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Full Length Research Paper

Mathematical modeling of dissolved oxygen in fish ponds

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A mathematical model was developed to predict the effects of wind speed, light, pH, Temperature, dissolved carbon dioxide and chemical oxygen demand (COD) on Dissolved Oxygen (DO) in fish ponds. The effects of organic feeds, aeration and fish activity were added to the model developed by Kayombo et al. for Waste Stabilization Ponds (Ecological Modelling 127(2000): 21 - 31) to reflect the situation in fish ponds. Model calibration and validation was done by use of average DO, pH, temperature, COD, CO_2 and algae biomass data measured from RETCO fish ponds in Dar es Salaam; and light intensity data were adopted from Kayombo et al. (2000). Model results showed a linear relationship between simulated DO and measured DO in fish pond (r^2 = 0. 87) for model calibration and (r^2 = 0.88) for model validation. Simulation results also showed a general decrease of DO with time in 13 days by 28 and 38% for first and second batch, respectively. Thus, the model developed in this study could be used to predict the DO dynamics in fish ponds. Based on the model results, successful cultivation of healthy fish may require that retention time for water in the fish pond be 10 days.

Key words: Calibration, light, pH, substrate, temperature, validation.

INTRODUCTION

Dissolved Oxygen (DO) is considered to be among the most important water quality parameters in fish culture. Chronic low levels of DO in fish culture cause stress to cultivated fish (Boyd, 1982) resulting into reductions in feeding, feed conversion and growth. Low DO in culture ponds is often associated with elevated levels of carbon dioxide (CO_2) and unionized ammonia (NH_3), both of which are toxic to fish, a combination of which dramatically increases the defenselessness of fish to diseases. DO concentrations less than 5 mg/L can create significant problems in the growth or even survival of fish in salt water, while 2 mg/L is the threshold concentration below which aquatic organisms can no longer survive.

The dynamic nature of DO results from a combination of three factors namely limited solubility, rapid use by phytoplankton, fish and other organisms as well as slow replenishment rate from the atmosphere into undisturbed water ((Bergheim and Agar, 1996). The concentration of DO in any water body varies over time and is affected by physical, biological, and chemical factors such as pH, temperature, atmospheric pressure, and salinity. According to Kayombo et al. (2000), combined effect of temperature, pH and light intensity may have a more marked effect on the microbial activities in the pond rather than when one factor is considered. This study therefore aimed at developing a mathematical model for determining the DO dynamics in the fish pond, and determines the effect of pH, BOD, temperature and growth of algae on the DO dynamics in the fish pond.

MODEL DEVELOPMENT

Model simulation was done using STELLA® 7.1 software which is based on the principle of conservation of mass. The case study is RETCO-owned fish ponds located at the Bagamoyo area, about 1 km from the coastal line of the Indian Ocean. The fish ponds receive salty water from the ocean. Water is held in the pond for approximately two weeks without additional inflow or out flows. Pond preparations before stocking of milkfish fingerlings involve the use of organic fertilizers such as humus to promote phytoplankton growth. Constant growth of fish is maintained by supplying artificial feeds

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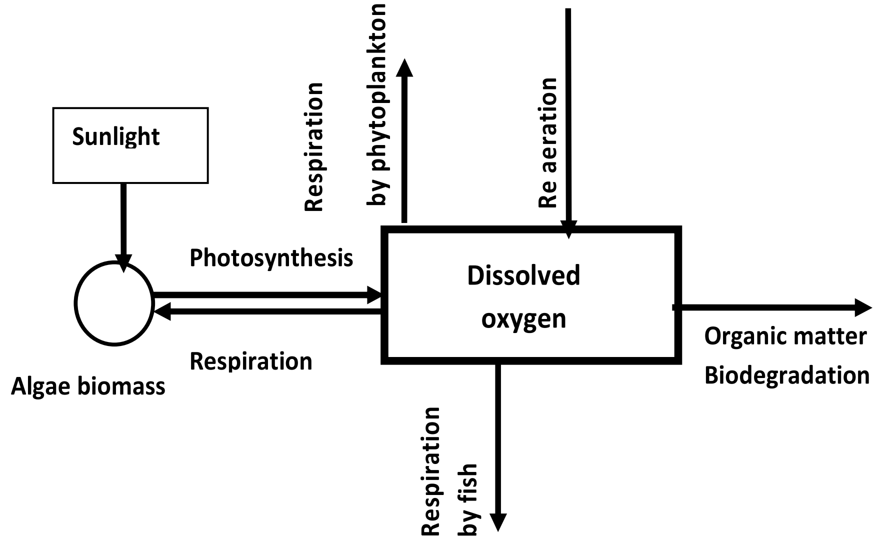

Figure 1. Conceptual model of DO dynamics in fish ponds.

such as chicken manure. As the pond system is operated in batch mode, the un-eaten feeds which are mainly organic in nature may sink and decompose at the pond bottom thereby creating BOD due to decomposition, consequently resulting into depletion of DO. Phytoplankton growth in the ponds may affect the DO concentration due to respiration, photosynthetic activities and die off. Under these interactive circumstances, development of an ecological model is viewed to be a relatively reliable tool to study the DO dynamics in fish ponds in order to understand the most appropriate time of water replenishment in the pond.

The model consists of one state variable namely; the concentration of DO in the fish pond (Figure 1). Forcing functions includes sunlight and organic matter (algae die-offs, fertilizers and artificial feeds such chicken manure). Parameters or forcing functions which affect the DO dynamics in the pond are pH, temperature, COD and concentration of phytoplankton. DO concentration in the pond at any time is dependent on consumption through respiration of phytoplankton and other microorganisms as well as mineralization of organic matter and re-aeration at the pond surface (Chapelle et al., 1999). When temperature, nutrient supply and available sunlight are optimal for algal growth, algae multiply their biomass at an exponential rate, eventually leading to exhaustion of available nutrients supplied by fertilizers and a subsequent die-off. The decaying algal biomass depletes oxygen in the pond water and pollutes it with organic and inorganic solvents such as ammonium ions, which frequently leads to massive loss of fish. The organic matter supplied to the pond undergoes biodegradation which deplete DO in water. The DO concentration in water is also a water quality parameter showing the state of the ecosystem.

PROCESSES AND MATHEMATICAL EQUATIONS

The DO model for waste stabilization ponds (Kayombo et al., 2000) did not consider the effects of addition of organic feeds and the fish activity, which are captured in the current model to reflect the prevailing situation in fish ponds. Since the ponds are shallow, the model has been developed based on the assumption that re-aeration at water surface and photosynthesis process by phytoplankton (algae) are the main sources of oxygen supply to the pond and that respiration by heterotrophic bacteria and fish are the main consumers of DO. Biodegradation of organics is also assumed to consume DO. Assuming that the pond is completely mixed, there are five main processes that are dominant in DO dynamics in fish ponds.

Photosynthesis

In photosynthesis process, phytoplankton use sunlight energy to synthesize oxygen and carbohydrates for growth. In this process violet light is absorbed by chlorophyll, the energy obtained splits water, and oxygen gas is produced through a reaction given in Equation (1).

$$6CO_2 + 12H_2O + Light \rightarrow C_6H_{12}O_6 + 6O_2 + 6H2\ O. \qquad 1$$

In general, changes in pH levels in marine systems appear to correlate with changes in temperature, DO, and phytoplankton production. Conditions of high pH, high phytoplankton production, and low oxygen conditions are characteristic of nutrient enriched systems and often are found in coastal waters or enclosed bodies of water (lagoons, salt ponds, embayment, etc.), which receive anthropogenic inputs such as sewage effluent or agricultural runoff (Marshall and Orr, 1948; King, 1970). The rate of growth of phytoplankton, which are the main source of DO in the pond, expressed as photosynthesis, is a function of temperature T, light L, substrate, and pH as shown in Equation (2) (Chapelle et al., 1999).

$$Photo = \mu_{\max} \times f(T,\ pH,\ substrate,\ L,\ A\lg ae) \qquad 2$$

Where: μ_{max} is the maximum daily growth rate of phytoplankton (d^{-1}).

