

Simulation of wastewater dispersion of recycling scrap paper from Muc Son Paper factory to the downstream Chu river

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Abstract

This research simulates and forecasts the area as well as the level of pollution dispersion of Muc Son Paper Factory's wastewater to the downstream of Chu River under two scenarios: Scenario 1 - wastewater treatment system is broken; treatment efficiency is equal to 0; Scenario 2 - wastewater treatment system is working with its designed capacity. The applied results of the MIKE 11 model show that: the impacted area from the plant's discharge is 0.2 km upstream and 2 km downstream of the confluence point. The simulation results under Scenario 1 show TSS, BOD₅ and COD contents being 18.3–35.7 mg/L, 8.3–17.2 mg/L and 12.2–23.7 mg/L, respectively, negatively affect the water environment downstream of Chu river. The results are then compared with measured data to confirm the reliability of the model. This research is a scientific and practical basis for the Muc Son Paper factory to operate the wastewater treatment system and manage the water quality output to ensure environmental regulations.

Keywords: Wastewater, pollution, paper factory and Chu river.

INTRODUCTION

Muc Son Paper Factory, which belongs to Muc Son Paper Joint Stock Company, has been operating since 1970. It is located downstream of Chu river, zone 3, Lam Son town, Tho Xuan district, Thanh Hoa province (figure 1). After

multiple times of improving production technology and adjusting product mix, the factory is currently being operated with a capacity of 41,000 tons/year and is expected to increase to 120,000 tons/year between 2021–2022.



Figure 1. Location of Muc Son Paper factory

Recycling scrap paper is a production type of Muc Son paper factory that poses a risk of causing environmental pollution (specified in Appendix IIa, Decree No. 40/2019/ND-CP, May 13th, 2019). About 85–90% of input materials are imported scrap paper while the rest are from domestic scrap paper. After impurities (plastic, nails, staples, soil, sand, etc.) are removed, scrap paper is transferred to the pulp preparation stage. The pulp is automatically mixed with additives and chemicals according to a specific ratio, and transferred to the papermaking stage, forming the output products of kraft paper, glued corrugated paper, and wallpaper.

After wastewater is discharged to the river water flow, pollutants will be diffused and dispersed by waves and wind. Therefore, the dynamics process plays an essential role in distributing, transmitting, and diluting wastewater from the plant. While many

techniques and models can be applied to assess pollution levels, the modeling method remains as the most popular in forecasting as waste sources are yet to be formed. Many models that have been used: WASP7, AQUATOX, QUAL2K (or Q2K), DELFT 3D, MIKE,... Each model has advantages and disadvantages; however, there have not been any evaluations or comparisons about the applicability to date.

MIKE model, which was mainly used in flow dynamics [1, 2], oil spills, dam breaks [3, 4], has been bringing positive effects to hydrological research. In the field of environment, several papers presented turbidity, salinity intrusion, heat, and load capacity assessment of river basins [5, 6]; those that applied the MIKE model for calculating the possibility of pollutant transmission for a specific discharge source or simulating an incident case has also existed, but with a limited number. One of the causes was due to

the small simulation range and lack of input data source.

Scrap recycling is an industry that poses a risk of environmental pollution due to the generation of large amounts of wastewater, high concentrations of pollutants, and complex treatment by physical-chemical methods [7]. According to calculated data, the amount of wastewater discharged into the Chu River, after increasing the capacity, is about 765 m³/day. Therefore, this research selects the MIKE model to simulate two scenarios: (1) Wastewater treatment system (WWTS) is broken, and wastewater is untreated, treatment efficiency is equal to 0; (2) Wastewater treatment system is stably operated, the treatment efficiency is suitable with the designed capacity.

According to the water resource planning of Thanh Hoa province, the Chu river is the water supply source for irrigation, industry, aquaculture and domestic water. In recent years, many articles and magazines have continuously mentioned the polluted river water [8–10]. The results of this study are the scientific and practical basis for Muc Son Paper Factory to operate a wastewater treatment system and manage output water quality. In addition, simulation results under different scenarios will support decision-makers to consider increasing plant capacity. Still, they will also lay a foundation for management agencies to determine the areas that suffered from water pollution in the lower Chu River if the wastewater treatment system encounters issues. More notably, this study will contribute to the scientific basis to explain whether or not the water pollution of the Chu river is caused by industrial activities, which will eventually reduce conflicts in the use of water resources for socio-economic development in this area.

METHODOLOGY AND INPUT DATA

Out of methods to approach a problem in the environment - hydrology, this research chose to apply the integrated approach. Based on the analysis of wastewater treatment technology, the technology of paper production

from scrap paper, the provisions of the law on environmental protection, this research builds typical scenarios for the operation of the wastewater treatment system. Simulation models are chosen using different data sources on Chu river's hydrological conditions and natural and socio-economic conditions.

In this research, MIKE 11 software was selected to be the hydrodynamic model to simulate pollution transmission in river basins with the following modules: Hydraulic (HD), diffuse load (AD), and water quality (Ecolab). HD is the core of MIKE 11 that forms the foundation for most other modules. In the calculation (1-dimensional), the water quality processes are related to the biochemical reactions. There is also the influence of the hydro-hydraulic processes of the flow. Therefore, to solve the quality problem simultaneously, this research uses both AD and Ecolab modules. Ecolab in MIKE 11 model can address the water quality aspect of the Cam river in areas affected by the operation of the Muc Son Paper Mill. The AD module to solve the quality variances of compounds in the river, while the load-diffusion (AD) module is used to simulate the diffusion transmission process of those compounds.

Input data for the model includes hydrological and hydraulic data at Bai Thuong station, which is the closest hydrological station to the plant (about 4 km away). More specifically, discharge of Chu river at Bai Thuong station is of 91 m³/s (minimum month discharge); water temperature is around 22–23°C (average temperature of 3 years from 2018 to 2020) with Northwest - Southeast flow direction; some other data of rainfall, wind, waves,... are also used from the series of statistics in the last three years (2018–2020).

Due to the lack of detailed measurement conditions, topography and depth data are using research results from Nguyen Thu Huyen's research on changes in the river bed of Chu river and baseline data from the Vietnam Disaster Management Project of the Ministry of Agriculture and Rural Development [8, 9].

