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Modelling carbon dioxide gas emission from *Notopterus chitala* fish ponds by stella software

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Abstract. The rapid development of the areas of *Notopterus chitala* fish ponds in Hau Giang province in recent years has raised a question about greenhouse gas emissions, in the form of total carbon dioxide equivalents (CO_{2e}). There are many parameters that affect greenhouse gas emissions in a fish pond, such as amount of feed, dissolved oxygen (DO), chemical oxygen demand (COD) in the water, pH, water temperature, windy velocity and sunlight reaching the pond surface. In this study, a System Thinking, Experimental Learning Laboratory with Animation, shortly called as Stella is applied as a visual programming language for system dynamics modelling in order to find the relationship between simulated CO_2 and measured CO_2 in *Notopterus chitala* fish pond. Three ponds were used for measuring average pH, temperature, feeds, DO, COD and phytoplankton inside the ponds while windy speed and light intensity data were collected from a Weather Station nearby. The results of model calibration and validation showed that the Stella 8.0 can be used as predictable tool for the change in time of CO_2 emission during 240 days of fishing. Model can help fishing farmers to adjust the quantity of feeds and control the water quality in their *Notopterus chitala* fish ponds to reduce greenhouse gas emissions appropriately.

Keywords: carbon dioxide, greenhouse gas emission, notopterus chitala fish ponds, stella model, water quality.

Classification numbers: 3.4.2; 3.7.1; 3.7.2.

1. INTRODUCTION

Global warming phenomenon leads to climate change due to a result of increasing greenhouse gas (GHG) emissions on global scale. The global average temperature has rapidly increased from the mid-twentieth century, proportional to the raise in the concentration of man-made GHG. According to the 5th IPCC [1], the concentrations of CO_2, CH_4, and N_2O in the atmosphere have increased with an unprecedented rate over the past 800,000 years. The CO_2 emissions have increased by more than 40 % since pre-industrial times, reaching about 413 ppm [2]. The trend will continue to rise in the future if there is no controlled solution. The consequences of climate change are constantly, appearing more extreme weather phenomena such as strong storms, cyclones, droughts, epidemics so on. The United Nations Conference on Climate Change from COP 21 to the newest COP 26 that promulgated the Paris Agreement 2015, and the Glasgow climate Pact 2021 with pledge of 147 nations will restrain GHGs toward net-zero emission in 2050.

The research and assessment of GHG emissions have been carried out quite a lot on a global scale, focusing on the fields of energy, industry, land use change, agriculture and forestry, but the aquacultural sector has been a few research. Although this field has also been contributing to global warming, through emissions of carbon dioxide (CO_2) and methane (CH_4) [3]. The emitted amount of CO_2 is related to the stocking density, the quantity of food, the volume of pond water, and temperature, pH, temperature, DO, phytoplankton, sunlight so on [4, 5, 6, 7, 8]. Therefore, the factors that affect the ability to create CO_2 can be the drivers for simulation in carbon cycle in fish ponds.

One of the cheapest methods is to use mathematical models to predict the possibility of GHGs emissions from fish ponds. Stella software, version 8.0, was used to assess, verify and compare the CO_2 emissions with actual measured data on fish ponds. It has helped to identify and determine the factors that affect the ability to generate CO_2. It has also supported fishing farmers taking measures to reduce CO_2 emissions for the sake of sustainable development. The research results have been supplemented the scientific and practical bases to prove the emission calculation. With above goals, the study of "Modelling carbon dioxide gas emission from *Notopterus chitala* fish ponds by Stella software" was carried out in Hau Giang province which is considered the province having a largest *Notopterus chitala* fish farming area in Viet Nam.

2. MATERIALS AND METHODS

2.1. Process of carbon dioxide exchange in an aquaculture system

CO_2 in an aquacultural system with the interaction of climatic conditions, atmosphere, feeding impacts and metabolic mechanisms in the fish pond habitat system is quite complex and fluctuated constantly (Figure 1).