Light intensity

Light is used as a source of energy for the photosynthesis process to produce oxygen. When light penetration is high in the fish pond, photosynthesis takes place over the whole depth of pond, but as time goes on the growth of phytoplankton and increasing turbidity decreases light penetration, making it a limiting factor for phytoplankton growth. The function of light can be expressed by using Monod kinetic Equation (3).

$$f(L) = \frac{I}{IK + I} \qquad 3$$

Where: I is light intensity $uE(m^{-2}s^{-1})$ and IK is the half saturation light limitation $uE(m^{-2}\,s^{-1})$.

Function of pH

Variation of pH affects algal growth in fish ponds in a number of ways. It can change the distribution of carbon dioxide species and carbon availability, alter the availability of trace metals and essential nutrients, and at extreme pH levels it can cause direct physiological effects (Chenl and Durbin, 1994). The influence of pH on the growth rate is modeled using the model presented by Henze et al. (1995) as shown in Equations 4 and 5.

$$f(pH) = \left(\frac{K_{pH}}{K_{pH} - y} \right) \qquad 4$$

$$y = 10^{|optH - pH|} - 1 \qquad 5$$

Where: K_{pH} is the pH constant and optpH is the maximum pH at which the growth of phytoplankton is maximum.

Function of temperature

Temperature has strong influence on the chemical composition of marine phytoplankton. Eppley (1972) has also reported that within defined temperature limits, division rates increase with increasing temperature. Equation (5) (Jorgensen et al., 1978) describes the function of temperature on growth of phytoplankton.

$$f(T) = \exp\left[-2.3 \left(\frac{T - T_{opt}}{T_{opt} - T_{\min}} \right) \right] for T \le T_{opt},\ f(T) = 1..for..T \ge T_{opt} \qquad 6$$

Where: T_{opt} and T_{min} are optimum and minimum temperature (℃), respectively.

Function of substrate

Inorganic carbon limitation of growth is the main mechanism in phytoplankton response to pH. Molecular dissolved CO_2 is considered to be the major species of inorganic carbon utilized in photosynthesis (Blackman and Smith 1911; Rabinowitch 1945). It has also been shown by Cooper (1969) that CO2 is the carbon compound within a cell that is critical to photosynthesis in binding with the enzyme ribulose bisphosphate carboxylase (Rubisco). Equation for function of substrate has been described in Equation (7).

$$f(substrate) = \left(\frac{CO_2}{K_{CO_2} + CO_2} \right) \qquad 7$$

Where: CO_2 is the concentration of dissolved carbon dioxide in pond (mg/L) and K_{CO2} is the half saturation constant for dissolved carbon dioxide (mg/L).

Respiration and excretion

Respiration by phytoplankton occurs during the night time, where they utilize molecular oxygen present in water to obtain energy as seen in respiration chemical Equation (8). Other microorganisms present in water also respire and excrete in water which makes further utilization of DO.

$$C_6H_{12}O_6 + 6H_2 = 6CO_2 + 6H_2O_2 + Energy \qquad 8$$

Respiration by phytoplankton and other microorganisms is a function of temperature. Respiration increases with temperature up to an optimum temperature and decreases at higher temperatures. Dame and Dankers (1988) have also reported dense populations of animals such as farmed fish, as well as shellfish beds to be the source of organic and inorganic compounds in water bodies. Such high densities may produce marked changes in the chemical composition of seawater (e.g. dissolved organic components and N/P ratio) that may subsequently affect populations of phytoplankton differentially. The equations which combine respiration and excretion are indicated in Equations (9) and (10) (Kayombo et al., 2000).

$$RE = R_{\max} f(T) A \lg B. \tag{9}$$

$$RE = \left(R_{\max} \exp\left(-2.3 \left| \frac{T - T_{opt}}{T_{opt} - T_{\min}} \right| \right) \right) A \lg B. \tag{10}$$

Where: RE is respiration and excretion rate (d^{-1}), and R_{max} is rate of maximum respiration (d^{-1}).

Oxygen exchange

The aeration process is a diffusion process between the oxygen dissolved in the water and the oxygen present in the atmosphere. The rate of oxygen transfer between air and water depends on the depth and degree of turbulence. Oxygen moves to and from the air water interface, the turbulence process restore oxygen by diffusion to water. The exchange at the surface depends on the gradient between DO concentration and saturated oxygen in water (O_{2sat}) which is calculated with temperature and salinity, from Aminot and Chaussepied (1983) in Equation (11).

$$O_{air} = (O_{2sat} - O_2) \times rearation \tag{11}$$

Aeration (d^{-1}) is the daily exchange rate of oxygen at surface level which depends on wind speed (in mph, to be converted on mpd) and water depth (m), according to the relation of Riley and Stephan (1988) described in Equation (12).

$$Aeration = \frac{0.641 + 0.0256 \times \left(\frac{Ws}{0.0447} \right)^2}{Pond.Depth} \tag{12}$$

Oxidation of organic matter

Biodegradation is the process by which organic substances are broken down by heterotrophic bacteria present in water, thereby consuming the DO available in water. The rate of oxidation of organic matter by bacteria is influenced by temperature and the function of temperature can be expressed using Equation (13).

$$k_T = k_{20} \theta^{(T-20)} \tag{13}$$

Where: k_T and k_{20} stand for the rates of oxidation of organic matter at operating temperature and a standard temperature of 20°C (day^{-1}), respectively, and Θ is the coefficient of temperature for oxidation. The rate of oxidation depends on DO and it increases as the level of DO increases to the point of DO saturation. According to Monod kinetic equation, volumetric yield of carbon dioxide to oxidation is as shown in Equation (14) (Henze et al., 1995).

$$r_v CO_2 = k_{20} \theta^{(T-20)} \times \left(\frac{DO}{K_{DO} + DO} \right) \times COD \tag{14}$$

Where: $r_v.CO_2$ is volumetric yield of carbon dioxide (mg/L), K_{DO} is the half saturation constant for dissolved oxygen (mgDO/L) while DO is the concentration of DO in water (mgDO/L) and COD is the chemical oxygen demand.

Respiration by fish

Like other living organisms, fish need energy to move, find and digest food, grow, reproduce, in addition to maintaining the body and internal environment (Moyle and Chech, 1982). This energy must be obtained from the environment and then assimilated. Assimilation in fish depends on the use of oxygen to metabolize their food, consequently depleting the DO in water. The Herring's respiration rate equation explains that respiration or metabolic rate is dependent on fish body weight, water temperature, and activity (swimming speed). Equation (15) presents an algometric function to represent standard metabolism and multiplied it by a temperature function and an activity factor to estimate total respiration rate (Rudstam, 1988).

$$R_i = a_r W_i^{-b_R} f(T) \times activity \times 5.258 \tag{15}$$

Where: Ri is the resting respiration rate i.e., standard metabolism (g prey g $fish^{-1}$ d^{-1}), a_r is the intercept of the allometric mass function which represents the respiration rate of a 1 g fish which is 0.0033b, b_R is the slope of the allometric mass function for standard metabolism which is 0.227b and f(T) is temperature dependent function for respiration (C) and Wi is the wet weight of fish (g), b is Herring different sets of the parameters values which depends on physical conditions and type of fish, which correspond to fish of 2 years age. The coefficient 5.258 converts g O_2 g $fish^{-1}$ d^{-1}. Fish activity is given using by Equation (16).

$$Activity = e^{dR \times U}. \tag{16}$$

Where: U is the swimming speed in cm/s and dR is a coefficient relating swimming speed to metabolism, for milkfish dR=0.03b, Coefficient U verses temperature (<ktu) is 0.149b (Rudstam, 1988).