Water quality data of the Chu river are gathered according to the average data of water quality monitoring sessions, four times in 2020 (table 1) at the confluence point of wastewater from the plant (19°54'31.6"; 105°24'13.5"). The results are issued by Thanh Hoa Center for Environmental Monitoring and Protection through the monitoring contract with the Muc Son Paper Factory.

Selected parameters include TSS, COD, BOD₅. The monitoring results of the

wastewater quality before treatment at the existing plant (before its capacity increases) show the concentrations of these parameters exceed the allowable limits of QCVN 12-MT:2015/BTNMT and QCVN 40:2011/BTNMT. For other parameters such as NH₄⁺, total N, the total P in untreated wastewater has low values within the allowable limits. Therefore, the three parameters of TSS, COD, and BOD₅ are selected to evaluate the pollution spread of wastewater discharge.

Table 1. Results of monitoring the water quality of Chu river in 2020

Parameter	Results of monitoring				Average	QCVN 08-MT:2015/BTNMT
	Quater I	Quater II	Quater III	Quater IV		
BOD ₅	15.6	15.2	13.5	14.9	14.8	15
COD	30.7	28.2	27.4	31.0	29.3	30
TSS	51.5	50	48.8	49.2	49.8	50

[Source: Thanh Hoa Center for Environmental Monitoring and Protection].

There were some incidents related to wastewater treatment systems such as pump failure, clogged pipeline system, the cracked tank, which affected the treatment efficiency during the actual operation at the plant since the 1970s. However, because these were small incidents, it does not significantly affect the output water quality requirements.

On that basis, this research selects 2 scenarios: (1) Wastewater treatment system is inefficient or inactive, and the wastewater has not been treated up to the standards. Treatment efficiency is zero, corresponding to the pollutant content of untreated wastewater showed table 1; (2) Wastewater treatment system operates effectively, treated

wastewater meets QCVN 12-MT:2015/BTNMT (column B1, $Kq = 1.0$; $Kf = 1.1$) and QCVN 40:2011/BTNMT (column B, $Kq = 1.0$; $Kf = 1.0$), assuming to be equal to the allowable limit of 2 standards. Data on wastewater concentration under each scenario is shown in table 2.

As mentioned above, one characteristic of scrap paper recycling is the high pollutant content. Therefore, the simulation area scale is mainly based on water quality and discharge of wastewater. The boundary conditions are selected as follows: The starting point is about 1 km upstream from Khe Muc and Chu river; the endpoint is about 5 km downstream from the joint point of Khe Muc and Chu river.

Table 2. Concentrations of pollutants in wastewater before and after treatment scenarios

Scenario	Characteristic	COD (mg/L)	BOD ₅ (mg/L)	TSS (mg/L)	Discharge of wastewater (m ³ /day)
Scenario 1	Wastewater after treatment	1,512*	760*	328*	764.1
Scenario 2	Wastewater before treatment (after flotation)	12.7*	8,0*	68.2*	764.1

Note: (*): The highest concentration in wastewater before treatment of the existing Paper Factory in the operating period from March 2019 to February 2020 (Source: Thanh Hoa Center for Environmental Monitoring and Protection).

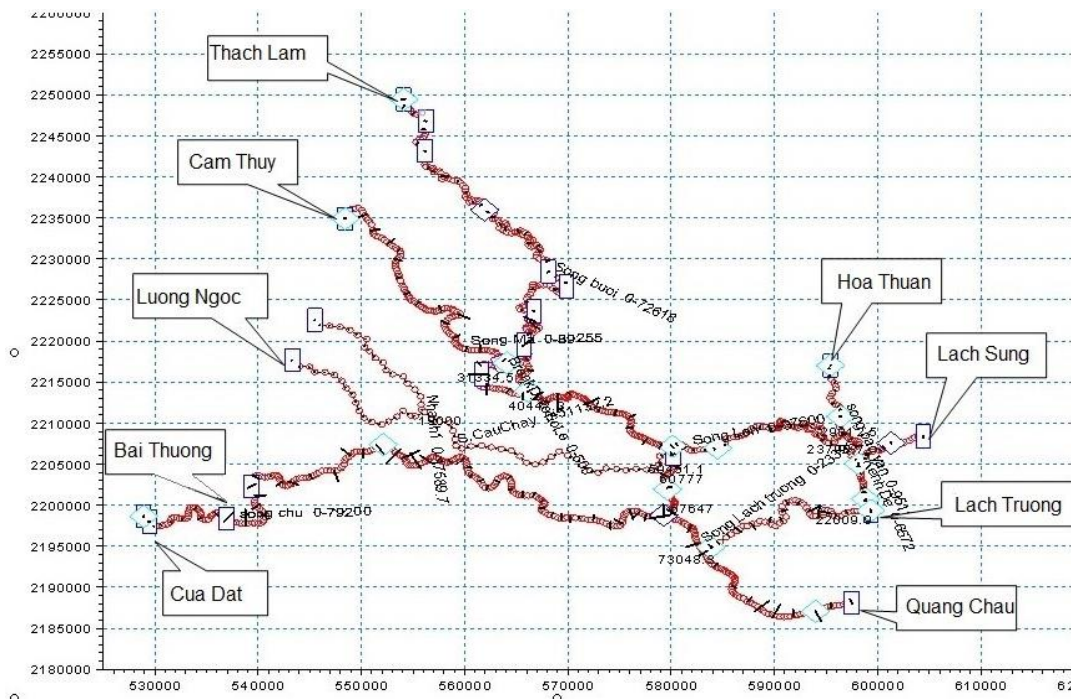


Figure 2. Hydraulic diagram of the study area

RESULTS AND DISCUSSION

Calibration and Validation

The existing Muc Son Paper Factory is operating stably with a capacity of 41,000 tons/year. Therefore, this research uses actual measured data to calibrate and validate the model. The Nash–Sutcliffe model efficiency coefficient [10] is used in this research to assess the accuracy of hydrological models. It is defined as:

$$R^2 = \frac{\sum_1^N (H_i - \bar{H})^2 - \sum_1^N (H_i - H_{ci})^2}{\sum_1^N (H_i - \bar{H})^2}$$

Where: H_i is the observed velocity (water level) at the time i ; \bar{H} is the mean of observed velocity (water level); H_{ci} is the calculated velocity (water level) at the time i ; N is the total number of calculated data.

