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Assessment of the Upstream Water Quality of a Narrow River using Numerical Modelling

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Abstract *— Water quality in Nhue River has been degraded to alarming level, which had some dead parts. Applying MIKE which is a modeling tool for upstream water quality assessment in Nhue River is feasible and reliable. The tool not only simulates results but also helps users assess scenarios and select suitable the scenarios for decision making. In the scenario 1, the water of Nhue River would be polluted more seriously than 2020 and later years because of untreated waste water and fast growth of population and socio-economy. Therefore, the scenario 1 is not suitable for future management planning. In the scenario 2, if 40% of waste stream was treated and the concentration of pollutant in the stream reduced as national regulation, the water quality in Nhue River would continue to decrease slowly but the concentration of pollutants in 2010 would not be slightly different to the figure for 2012. The scenario 2 could be applied in a short-term plan of improving water quality in Nhue River. In the scenario 3, if the waste stream was treated perfectly before discharging into the river, the water quality would improve significantly and no longer be heavy pollution which means that most parameters for water quality would lower than those in 08/2008 regulation. Therefore, the scenario 3 was an optimal scenario for decision makers in management levels.*

Keywords *— **water assessment tool; water quality; simulation; numerical modelling; river pollution.***

I. INTRODUCTION

The water in Nhue River from Red River at Lien Mac Drain in Tu Liem District, Hanoi and the end of down stream is confluence between Nhue River and Day River at Phu Ly, Ha Nam. The river runs through Cau Giay, Ha Dong, Thanh Tri, Hoai Duc, Thuong Tin, Thanh Oai, Phu Xuan and Phu Ly. It is 74 km long and 15 to 30 meters wide. The river plays a vital role in ecology, environment and water supply and drainage for Hanoi and near provinces.

The Nhue River has been polluted by waste water from agricultural, industrial, domestic and craft village activities and the pollution has impacted negatively seriously to local people's health living near the river. The concentration of Dissolved Oxygen (DO) in some parts of the river was very low so aquatic animals cannot live. In dry season, the river bed with a lot of rubbish appears in many places. [1]

There are several researches to examined water quality from the Nhue River as the heavy metal pollution (Kikuchi et al., 2009) [2], Pollution from Capital Urbanization (APEC) , Industrial Science and Technology Working Group, 2010 [3], Industrial Wastewater Management (World Bank. 2010) [4], the chemicalProperties (Nguyen et al., 2013) [5] but has not any research for modelling application at this area.

Based on this fact, there was an urgent need for water quality forecasting as a basis for overall environmental management and socio-economic development can be in harmony with river protection.

Thanks to the development of science and technology, there are more and more modeling tool used for simulation studies and water quality forecast. An undeniable advantage of using the model is cost savings, high efficiency, high accurate when study in a large areas such as the river basin.The one-dimensional model was used in this study because it is suitable for narrow rivers.

In the present study, we applied a modeling to classify and assess Nhue river water quality.

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II. METHODOLOGY

2.1. Method for water use and waste water calculation in Nhue River parts

The method for calculating water use and waste water in the research has 2 stages: [6], [7]

Stage 1: Collecting the data on pollution sources in river sections in 2015 for the simulation and validation of the MIKE11 model, this data is collected from documents and partly estimated by this method.

Stage 2: Forecasting the number of water demand and wastewater of each source by 2020 and 2025 by using this method based on data on population prediction and water demand and wastewater as different purposes. For example, the amount of waste water is 70% of that of water use for domestic purpose.

2.2. The method for water quality simulation by the model

The research uses the MIKE 11 to simulate the requirements of three modules: the HD hydraulic module, the AD-transmission module, the Ecolab - ecological module. Integrating these three modules can simulate water quality. [8], [9]

The scope of construction of one-dimensional hydrodynamic model is the all watershed of Nhue River from Lien Mac Drain to Hong Phu Bridge.

2.3. Simulating and testing Nhue River water quality by MIKE 11 model

The process of applying Mike 11 to calculate Nhue river water quality changes follows the below chart:[10]

