Simulation of Water Quality in Bung Binh Thien Lake, An Giang Province, Vietnam, Using the Delft3D Model

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Abstract
Bung Binh Thien Lake, the largest freshwater lake in An Giang, is vital for providing drinking water, supporting agriculture, and sustaining local services. Recently, the lake has been facing organic pollution from household wastewater and local production activities. This study evaluated the water quality using biochemical oxygen demand (BOD_5) and dissolved oxygen (DO) parameters, collecting nine water samples from different locations. The DELWAQ model was applied to assess seasonal changes and water quality distribution. During the 2022 rainy season, the average DO value was 5.42 mg/L, meeting the A2 class standard (≥ 5 mg/L), while the BOD_5 value was 12.25 mg/L, within the B1 class standard (≤ 15 mg/L). In the dry season, the DO value dropped to 4.82 mg/L, and the BOD_5 value increased to 12.63 mg/L, indicating higher phytoplankton density and organic pollution. The simulated DO and BOD_5 values closely matched observed values, with NSE values of 0.74 and 0.87 for DO and BOD_5, respectively, in the flood season, and 0.86 and 0.88 in the dry season. The DELWAQ model proved effective in simulating water quality at Bung Binh Thien Lake, providing valuable data for environmental management and decision-making. This study also serves as a useful reference for further research and water quality management.

Keywords: Bung Binh Thien, BBT, Water Quality, Delft3D-FLOW, DELWAQ

1. Introduction

In modern times, the process of industrialization coupled with population growth has exerted immense pressure on natural water sources, including lakes. Pollutants from agricultural, industrial, and domestic sources have significantly increased, leading to a marked deterioration in the quality of surface waters, including lakes [1]. The resulting degradation impacts ecosystems, leading to phenomena such as algal blooms, which can cause excessive aquatic plant growth, and disrupt human activities such as leisure, industry, and agriculture [2].

Water is a critical, non-renewable resource essential for the development of human civilization. While water covers 71% of the Earth's surface, only 2.5% is freshwater, with the majority trapped in glaciers and underground reservoirs. A mere 1.2% of all freshwater is surface water, of which natural lakes comprise about 20.9% [3]. These lakes are vital for various human activities, including industry, agriculture, forestry, fisheries, and daily life. They also provide habitats for numerous species, contribute to groundwater replenishment, regulate the climate, and mitigate floods and erosion [4]. The parameters including flow velocity, DO, BOD, and BOD_5 play a crucial role in assessing the health and water quality of the lake, accurate measurement and monitoring are essential for effective lake management. Flow velocity in lakes influences the circulation patterns, water mixing, and the distribution of nutrients, and pollutants, impacting aquatic habitats and lake health, and it is typically measured using a current meter. DO is necessary for the respiration of fish and other aquatic organisms, low DO levels can lead to low oxygen conditions, which can harm or kill aquatic life, typically measured with a DO meter or portable probe.

BOD measures the amount of oxygen consumed by microorganisms while decomposing organic matter in the water, and BOD5 is a specific measure of BOD over 5 days. High BOD values indicate high organic pollution, signaling excessive nutrients and the risk of algal blooms which lead to deteriorating lake water quality, and BOD is typically measured in the laboratory.

The escalation of urban and domestic wastewater, coupled with agricultural expansion, has led to significant lake pollution by nutrients and other pollutants [5]. Overexploitation of lake water by humans further depletes these resources, making them unsuitable for use. Consequently, numerous studies on lake water quality have been undertaken globally to assess current conditions, predict future scenarios, and devise strategies for effective management and maintenance of lake water quality. For instance, research at Mere Lake and Acigol Lake in Turkey utilized a combination of parameters like hardness, mineral solids, and nutrient content analyzed through inverse distance weighting (IDW) and Geographic Information System (GIS) technologies to create integrated maps for water quality prediction [6]. Similarly, studies at Morgan Lake in Turkey assessed water quality by analyzing 29 domestic parameters, including surface water and bottom mud characteristics, using samples from various locations [7].

In Malaysia, Beris Dam Lake's water quality was assessed using methods like DOE-WQI, IDW, Spline Kriging, and the Carlson Nutrition Status Index (CTSI), highlighting the effectiveness of spatial analysis methods in water quality evaluation [8]. Ensemble learning and remote sensing have also proven effective in monitoring and managing water quality in inland areas. A case study in Poyang Lake, China, used Sentinel-2 satellite imagery and multi-spectral data to predict water quality parameters [9]. Other studies have employed remote sensing techniques to evaluate water quality, such as in Chilika Lake, India, where data from Google Earth Engine and Sentinel-2 satellite imagery were used to analyze parameters like turbidity, total dissolved solids, and chlorophyll levels [10]. Statistical techniques, including cluster analysis and factor analysis, have been used to assess water quality in Habbaniya Lake, Iraq, identifying relationships between water quality indicators and pollution sources [11].

In China, the impact of water transfer and wind on Chaohu Lake's water quality was studied using a three-dimensional hydrodynamic-ecological model, demonstrating the significance of these factors in nutrient concentration and water flow dynamics [12]. Studies at Laguna Lake in the Philippines used multivariate cluster analysis to evaluate water quality and spatial differences between sampling stations, underscoring the utility of statistical methods in environmental assessment [13]. Various indices, such as the single-factor pollution index and the Nemerow pollution index, have been applied to assess water quality in lakes, as seen in research at Lugu Lake, China. These indices help determine water quality by comparing monitoring results with classification standards and calculating a weighted multi-factor environmental quality index [14]. Advanced modeling techniques, such as the Kalman filter method, have been used to predict water quality in lakes, accounting for the high uncertainty in water data [4]. Besides, a prominent study of the Delft3D model is that Gatun Lake, located in the Panama Canal basin, serves as the main freshwater for the canal and drinking water for 600,000 people. The study used Delft3D-FLOW of Delft3D as well as open-source data including bathymetry from GEBCO and hydrodynamic data from ACP's AQUARI along with salinity and temperature water quality parameters to build a 3D hydrodynamic model. The results determine the accuracy of the simulated water level RMSE < 0.1m, therefore the simulated result is closer to reality, reliable, and achieves high efficiency due to RMSE being close to zero [15].

Lakes play a crucial role in supporting biodiversity and providing essential resources for various species. In Vietnam, numerous lakes, both natural and artificial, have significantly contributed to socio-economic development. However, pollution and declining water quality have become major concerns, necessitating research to propose solutions for improving lake water quality to enhance climate conditions, disaster prevention, and environmental sustainability. For example, a study of Than Tho Lake and Van Quan Lake in revealed pollution and foul odors due to sewage discharge. Water quality assessments using tools like the Water Quality Index (VN-WQI) and Pearson correlation analysis showed better water quality in the rainy season compared to the dry season [16].

Hoa Binh artificial reservoir's water quality was evaluated using systematic succession and approach methods, revealing an increase in TSS, COD, and BOD_5 levels in recent years [17]. Truong Xuan Lake in Quang Ninh province, crucial for supplying drinking water, was found to have good water quality, though some parameters approached threshold limits. Regular monitoring was recommended to ensure sustainable water quality [18].

Studies at Hoan Kiem Lake in Hanoi identified severe eutrophication, necessitating measures to improve the lake's ecosystem [19]. Da Den Lake in Ba Ria - Vung Tau province faces pollution from various sources, especially during the rainy season. Analysis indicated significant increases in TSS, COD, and nutrient levels, highlighting the need for targeted pollution control measures [20]. Similarly, Xanh Lake, Cong Vien 29-3 Lake, and Bau Sau Lake in Da Nang city require interventions to address high levels of organic pollution and nutrient enrichment [21].