The model is calibrated for the observed water level at Bai Thuong hydrological station for the winter and summer season periods of the year 2020. This hydrological station near

the project has a complete series of observed data in recent years. Nash coefficient is calculated at $R^2 = 0.84$ for calibration and $R^2 = 0.88$ for validation. Therefore, the calibration and validation both present relevant results; the obtained Nash index is satisfied. Thus, the parameters are suitable and can be used for simulation.

While comparing the results of running the model in the factory 2020 environmental monitoring report, it is shown that: At the discharge source point, the calculated BOD₅, COD, and TSS concentrations are within the range of monitoring data (BOD₅: 13.5–15.8 mg/L; COD: 25.5–31.4 mg/L; TSS: 48.7–52.8 mg/L). The calculated results are not significantly different from the actual measured results in two sampling locations of 0.2 km upstream and 0.6 km downstream from the confluence point.

Scenario 1: The wastewater treatment system is inefficient or inoperable, wastewater has not been treated up to standards

In the scenario of the inefficient or inactive wastewater treatment system, wastewater source will affect the upstream and downstream

of the Chu river (from the point of receiving wastewater from Khe Muc into the Chu river). The TSS concentration tends to increase about 18.3–35.7 mg/L at 1.0 km from the wastewater source in the Chu river. After 1.0 km from the

wastewater source, the TSS concentration decreases gradually and doesn't determine the variation at about 1.5 km. The TSS concentration reaches the maximum value in the distance from 0.2–0.6 km.

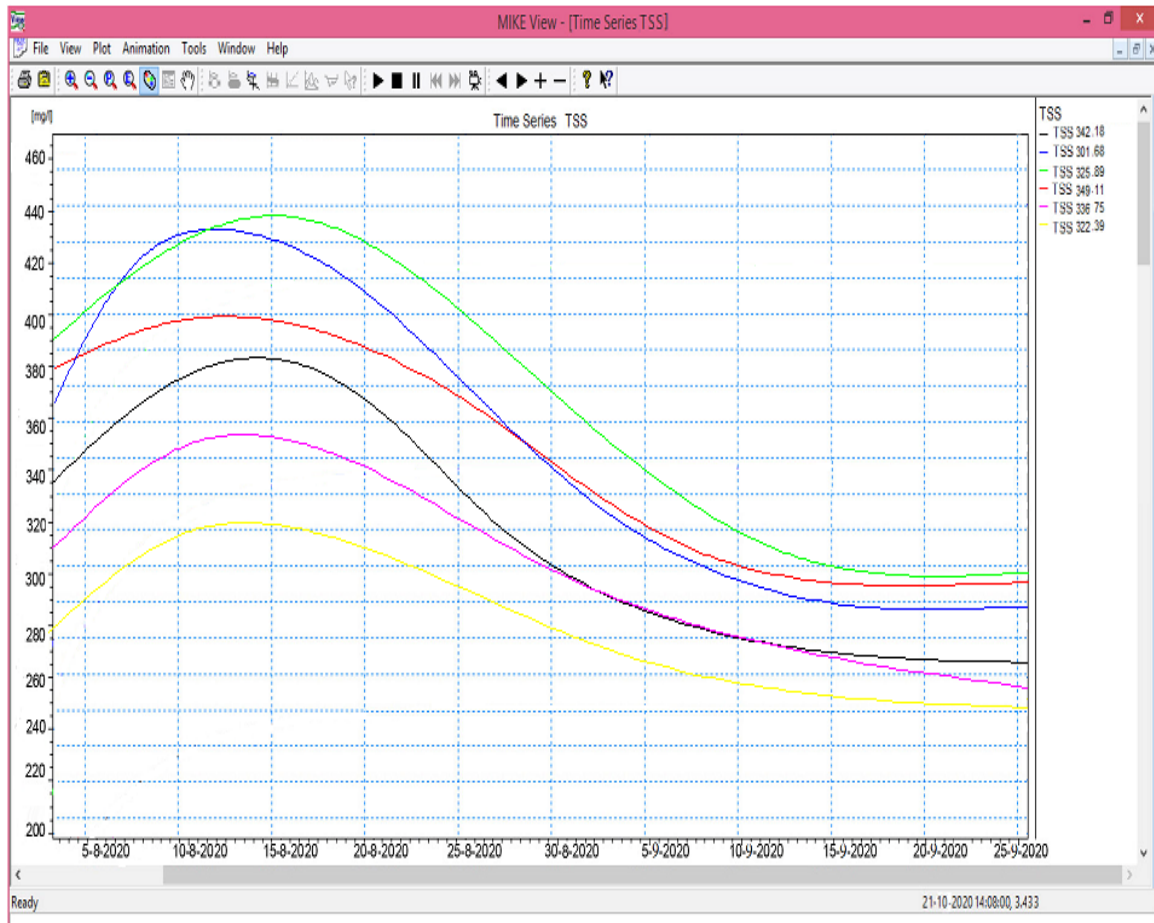


Figure 3. Simulation results of TSS concentration from the confluence point to the downstream (Scenario 1)

The BOD₅ concentration increases gradually in the distance of 1.0 km downstream. The increase is about 8.3–17.2 mg/L. After 1.5 km, the BOD₅ concentration decreases compared to the concentration of BOD₅ at the confluence point. The COD concentration reaches the maximum concentration at the distance of 1.0 km from the wastewater point to the downstream. The increase is about 12.2–23.7 mg/L. After that, it decreases gradually until the end of the calculated segment of Chu river.

The increasing/decreasing trend of pollution spread is explained as follows: after about 0.2 km from the wastewater point, the concentration of pollutants increases to reach the maximum level at about 0.6–1 km. The concentrations of contaminants TSS, COD, and BOD₅ also tend to grow at roughly 0.2 km from the confluence point to upstream. Apart from the distance of 0.2 km, the concentration of pollutants is almost unchanged. Due to the self-purification and dilution processes, the quality returned to the original value of about 1.5 km.