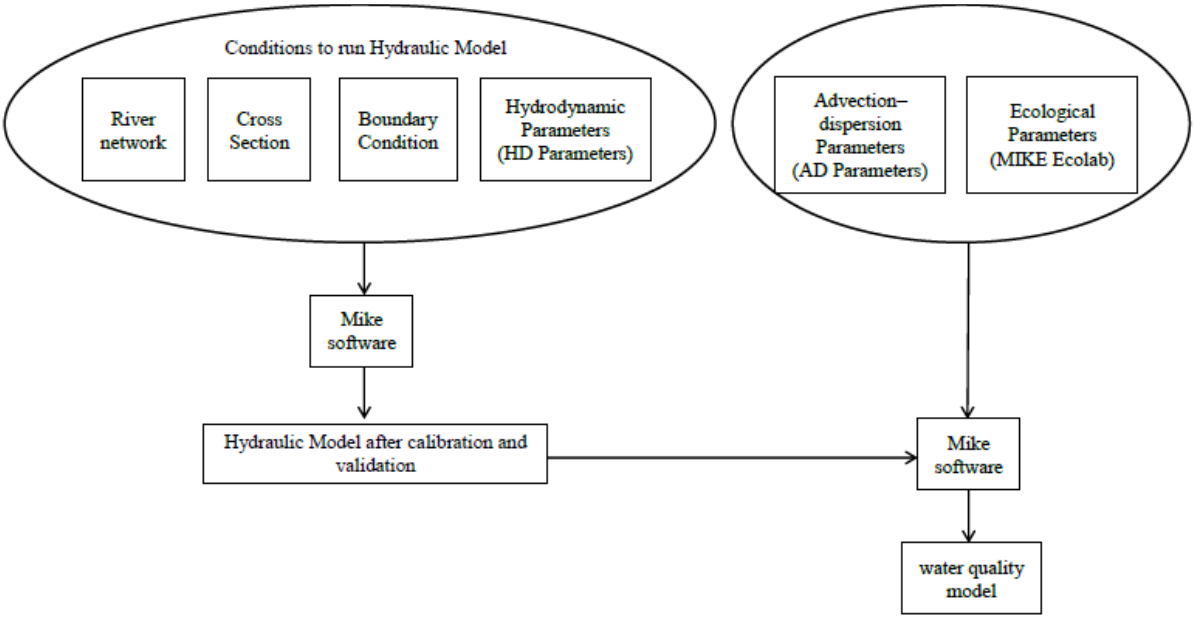

Fig.1: The principle of applying Mike 11 to calculate the changes of water quality

2.4. The method of data analysis and calculation

The report will calculate water quality for assessment after having the result of water quality simulation. In particular, the report calculates the water quality index (WQI) as Decision 879 / QD-TCMT on the issuance of handbook for calculating the water quality index. The predict data of nutrient will be compared with Vietnam National Technical Regulation on surface water quality (QCVN 08:2008/MONRE, means QCVN A2 and QCVN B1 in this report) to assess the water quality in the studied watershed area.

III. RESULTS AND DISCUSSION

3.1. Building hydraulic model for the system

- River cross-section

River cross section data was mainly provided by the Hydro-Meteorological Center measuring in the river from 2009 to 2014. The data on the sections were added to the model as a cross-sectional database. The sections was marked on left bank, right bank and the deepest point. The average distance between the two sections is 200 m (after being increased thick). The elevation of the terrain in the terrain document and the hydrological document is the same which is taken according to VN2000 standard.

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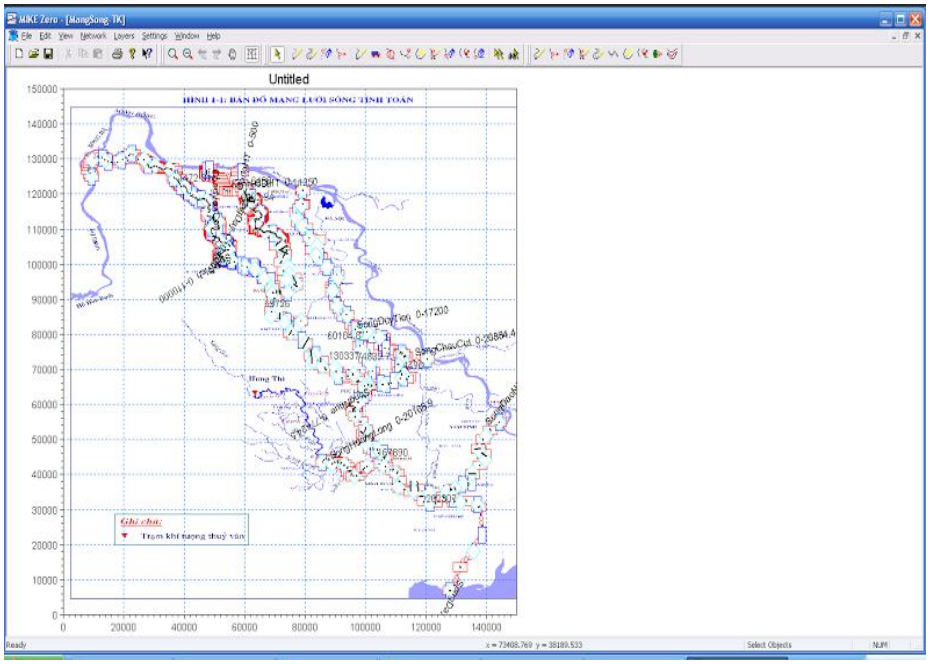