In conclusion, the quality of lake water is under significant threat due to industrialization, urbanization, and agricultural practices. Various studies across the globe have employed diverse methods to assess, monitor, and improve lake water quality. These efforts are crucial for maintaining the ecological balance, supporting biodiversity, and ensuring sustainable water resources for human activities. Effective management strategies and regular monitoring are essential to mitigate the impacts of pollution and protect these vital water bodies for future generations. Recognizing the threat to lake water quality due to urbanization, living habits, agricultural activities, and ecological tourism in Bung Binh Thien (BBT) Lake, many studies on lake water quality have been conducted rapidly to improve the current state of lake surface water pollution. These studies provide a variety of effective methods for assessing and monitoring water quality. However, there has not been research on water quality simulation in Bung Binh Thien, An Giang province. Therefore, applying the Delft3D-FLOW hydrodynamic model to simulate flow and the DELWAQ model to model water quality for DO and BOD_5 parameters will help assess water quality in Bung Binh Thien. This will support the environment manager in developing effective water resource management resolutions and serve as a reference for future research on water quality, the ecological environment in lakes, and simulation research.

2. Material and Methods

2.1 Study Area

BBT is located in Khanh Binh, Nhon Hoi, and Quoc Thai communes, An Phu district, is the largest freshwater lake in An Giang province (Figure 1). The lake plays an important role in supplying domestic water, supporting agricultural production, and providing services of local individuals. The north of BBT is bordered by Khanh Binh commune, while the south is bordered by Nhon Hoi commune and Quoc Thai commune. Besides, the lake connects with the Binh Di River by a small creek but does not connect with the Hau River. BBT Lake is home to many aquatic species, consisting of a variety of unique aquatic products migrating from the Mekong Delta, which produce a livelihood for local people.

2.2 Model Set-Up

Nine water samples were collected in BBT (Table 1) and analyzed for two parameters including dissolved oxygen (DO) and biochemical oxygen demand (BOD_5). These values were used to build a model. In this study, Delft3D software was used to study critical areas of BBT Lake in An Giang province, Vietnam.

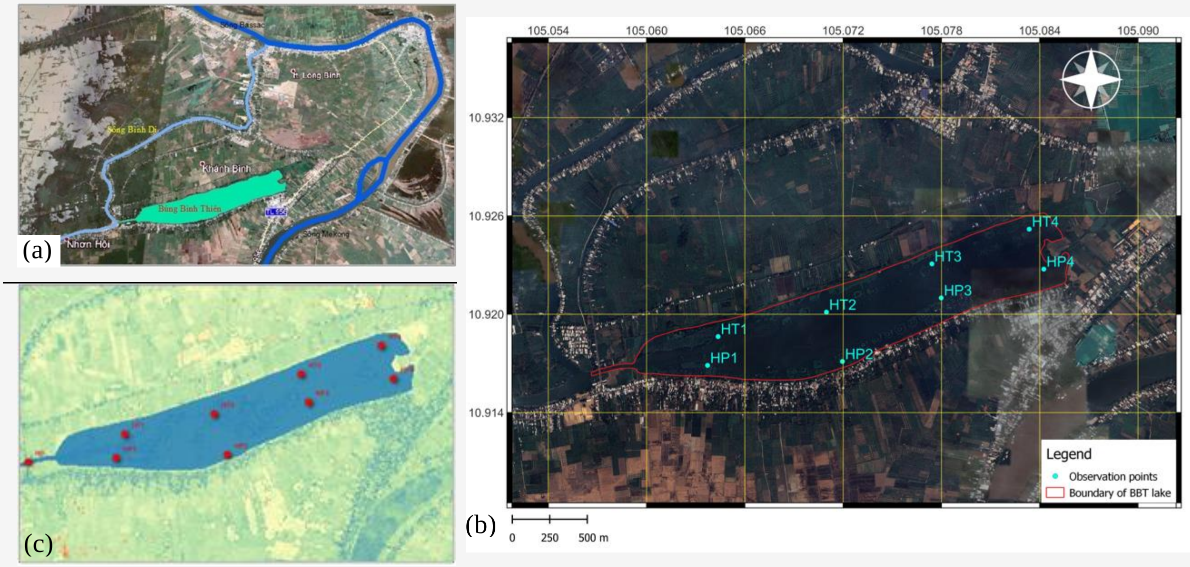

Figure 1: (a) Location of BBT lake; (b) Nine sampling sites at BBT Lake, An Phu district, An Giang province; (c) Nine sampling sites on Delft 3D model

Table 1: Sampling sites at BBT lake

Sample	Symbol	Coordinate		Description
		X	Y	
1	H0	10.916690	105.05789	The head of a lake
2	HP1	10.915840	105.062365	Big cathedral
3	HP2	10.917179	105.071814	The end of eichhornia crassipes row
4	HP3	10.919709	105.077117	Rafting village area (20 - 25 rafts)
5	HP4	10.921366	105.085235	Kieu Oanh motel
6	HT4	10.925875	105.083661	The end of a lake
7	HT3	10.925875	105.083661	Agricultural area
8	HT2	10.921038	105.069624	Lotus pond Banana row
9	HT1	10.918296	105.061421	Water mimosa pond

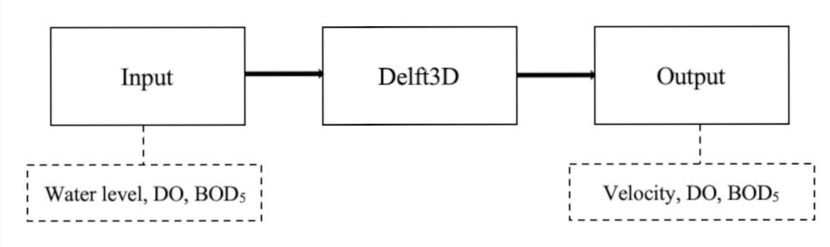

Figure 2: The workflow of study

Furthermore, Delft3D has proven to be an effective tool for assessing water resource and pollution problems [22]. Therefore, Delft3D model can be server as a useful tool for water resources management and land use planning in An Phu district. The process of study for BBT Lake is shown in Figure 2, and the followings are three steps of the process.

Delft3D is a software package developed by the Deltares Hydraulic Institute, formerly Delft Hydraulics (https://svn.oss.deltares.nl/repos/delft3d). Researchers in many nations frequently use Delft3D to simulate the hydrodynamics and water quality of lakes, rivers, estuaries, and other water bodies because the model is quick and stable, the components are open source, and they can be used in conjunction with external software like MATLAB to provide more powerful simulation capabilities for more complex simulations of eutrophication and water ecology. The model with the highest computational efficiency both when running on multiple cores is MIKE 21 FM and running on a single core is Delft3D-FLOW the most efficient. In addition, Delft3D-FLOW can be multiple concurrent runs, with the ability to combine the deeper curved and triangular plots in areas with complex terrain. Besides, Delft3D-FLOW has variable resolution within a model domain, thus avoiding too high resolution in less relevant areas as well as helping to reduce computation time.

Delft3D software is one of the two-dimensional simulation tools for surface water. It includes two main models Delft3D-FLOW (hydrodynamic model) and DELWAQ (water quality model). Delft3D-FLOW is a hydrodynamic model, its limitations include high data requirements, computational cost, and input errors that can propagate in time. The Delft3D-FLOW model with the highest computational efficiency when running on single cores but running on multiple cores is MIKE 21 FM the more efficient. However, Delft3D-FLOW can be multiple concurrent runs, with the ability to combine the deeper curved and triangular plots in areas with complex terrain. Besides, Delft3D-FLOW has variable resolution within a model domain, thus avoiding too high resolution in less relevant areas as well as helping to reduce computation time.