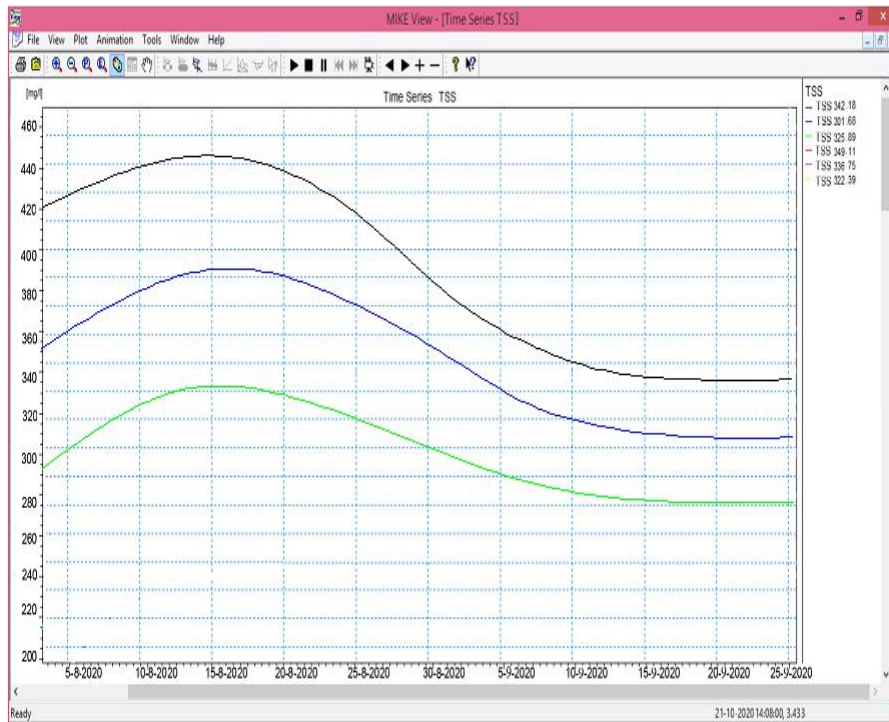


Figure 4. Simulation results of TSS concentration from the confluence point to the upstream (Scenario 1)

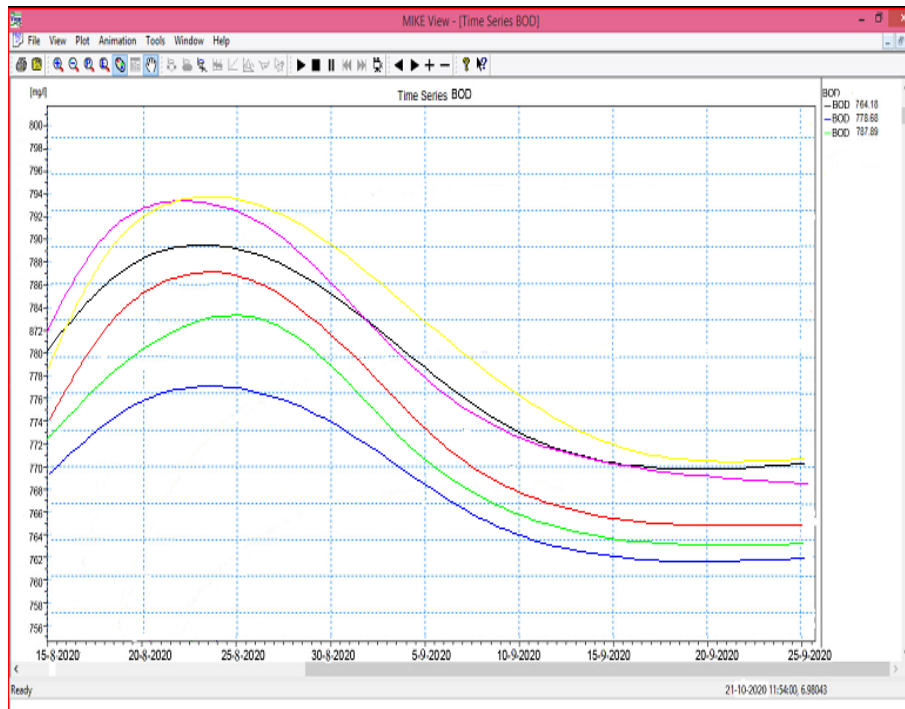


Figure 5. Simulation results of BOD₅ concentration from the confluence point to the downstream (Scenario 1)

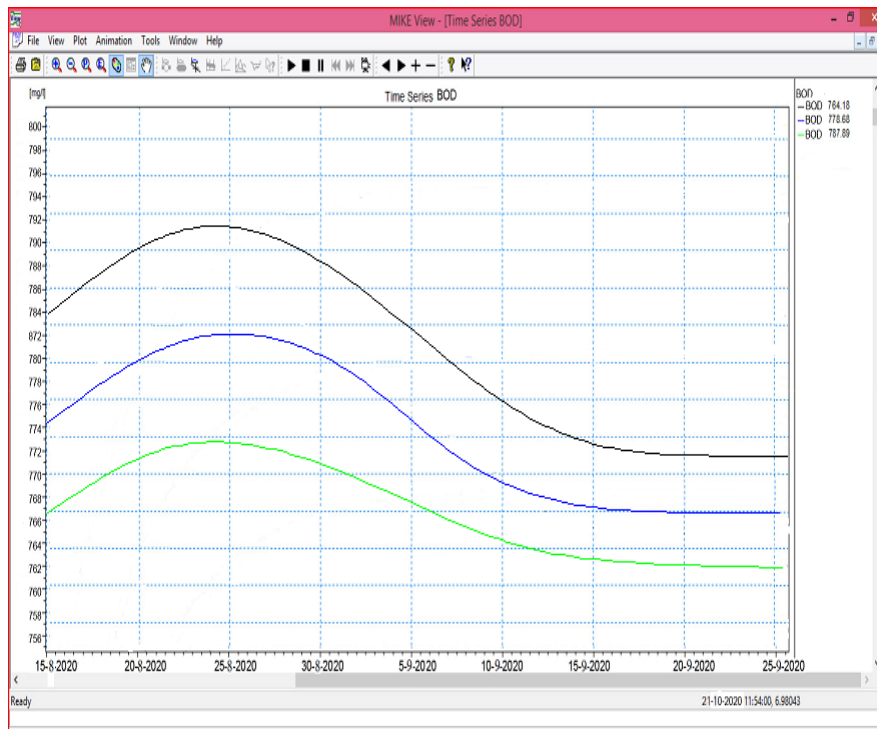


Figure 6. Simulation results of BOD₅ concentration from the the confluence point to the upstream (Scenario 1)