Fig.2: The locations of the cross sections in the river network

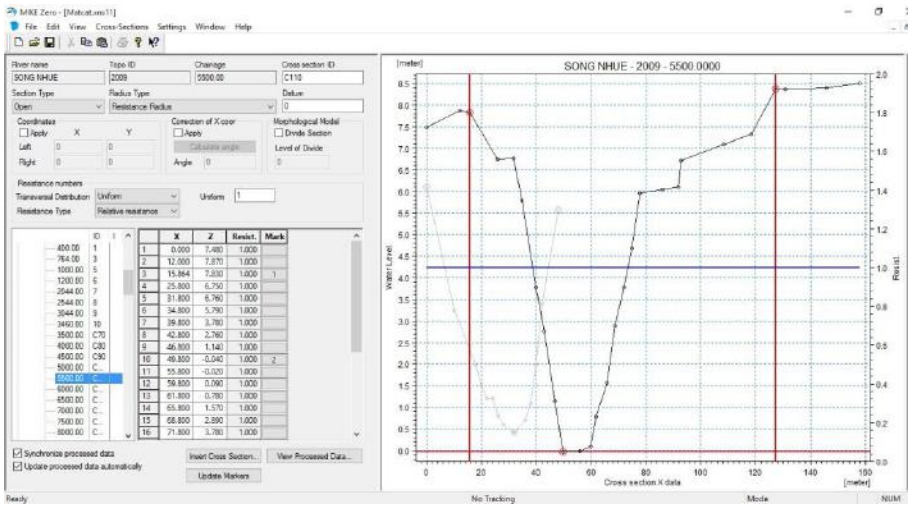

Fig.3: Cross section in Nhue River

3.2. Correcting and testing the hydraulic flow model

- Marginal conditions

There is not any monitoring system in Nhue River system therefore the report must use the upper and lower, the middle bound access indirectly. To ensure objectivity, the upper is the flow and the lower bound is the water level.

Because of insufficient the data collected from the Center for Hydrometeorology Data - Center for Hydrometeorology, the research simulated the flow and water level in Thuong Cat, Hanoi, Nhat Tan…at marginal conditions based on available water level data.

Input data for correcting and testing hydraulic models was from the National Hydrometeorology Center - Ministry of Natural Resources and Environment. Thus, the data are completely reliable and high accurate.

- The results of correcting and testing the hydraulic model

The result of hydrodynamic shows that the water level at comparative points correspond to the actual water level therefore the simulation results can be considered to be successful in building a hydrodynamic model for calculating the dry flow in a basin such as the Nhue River basin.

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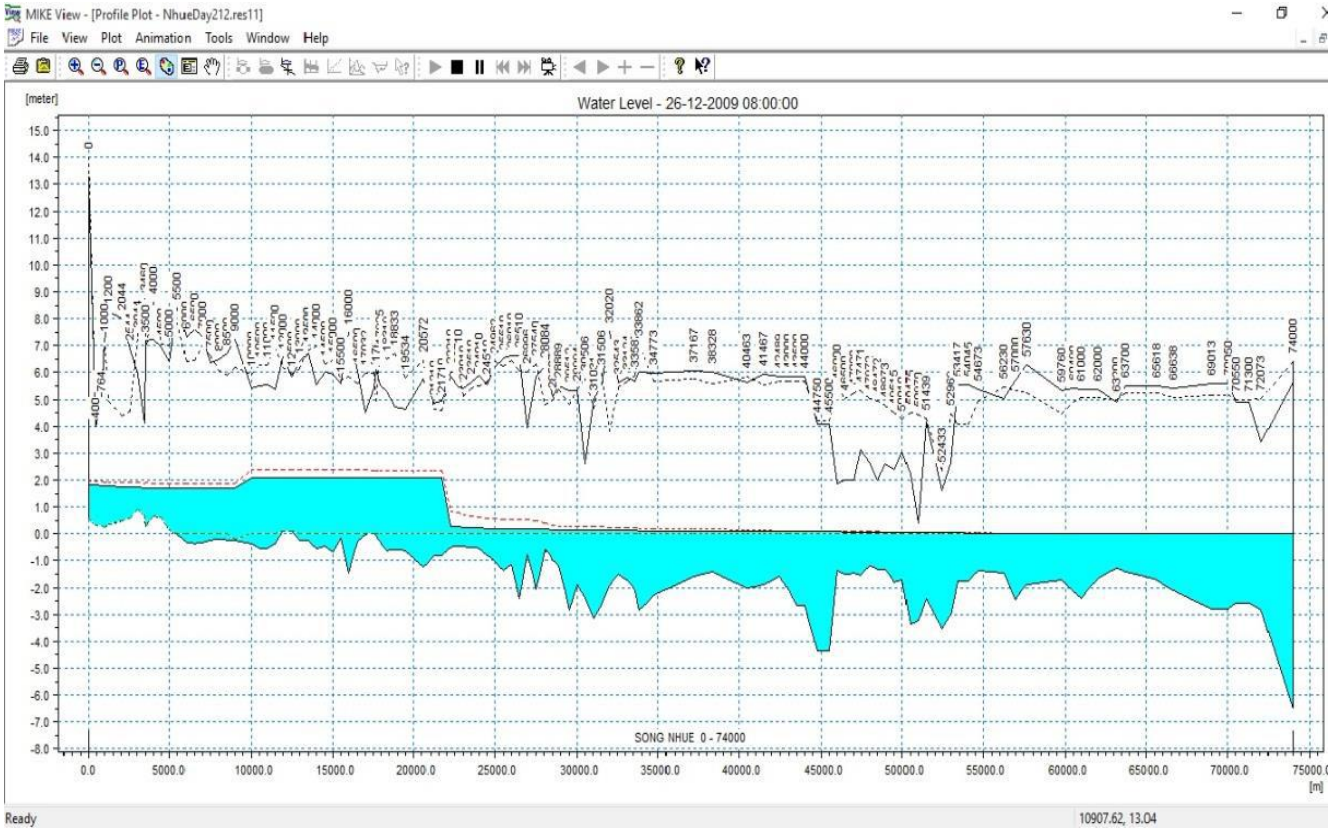
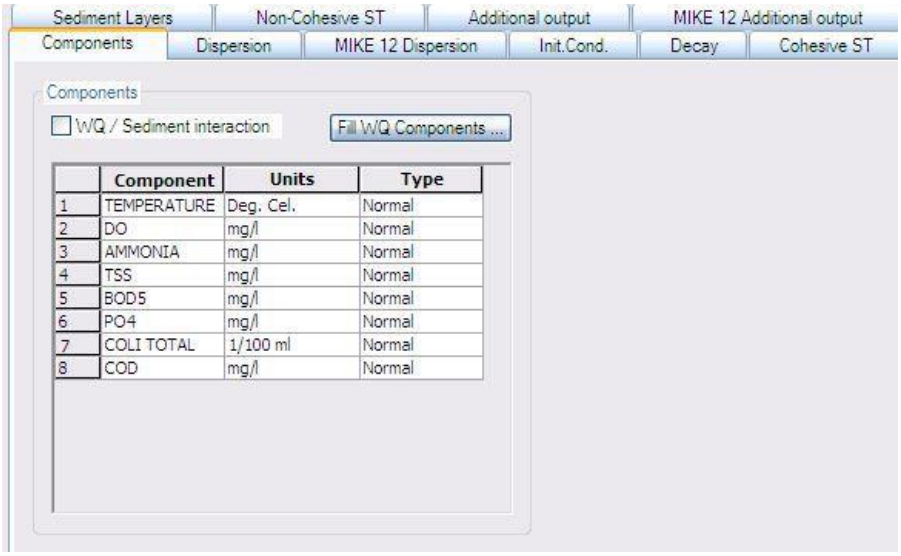