The Delft 3D program comprises various modules, each addressing different aspects of research and engineering. Each module is performed independently or connected to the modules using a communication file containing the results of the previous module [23] (Figure 3). The calibration and validation processes of Delft3D were used in the study shown in Figure 4.

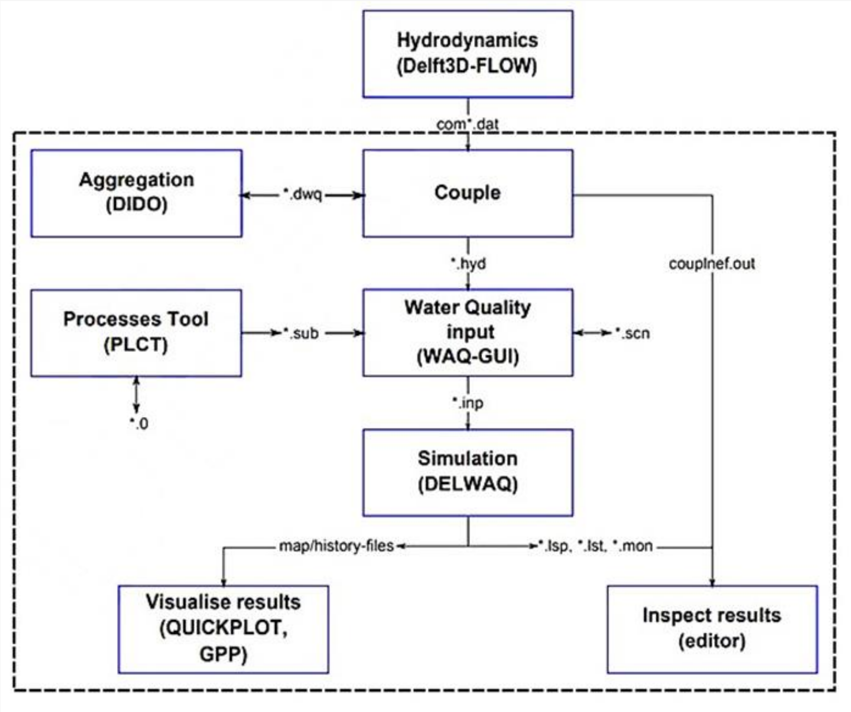

Figure 3: Delft 3D simulation process [23]

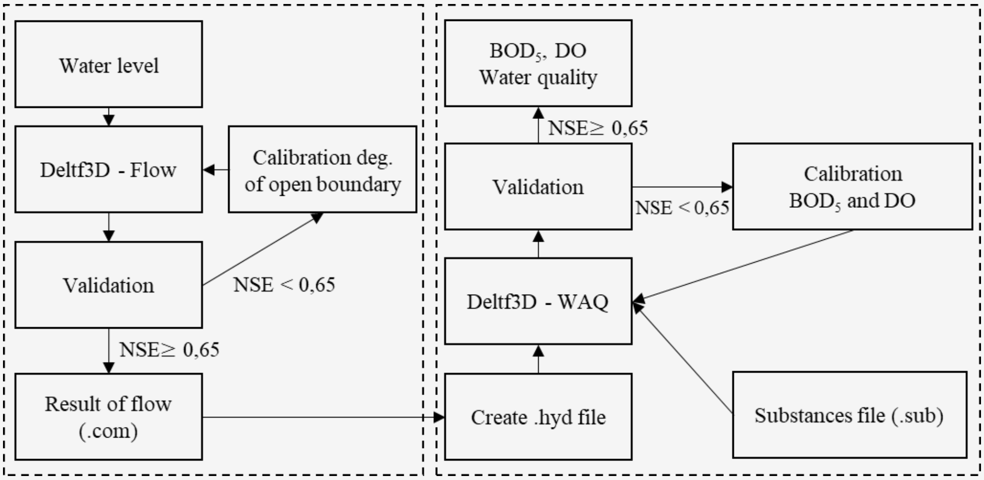

Figure 4: The calibration and validation processes of Delft3D in BBT lake

$$NSE = 1 - \frac{\sum_{i=1}^{n}\left(y_i^{obs} - y_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(y^{obs} - \bar{y}\right)^2}$$

Equation 1

Where:

y_i^{obs} represents the observed value

y_i^{sim} represents the simulated value

$\bar{y}$ denotes the average of observation values

The Nash-Sutcliffe efficiency (NSE) is a widely used metric in simulation to assess the performance of a model relative to observed data, and is calculated in Equation 1. NSE values range from negative infinity to 1. A perfect model fit to the observed data yields an NSE of 1, indicating a complete match between simulated and observed values. The modeling performance of the measured and observed value is determined by NSE value as shown in Table 2. The advantage of this model is the combination of complex computational modules to provide simulation results for many substances and participatory processes, offering free and user-friendly tools with modules that support both input management and output generation.

The simulation process of lake water quality is carried out in the following sequence:

Building a module needs to collect the input data. After gathering necessary data, enter the input data and run the module. Next, carrying out to check simulation. Evaluating water quality as well as explaining about causes water contamination. Finally, simulation is analyzed to know effectiveness and assess application of simulation. Builting simulation including three main stages: (1) Prepare input data for module; (2) Delft3D-FLOW; (3) DELWAQ.

(1) Input data

The flow configuration includes a period time from 01 October 2022 to 31 October 2023 with a time step of 10 minutes, local time (+7); initial conditions were high water level 5.3 m; type of open boundary is water level, the forcing type is astronomic, flow conditions and finally the physical parameter is roughness. And in roughness, the manning value of 0.02 is the typical value recommended by Deltares. Besides, the study referred to the national standard TCVN 13615: 2022 on the calculation of design hydrological elements in section 2, choosing the roughness coefficient as 0.02. The roughness coefficient represents the friction force when water moves in the mesh horizontally (u) or vertically (v) between similar pixels (Table 3).

Parameters of DO, BOD_5 in October 2022 has a model configuration including hydrodynamics as the result of simulating the flow from 1 October 2022 to 31 October 2023; boundary conditions are top-bottom 1 (6,2 DO [g/m^3] and 12,8 $cBOD_5$ [gO_2/m^3]); process parameters and discharges (Table 4). Specifically, 6.2 mg/L DO value and 12.8 mgO_2/L $cBOD_5$ at the top-bottom boundary represent the DO and $cBOD_5$ values in the inflow to the lake, it is taken based on measured values and parameter estimates at the initial time.

(2) Hydrodynamic model (Delft3D-FLOW)

The simulation of flow was carried out following the process (Figure 5). After creating data boundary (.ldb), grid (.grd), depth (.xyz) and depth (.dep) files w for BBT Lake area, margins were set using the Delft Dashboard to establish open boundaries and boundary conditions. Subsequently, flow rates at the sample points were determined based on .ldb files created during the input data preparation stage, ensuring accurate point placement on the grid. The input process for simulation was then completed. A successful process generates the .dat file in the folder, which serves as input for the water quality model.