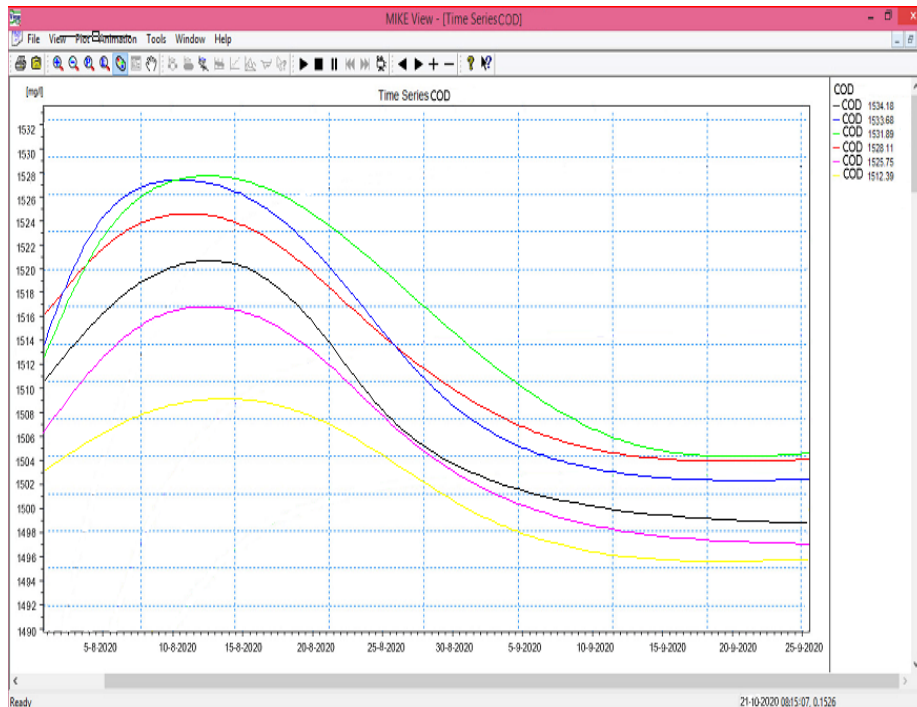


Figure 7. Simulation results of COD concentration from the confluence point to the downstream (Scenario 1)

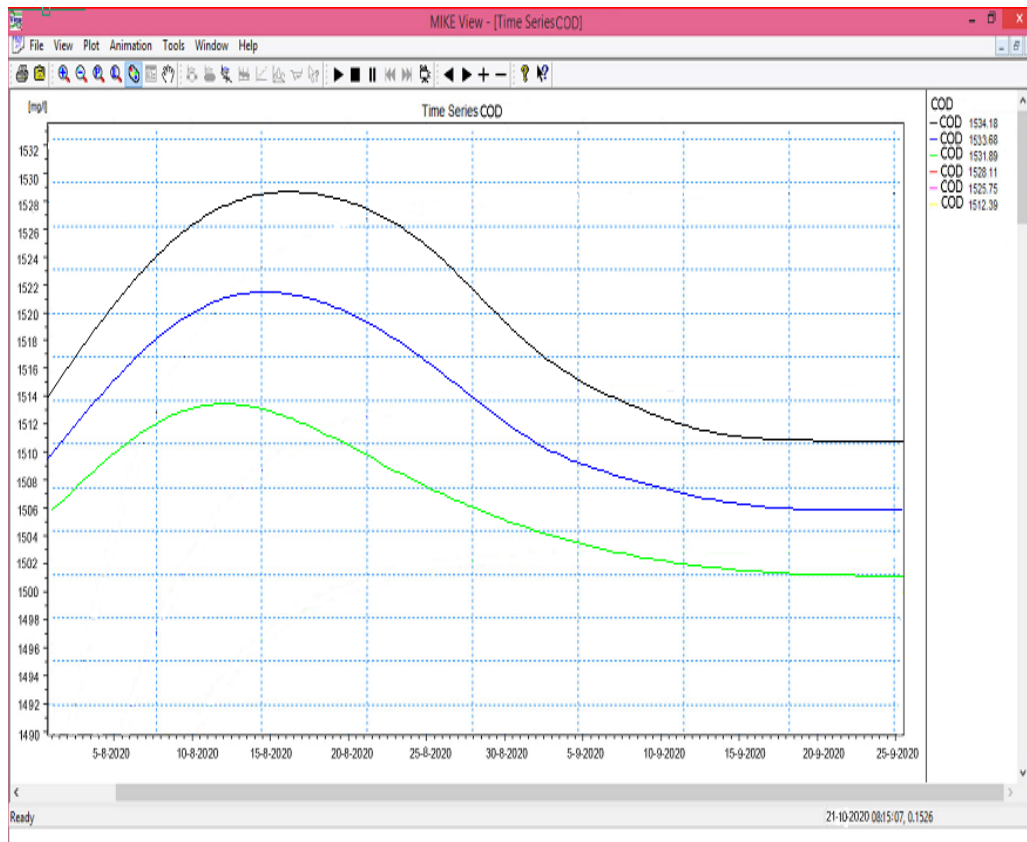


Figure 8. Simulation results of COD concentration from the confluence point to the upstream (Scenario 1)

According to the calculated results, the concentration of pollution parameters from Khe Muc into Chu river tends to increase because of other waste sources. Due to the wastewater of the Muc Son Paper Factory and other waste sources are the resonance effect of increasing the concentration of pollution parameters. Because of the self-purification and dilution of water in the Chu river, the concentration of pollutants is gradually reduced.