Fig.4: Hydraulic model of Nhue River basin

3.3. Setting up the water quality module

3.3.1. Setting the levels for water quality modules

Depending on the requirements of the formular and the measured water quality data, the model level can be set up with the following parameters:



	Component	Units	Type
1	TEMPERATURE	Deg. Cel.	Normal
2	DO	mg/l	Normal
3	AMMONIA	mg/l	Normal
4	TSS	mg/l	Normal
5	BOD5	mg/l	Normal
6	PO4	mg/l	Normal
7	COLI TOTAL	1/100 ml	Normal
8	COD	mg/l	Normal

Fig.5: Setting up the levels of water quality module

3.3.2. Water quality data analysis

To simplify the process of water quality calculation for the river system, there are three types of WQ water quality were simulated in the model:

- The upper and lower: Add water quality data to the HD (inflow or water level).

- Distributed source of each river section: waste discharge points, non-point source in each river section.

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- Point source: single discharge points with significant flow (large channels).

3.3.3. Set up parameters for AD

In the AD module, there are some important components need to be set up: Dispersion, Initial Condition and Decay.

+ Dispersion:

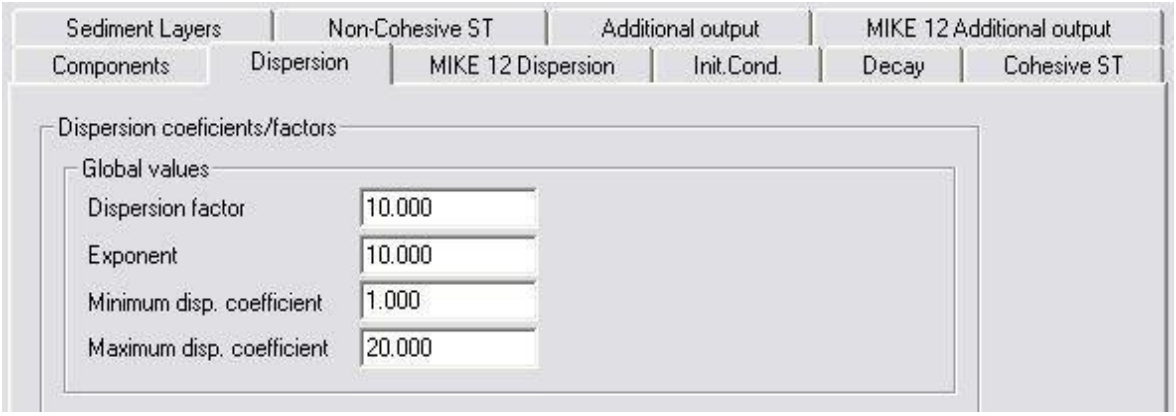

Fig.6: Dispersion value

Decay is also an important parameter demonstrating the decay of pollutants over time. However, for parametors of pollutants which are included in Mike Ecolab, the parametor should not set up in the AD Decay tab.

Based on the actual data of the water quality in Dong Nai - Sai Gon River from the Center for Environmental Monitoring in order to set initial water quality conditions for the model.