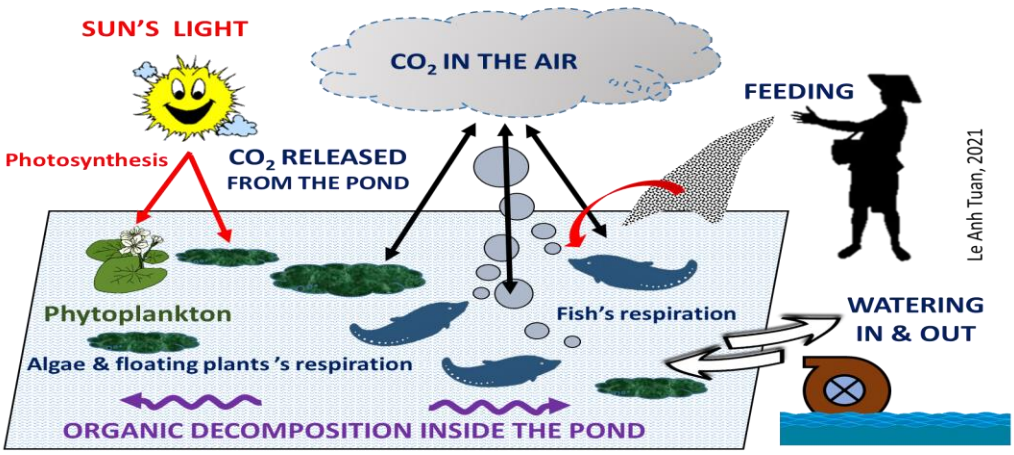

Figure 1. Illustrating carbon dioxide exchange in an aquaculture system.

The function of light f(L) can be explained by the kinetic equation Equation 1 by Monod [9, 10].

$$f(L) = \frac{I}{IK+I} \tag{1}$$

where, I is the light intensity (μE/m^{2}s) and IK is the limit of half-saturated light μE/m^{2}s.

The photosynthesis process in green plants, presented as Equation 2.

$$6CO_2 + 12H_2O + sunlight \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O \tag{2}$$

Photosynthesis is related to temperature (T), light (L), substrate and pH as shown by Equation 3.

$$Photo = \mu_{max} x f(T, pH, substrate, L, Algae) \tag{3}$$

where, μ_{max} is the max date of the major days of the top rate of the float (on day).

The effect of pH or f(pH) on growth rate was modelled by Henze *et al.* [11] by Equation 4 and Equation 5:

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

$$y = 10^{|optpH-pH|} - 1 \tag{5}$$

where, K_{pH} is constant pH and optpH is pH maximum at the point of highest phytoplankton growth.

The equation of the substrate function, as f(substrate), is presented by Equation 6.

$$f(substate) = \left(\frac{CO_2}{K_{CO_2}+CO_2}\right) \tag{6}$$

where, CO_2 is concentration of dissolved CO_2 in pond (mg/L) and K_{CO2} is the partial saturation constant of dissolved CO_2 (mg/L).

The temperature in the water plays a role in regulating the exchange of physicochemical processes in the system, as in Equation 7.

$$f(T) = exp\left[-2,3\left(\frac{T-T_{opt}}{T_{opt}-T_{min}}\right)\right] for\ T \leq T_{opt}, f(T) = 1, T \geq T_{opt} \tag{7}$$

where, T_{opt} and T_{min} are the optimum and minimum temperatures, respectively.

The rate of organic matter oxidation by bacteria that is affected by temperature and is expressed by the Equation 8.

$$k_T = k_{20}\theta^{(T-20)} \tag{8}$$

where, k_T and k_{20} are the organic matter oxidation rate of temperature at 20 ^{0}C (day), respectively and θ is the coefficient of temperature for oxidation. According to the Monod kinetic equation, the volume of CO_2 for oxidation is shown by the Equation 9 [11].

$$r_vCO_2 = k_{20}\theta^{(T-20)} x \left(\frac{DO}{k_{DO}+DO}\right) xCOD \tag{9}$$

where, r_vCO_2 is the volume of CO_2 (mg/L), k_{DO} is the partial saturation constant for dissolved oxygen (mgDO/L), DO is the concentration of dissolved oxygen in water (mgDO/L) and COD is the chemical oxygen demand.