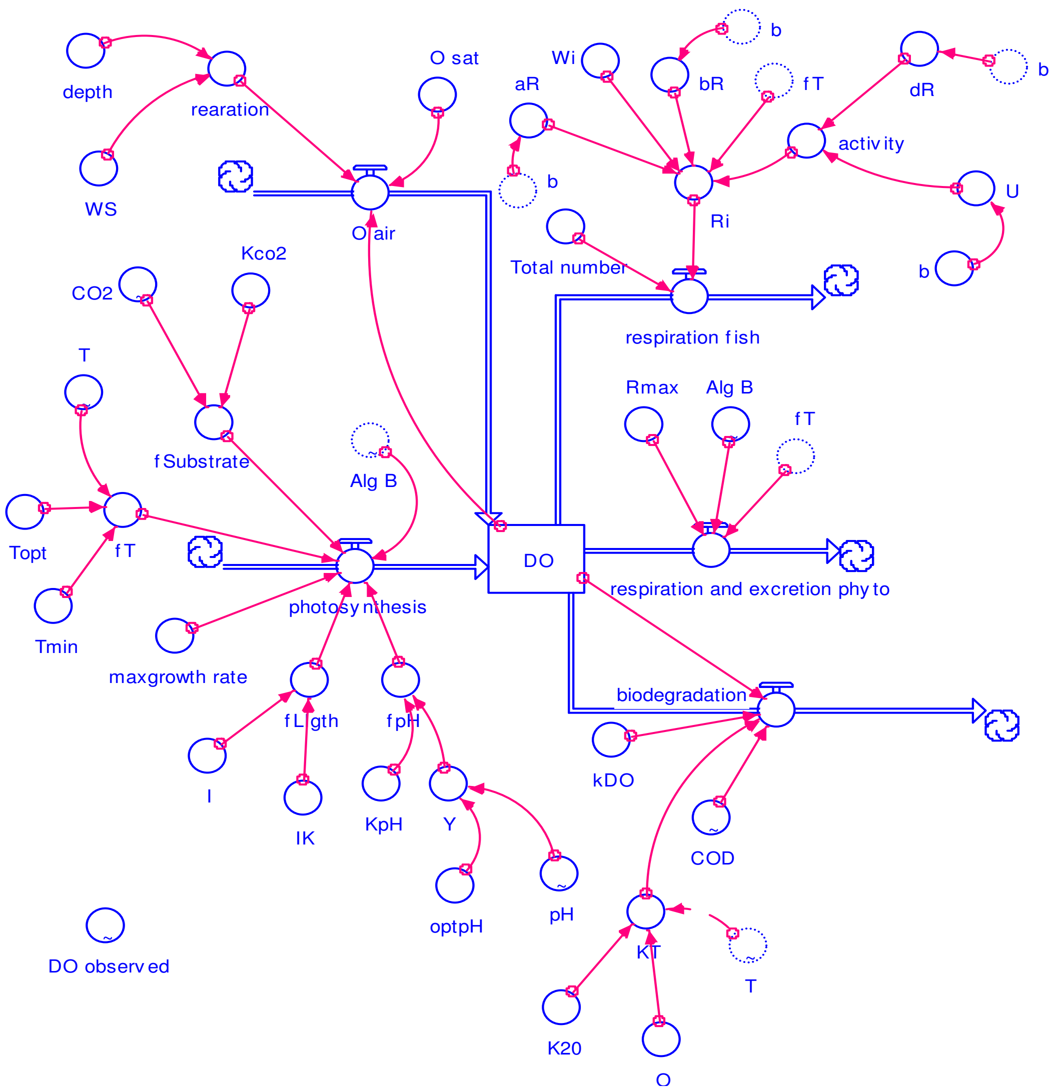

Figure 2. Flow diagram of DO dynamics in fish pond using STELLA simulation program.

Total Ri (mgO_2/day) = Ri x total number of fish x average weight (g) x10^3 (17)

The nitrification process also consumes oxygen from the water column to transform ammonium into nitrate and then nitrite. This process is dependent on ammonium concentration in the water, which was not measured in this study.

The general mathematical equation which expresses the rate of change of DO in fish pond is as indicated in equation (18) as follows:

$$\frac{\partial DO}{\partial t} = \mu_{max} \times f(T, pH, substrate, L)AlgB - K_{20}\theta^{(T-20)}\left(\frac{DO}{K_{DO}+DO}\right)COD + (O_{sat}-O_2)\frac{0.641+0.0256\times\left(\frac{Ws}{0..447}\right)^2}{depth} - \left(R_{max}\exp\left(-2.3\left|\frac{T-T_{opt}}{T_{opt}-T_{min}}\right|\right)\right)AlgB - R_i \times \text{number of fish} \quad 18$$

MODEL CALIBRATION

The model developed was simulated using STELLA® 7.1 software (Figure 2), which is based on the principle of conservation of mass. The parameters defined in the model calibration are shown in Table 2.

MATERIALS AND METHODS

The study was carried out in Bagamoyo Township about 25 km north of Dar es Salaam city, Tanzania. The ponds are located about 1 km from the Indian Ocean shoreline. The setup consists of six fish ponds covering a total area of 90 x 180 m (Figure 3). The middle ponds (N1 and N2) are used as nursery ponds for growth of fingerlings before they are transferred to the four ponds (P1, P2, P3, and P4) that are used for fish growth. Water enters the pond system through an inlet at pond N1 and flows to the gate valve which spreads the water by gravity to ponds P1, P2, P3 P4 and N2. After approximately two weeks, water is allowed to flow out of the

Table 1. Average parameters in ponds P2 and P4.

		DO (mg/L)	Temperature (℃)	pH	COD (mg/L)	Algae (mg/L)	CO_2 (mg/L)
Pond 2	Batch 1	3.63±0.44	30.41±1.23	9.18±0.27	1032.75±278.98	11.36±6.15	13.69±2.02
	Batch 2	5.60±1.11	29.26±1.15	7.81±0.49	996 ±215.64	18±12.12	14.71±3.58
Pond 4	Batch 1	4.56±0.75	29.29±1.09	8.01±0.64	1151.86±238.15	12.88±7.28	13.04±4.29

n=12.

Table 2. Model parameters.

Parameter	Range	Selected value	Unit	Source
IK	10-300	100	$\mu E/m^2.s$	Asaeda and Bon, 1997
K_{20}	0.0015	0.0015	mg/L	Tetra Tech, 1980
K_{co2}	0.5-0.6	0.5	mg/L	Kayombo et al., 1999
k_{DO}	0.1	0.1	mg/L	Okabe et al., 1995
K_{pH}	150-250	200		Henze et al., 1995
μ_{max}	1.8- 3	2.2	Day^{-1}	Kayombo et al., 1999
Θ	1.047	1.047	℃	Tetra Tech, 1980
pH_{opt}	6-9	6.8		Kayombo et al., 1999
R_{max}	0.065-0.6	0.5		Kayombo et al., 1999
T_{min}		27.3	℃	Calibration
T_{opt}	23-35	28	℃	Kayombo et al., 1999

pond system by gravity through an outlet pipe at pond P2. Both the outlet and inlet pipes are of 8-inch diameter. The effluent water is discharged back to the ocean.