3.3.4. Set up parameters for Ecolab

The ecosystem module contains many complex parameters affecting biological processes in river water. The important parameters are set up as below figure:

Model definition | State variables | Constants | Forcings | Auxiliary variables

	Description	Unit	Value	Loca
1	Temperature: Latitude	Degrees	21	
2	Temperature: Maximum absorbed solar radiation	per day	5000	Edit
3	Temperature: Displacement of solar radiation max. fr	hours	1	
4	Temperature: Emitted heat radiation	per day	5000	Edit
5	Oxygen Processes: No. of reaeration expression	dimensionless	3	
6	Oxygen Processes: Reaeration temperature coefficie	dimensionless	1.03	Edit
7	Oxygen Processes: Respiration of animals and plants	per day	3	Edit
8	Oxygen Processes: Respiration temperature coefficie	dimensionless	1.05	Edit
9	Oxygen Processes: Max. oxygen production by phot	per day	2	Edit
10	Oxygen Processes: Production/respiration per m2 (=		1	
11	Degradation: 1. order decay rate at 20 deg. C	per day	0.5	Edit
12	Degradation: Temperature coefficient for decay rate	dimensionless	1.03	Edit
13	Degradation: Half-saturation oxygen concentration	mg/l	10	Edit
14	Oxygen Processes: Own #1 Reaeration constant	per day	2	
15	Oxygen Processes: Own #1 Exponent, flow velocity	dimensionless	0	
16	Oxygen Processes: Own #1 Exponent, water depth	dimensionless	0	
17	Oxygen Processes: Own #1 Exponent, river slope	dimensionless	0	
18	Oxygen Processes: Own #2 Reaeration constant	per day	1	
19	Oxygen Processes: Own #2 Exponent, flow velocity	dimensionless	0	
20	Oxygen Processes: Own #2 Exponent, flow velocity	dimensionless	0	
21	Oxygen Processes: Own #2 Exponent, river slope	dimensionless	0	
22	Oxygen Processes: Own #3 Reaeration constant	per day	1	
23	Oxygen Processes: Own #3 Exponent, flow velocity	dimensionless	0.29	
24	Oxygen Processes: Own #3 Exponent, flow velocity	dimensionless	0.29	
25	Oxygen Processes: Own #3 Exponent, river slope	dimensionless	0.29	

Fig.7: Set up parameters

The water quality model runs stable in 5 minute for calculating (for calibration) and 3 or 4 minutes for other calculating options.

The results of water quality simulations by the MIKE 11 model tend to match the trend of actual results from river measurements. Therefore, it is possible to use the

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simulation results for the assessment of water quality in the Nhue River.

3.4. The results of water quality simulation

The simulation of water quality in Nhue River basin aims to increase the quantity and quality of available monitoring points in order to increase the accuracy of water quality assessment in the Nhue river basin.

The quantity and quality of monitoring points in Nhue River as well as the accuracy increased as initial target by surface water quality simulation in the basin. In particular, the number of the actual monitoring points in the river basin was 5 increasing to 133 points after running the Mike 11.

Table 1. Initial monitoring data and interpolated data by MIKE

No	Points	Parameter									
		t°C	**pH**	**Turbidity**	**DO**	**COD**	**BOD_5**	**N-NH_4**	**P-PO_4**	**TSS**	**Coliform**
		°C		NTU	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	(MPN/100ml
1	**Lien Mac Drain**	**19.4**	**7.8**	**23.5**	**4.1**	**68.5**	**25**	**18.9**	**1.85**	**25.5**	**110,000**
2	Nhue River 200	20.1	7.5	23.6	4.1	68.9	26.7	29.41	1.87	25.3	103,00
30	Nhue River 6250	20.7	7.4	27.9	3.9	79.3	31.1	20.54	1.85	15.8	74,000
68	Nhue River 16000	20.6	7.6	32.3	1.6	88.5	36.4	24.42	2.2	15.2	30,200
69	**Phuc La**	**20.9**	**7.5**	**32.3**	**1.4**	**88.5**	**36.5**	**23.75**	**2.19**	**15**	**29,000**
70	Nhue River 16250	20.6	7.5	32.7	1.2	89.3	34.2	29.98	2.33	35.4	31,000
77	Nhue River 17669.7	21	7.6	37.1	1.4	98.2	39	28.25	2.25	41.3	54,000
85	Nhue River 19533.5	20.7	7.7	48.4	1.5	107.6	48	28.8	2.25	100.7	389,000
86	**Ro Bridge**	**20.5**	**7.5**	**48.5**	**1.2**	**119.5**	**48**	**28.55**	**2.66**	**101.5**	**1,100,000**
87	Nhue River 20052.8	20.7	7.7	38	1.4	118.2	46.4	28.75	2.65	91.3	1,150,000
92	Nhue River 21710	20.5	7.4	36.2	1.2	119.4	46.3	29.41	2.65	86.7	890,000
96	Nhue River 22710	21	7.6	33.5	1.4	118	48	29.98	2.65	80	1,005,000
97	**Cu Da**	**20.7**	**7.5**	**34**	**1.4**	**118**	**47.5**	**29.65**	**2.69**	**75.5**	**893,000**
98	Nhue River 22860	20.7	7.7	38	1.4	118.2	46.4	28.75	2.65	91.3	976,000
119	Nhue River 28084	20.5	7.4	27.9	2.1	84	34.2	20.54	1.96	17.9	1,029,000
132	Nhue River 33123.5	20.5	7.4	27.9	2.1	75.9	27.4	18.16	2	19	283,000
133	**Chiec Bride**	20.6	7.5	25	1.8	62	18.5	17.25	1.54	19	146,000