Table 2: The criteria of Nash-Sutcliffe coefficient

Properties	Value
Very good	0.75 < NSE ≤ 1.00
Good	0.65 < NSE ≤ 0.75
Satisfactory	0.50 < NSE ≤ 0.65
Unsatisfactory	NSE ≤ 0.5

Table 3: Parameter for building Delft3D-FLOW at BBT lake

Grid resolution	18 - 25 m			
Time frame	Reference date	01-10-2022		
	Sim. start date	01-10-2022 00:00:00		
	Sim. end date	31-10-2023 23:30:00		
	time step	10 min		
	local time	7		
Initial condition	water level	5.3 m		
Boundaries	Type of open boundary	Water level		
	Forcing type	Astronomic		
Physical parameter	Roughness	Manning	u	v
		Uniform	0.02	0.02

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Table 4: Parameters of building DELWAQ for DO, BOD_5 in raining season at BBT lake

Hydrodynamics	Flow simulation results 01/10/2022 - 31/10/2023		
Substances	input	DO	
		BOD_5	
	output	BOD_5	
		DO	
Timeframe	Sim. start date	01-10-2022 00:00:00	
	Sim. end date	31-10-2022 23:30:00	
Boundary conditions	Top-bottom 1	DO [g/m^3]	6.2
		BOD_5 [gO_2/m^3]	12.8

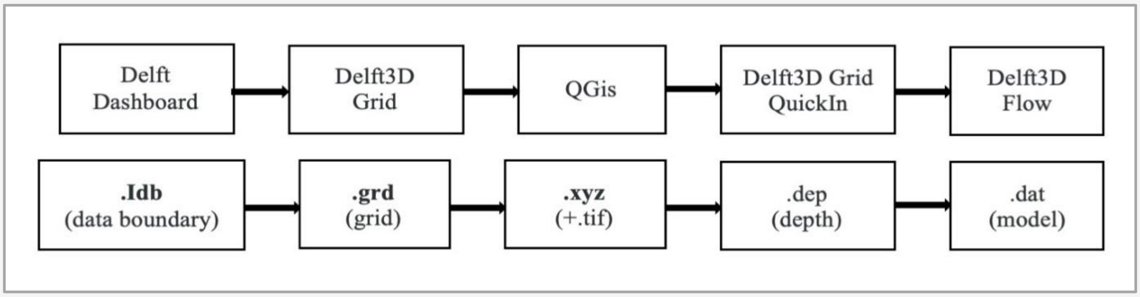

Figure 5: The process of flow simulation by Delft 3D [24]

(3) Water Quality Model (DELWAQ)
The water quality data of DO and BOD_5 parameters were combined with the water flow results via a com*.dat file in the Couple module to generate the *.hyd file, which serves as an input to the DELWAQ model. The selection of output data involves deciding which results are stored for further analysis in another module and which output data is printed. The Delft3D modules use multiple Map, history, communication, and restart files to store the results and necessary information.

3. Result and Discussion

3.1 Hydrological Simulation

The configured flow model covers an area with grid size (M, N) = (96,37). The time frame is from October 2022 to October 2023, with a time step (Δt) of 10 minutes. The open boundary is created with 2 boundaries (West01, West02) of the "water level" type, the forcing type is selected as the astronomical type. For physical parameters, mainly set roughness to 0.02 for two dimensions U- and V-, and set up 8 observation points. The results of the Delft3D-FLOW model show that the NSE value of the water level was 0.93, indicating high reliability and validity of the water level, with an RMSE of 0.17, proving the simulated value is close to reality. According to previous research, an NSE close to 0.6 indicates the model's ability to reliably predict and create flow maps of the lake. If the NSE exceeds 0.6, the model thrives in terms of the output simulation model [25]. In the case of BBT, the calculated NSE of 0.93 for October 2022 demonstrates the durability and effectiveness of the lake water flow model. Moreover, the Root Mean Square Error (RMSE) of the model is 0.17, indicating that the model closely approximates reality due to its low RMSE value.

The results of hydrological simulation in BBT indicate that the flow velocity at the beginning of the BBT area is higher than other locations, gradually decreasing towards the end of the Bung area. During the rainy period, the water velocity varies from 0 - 0.2 m/s, reaching the highest speed at the estuary (Figure 6). In the dry season, the flow velocity continues to vary from 0 - 0.3 m/s and the flow velocity at estuary reaches the highest 0.2 - 0.3 m/s and higher than in the rainy season (Figure 7) The difference between the two seasons is due to higher water levels in the river between BBT and Binh Di rivers, resulting in increased flow during the dry season. It can be seen that the flow velocity in the BBT is very low, the further you go towards the end of the Bung area, the velocity decreases gradually, approaching zero value. The water state at the end of the Bung is very calm.

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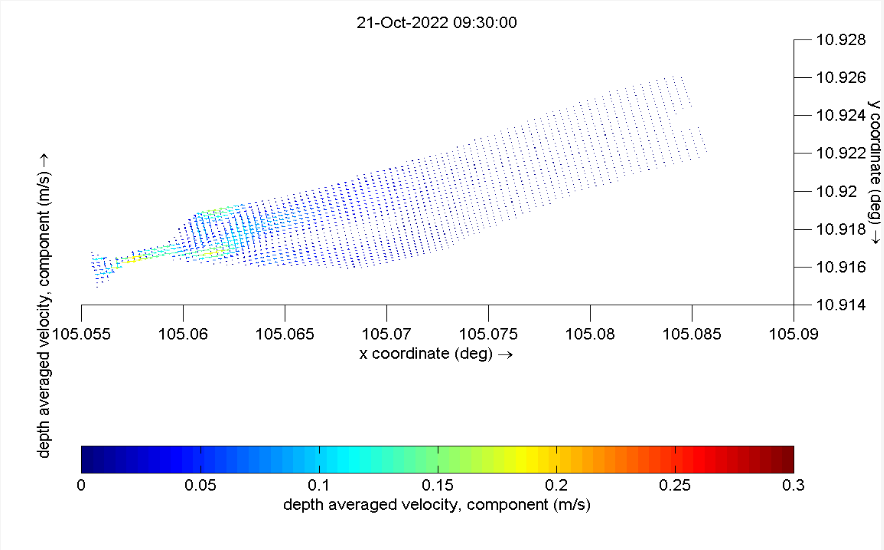