The respiration of phytoplankton takes place at night [12], it uses oxygen molecules that found in water to obtain energy according to the chemical equation (Equation 10). Besides, other microorganisms that also respires and excretes to reduce DO in water.

$$C_6H_{12}O_6 + 6O_2 + 6H_2O = 6CO_2 + 12H_2O + energy \tag{10}$$

Respiration increases with increasing temperature to the optimum temperature and begins to decrease respiration at higher temperatures. The combined equation of respiration and excretion is shown in Equations 11 and 12.

$$RE = R_{max} f(T) AlgB \tag{11}$$

$$RE = \left(R_{max} \exp(-2{,}3 \left|\frac{T-T_{opt}}{T_{opt}-T_{min}}\right|)\right) AlgB \tag{12}$$

where, RE is respiration and excretion per day and R_{max} is the highest respiratory rate per day. The respiratory rate equation explains that respiration or metabolic rate depends on fish weight, temperature and swimming speed. Equation 13 introduces a measure of standard metabolism multiplied by temperature, the factor that works to estimate the total respiratory rate [13].

$$R_i = a_r W^{-b_R} f(T)\ X\ activity\ X\ 5.258 \tag{13}$$

where, R_i is the rate of residual respiration, standard metabolism (ggrey/gfish/day), a_r is a fraction of the present growth mass function, the respiration rate of 1 g fish is 0.0033b, b_R is the difference of the growth mass function for standard metabolism of 0.227b and f(T) is the temperature discrepancy on the respiratory function C and Wi is the fresh weight of the fish (g), b is the coefficient difference of the measured value depending on the natural conditions and the type of fish corresponding to a year old fish. The factor of 5.258 converts to gO_2/gfish/day. Fish activity is calculated using Equation 14.

$$Activity = e^{dRxU} \tag{14}$$

where, U is swimming speed of fish, 0.2 m/s and dR is the coefficient that relates swimming speed to metabolism, for knifefish (chitala) dR=0.6b [14].

$$\text{Total Ri } (mgO_2/day) = \text{Ri x total fish x average weight (g)} \times 10^3 \tag{15}$$

The mathematical equation showing the rate of change of CO_2 in the pond is made according to the Equation 16.

$$\frac{\eth CO2}{\eth t} = \mu K_{20} \theta^{(T-20)} \left(\frac{DO}{K_{Do}+DO}\right) COD + \left(R_{max} exp\left(-2{,}3 \left|\frac{T-T_{opt}}{T_{opt}-T_{min}}\right|\right)\right) AlgB + T_{opt} T_{min} x\ total\ fish - \mu_{max} x f(T, pH, substate, L) AlgB - CO_2 lost \tag{16}$$

2.2. Methodology of data collection and analysis and factors affecting fish pond carbon input

Collecting CO_2: A floating chamber was put on water during 24 hours, from 9 a.m. one day to 9 a.m. the next day, with three replicated times in each pond, once a month, 18 samples for a pond, collecting during 6 months from April to October in 2019 at 3 ponds in zone 3, ward VII, Vi Thanh city, Hau Giang province. The chambers were designed by plastic tub with 10 litre volume to put adversely on surface water. In addition, to edge plastic tub was wrapped by soft fabrics to ensure no flux gases.

Table 1. Variables and methods to measure.

Variables	**Unit**	**Methods**
CO_2	mg/m^3	52/TCN 353-89 at CATECH*
Pond temperature	^0C	Measured by MW 600
DO	mg/L	Measured by MW 600
COD	mg/L	SMEWW 5220.C:2012 at CATECH*
pH		Measured by MW 600
Phytoplankton	mg/L	SMEWW 10200:2005 at CATECH*
Liming	kg/m^2	Real collecting on site
Feeds	kg/pond	Real collecting on site

** Cantho Technical Center of Standards Metrology and Quality*

Table 2. Average values of ponds 1, 2 and 3.