Water samples were collected from ponds P2 and P4. Data from these ponds were used for model calibration and validation. Water sampling was done before 9 a.m. everyday because this is the critical time for DO concentration in the fish pond after which DO starts to increase due to increase of sunlight (Kayombo et al., 2000). DO, temperature and pH were measured onsite. DO and temperature was measured using DO hand-held meter OXI 340, pH was measured using HANNA INSTRUMENT® pH meter model CE H 198128. COD was determined using closed reflux method according to American Public Health Association (1992). Chlorophyll-*a* was obtained by filtering 50 mL of sample through 0.47 µm Whatman® filter paper.

Prior to filtering the sample, a solution of 1% $MgCO_3$ was filtered to speed up reaction. Then the filter paper with the algae cells was grounded and soaked in a 90% methanol and kept in darkness for 15 min at ambient temperature. The filtrate which contains chlorophyll-*a* was then extracted and analyzed for absorbance at wavelength 663 and 750 µm in a Milton Roy® Spectronic 21D according to APHA (1992). The concentration of chlorophyll-*a* in µg/L was computed using equation (19) as explained by Mara et al. (1992). This was based on the conversion of algal chlorophyll-*a* to dry weight which usually accounts for the 15% of the chlorophyll-*a* content (APHA, 1992).

$$Chloropyl\,1-a=\left(\frac{Abs\,663-Abs\,750}{77}\right)\times\frac{V}{S}\times10^{6} \quad 19$$

Where: Abs 663 and Abs 750 are absorbance at wavelengths of 663 and 750 µm respectively, V and S are the volumes of sample and solvent extract respectively, 77 is the extinction coefficient for chlorophyll-*a* in 90% Methanol (L/g.cm). The dry weight of algae is obtained by using Equation (20).

$$\text{Volatile weight of algae}\,(\text{mg/L})=\text{chlorophyll}-a\times10^{-3}\times67 \quad 20$$

Dissolved CO_2 was determined according the standard method (APHA, 1992). Light intensity data used was based on the average data of light intensity obtained from University of Dar es Salaam (UDSM) Waste Stabilization Ponds site in another study (Kayombo et al., 2000). The average wind speed was measured at the meteorological station, University of Dar es Salaam. The average wind speed of data from the months of February to April which the experiment was conducted was 0.099 km/d, with the readings taken at the height of 10 m above the ground. Since the fish ponds are at the height of 1.5 m above the ground, power law from Cooper and Alley (1997) was used to convert wind velocity from one height to another by using Equation 21.

$$u_{1.5}=u_{10}\times\left(\frac{z_{1.5}}{z_{10}}\right)^{0.2} \quad 21$$

Where u_{10} and $u_{1.5}$ are the wind velocity at 10 and 1.5 m elevations respectively, and z_{10} and $z_{1.5}$ are 10 and 1.5 m elevations respectively. The computed value for wind speed was 0.0705 km/ d.

RESULTS AND DISCUSSION

Model calibration

Data presented in Table 1 were used as input for model calibration. The model calibration results for DO in fish pond for first and second batch in pond P2 are presented

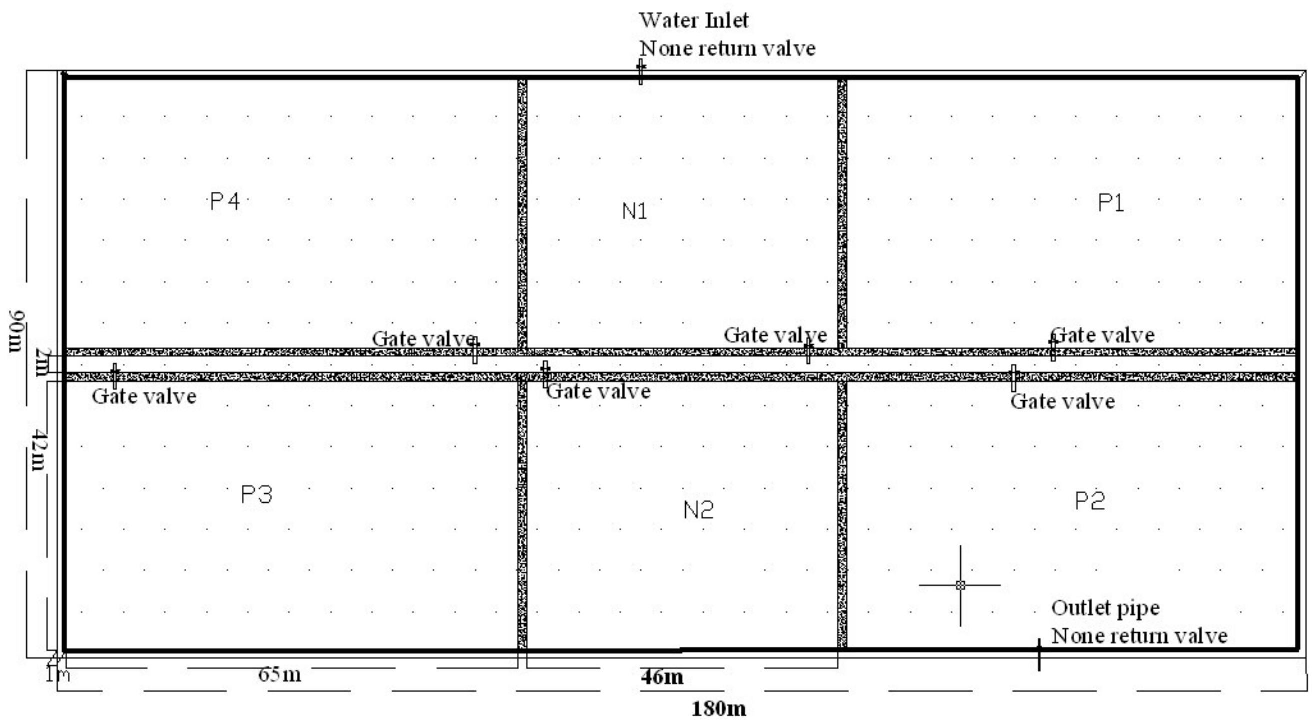

Figure 3. Layout of fish ponds.

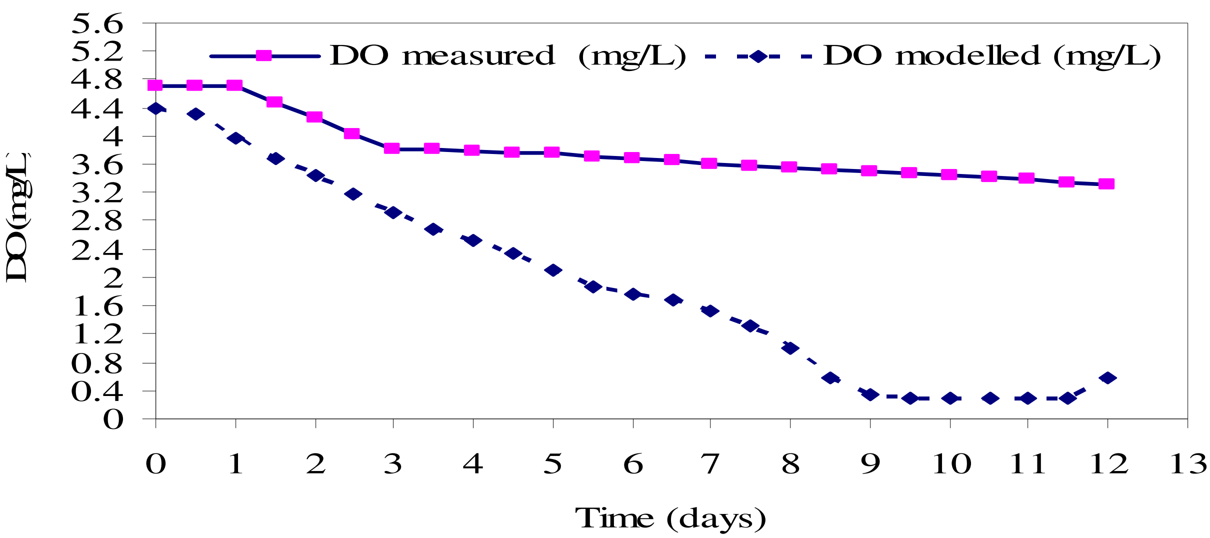

Figure 4. Simulated and observed results of DO in fish pond during first batch.

in Figures 4 and 5, respectively. The data used to calibrate the model was obtained from the ponds for the period of 12 days (Table 1), which was the period of one batch before water was emptied and replenished. Results show agreement between simulated and observed DO in the fish pond and that DO in fish pond decreased with time.