The bold is the initial data and the original is the interpolated data

After increasing the number of monitoring points, the WQI water quality index was calculated according to the Decision No. 879 / QD-TCMT on hand book for calculation of water quality index to assess water quality.

In this article, the research shows 5 points out of a total of 133 points to present the results including points in Lien Mac Drain, Phuc La, To Bridge, Cu Da and Chiec Bridge. Then the research compared the WQI to WQI rule to determine the water quality as the below table:

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Table 2. WQI results

No	Point	WQI										
		BOD_5	COD	$N\text{-}NH_4$	$P\text{-}PO_4$	Turbidity	TSS	Coliform	DO	PH	WQI	Colour
1	**Lien Mac Drain**	25	10.2	1	19.11	66.25	86.25	1	45.74	100	**12**	Red
2	Nhue River 200	23.37	9.88	1	19.02	66	86.75	1	46.28	100	**11**	Red
30	Nhue River 6250	19.14	1.56	1	19.11	54.2	100	1	44.87	100	**11**	Red
68	Nhue River 16000	14.06	1	1	17.58	48.56	100	1	1	100	**8**	Red
69	**Phuc La**	13.96	1	1	17.63	48.56	100	1	1	100	**8**	Red
70	Nhue River 16250	16.17	1	1	17.01	48.31	68.25	1	1	100	**7**	Red
77	Nhue River 17669.7	11.56	1	1	17.36	45.56	60.88	1	1	100	**7**	Red
85	Nhue River 19533.5	2.92	1	1	17.36	38.5	1	1	1	100	**5**	Red
86	**To Bridge**	2.92	1	1	15.57	38.44	1	1	1	100	**4**	Red
87	Nhue River 20052.8	4.46	1	1	15.62	45	29.35	1	1	100	**6**	Red
92	SONG NHUE 21710	4.55	1	1	15.62	46.13	31.65	1	1	100	**6**	Red
96	Nhue River 22710	2.92	1	1	15.62	47.81	35	1	1	100	**6**	Red
97	**Cu Da**	3.4	1	1	15.44	47.5	37.25	1	1	100	**6**	Red
98	Nhue River 22860	4.46	1	1	15.62	45	29.35	1	1	100	**6**	Red
119	Nhue River 28084	16.17	1	1	18.63	51.31	100	1	27.93	100	**10**	Red
132	Nhue River 33123.5	22.7	4.28	1	18.45	54.2	100	1	27.93	100	**10**	Red
133	**Chiec Bridge**	31.24	15.4	1	20.46	60	100	1	25.16	100	**11**	Red

The color for water quality was red (at class 5) and WQI is very low ranging from 9 to 12. It means that Nhue

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River water at the upstream (from Lien Mac Bridge to Chau Bridge) is heavily polluted so it is necessary to take measures to prevent pollution and improve water quality.

The results of WQI illustrate that the quality of river water decreased from Lien Mac Bridge to Cu Da and the closer central city is, the lower the quality of river water is. This is because the number of drainage from residential areas and industrial areas was high and the density of the population and companies were high as well.

The WQIs of the DO, NH_4^+-N, Coliform was very low (at 1) because of domestic wastewater accounting for 60% of total wastewater in the whole basin. The wastewater contains organic substances, nutrients, suspended particles and high bacteria which reduced 71% of water quality.

Next reason is waste water from industrial plants, factories and service places in Hanoi. There are a few big factories with waste water treatment systems and the most of factories discharged directly to the Nhue River or through the irrigation system. The Nhue River gets River about 400,000 m^3 of waste water every day from Lo, Clay, Taurus Rivers. The flow also affected by waste water from Van Dien cemetery, Van Dien industrial zone (phosphate plant, battery ...) and municipal landfill.