Figure 6: Simulation results of rainy season flow in October, 2022 at BBT lake

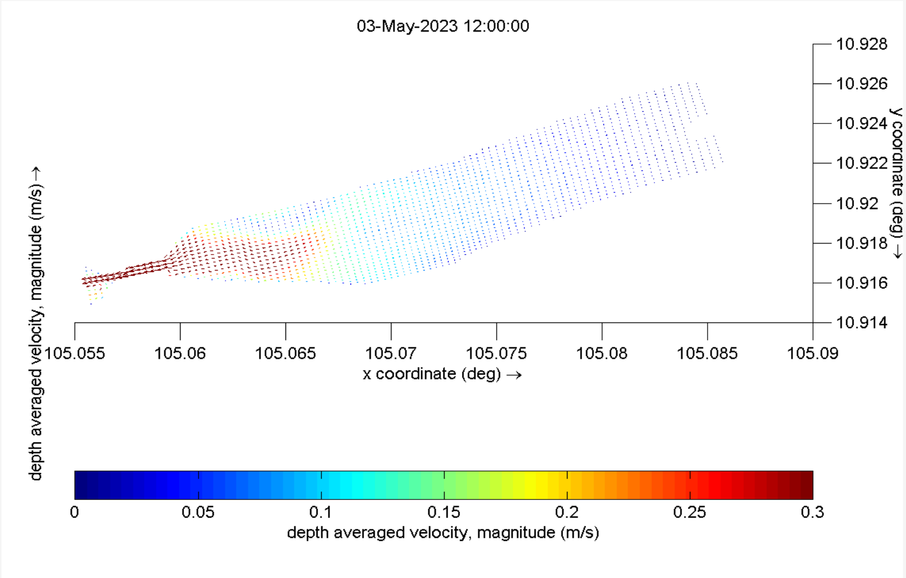

Figure 7: Simulation results of dry season flow in May, 2023 at BBT Lake

3.2 Simulation Results of DO Parameters in Dry Season and Rainy Season

3.2.1 In rainy season (2022)

During the rainy season in 2022, the simulated DO concentration on BBT ranges from 5.0 to 5.7 mg/L (Figure 8 and Figure 9), gradually decreasing from the beginning to the end of the lake. According to Figure 8, the simulated results in general are quite compatible with the 4 locations compared to the observed value, but HP4 has a lower compatibility value than the 3 locations (HP1, HP2 and HP3). In addition, Figure 9 depicts the model's DO values at four positions, with simulation results quite compatible with observations on the left side, but HT4 shows lower compatibility compared to HT1, HT2, and HT3 on the right side. In summary, the simulation results at the two locations at the end of the lake are less compatible with observations, as shown in Figure 10.

3.2.2 In dry season (2023)

During the dry season in 2023, the simulated DO ranges from 4.3 to 5.3 mg/L, which is lower compared to the rainy season (Figure 11, Figure 12, and Figure 13). This finding is consistent with the analysis conducted across both periods of the year.

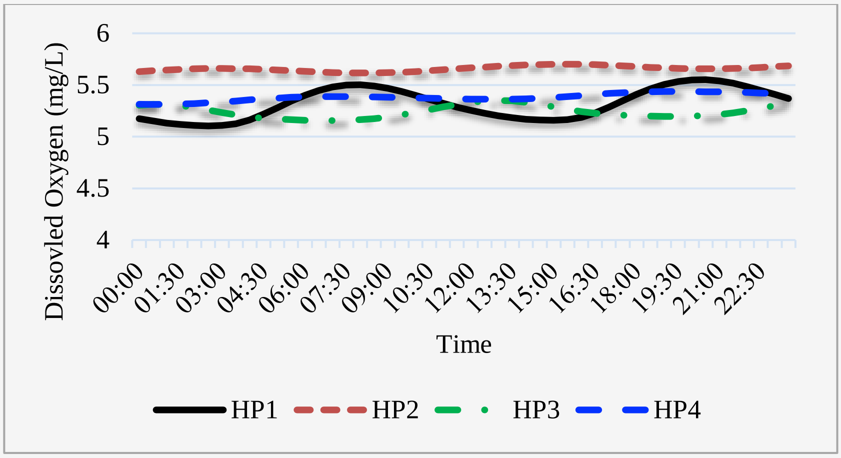

Figure 8: Simulation results of DO concentration in October, 2022 at right side of BBT lake

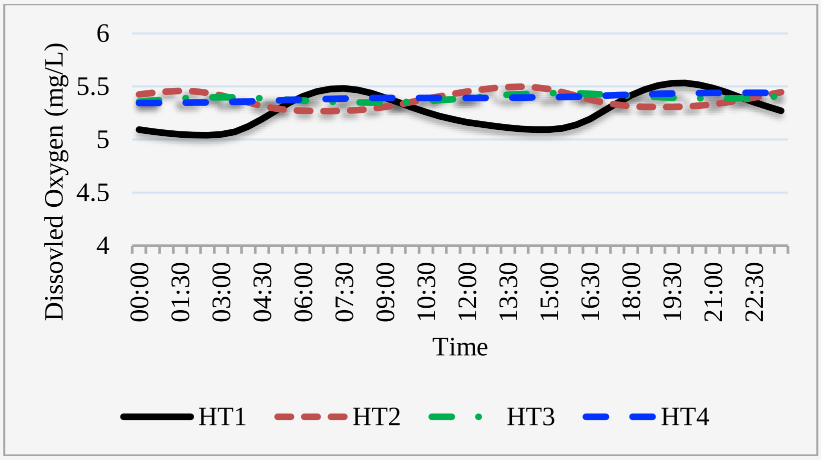

Figure 9: Simulation results of DO concentration in October, 2022 at left side of BBT lake

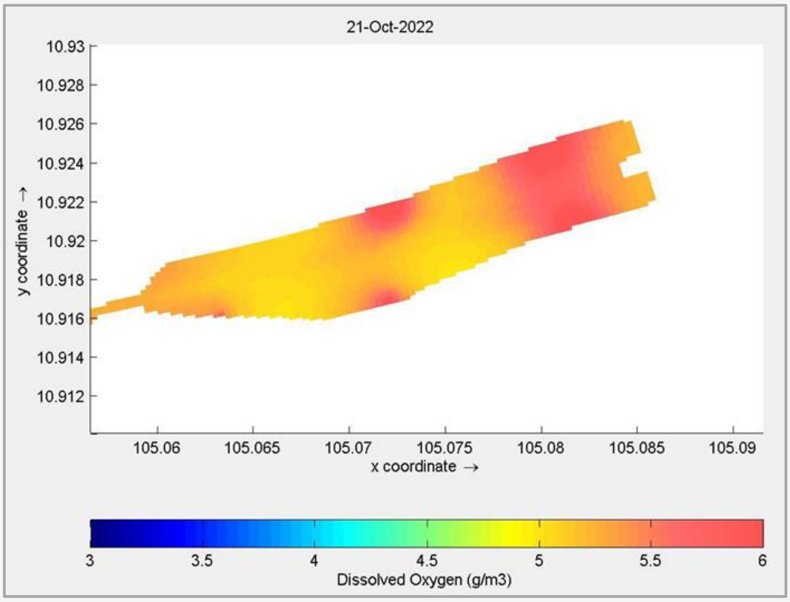

Figure 10: Simulation results of DO concentration in October, 2022 at BBT lake

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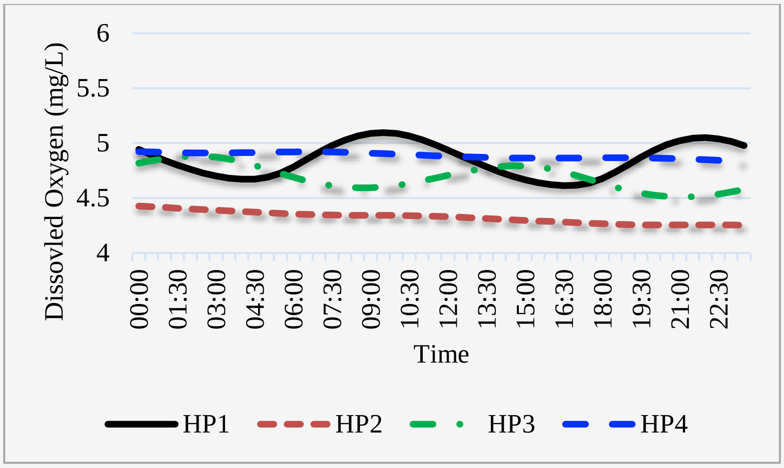

Figure 11: Simulation results of DO concentration in May, 2023 at right side of BBT lake