Nevertheless, measured DO did not fit exactly with the simulated DO results. This shows that further calibration of the model is probably needed and changing the model complexity so as to obtain the best fit possible. The linear regression analyses between DO observed and DO measured showed a reasonably good fit (R^2 = 0.875 and 0.784) during the first and second batches, respectively as presented in Figures 6 and 7. This indicated that mathematical formulation of the model was sufficient for

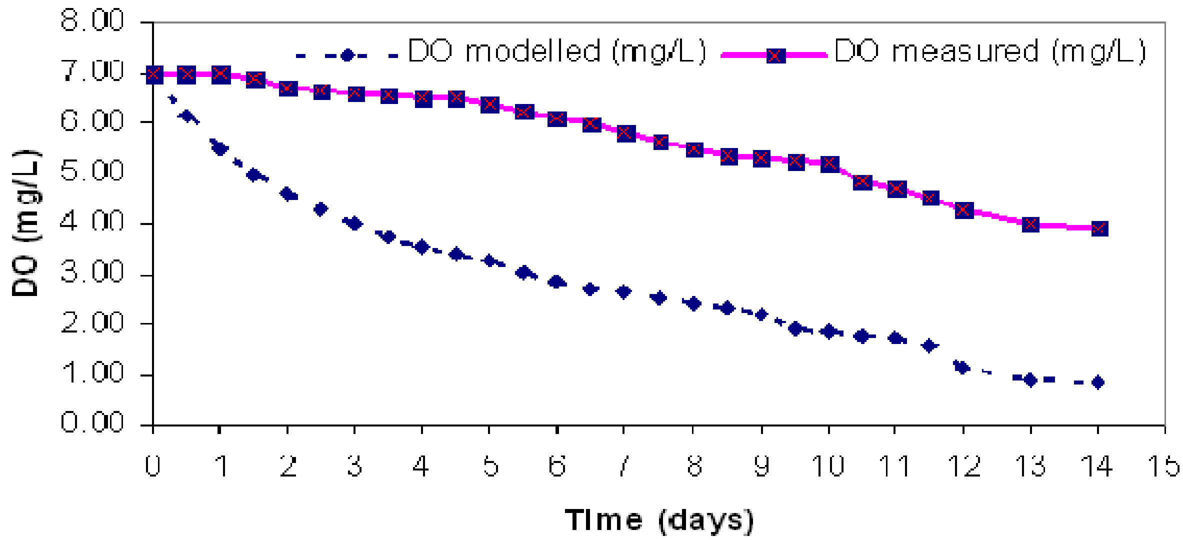

Figure 5. Simulated and observed results of DO in fish pond during second batch.

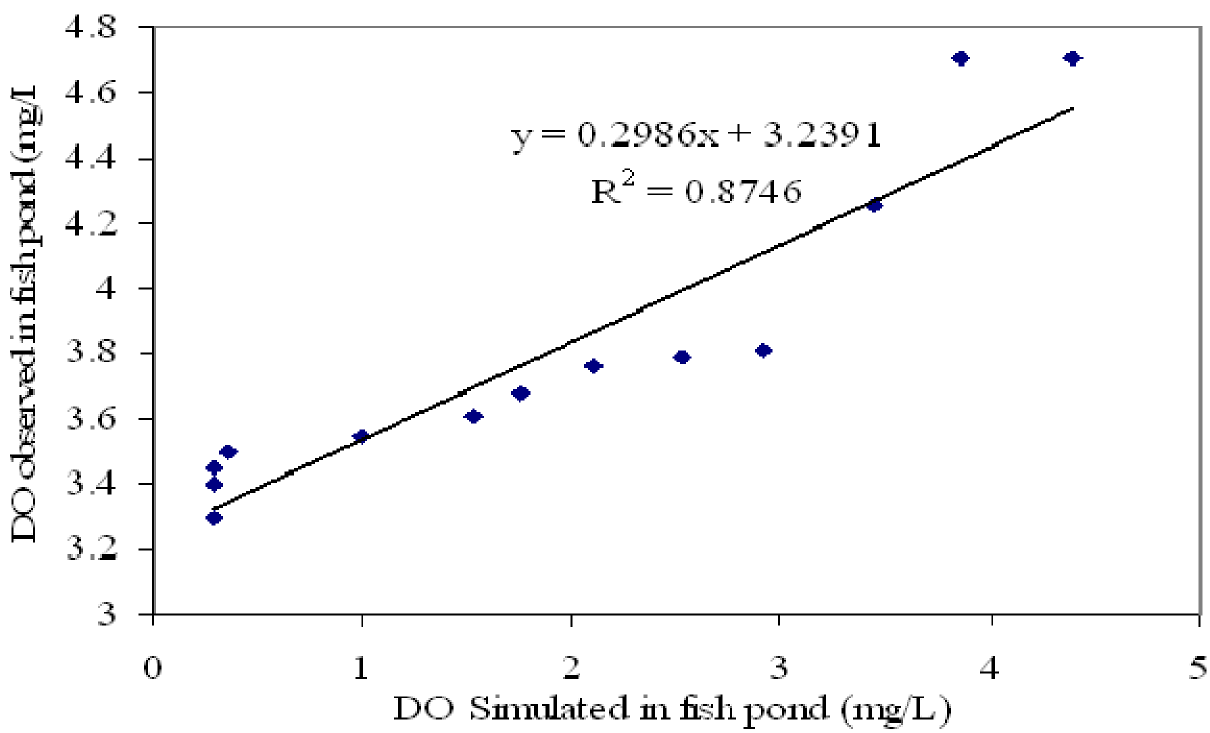

Figure 6. Relationship between observed and measured DO in fish pond during first batch.

description of DO dynamics in fish ponds.

PARAMETERS FOR THE MODEL

Table 2 shows different parameters used in model calibration and validation. During model validation, the constants obtained during calibration were maintained constant. Most of the parameters are valid within a specified range required for survival of b.