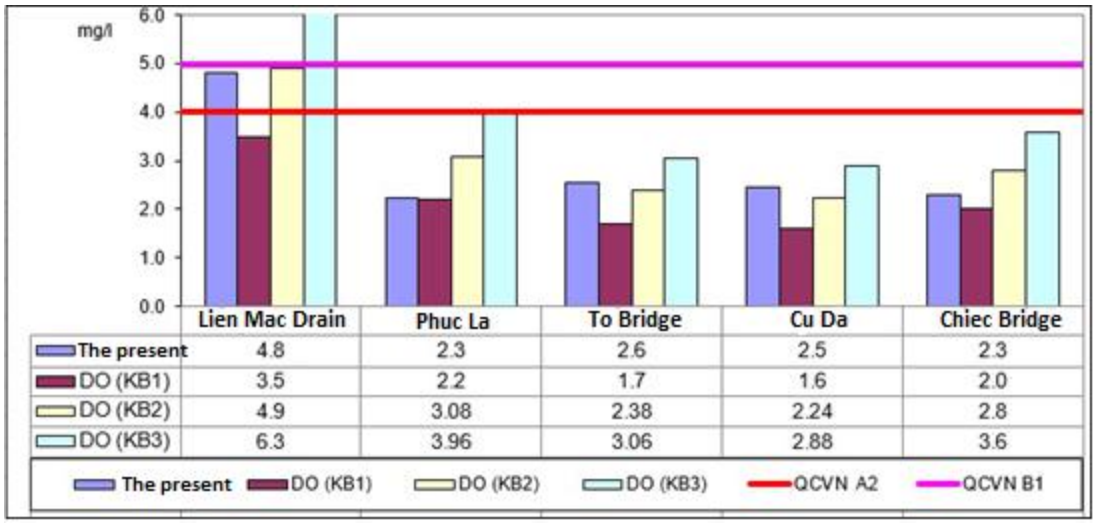
3.2. Forecasting the Nhue river water quality changes run through Hanoi by 2020

The study has retained the central component of the HD model according to the data on pollution in 2020 and replaces the WQ water quality by predicted data on pollution sources in 2020 then incorporated three modules to simulate results of pollution in 2020. There were 3 scenarios (no treating – KB1, treating 40% - KB2 and treating 80% - KB3 on the same chart) at the same time for each parameter, then evaluates the simulation result of 3 parameters respectively (DO, BOD, N-NH_4^+) in 2020, according to the following criteria:

- The lower the DO is, the lower the water quality is.
- The higher the BOD is, the lower water quality is.
- The higher the NH_4^+-Nis, the lower the water quality is.

The results of water quality prediction by MIKE 11 after changing the input data:

a/ The prediction for concentration of DO in Nhue River (from Lien Mac Drain to Chiec Bridge) by 2020:



	Lien Mac Drain	Phuc La	To Bridge	Cu Da	Chiec Bridge
The present	4.8	2.3	2.6	2.5	2.3
DO (KB1)	3.5	2.2	1.7	1.6	2.0
DO (KB2)	4.9	3.08	2.38	2.24	2.8
DO (KB3)	6.3	3.96	3.06	2.88	3.6

Fig.8: The prediction for concentration of DO by 2020

The concentration of DO in 2020 is predicted to be higher than the figure for observation time due to the fact that there are some measures have been implemented to prevent pollution and improve water quality. In 2020, the figures for To Bridge, Cu Da and Chiec Bridge were lowest. The concentration of DO in Lien Mac Drain is predicted to be a high. In the prediction for the three scenarios, it is clear that the scenario with 80% of the treated wastewater is forecasted to have best results. Therefore, this will be one of the optimal solutions to be applied in the future. However, the government should have a clear plan to treat waste water from 0% to 40% of total then increase the rate to 80% and over 80%.

b/ The prediction for concentration of BOD in Nhue River (from Lien Mac Drain to Chiec Bridge) by 2020:

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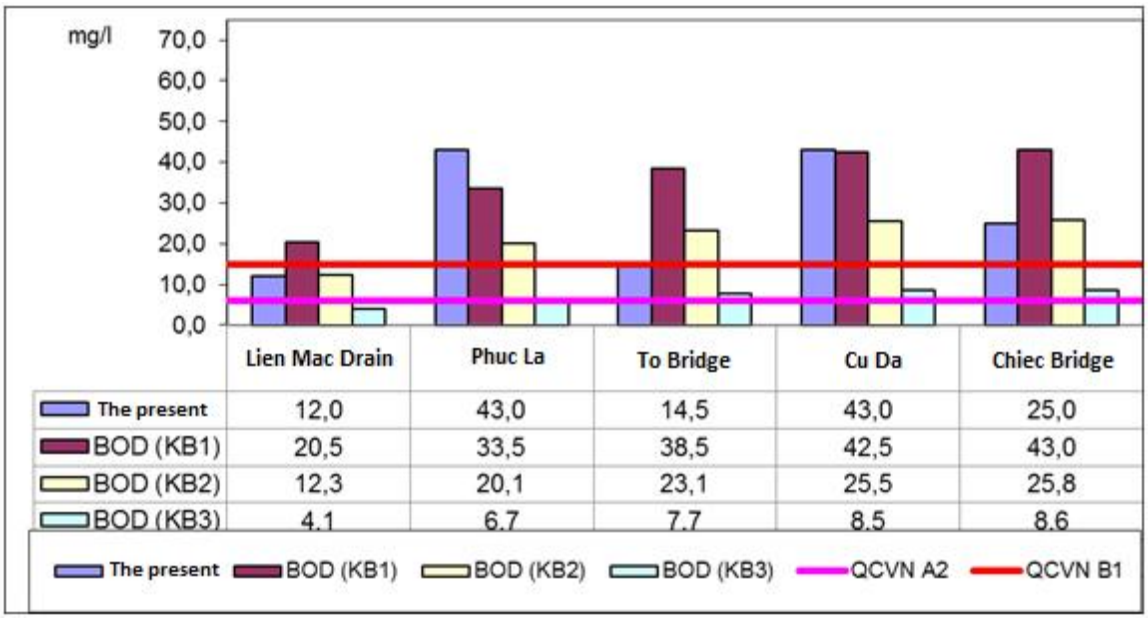