Name	CO_2 (mg/L)	T (^0C)	DO (mg/L)	COD (mg/L)	pH	Phytopl -ankton (mg/L)	Density (fish/m^2)	Area (m^2)	Feeding rate (kg/day)
Pond 1	12.08	29.86	4.32	149.21	6.59	12.2	35	2,400	120
Pond 2	13.78	30.00	4.37	110.44	6.66	13.7	50	4,000	340
Pond 3	12.01	28.00	4.15	131.17	6.62	11.8	25	2,000	90

Table 3. Variables input to the model.

Variables	Units	Value	Selected value	Sources
μ_{max}	day	1.8 - 3	2.2	[15]
IK	$\mu E/m^2s$	10 - 300	100	[16]
T_{min}	$^\circ C$		27	This study
T_{opt}	$^\circ C$	23 - 35	28	[15]
pH_{opt}		6 - 9	7	This study
R_{max}		0.065 - 0.6	0.5	[15]
K_{pH}		150 - 250	200	[11]
K_{20}	mg/L	0.0015	0.0015	[15]
K_{CO2}	mg/L	0.5 - 0.6	0.5	[15]
K_{DO}		0.1	0.1	[15]
θ		1.047	1.047	[15]
a			0,642	[13]
b			-0.256	[13]
e			0,1	[13]
Diffusive factor	Kg/m^3		1.45	[17]
I	$Lux/m^2/day$		3.489	Weather Station
Factor (k1)			0.2	This study
Windy speed	m/s	5 - 10	5	Weather Station
Time	day		240	This study
Lime	kg/crop	17 - 30	30	This study

The above head of chamber has three-way valves connected a pipe to extract CO_2. Water quality: pond temperature (T), (DO), (COD), pH, phytoplankton and liming were directly measured on field and analyzed with the methods in Table 1. The measures were collected at the same time with CO_2 collection on each pond; sample quantities appropriated to CO_2 samples. Some meteorological data such as solar radiative intensity, windy speed and rainfall were used by weather Station nearby one kilometer in Vi Thanh city.

All data were analyzed by SPSS version 22 with Pearson test, significant values $p < 0.01$ and $p < 0.05$.

The CO_2 diffusion from the atmosphere into the fish pond through the respiration of plants in the pond and the diffusion process, depends on temperature, pH and total alkalinity. The fish density is various with feeds that are also used which are an important source for carbon cycle in ponds. The fish feed conversion factor (FCR) was calculated using the following formula.

$$\text{FCR} = \text{Total amount of feed/Total weight gain} \qquad (17)$$

where, the total amount of food and the measure of weight increase by kilogram.

$$\text{Feeding rate} = \text{Total feed/total fish/day} \qquad (18)$$

Total feed and total fish units are kilogram. The values input to the model are in Table 2 and Table 3.

CO_2 simulation: Stella software was used to design diagrams and mathematical equations that predicted CO_2 emission from *Notopterus chitala* fish ponds. The variables included stock (CO_2 and water), state (Tables 2 and 3), process, connectors to run modelling in 240 days (a crop). In Table 3, the research used the values of the variables for simulation after the values had high significant confidence when it was calibrated, sensed and validated of the model comparing with real values on site for the optimum results. In each pond, some parameters were changed such as feed, density, temperature, pH, lime and water.

Calibration and Verification

Although the factors of variables in three models of ponds are different, as model 1 was the best fit to predict simulated and measured CO_2, it was chosen to calibrate.

Adjusted methods: It was dependent on the quantity and speed to supply feeding for fish in pond that were used to calibrate the model; therefore, the most important variables were the feeding ones. The min and max values were set in the model.

