g * \mu_h * \left[\frac{S_F}{K_{SF} + S_F}\right] * \left[\frac{S_F}{S_F + S_A}\right] * \left[\frac{K_{OH}}{K_{OH} + S_O}\right] * \left[\frac{S_{NO}}{K_{NOH} + S_{NO}}\right] * \left[\frac{S_{NH}}{K_{NHN} + S_{NH}}\right] * \left[\frac{S_{H2SH}}{K_{H2SH} + S_{H2s*}}\right] * X_H$
4	Aerobic growth of X_H on S_A	$\mu_h * \left[\frac{S_A}{K_{SA} + S_A}\right] * \left[\frac{S_A}{S_F + S_A}\right] * \left[\frac{S_o}{K_{OH} + S_o}\right] * \left[\frac{S_{NH}}{K_{NHH} + S_{NH}}\right] * \left[\frac{S_{H2SH}}{K_{H2SH} + S_{H2s*}}\right] * X_H$
5	Anoxic growth of X_H on S_A	$\eta_g * \mu_h * \left[\frac{S_A}{K_{SA} + S_A}\right] * \left[\frac{S_A}{S_F + S_A}\right] * \left[\frac{K_{OH}}{K_{OH} + S_O}\right] * \left[\frac{S_{NO}}{K_{NOH} + S_{NO}}\right] * \left[\frac{S_{NH}}{K_{NHN} + S_{NH}}\right] * \left[\frac{k_{H2SH}}{K_{H2SH} + S_{H2s*}}\right] * X_H$

6	Lysis of X_H	$b_H * X_H$
7	Aerobic growth of X_A on S_{NH}	$\mu_h * \left[\frac{S_{NH}}{K_{NHH}+S_{NH}}\right] * \left[\frac{S_o}{K_{OA}+S_o}\right] * \left[\frac{k_{H2SH}}{K_{H2SH}+S_{H2s*}}\right] * X_A$
8	Lysis of X_A	$b_A * X_A$
9	Growth of X_{FB}	$\mu_{FB} * \left[\frac{S_F}{K_{SFB}+S_A}\right] * \left[\frac{K_{H2SFB}}{K_{H2SH}+S_{H2s*}}\right] * \left[\frac{K_{OFB}}{K_{OFB}+S_o}\right] * \left[\frac{K_{NOFB}}{K_{NOFB}+S_{No}}\right] * \left[\frac{S_{NH}}{K_{NH}+S_{NH}}\right] * X_{FB}$
10	Lysis of X_{FB}	$b_{FB} * X_{FB}$
11	Growth of X_{AMB}	$\mu_{AMB} * \left[\frac{A}{K_{SAMB}+S_A}\right] * \left[\frac{K_{H2SAMB}}{K_{H2SAMB}+S_{H2s*}}\right] * \left[\frac{K_{OAMB}}{K_{OAMB}+S_o}\right] * \left[\frac{K_{NOAMB}}{K_{NOAMB}+S_{No}}\right] * \left[\frac{S_{NH}}{K_{NHAMB}+S_{NH}}\right] * X_{AMB}$
12	Lysis of X_{AMB}	$b_{AMB} * X_{AMB}$
13	Growth of X_{ASRB}	$\mu_{ASRB} * \left[\frac{S_A}{K_{ASRB}+S_A}\right] * \left[\frac{S_{SO4}}{S_{SOASRB}+S_{SO4}}\right] * \left[\frac{K_{H2SASRB}}{K_{H2SASRB}+S_{H2s*}}\right] * \left[\frac{K_{OASRB}}{K_{OASRB}+S_O}\right] * \left[\frac{K_{NOASRB}}{K_{NOASRB}+S_{NO}}\right] * \left[\frac{S_{NH}}{K_{NHASRB}+S_{NH}}\right] * X_H$
14	Lysis of X_{ASRB}	$b_{ASRB} * X_{ASRB}$
15	Aerobic growth of X_{SOB} on S_{H2S}	$\mu_{SOB} * \left[\frac{S_{H2S}}{K_{SSOB}+S_{H2S}}\right] * \left[\frac{S_O}{K_{OSOB}+S_O}\right] * \left[\frac{S_{NH}}{K_{NHSOB}+S_{NH}}\right] * X_{SOB}$
16	Anoxic growth of X_{SOB} on S_{H2S}	$\mu_{SOB} * \eta_{SOB} * \left[\frac{S_{H2S}}{K_{SSOB}+S_{H2S}}\right] * \left[\frac{S_{NO}}{K_{NOSOB}+S_{NO}}\right] * \left[\frac{K_{OSOB}}{K_{OSOB}+S_O}\right] * \left[\frac{S_{NH}}{K_{NHSOB}+S_{NH}}\right] * X_{SOB}$
17	Lysis of X_{SOB}	$b_{SOB} * X_{SOB}$
18	Decomposition	$K_{decomp}.* XC$