MASS BALANCE DETERMINATION FOR CALIBRATION

Figures 8 and 9 are block diagrams that show the mass

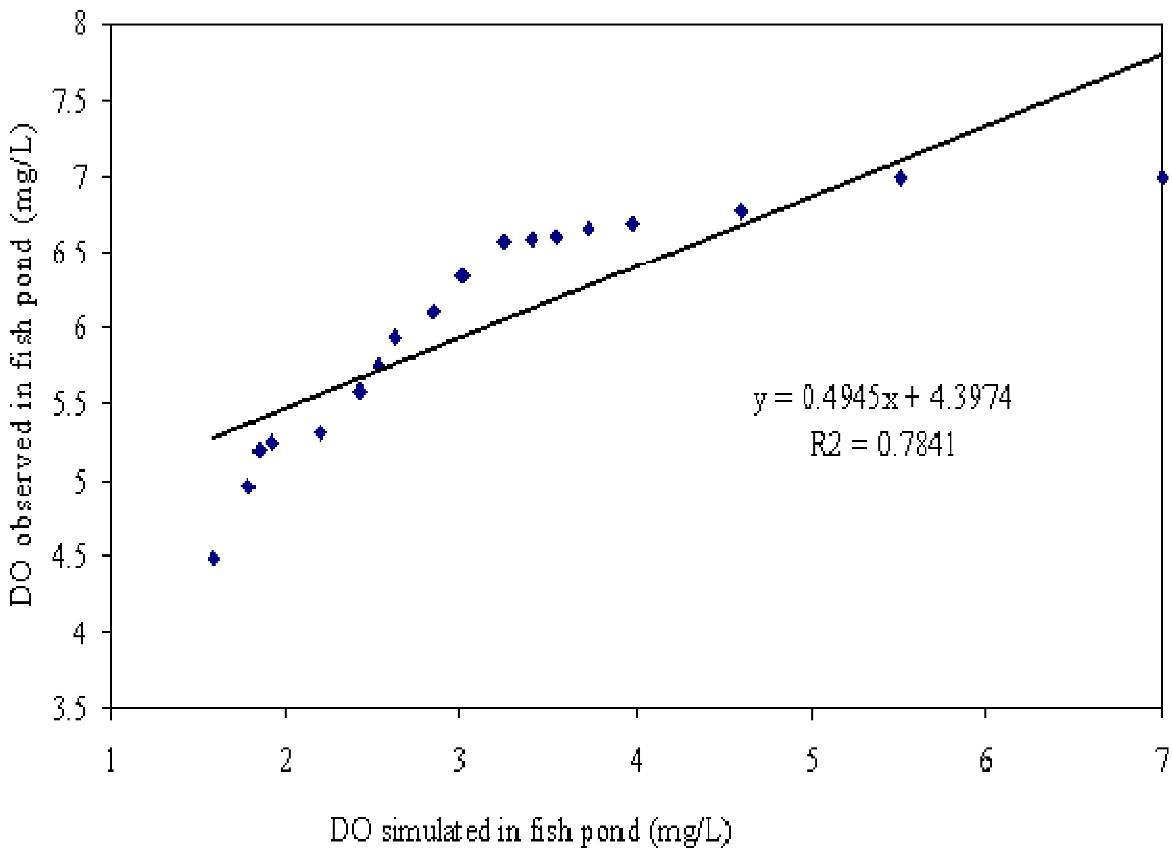

Figure 7. Relationship between observed and measured DO in fish pond during second batch.

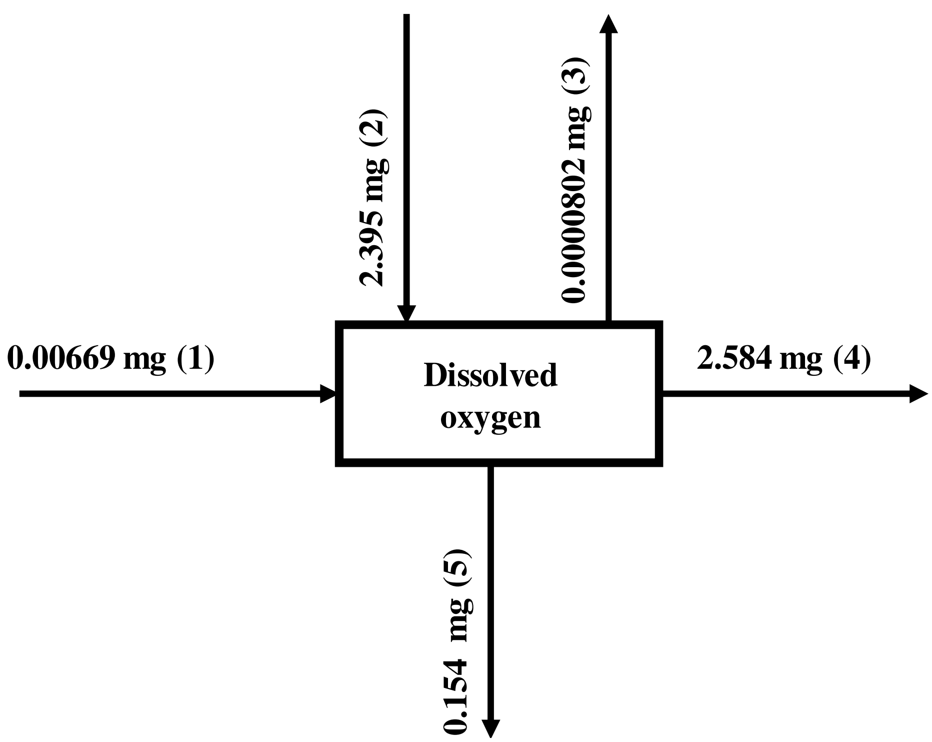

Figure 8. Mass balance of DO model in the fish pond first batch.

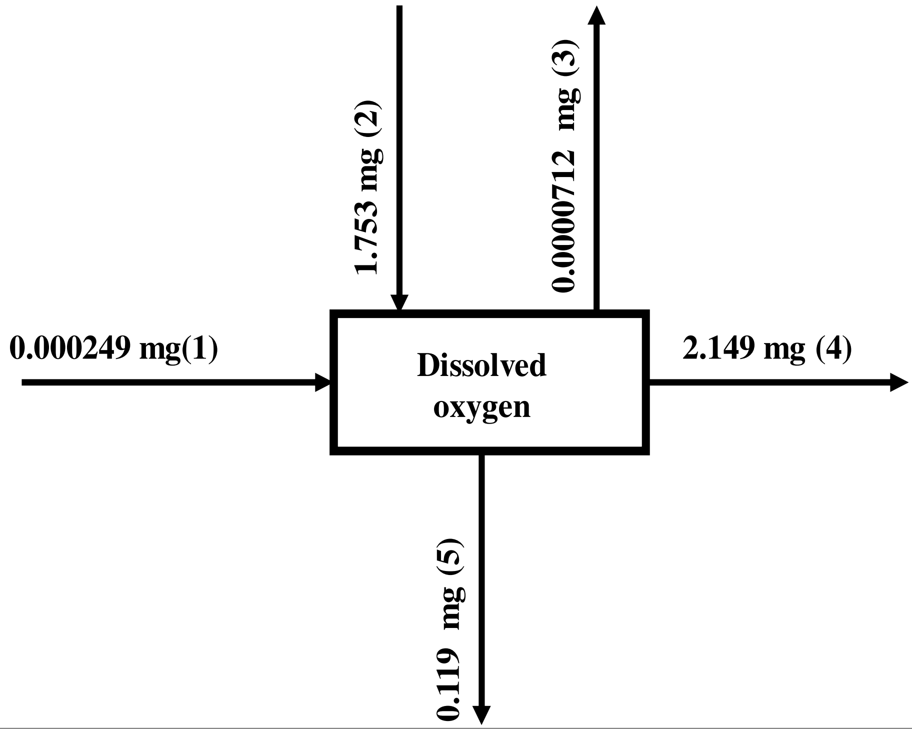

Figure 9. Mass balance of DO model in the fish pond second batch.