Step 1: Adjusting maximum feeding speed how to suitable between simulated and measured CO_2 for the highest value. Step 2: Adjusting minimum feeding speed value nearby the lowest measured values. Step 3: Readjusting the value in step 1 and 2 until the simulated and measured fitting, error amplitude is 0.5%, in addition adjusted factor (k_1) by 0.2 in Table 3 for the optimum of other variables.

3. RESULTS AND DISCUSSION

3.1. Variation of CO_2 over time in *Notopterus chitala* fish

Figure 2 shows the flowchart of the relationship of factors affecting the model during the 240 days (01 farming season) in *Notopterus chitala* fish ponds. Variables used in all 3 ponds studied such as weather (solar radiation amount, wind speed, rainfall), constancy. Each pond with quantity, density, area, feeding rate, pond temperature, pH, water quality factors will have very different scenarios.

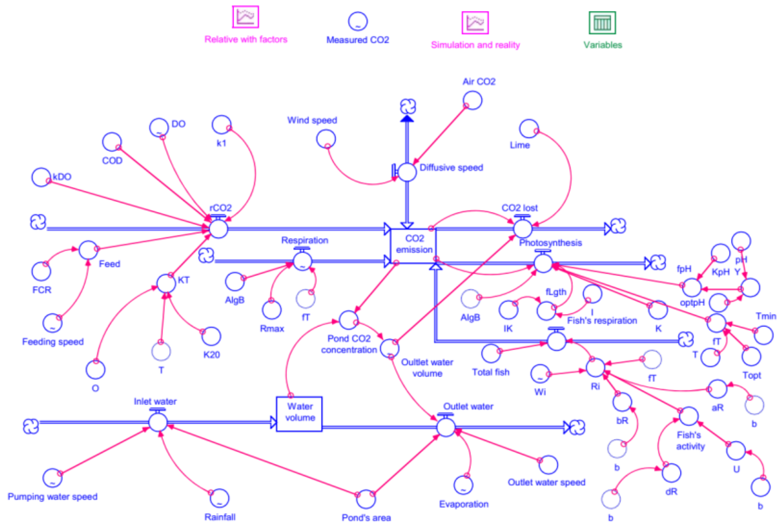

Figure 2. Diagram of CO_2 dynamics on *Notopterus chitala* ponds using Stella software.

Note: In this diagram, stocks are CO_2 and water in pond; double arrows direct into pond CO_2 that are available to supplement CO_2 for ponds that include rCO_2, CO_2 diffusion from the atmosphere, respiration of algae and fish's respiration; in contrary, double arrows direct out such as CO_2 lost speed, photosynthesis by algae and diffusion. Besides, the arrow lines are the connectors between variables with state in model.

3.2. Comparison of simulated and measured CO_2

Simulated and real result in ponds 1, 2 and 3 are presented in Figures 3, 4 and 5, respectively; the correlations in corresponding ponds are shown in Figure 6. The results of the correlated analysis show a high compatibility between the simulated data of the model and the actual measured data in all 3 experimental ponds.

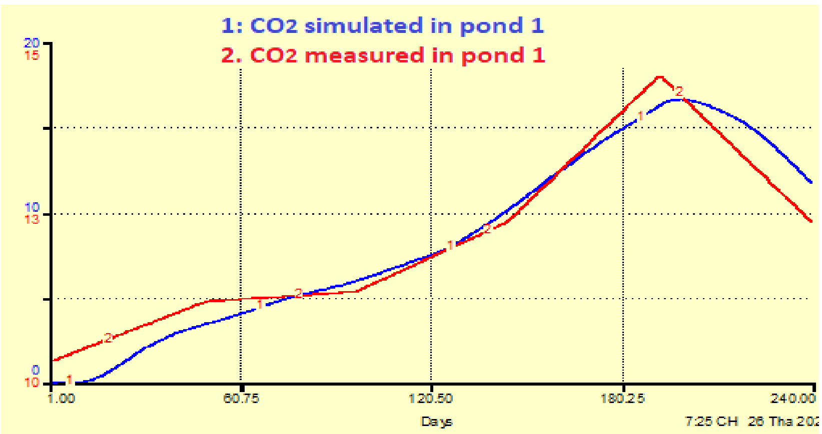

Figure 3. Comparison of simulated and measured result of CO_2 fluctuations in pond 1.