2.3. Mathematical formulation

In CWM1, a one dimensional, advection-dispersion-reaction equation with a source/sink term, describes the transport of each of the considered wastewater constituent. This equation is based on the conversation of mass principle and has the general form of equation 2 (Kadlec, & Wallace, 2008, Mariângela et al. 2003).

$$\frac{\partial C_i}{\partial t} = \frac{\partial}{\partial x}\left(D_x \times \frac{\partial C_i}{\partial x}\right) - u\frac{\partial C_i}{\partial x} + \sum_{i=1}^{np} R_{ci} \quad (2)$$

Where C_i is the concentration of components (No. I, and i=1… 17, ML^{-3}), t is the time (T), x is the longitudinal direction (L), D_x is the longitudinal dispersion coefficient (L^2T^{-1}) and u is the average flow velocity in x-direction (LT^{-1}).

This can be calculated from Darcy Law, as shown in equation 3.

$$u = k \times i = k \times \frac{dh}{dx} \quad (3)$$

Where k is permeability (LT^{-1}), i is slope, np is the number of components, R_{ci} is the source/sink term which represents the rate of increase or decrease in pollutant and No. i concentration due to reaction, ML^3T^{-1}.

The items of inflow and outflow masses are found by the physical characteristics of the process. The formative mass by the reaction is determined by the expression shown below (equation 4).

$$r_i = \sum_{j=1}^{R} V_{j,i} * \rho_j \quad (4)$$

Where *ri* is the formative mass by reaction, *vij* is stoichiometric coefficient and ρj is the rate of process for component i.

In equation 2, the first term on the right side represents the pollutants diffusion process, while the second term represents the pollutants advection, and the third term is all the phenomena responsible for the pollutants concentration variation along with time and space. For horizontal subsurface flow, the mass balance equation takes the following expression.

Equation 2 can be written for any soluble pollutants, as:

$$\frac{\partial S_i}{\partial t} = \frac{\partial}{\partial x}\left(D_x \times \frac{\partial S_i}{\partial x}\right) - u\frac{\partial S_i}{\partial x} + \sum_{i=1}^{np} R_{si} \quad (5)$$

For any particulate pollutants, equation 2 can be written as:

$$\frac{\partial X_i}{\partial t} = \frac{\partial}{\partial x}\left(D_x \times \frac{\partial X_i}{\partial x}\right) - u\frac{\partial X_i}{\partial x} + \sum_{i=1}^{np} R_{xi} \quad (6)$$

The reaction terms RSi, and Rxi in equations 5 and 6 respectively, were specified based on the CWM1 matrix given in Table 1.

3. AUXILIARY EQUATION

Auxiliary equations are those required to determine the longitudinal dispersion coefficient (D_x), computed from in equation 2 (Kadlec, & Wallace, 2008).

$$D_x = \frac{u \times L}{P_e} \quad (7)$$

Where u is velocity (LT^{-1}), L is distance from inlet to outlet (L) and Pe is the Peclet number, dimension-less.

Burno et al. (2013) specified the range of Peclet numbers to be 5-500. For HSSF wetland a Pe of 500 indicates low dispersion of constituent. While, Pe ranges between 40 to 500 indicate intermediate dispersion of constituent and Pe ranges between 5 to 40 indicate large dispersion of constituent. The dispersion coefficient (D_X) for HSSF is assumed to range between 100-150 m^2/day (Joel, 1999).

4. SOLUTION OF 1D-CWM1 BASIC EQUATIONS

This model implements fluid flow and transport equations together with the biokinetic model CWM1 into MATLAB 9.0.0 software, which solves the problem equations using the finite elements method (FEM). The basic equations of 1D-CWM1 are seventeen nonlinear partial differential equations. Explicit finite difference method was needed for solving the seventeen simultaneous nonlinear equations.

5. RESULTS AND DISCUSSION

The main objective of this study was to develop a mathematical model in simulating the distribution of pollutants removal in HSSF CWs.

The performance model was studied by comparing their results with the field measurements performed in the University of Basra Sewage Treatment Plant. Below are the results of comparison after presenting some aspects relating to the development of 1D-CWM1 such as the effect of space step on model results and calibration of model parameters.

5.1. Fractioning of Influent Wastewater

The fraction of the influent wastewater was based on the standard ratio in the ASM model; it contains the fraction of COD. The state variables of the 1D-CWM1 model (SI, SF, SA, XC, XS, XI) are obtained as fractions of COD. The values of this fraction were derived based on those of municipal wastewater and they are listed as in Table 4.