The concentrations of TSS, BOD₅ and COD both upstream and downstream exceed the allowable limit of QCVN 08-MT:2015/BTNMT (column B1: For irrigation or other purposes). Therefore, it will adversely affect the water environment of the Chu River and other purposes of irrigation and aquaculture in the distance of 0.2 km upstream and 1 km downstream from the waste source belonging Tho Xuong, Xuan Thien, and Phu Xuan communes, Tho Xuan district.

According to the results of Scenario 1, the water quality of the Chu river has high variation, mainly occurring within a distance of 1km downstream and 0.2 km upstream from the confluence point. After a distance of 1.5 km, river water quality is gradually stabilizing and less affected by wastewater from the Muc Son Paper Factory.

Scenario 2: The wastewater treatment system is complete, and wastewater is treated up to standards QCVN 12-MT:2015/BTNMT and QCVN 40:2011/BTNMT

In the scenario that wastewater is wholly treated to satisfy QCVN 12-MT:2015/BTNMT (column B1, $Kq = 1.0$; $Kf=1.1$) and QCVN 40:2011/BTNMT (column B, $Kq = 1.0$; $Kf = 1.0$) and does not affect the water quality of the river. The pollution parameters are selected below the threshold of column B1, QCVN 08-MT:2015/BTNMT.

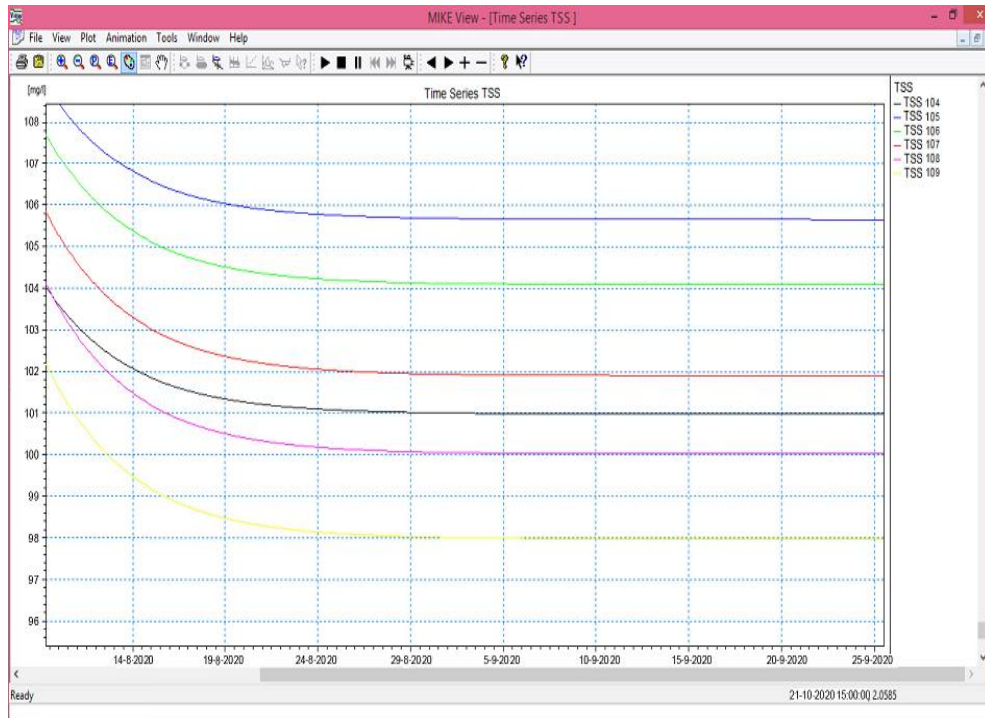


Figure 9. Simulation results of TSS concentration from the confluence point to the downstream (Scenario 2)

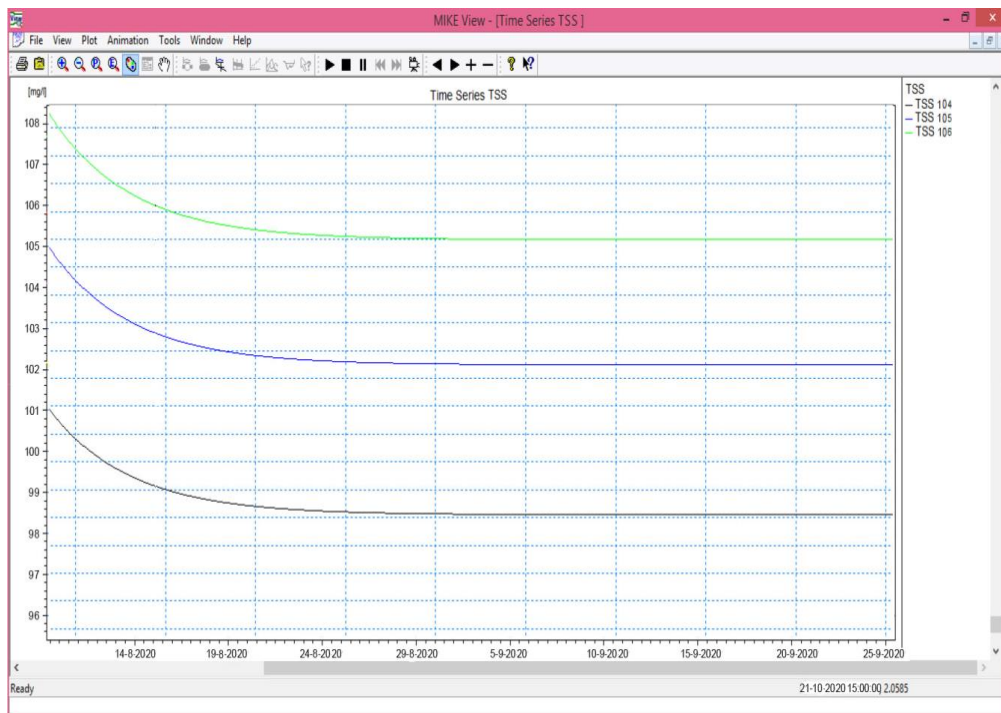


Figure 10. Simulation results of TSS concentration from the confluence point to the upstream (Scenario 2)