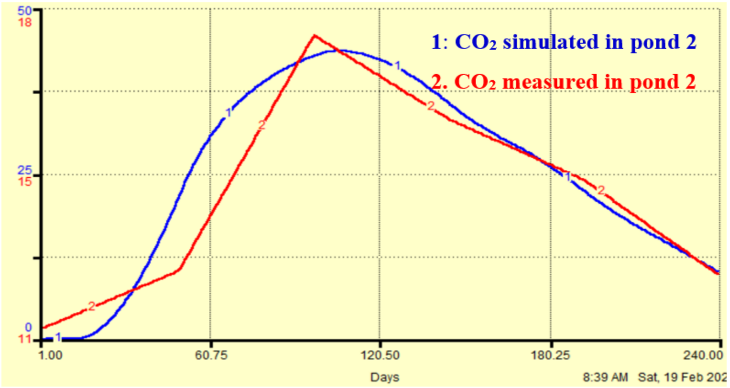

Figure 4. Comparison of simulated and measured results of CO_2 fluctuations in pond 2.

Figure 3 illustrated that simulated and measured CO_2 stably increased by the quite same trend; it did not largely fluctuate and trend toward the harvest time. It has lowest value at begin time at the peak on 200 days after farming start with the highest values at 17 mg/L. Figure 3 showed that simulated CO_2 highly fitted with measured results in pond 1. The actual value that measured in pond 1 is 12.08 ± 1.3 mg/L, while the model run with boundary conditions that has shown a rather high degree of compatibility between the model and the measured reality.

Figure 4 showed the simulated and measured result in pond 2 that was highly compatible, the degree of variation tended to change with the fishing time. However, the highest measured value was not fitted with simulated finding, but it samely trended in overall. Explaining this case was caused by input variables as feeding rate, fish density (35 individual/m^2) and water volume had adjusted by farmer in this pond.

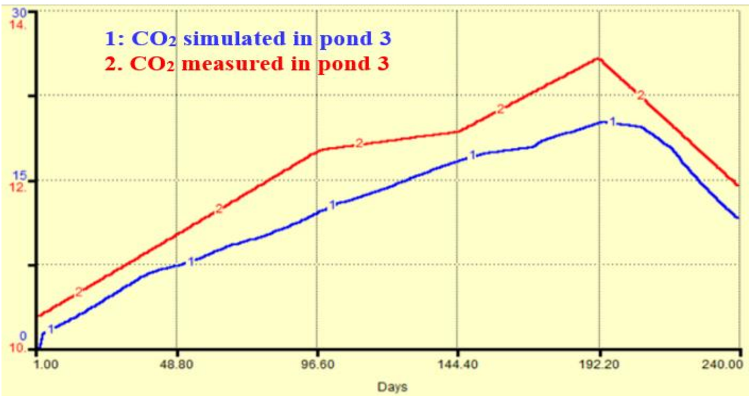

Figure 5. Comparison of simulated and measured results of CO_2 fluctuations in pond 3.

Figure 5 also demonstrated that the simulated result of CO_2 dynamics and the actual measured values on pond 3 was high compatible, after calibrating the model has shown quite fitting between simulated and measured CO_2. It displayed that the CO_2 fluctuations correspond to the time of fishing culture, it stably raised during all crop; meanwhile, measured CO_2 results steadily had value from low to high next to harvesting because of reducing the feed quantity in site by farmer. Besides, pond 3 has the lowest density in three ponds (25 individuals/m^2). In addition, farmers remained longer water, and thus water volume is more stable in pond 3 than in the ponds 1 and 2.