Fig.9: The prediction for concentration of BOD by 2020

The concentration of BOD in 2020 at Phuc La, To Bridge, Cu Da and Chiec Bridge were predicted to be exceeded the regulated figure for QCVN 08/2008. The figures also will be insignificant different from the figure for the observation time. To improve Nhue River water quality and avoid heavier pollution in the future, people should start actively treating the waste water before discharging.

c/ The prediction for concentration of NH_4^+-N in Nhue River (from Lien Mac Drain to Chiec Bridge) by 2020:

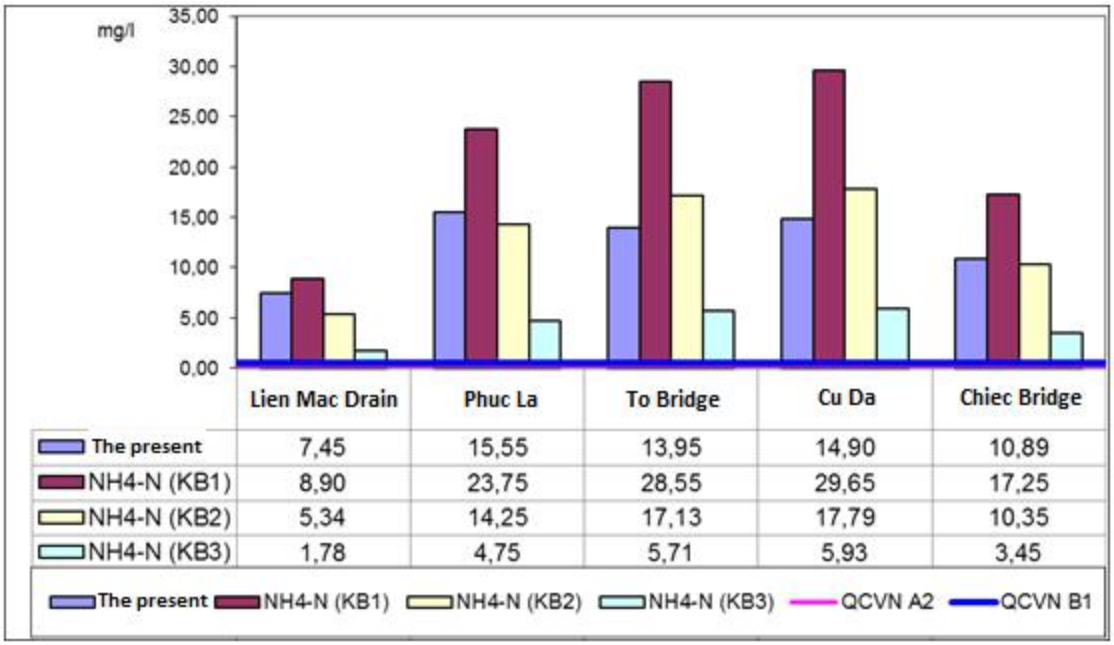

Fig.10: The prediction for concentration of NH_4^+-N by 2020

For or scenario 1, it is forecasted that the concentration of NH_4^+-N in 2020 will be higher than the figure for current status and much higher than that of QCVN. Moreover, the highest concentration will be in Phuc La, To Bridge, Cu Da and Chiec Bridge. If about 40% of total wastewater is treated, the concentration of NH_4^+-N will remain stable by 2020. If 80% of total wastewater is treated, the concentration of NH_4^+-N is predicted to be significantly increased by 2020, but it could be higher than the QCVN because there are many ammonium sources from the villages, animal husbandry, cultivation, etc.

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Overall, the quality of the Nhue River has been deteriorated for the scenario 1. For the scenario 2, 40% of waste streams were treated, Nhue River water quality will maintain the quality at the time of observation while for the scenario 3 with 80% of treated waste streams the quality of Nhue River will improve.

IV. CONCLUSTION

- The quality of the Nhue River has been being degraded at warming level with dead sections. The Nhue River is becoming a sewerage.

- Applying the MIKE to assess the upstream water quality of the Nhue River is entirely feasible and reliable. This toolkit not only provides simulation results, but also helps users evaluate and select suitable scenarios.

- For scenario 1, because of all untreated waste streams and the rapid development of population and the economy, the Nhue River water is predicted to be more and more seriously polluted by 2020 and later therefore it is not suitable for selecting scenario 1 for future management.

- For the scenario 2, 40% of waste stream is treated the quality of Nhue River will be degraded slowly. Therefore, scenario 2 could be used for short-term plan to improve the quality of Nhue River.

- For the scenario 3 with 80% of total waste stream is treated Nhue river quality is predicted to increase remarkably, and there will be not serious pollution. This will be the optimal scenario for decision maker at all level of management.

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