Table. 4 The fractions of COD on municipal wastewater (Rousseau, 2006).

Component	SI	SF	SA	XC	XS	XI
Fraction (%)	3	35	10	3	44	5

5.2. Model Simulation

COD fractions and nitrogen compounds effluent concentrations during the observation time were simulated using the 1D-CWM1 model according to the calibration loop presented in figure 2. Simulations were carried out in the CWM1 model, based on the comparison between measured and simulated effluent concentration.

In this study, the most important results are those of chemical oxygen demand (COD) and ammonium (NH4). Thus the calibration process has been implemented to get the best approval between the model results and the field measurements. Figures 3 and 4 show the verification between predicted and observed for COD and ammonium concentration in the effluent.

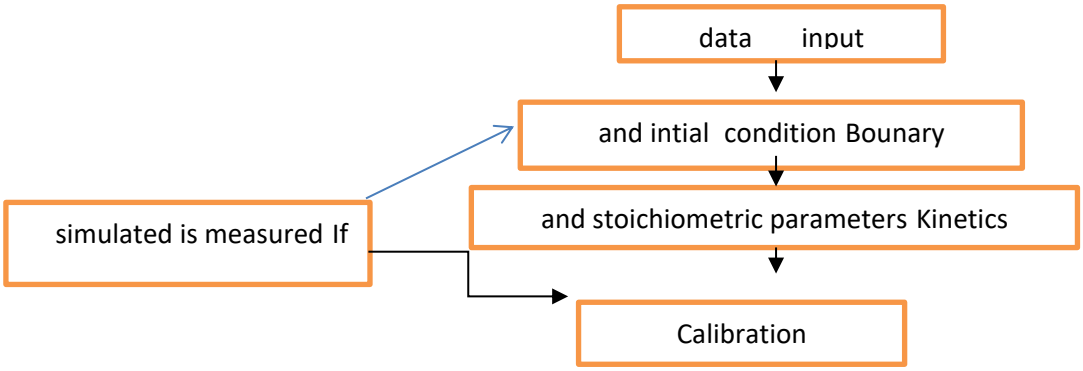

Fig. 2. Different stages in calibrating CWM1.

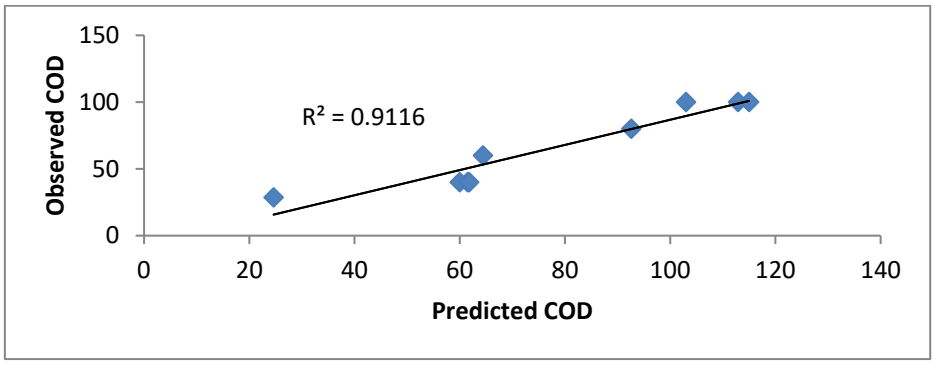

Fig. 3. Comparison between observed and predicted COD.

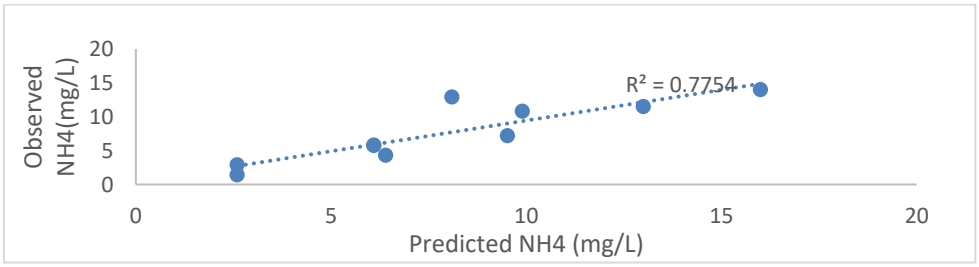

Fig. 4. Comparison between observed and predicted NH4.