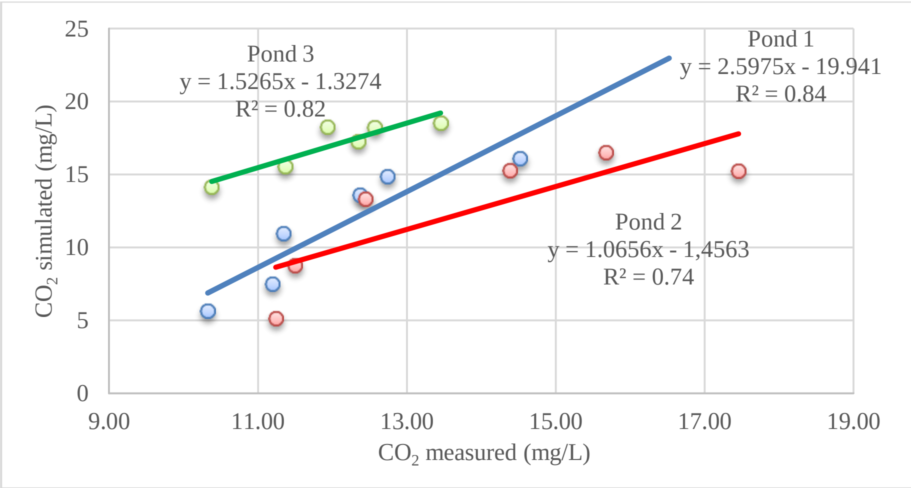

Figure 6. Correlation between model and measured of CO_2 fluctuations in ponds.

After calibrating and validating the models in simulated conditions with experimental measurement value, Figure 6 has shown that the models have highly been compatible. Among three ponds in research, relative analysis result of pond 1 was the highest value, with R^2 was 0.84; pond 3 is the secondly relative; in the meantime, pond 2 is of the lowest relativity. All ponds have increased CO_2 both real and simulated model with high confidence for fishing period.

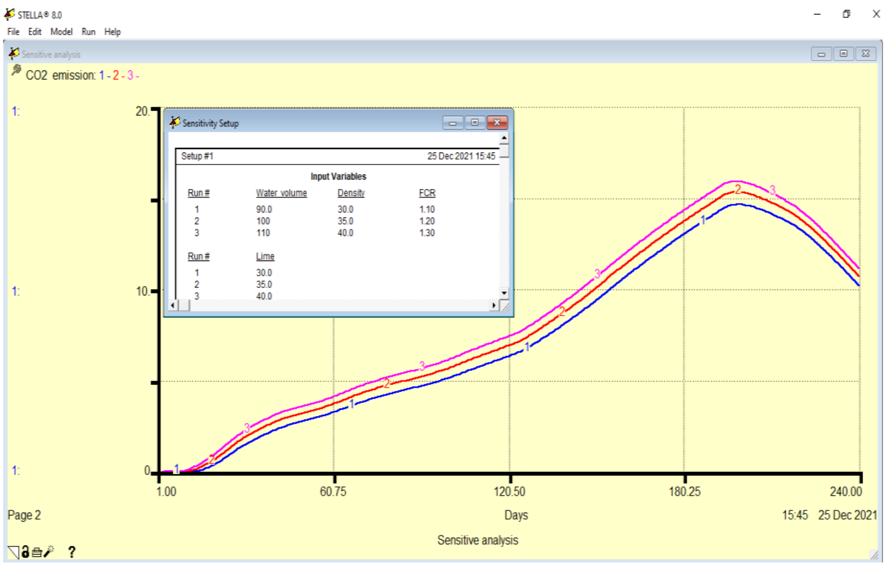

Figure 7. Sensitive analysis on water volume, density, FCR and lime.

Sensitive analysis with three levels of water volume, fish density, FCR and lime, the results in Figure 7 demonstrated that CO_2 emission respectively increased by about 10 % to 30 % of water volume, fish density, FCR and lime at level 1, 2 and 3 on sensitivity setup, high confidence with the tested variables. In the near harvest time, CO_2 curve sharply decreased of reducing the feeding quantity.