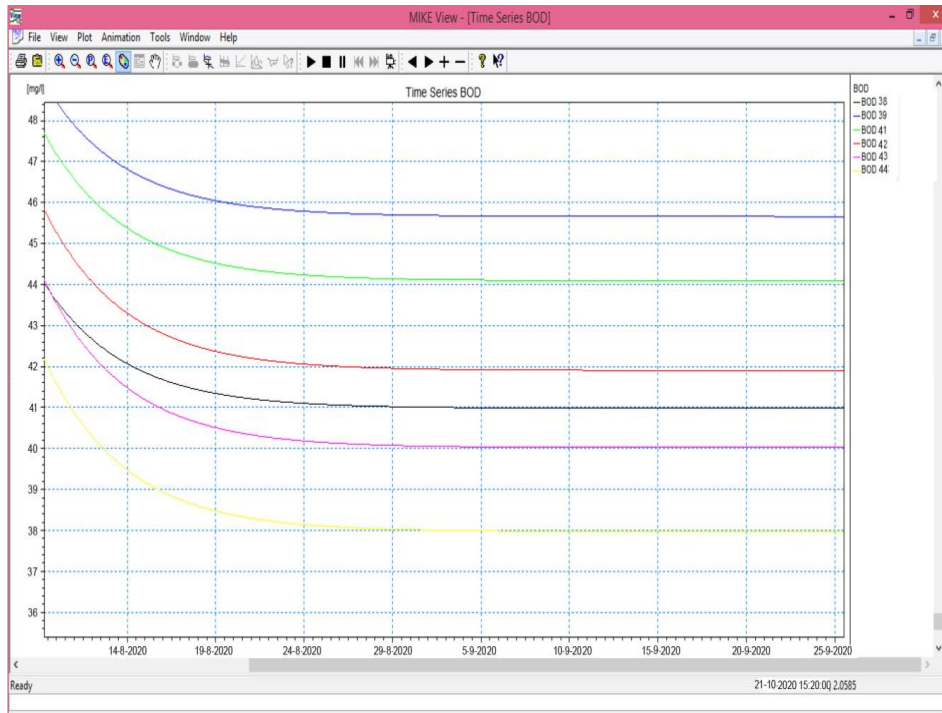


Figure 11. Simulation results of BOD₅ concentration from the confluence point to the downstream (Scenario 2)

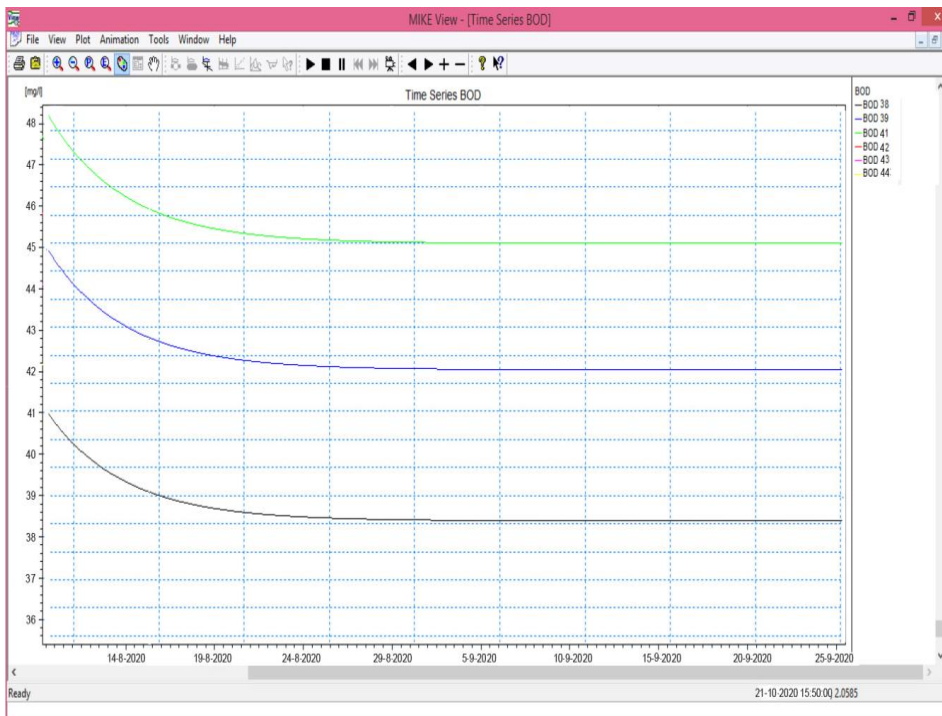


Figure 12. Simulation results of BOD₅ concentration from the confluence point to the upstream (Scenario 2)

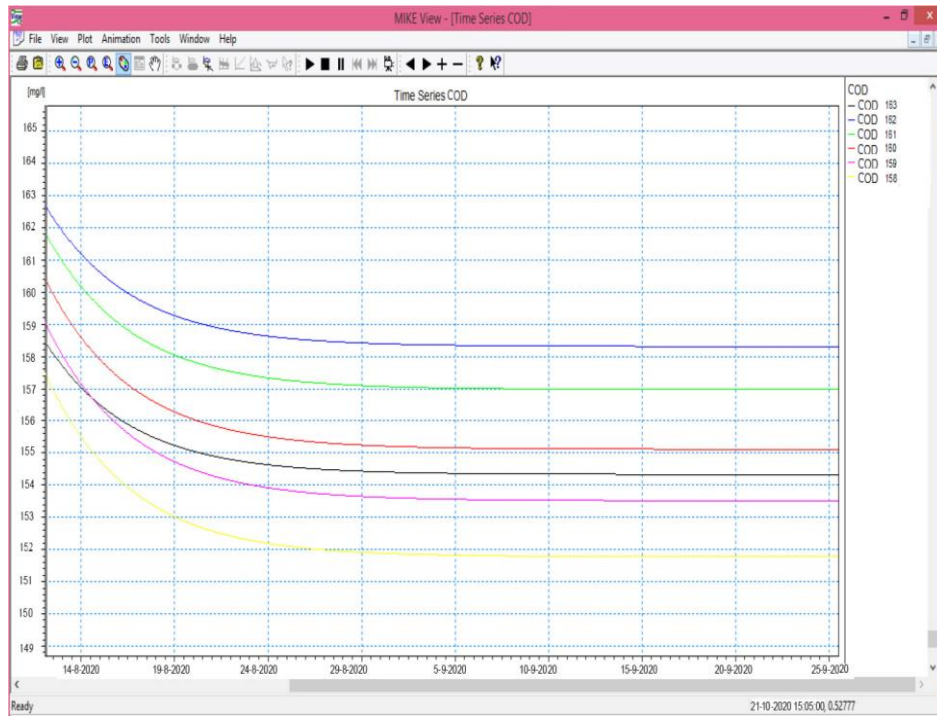


Figure 13. Simulation results of COD concentration from the confluence point to the downstream (Scenario 2)