The average difference between predicted and observed concentrations, the standard error (SE, equation 8) and coefficient of variation (Cv, equation 9) (Ambrose, and Roesch, 1982), (Mary L., 2008).

$$SE = \left[\frac{1}{N}\sum_{i=1}^{N}(P_i - O_i)^2\right]^{1/2} \quad (8)$$

$$cv = \frac{SE}{\bar{O}} \quad (9)$$

Where SE is the standard error, N is the number of effluent concentration, P_i is the predicted concentration (mg/l), O_i is the observed concentration (mg/l), Cv is the coefficient of variation and $\bar{O}$ is the mean observed concentration (mg/l).

From equations 8 and 9 the values for SE for COD, and NH_4 are 14.6 and 2.71 respectively. The Cv was 0.22 and 5.19 for COD and ammonium, respectively. Hence, the CWM1 was considered as suitable for further simulations (Kwanchai, and Gomez, 1984).

5.3. Sensitivity Analysis

The sensitivity analysis performed with the calibrated model showed that the changes in the values of microorganisms (XA) and XAMB result in a change in COD and NH_4 as shown in figures 5 and 6. As XA and XAMB increase and reach 40 mg/l, the model behaves in a similar way to the real system, hence the sensitivity analysis showed that the calibrated model is sensitive to change in XA and XAMB.

5.4. Calibration Analysis

In this study, the most important results are those of COD and NH_4. Thus the calibration process has been implemented to get the best approval between the model results and the field measurements for 3 days.

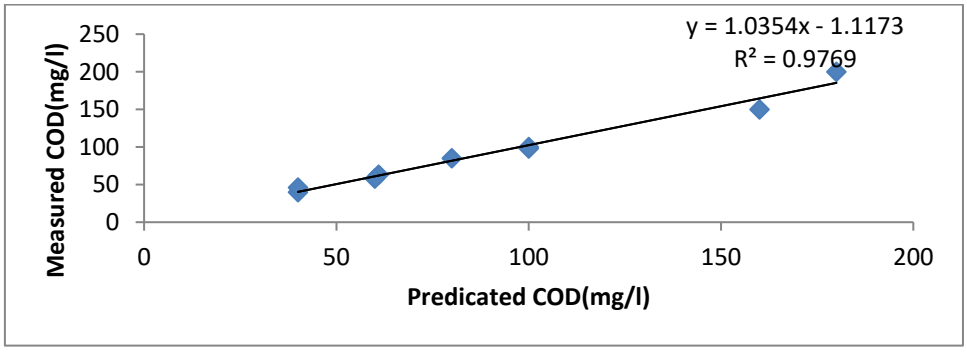

Fig. 5. Comparison between observed and predicted COD after calibration.

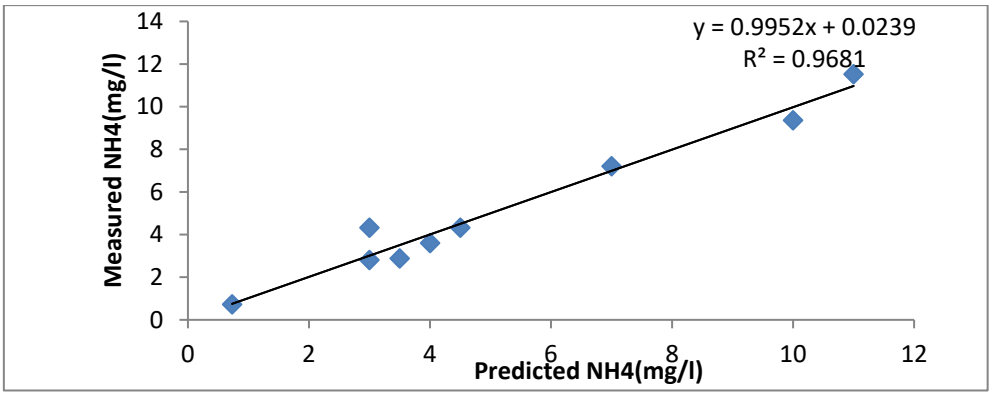

Fig. 6. Comparison between observed and predicted NH_4 after calibration.

5.5. Validation Analysis

The validation results show that the CWs-model prediction matches fairly well with the observed data for 3 days. Figures 7 and 8 show the verification between predicted and observed for COD and NH_4 concentration in the effluent.

6. CONCLUSIONS

Based on the results of the numerical modeling we can make the following conclusions:

1. The CWM1 model showed that the values for COD and NH_4 concentrations were similar to the corresponding field data along the HSSF wetlands.

2. The distinction of the results from this study showed that CWM1 is a superior numerical solution for the study of the biochemical transformation in HSSF CWs receiving varying concentrations

3. A perfect fit for progressive and border flow of the simulated and measured data was carried out

4. Results of simulation showed that by changing the two parameters XA and XAMB, results in a similar change in COD and NH_4 concentrations.

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