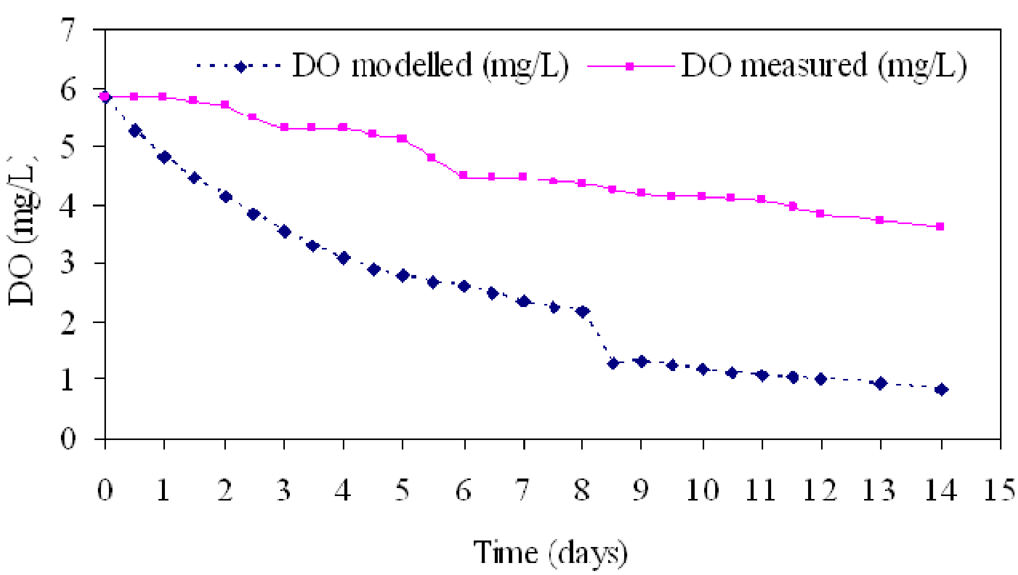

Figure 10. Simulated and observed DO in fish pond during validation.

balance of the simulated DO for first and second batches, respectively. The figures were obtained by taking the average values of DO simulated using STELLA® 7.1 software. Mass balance determination showed that the main process that consumes DO in the pond is biodegradation of organic matter which accounts for 94% DO removal for first batch and 96% for second batch, followed by respiration by fish which utilized 5.6% DO for the first batch and 3.2% DO for second batch. In addition 0.03% DO for first batch and 0.002% DO for second batch was used for respiration and excretion of algae and other microorganisms, respectively. On the other hand

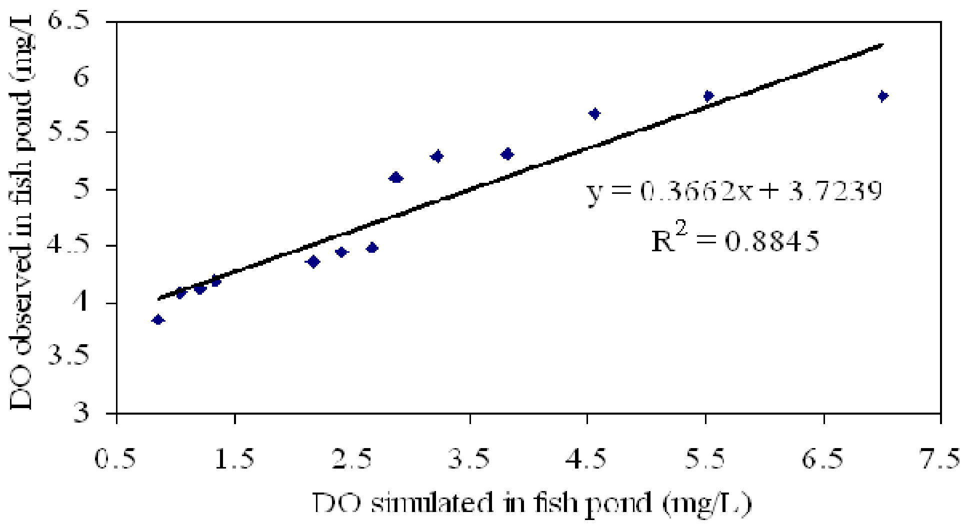

Figure 11. Relationship between observed and measured DO in fish pond during validation.

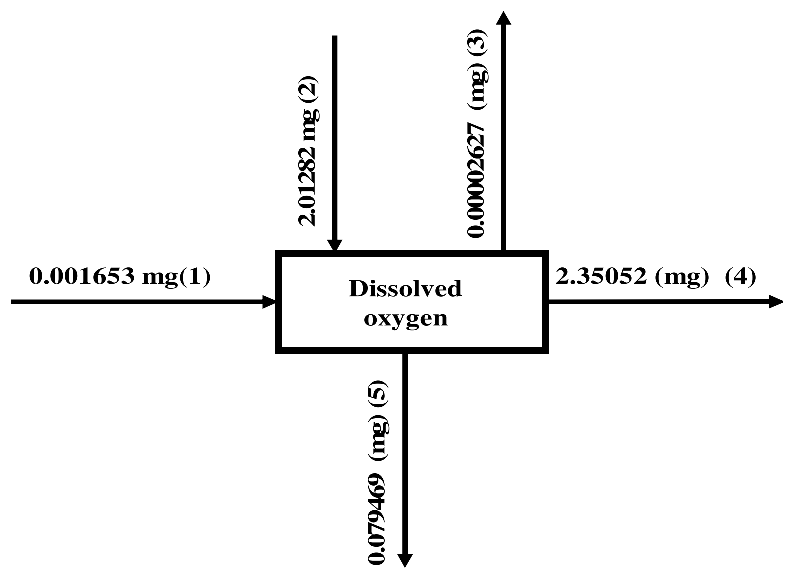

Figure 12. Mass balance of DO model in the fish pond second batch.

reaeration of water due to turbulence was the dominant natural process which added 99.97% of DO first batch and 99.99% of DO for second batch in water while 0.03% and 0.009 of DO was added by photosynthesis for first and second batches respectively.

MODEL VALIDATION

Validation of the model was done using data collected from pond P4, at the same site (Table 2). The model simulation results show a decrease of DO concentration with time for the 14 day experimental period. Figure 10 shows simulated and observed results of DO in fish pond for validation. Regression analysis (Figure 11) shows a positive linear relationship between observed and measured DO in fish pond during validation (R^2 = 0.88).

MASS BALANCE DETERMINATION FOR MODEL VALIDATION

Figure 12 shows the DO mass balance at the end of the batch during validation. The mass balance results obtained for validation were in agreement with results obtained during calibration, which shows that the processes and formulations used are valid for the fish pond situation. Validation results were consistent with the

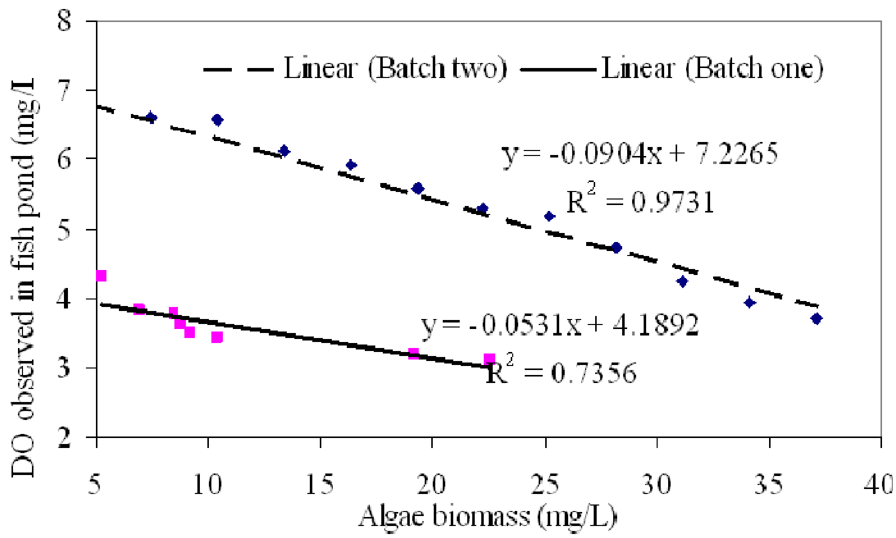

Figure 13. Relationship between observed DO and algae biomass in fish pond.