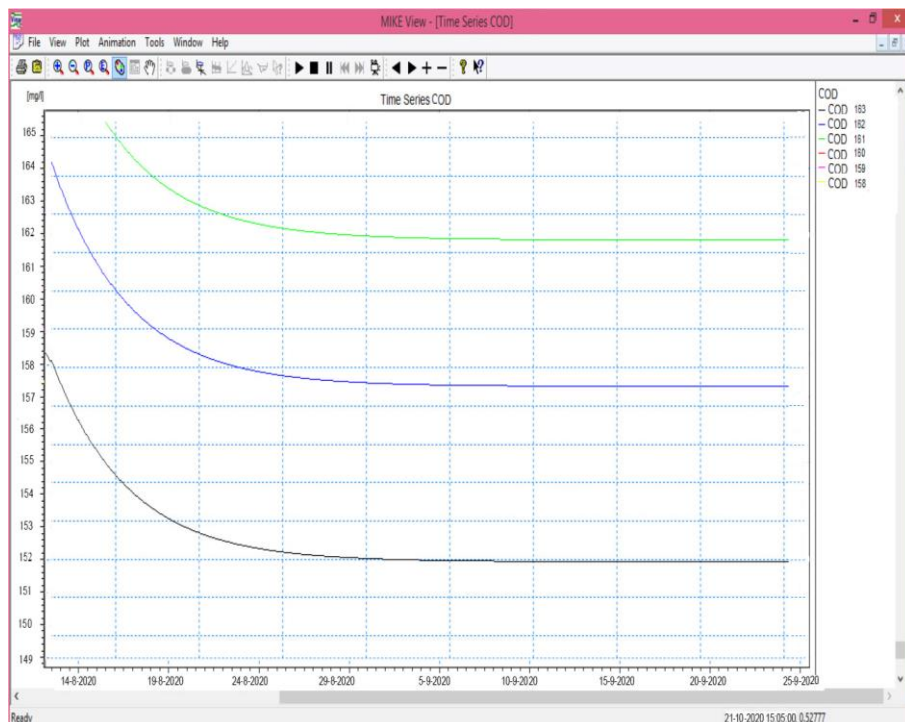


Figure 14. Simulation results of COD concentration from the confluence point to the upstream (Scenario 2)

Comparing the results of 2 scenarios with and without incident shows that: Scenario 1 - the concentration of pollutants discharged into the Chu river is higher than Scenario 2, the values of pollutant parameters exceed the allowable values of the column B1, QCVN 08-MT:2015/BTNMT, negatively affecting river water quality. Scenario 2 - the wastewater treatment system operates stably and achieves designed capacity, the water quality of the Chu river is not degraded. In both scenarios, the water quality of the Chu river changes within < 1 km. From 1.5 km or more, river water quality gradually stabilizes at about > 2 km.

The affected area in the case wastewater treatment system has efficiency equal to 0 is 0.2 km upstream and 2 km downstream. Agricultural irrigation and aquaculture activities of some communes along the Chu River, namely: Tho Xuong, Xuan Thien, Phu Xuan in Tho Xuan district, will be adversely affected accompanied by economic and environmental damage, lawsuits, political instability, and conflicts in water resources use.

This study used observed data for the year 2020. However, the rapid socio-economic development leading to an increase in industrial, aquaculture, and other domestic waste sources will negatively impact the Chu river's water quality in a negative direction without proper management. Therefore, research results and measurement data from enterprises and management agencies will be tools to protect water resources in the Chu river basin.

CONCLUSIONS

Muc Son Paper factory has been operating since 1970. After many improvements, the current capacity of the factory is 41,000 tons/year and in the future, it is expected to adjust to increasing the ability to 120,000 tons/year. In expanding the capacity three times, the total amount of wastewater discharged into the Chu river is about 765 m³/day. Using the modeling method that considers the level and extent of pollutant dispersion under two scenarios, this research show that MIKE 11 has satisfied the simulation.

According to the results of Scenario 1, the water quality of the Chu river has high variation, mainly occurring within a distance of 1 km downstream and 0.2 km upstream from the confluence point. After a distance of 1.5 km, river water quality gradually stabilizes and become less affected by wastewater from the Muc Son Paper factory. Wastewater discharged from Muc Son Paper factory does not affect the river water quality in Scenario 2. The selected pollution parameters included in the model are all below the threshold of column B1, QCVN 08-MT:2015/BTNMT.

The results of running the model in 2 scenarios are the basis for Muc Son Paper Factory to operate and manage the wastewater treatment system, build plans to prevent and respond to incidents, and prevent untreated wastewater into the environment. Simultaneously, the model results also identified the affected area of 0.2 km upstream and 2 km downstream of the confluence point. In this consideration, the main affected objects are irrigation and aquaculture activities in the communes Tho Xuong, Xuan Thien, Phu Xuan of Tho Xuan district. However, an adverse effect may occur if the wastewater treatment system encounters a failure.

The limitation of the research lies in the fact that it is not possible to calculate when other waste sources are entering the flow. More specifically, in the future, if a planned project within the area is implemented, restaurants and business establishments become more developed along with spontaneous migration, there will be an increase in the source of waste to Chu river. Within the scope of the research, we have not forecasted the development of these waste sources. The corporations with specialized agencies must assess the current state of surface water in time series or before and after the factory's operation to forecast the outcome. In addition, the research has not conducted a simulation of all the indicators of wastewater pollution from the paper recycling industry.

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