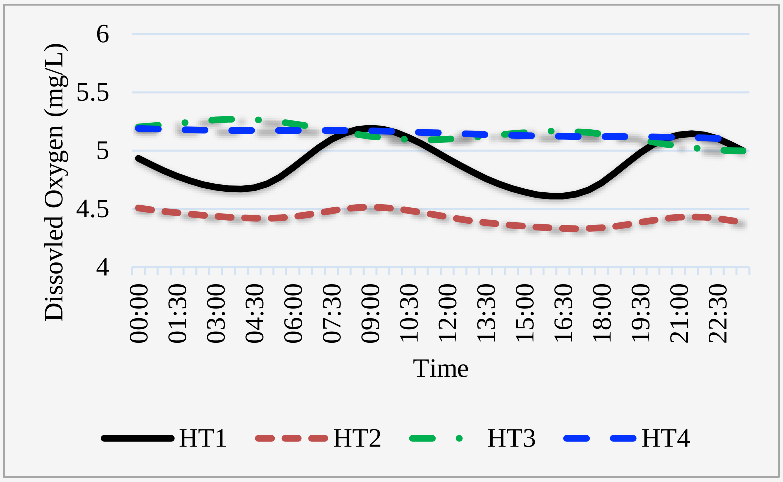

Figure 12: Simulation results of DO concentration in May, 2023 at left side of BBT lake

According the model chart (Figure 11), the model's results are most compatible with observed values at the beginning and end of the lake (HP1 and HP4), while HP2 shows results that are not in line with reality, similar to three locations. The results from Figure 12 show that the lake head (HT1) has a lower compatibility with observations compared to the remaining locations (HT2, HT3 and HT4), with HT3 showing the least compatibility among these locations.

After performing the simulation, the simulated dissolved oxygen (DO) concentration at the beginning of BBT showed the highest compatibility (Table 5), and the flow velocity also reached the highest level compared to the entire BBT. The DO values obtained from the simulation process are appropriate since the water surface is disturbed at the lake inlet, and the amount of oxygen brought in from the Binh Di River. In May 2023, the NSE attainment model of 0.86 shows more effective and durable simulated results compared to October 2022, thanks to the higher NSE value. Besides, the RMSE is 0.10 which is slightly higher than in the rainy season, yet still indicating good simulated results closely approximate reality, as the RMSE value approach zero value. According to the research from Gupta [25], the NSE value close to 0.6 indicates reliable predictive skills of the model. When the NSE exceeds 0.6, the output simulation of the model is considered even more powerful [25]. And the simulation of DO concentration at BBT in October 2022, an NSE of 0.74 proves success, durability, and efficiency of the model in simulating DO water quality. In addition, the model's Root Mean Square Error (RMSE) is 0.09 (Table 5), indicating that the model's predictions are very close to reality, as the lower RMSE value indicates higher accuracy. During the dry season, the average observed DO value of 4.82 mg/L indicates middle water quality, meet B1 class of the national technical regulation on surface water quality, and it is lower than in the rainy season.

Table 5: Simulation results of DO concentration in May, 2023

Symbol	October, 2022			May, 2023		
	Observation (mg/L)	Simulation (mg/L)	Difference (Obs-Sim) (mg/L)	Observation (mg/L)	Simulation (mg/L)	Difference (Obs-Sim) (mg/L)
HP1	5.190	5.187	0.003	5.120	5.096	0.024
HP2	5.740	5.701	0.039	4.480	4.427	0.053
HP3	5.440	5.349	0.091	4.860	4.830	0.030
HP4	5.590	5.408	0.182	5.090	4.923	0.167
HT4	5.190	5.346	0.156	4.990	5.097	0.107
HT3	5.380	5.379	0.001	5.050	5.055	0.005
HT2	5.510	5.498	0.012	4.560	4.486	0.074
HT1	5.320	5.310	0.010	4.420	4.609	0.189
MEAN OBS		5.420			4.820	
NSE		0.74			0.86	
RMSE		0.09			0.10	
R^2		0.76			0.86	

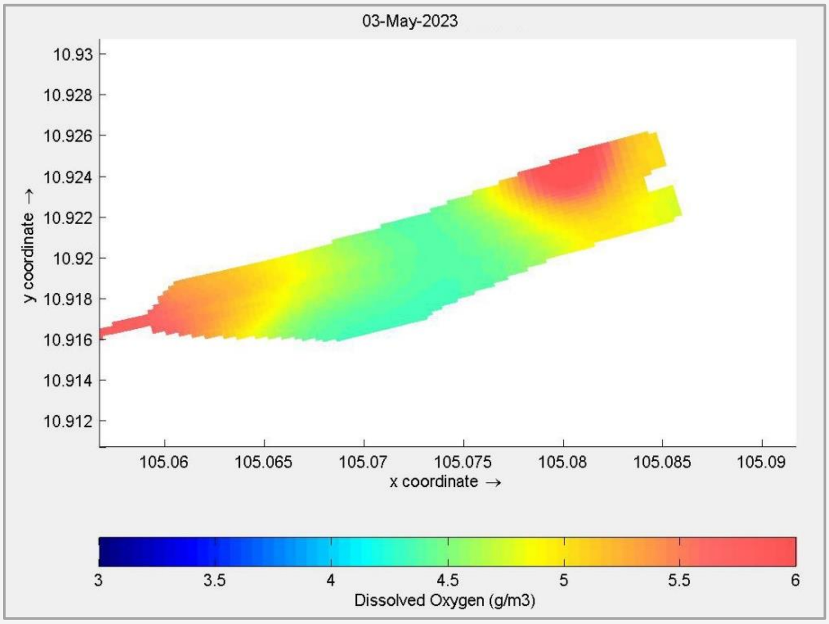

Figure 13: Simulation results of DO concentration in May, 2023 at BBT lake

In addition, the end of the lake has a lower DO value than the beginning of the lake due to wastewater discharge into the lake. Finally, both the left and right sides have the similar DO concentrations, but upon closer inspection, the values on the left side are slightly higher and more consistent. This difference is attributed to flow characteristics and the greater distance from residential areas compared to the right side. Conversely, the lake's head and end exhibit higher DO values due to inflow from the Binh Di River at the lake's head. However, DO values are lower in the middle of the lake. Generally, DO values are higher on the left bank, as well as at the beginning and the end of the lake.

3.3 Simulation Results of BOD_5 Parameters in Dry Season and Rainy Season

3.3.1 In rainy season

The simulation results show that the highest BOD_5 concentration is recorded at the beginning of the BBT and tends to decrease towards the end of the BBT Lake. The BOD_5 values are lower on the left bank compared to the right bank of BBT. During the rainy season in 2022, the simulated BOD_5 value ranges from 11.1 – 13.9 mg/L (Figure 14, Figure 15, and Figure 16), meeting national technical regulation on surface water quality at class B1, water only can be used for irrigation or other uses with similar water quality requirements.