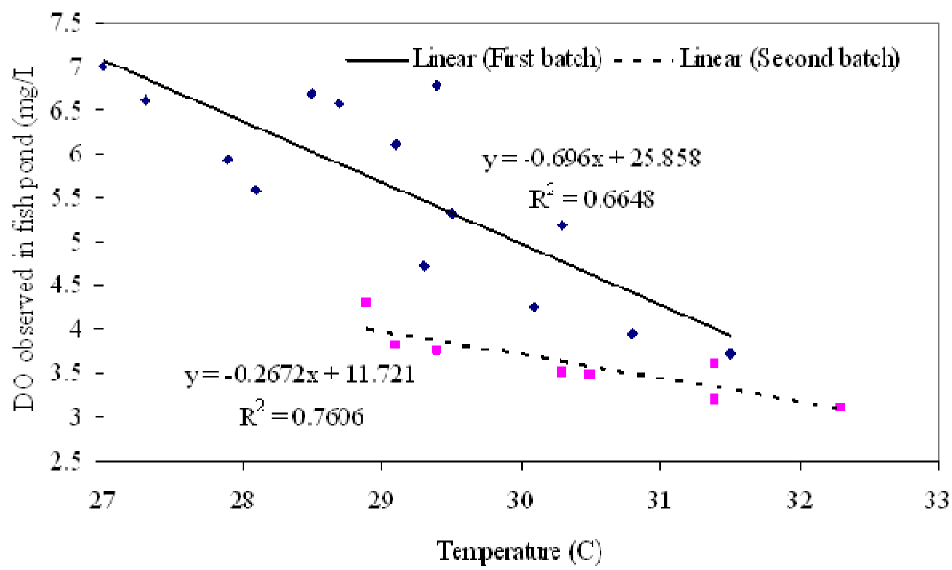

Figure 14. Relationship between observed DO and temperature in fish pond.

calibration results whereby the main process which utilizes DO in fish pond was the biodegradation of organic matter which accounted for 96.7% of DO consumption, followed by respiration by fish (3.3% of DO consumption), with respiration and excretion of algae and other microorganisms accounting for the remaining 0.002% consumption. As previously noted, rearation of water due to turbulence was the dominant natural process which added 99.98% of DO in water and 0.08% was added through photosynthesis.

Regression analysis in Figure 13 shows a negative linear relationship between observed DO and algae biomass in fish pond for first and second batches; with linear regression coefficient (R^2) of 0.97 for first batch and0.74 for the second batch. This is on the contrary with what was expected from literature that is DO increases as algae biomass increase due to their contribution to photosynthesis process. This is probably an indication that algae growth rate was not fast enough and its subsequent addition of oxygen by photosynthesis was not sufficient enough to offset the DO consumption by decomposition of organic matter. In addition, phytoplankton utilizes DO during darkness for respiration and upon die off they undergo decomposition which further utilizes DO.

The effect of temperature on DO in the fish pond has been shown in Figure 14. As water temperature increased,

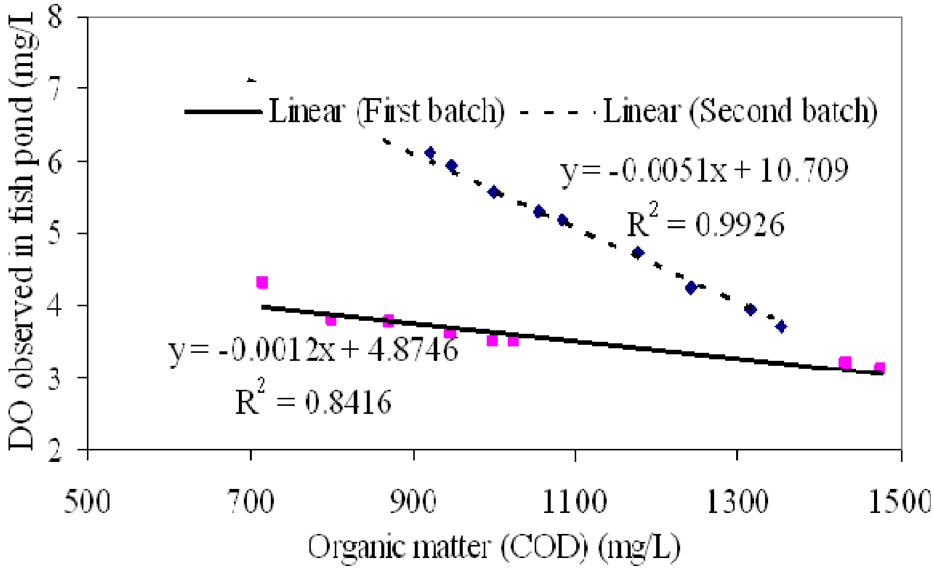

Figure 15. Relationship between observed DO and organic matters in fish pond.

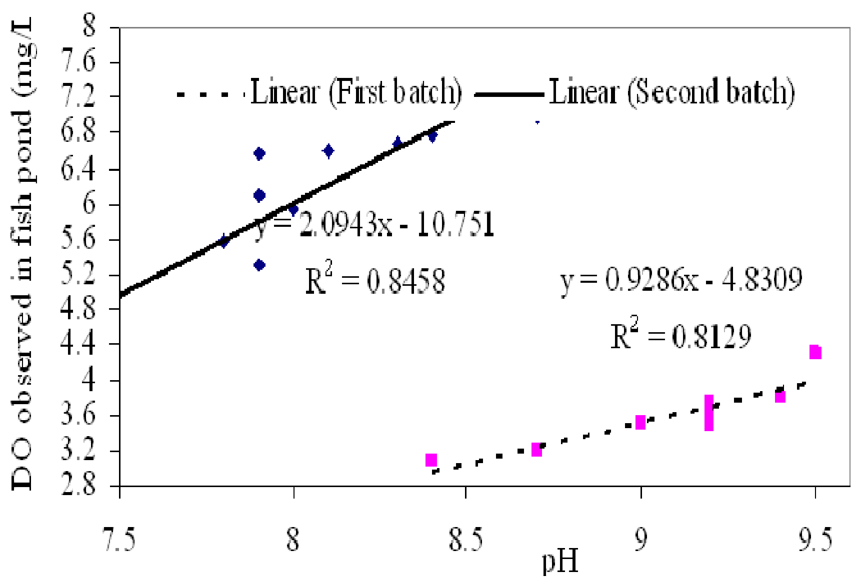

Figure 16. Relationship between observed DO and pH in fish pond.

the concentration of dissolved oxygen decreased (R^2 = 0.55). This is an indication that the increase of temperature is associated with increased microbial decomposition of organic matter, consuming the available DO. Water temperature is an indicator of the maximum amount of oxygen gas that water can dissolve. Figure 15 shows a relationship between organic matter in terms of COD and the DO in the fish pond. There is a negative relationship such that when COD increased, the DO concentration decreased (R^2 = 0.99). The Figure indicates that the available dissolved oxygen is utilized by microorganisms during the decomposition of organic matter. Figure 16 shows the relationship between observed DO and pH in fish pond whereby the increase of DO in fish ponds corresponded with the increase of pH (R^2 = 0.85).

Conclusion

Model verification and validation showed that the model developed behaved as expected. The relationship between observed and measured DO in the fish pond showed a close agreement (R^2 = 0.88), which shows that various processes and formulations were valid for description of DO dynamics in fish ponds. According to model results, maintenance of fish health and feed conversion will require that the retention time for each batch be 10 days since for the first 10 days, temperature and DO which are the most important factors are still within the required ranges for fish survival. Further study should look into the effect of nitrification process on DO dynamics in the pond. A separate experiment should be conducted to determine the maximum growth rate of phytoplankton which grows in marine aquaculture and later be incorporated in the model, since it is very sensitive in affecting the DO in fish ponds.

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