3.3. General discussion

Notopterus chitala fish pond like other aquaculture and pond ecosystems where take place material cycle, while carbon cycle via carbon dioxide. Dissolved CO_2 is considered to be the primary form of inorganic carbon used for photosynthesis [18, 19], compounds in a cell are photosynthetic limitation in association with the enzyme ribulose bisphosphate carboxylase [20]. In normal pond water condition, input and output CO_2 is nearby equivalent [21]. When the light intensity penetrates into the pond, photosynthesis occurs throughout the pond depth, but over time plants continue to grow and reduce light penetration, making it a limited factor of phytoplankton growth. The algae will be active during the day, significantly reducing the amount of CO_2, but at night the algae also respire and produce highly CO_2. The findings showed that mathematical simulation has fitted the real values in every pond.

In each pond, results have differently shown at the low and peak CO_2 emission in simulated and real condition, meanwhile the pond 1 and 3 get peak of CO_2 concentration at about 180-190 days while pond 2 has gotten peak at about 120 days. The reason for the difference in peak time in 3 ponds was due to the different stocking densities in 3 ponds, respectively 50, 25 and 35 individuals/m^2. Besides, the amount of feed that provided to the respective ponds was also different in the 3 experimental ponds. On the other hand, background data (windy speed, temperature, light intensity, rainfall) are near same, but water volume, and area are not similar. In addition, fishing farmers use from 17 kg to 30 kg of $CaCO_3$ per 1000 m^2 to reduce pH and CO_2 during the farming process during 240 days (8 months). This is one of the factors that significantly reduce the amount of CO_2 in the surveyed ponds. Moreover, the ponds have a drainage system to discharge water and change the water periodically. It helped farmer to regulate the feed, water volume and lime to be good quality on *Notopterus chitala* fish to minimize greenhouses gas. The results showed that it can be used to control the quantity of CO_2 emission by models that were set. The results of this study once again confirm that CO_2 in the *Notopterus chitala* fish pond is formed from dissolution or diffusion from the atmosphere as many articles published in shrimp by Yang *et al.* [5]; in talapia fish by Amon *et al*. [22] and the respiratory process of plants and fish; the decomposition of organic matter in the fish pond. Through the three models mentioned above, model of pond 1 has calibrated the lowest difference and highest coefficient of R^2 (0.84), so it can be used to control the CO_2 quantity of fish ponds.

A model with changed input values that include water volume, density, feeding speed, FCR and lime. During the actual modelling, sensitivity analysis is performed by changing the parameters, control functions and submodules. The corresponding change of the selection state variables will be monitored. Through simulation, the CO_2 emissions in an aquacultural pond such as *Notopterus chitala* fish ponds depend on two main factors: (i) the density of fish population and feeding speed in each pond, and (ii) as well as the frequency, quality and quantity of water exchanged between the external source and the pond. In fact, farmers give more or less food often based on stocking density. Weather factors such as temperature, solar radiation, rain, humidity, wind, although they have the impacts on greenhouse gas emissions in ponds, but there are not significant in case of the simulated model.

4. CONCLUSIONS

The results from 3 models with 3 corresponding *Notopterus chitala* fish ponds showed that CO_2 can be controlled partly under the scenarios with the corresponding levels. The amount of lime powder is recommended to be used to stabilize the water quality indicators and control the amount of CO_2 generated. Through simulated and measured results, if considering the balance between the economical density, feeding speed control and the greenhouse gas emissions, the pond with a stocking density of 35 individuals per square meter is reasonable as the case of pond 1, change the water in the pond once a week with the amount of water changing about 30 % of the total capacity of the pond. Model was validated by correlative analysis in each pond.

This study has been clarified that Stella model may be a useful tool to control GHG emissions in aquaculture. It is necessary to connect with GIS and automatic sensor to observe in GHGs should be deployed in the next time.

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CRediT authorship contribution statement Nguyen Van So: Methodology, Investigation, Funding acquisition, Formal analysis. Le Anh Tuan: Formal analysis, Supervision, Drawing of Figure 1.

Declaration of competing interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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