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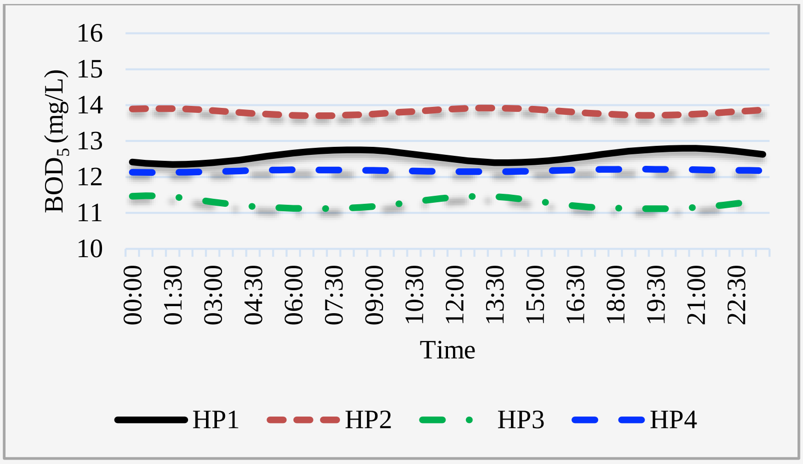

Figure 14: Simulation results of BOD_5 concentration at October, 2022 at right side of BBT lake

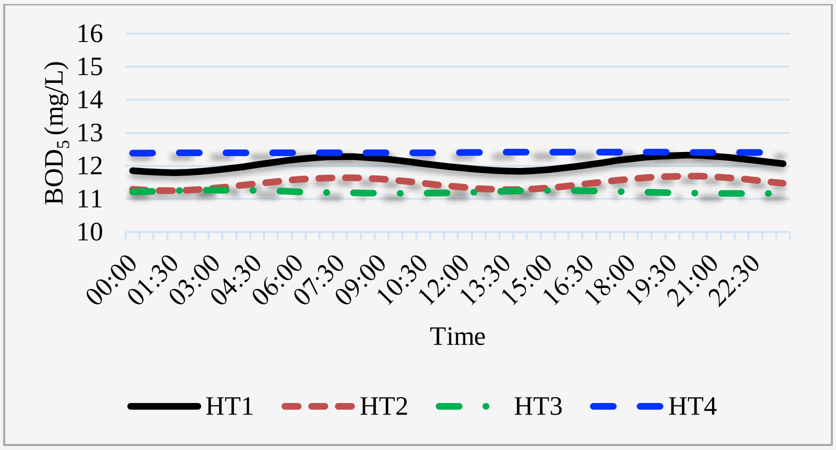

Figure 15: Simulation results of BOD_5 concentration at October, 2022 in left side of BBT lake

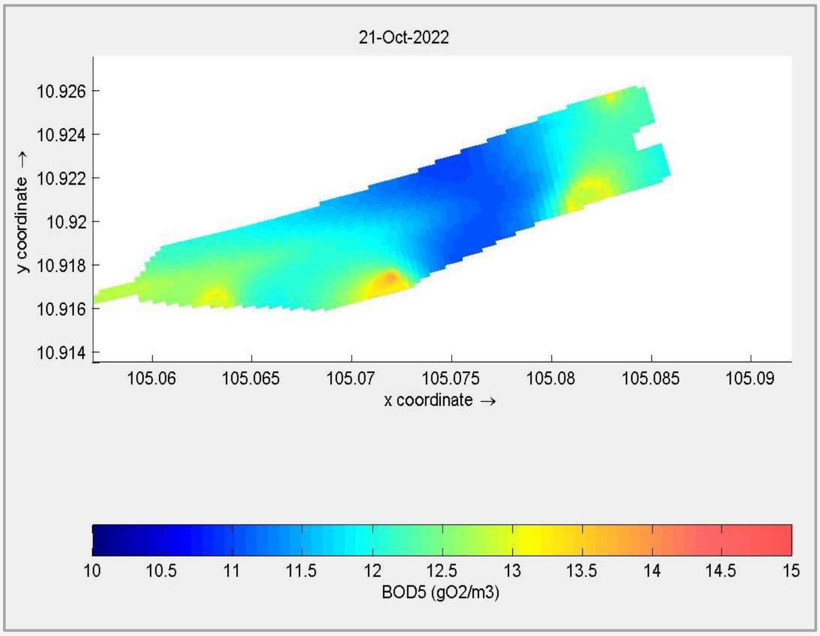

Figure 16: Simulation results of BOD_5 concentration at October, 2022 BBT lake

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The BOD_5 concentration model chart displays simulation results at four locations (HP1, HP2, HP3, and HP4) with HP4 showing the highest compatibility with reality value, and HP3 showing the lowest. In Figure 15, the simulation results for the four positions on the left side indicate that HT4 is less compatible with observations compared to the other three positions.

During rainy season, the average simulated BOD_5 concentration is 12.1 mg/L, which is quite high, indicating poor lake water quality suitable only for irrigation or other uses with similar water quality requirements. The middle of the lake has lower BOD_5 concentration than both of the beginning and the end of BBT. The left side of the lake also shows lower BOD_5 than the right side,with some locations reaching BOD_5 levels of about 13 - 15 mg/L.

3.3.2 In dry season

During the dry season, the water velocity was very low, causing stagnation in the middle of the lake and almost zero flow similar to the rainy season, the high simulated BOD_5 value ranges from 11.7 – 13.6 mg/L. The highest value is at the upstream area of the BBT and tend to increase gradually towards the end (Figure 17 and Figure 18). The results of model diagram (Figure 17) show that the simulation results of the lake head (HP1) are not highly compatible with observations compared to other locations including HP2, HP3 and HP4. Besides, on the left side of the lake, BOD_5 simulation results (Figure 18) at HT3 show lower compatibility with observations compared to the other locations (HT1, HT2 and HT4). Despite HP1 and HT3 showing lower compatibility than the other positions, their results are still close to reality.

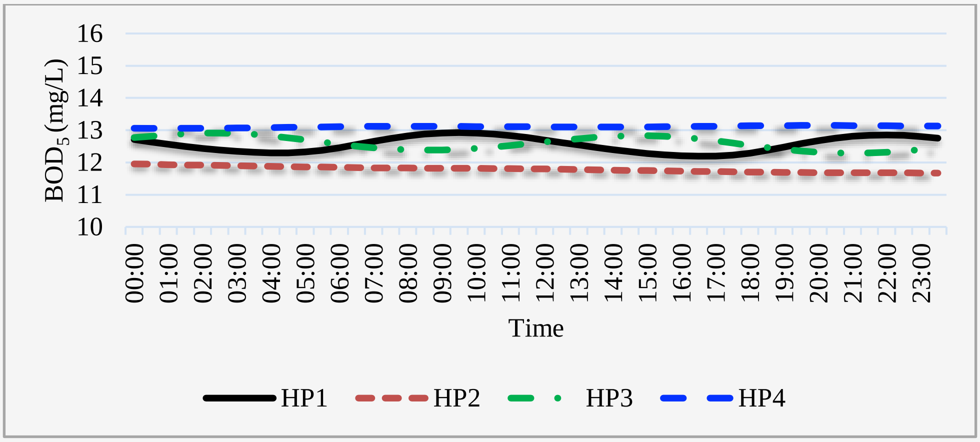

Figure 17: Simulation results of BOD_5 concentration in May, 2023 at right side of BBT lake

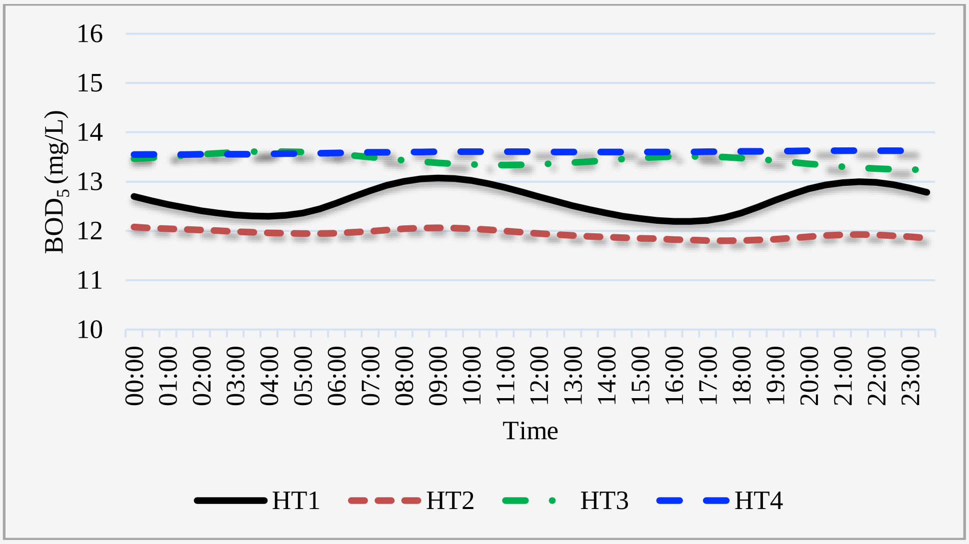

Figure 18: Simulation results of BOD_5 concentration in May, 2023 at left side of BBT lake

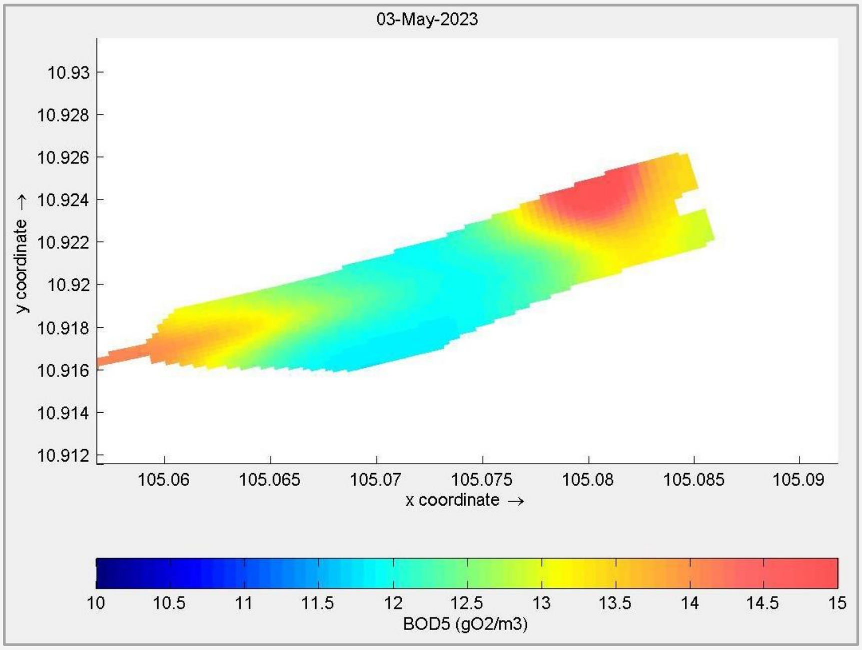

Figure 19: Simulation results of BOD_5 concentration at May, 2023 BBT lake

Table 6: Simulation results of BOD_5 concentration in October, 2022 and May, 2023

Symbol	October, 2022			May, 2023		
	Observation (mg/L)	Simulation (mg/L)	Difference (Obs-Sim) (mg/L)	Observation (mg/L)	Simulation (mg/L)	Difference (Obs-Sim) (mg/L)
HP1	13.000	12.748	0.252	12.000	12.313	0.313
HP2	14.000	13.826	0.174	12.000	11.953	0.047
HP3	12.000	11.455	0.545	13.000	12.907	0.093
HP4	12.000	12.162	0.162	13.000	13.072	0.072
HT4	13.000	12.396	0.604	13.000	13.057	0.057
HT3	11.000	11.176	0.176	13.000	13.336	0.336
HT2	11.000	11.300	0.300	12.000	12.057	0.057
HT1	12.000	12.219	0.219	13.000	13.002	0.002
MEAN OBS		12.250			12.625	
NSE		0.87			0.88	
RMSE		0.34			0.17	
R^2		0.89			0.86	

The results show that the average simulated BOD_5 concentration is 12.7 mg/L, which is quite high. Additionally, BOD_5 concentrations are slightly higher during the dry season compared to the rainy season, indicating poor water quality in terms of BOD_5 concentration throughout both seasons. Furthermore, the beginning of the lake exhibits lower BOD_5 concentrations compared to the end, where the flow velocity reaches zero. The BOD_5 values on the left bank are higher than on the right, with some locations on the left side reaching 15 mg/L. Overall, BOD_5 concentrations classify the water as relatively polluted (B1 class) during both the dry and rainy seasons, indicating poor water quality persisting throughout the year, particularly heightened during the dry season. The DELWAQ model simulated BOD_5 in the rainy season achieved a NSE of 0.87, demonstrating its success, and efficiency in simulating the BOD_5 parameter. Additionally, the RMSE is 0.34, indicating that the model's predictions are close to reality due to the relatively low RMSE value. In dry season, the modelling still attained an NSE of 0.88, indicating high effectiveness and durability. Moreover, the RMSE for May 2023 is 0.17, which is lower than in October 2022, suggesting that the model's results are even closer to reality as the RMSE value approaches zero (Table 6).

4. Conclusion

The assessment of water quality in BBT Lake included measuring DO and BOD_5 concentrations during both rainy and dry seasons. The average observed DO value in the surface water during the rainy season is higher at 5.42 mg/L compared to 4.82 mg/L in the dry season. In both rainy and dry seasons, BOD_5 values fluctuate around 12 mg/L, with a slight increase observed in the dry season, but not significantly. Generally, BOD_5 concentrations classify the water in the B1 class according to national technical regulations on surface water quality (6 mg/L < BOD <= 15 mg/L), this indicates that the water can only be used for irrigation or other uses with similar water quality requirements; or uses as type B2 (transportation, BOD value <= 25 mg/L). These findings highlight organic pollution in BBT Lake, affecting its water quality. Therefore, the water quality cannot be met for domestic water supply purposes (BOD <= 4 mg/L), and for domestic water supply purposes but must apply appropriate treatment technology (BOD <= 6 mg/L).

The results of the Delft3D-FLOW model show the water level that aligns with closely with measured data, with the velocity near the end of the lake approaching zero. The water level model achieved an NSE of 0.93 and an RMSE of 0.17, demonstrating its reliability, effectiveness, and close approximation to reality. For DELWAQ in terms of DO and BOD_5 parameters, DO value simulation has an NSE of 0.74 with an RMSE of 0.09 during the rainy season, and during the dry season, the NSE is 0.86 with an RMSE of 0.10. In summary, the simulation in both seasons is effective, highly durable, and close to reality, particularly during the rainy season. Regarding BOD_5 concentration, the model achieved an NSE of 0.87 with an RMSE of 0.34 in the rainy season, and an NSE of 0.88 with an RMSE of 0.17 in the dry season. The results show that the model is reliable, and highly durable when simulating BOD_5 concentration in BBT lake close to reality.

This study has shown that using the DELWAQ model to evaluate the water quality of BBT Lake is completely appropriate. However, further research is necessary to enhance the model's capabilities, including increasing the number of sampling locations, enhancing sampling frequency, and simulating additional water quality parameters. These efforts are crucial for effectively supporting lake water quality management. Finally, Bung Binh Thien Lake has been facing organic pollution due to household wastewater, agricultural activities, and the development of ecotourism services by the local community. Specifically, improperly treated or untreated sewage from local households can contribute significantly to organic pollution in the lake. Agricultural runoff may contain fertilizers, pesticides, and other organic materials which lead to increased nutrients and pollution. Ecotourism services disturb habitat, increase waste generation, and organic pollutants to the lake.

This type of pollution is common in areas with inadequate waste management, leading to the accumulation of organic matter in water bodies. Addressing these issues typically involves improving wastewater treatment, implementing sustainable agricultural practices, and managing tourism activities to minimize their environmental impact.

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