

Original Research Article

Water Quality Simulation and Dissolved Oxygen Change Scenarios in Lam Takhong River in Thailand

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ABSTRACT

Dissolved oxygen (DO) in Lam Takhong River gradually reaches zero value during the dry season on several occasions in the past decade causing the unsuitable quality for use as the raw water for Nakhon Ratchasima Town. Discharges of point sources and diffuse sources containing pollutants with organics and nutrients are the major cause of water quality deterioration in the river. To find the sources of impact on the water quality in the river, a one-dimensional steady-flow systems river water quality model, QUAL2Kw, was constructed and simulated. The model was calibrated and validated using the water quality data from 2008 to 2017 for the Lam Takhong River by seven monitoring stations. The modelling was applied to simulate various water quality parameters during the critical period to compare to the designated surface water quality criteria third class in Thailand (minimum dissolved oxygen at or above 4 mg/L; maximum biochemical oxygen demand (BOD), nitrate-nitrogen, and ammonia-nitrogen at or below 2.0, 5.0 and 0.5 mg/L, respectively). The study reach of the river flows 122 km from Lam Takhong Dam to the Mun River at Chaloe Phra Kiat district through the urban central area. Several segments of the river have been alarmed for many constituents with the dissolved oxygen impairment is the focus of the study. The scenarios of loads and upstream dissolved oxygen modification were conducted to assess the change of dissolved oxygen concentration. The result of the QUAL2Kw model showed that the decomposition of organic matter and a poor reaeration were the primary cause of the impairment. The local oxygenation causes fluctuations in dissolved oxygen levels along the river and the dissolved oxygen concentration decreases downstream of the river with some values fell the meet the fourth class of surface water quality criteria in Thailand (DO above 2 mg/L and BOD₅<4 mg/L). The QUAL2Kw model is suitable for simulating the current and future river water quality and help water resources managers to issue the appropriate policy options for the Lam Takhong River.

KEYWORDS

Water quality model, QUAL2K, QUAL2Kw, Lam Takhong, Diffuse resources, Point source.

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INTRODUCTION

Water pollution comes from two different kinds of sources including point and nonpoint sources. Point source (PS) of pollution from which pollutants are discharged, such as a pipe, ditch, ship, or factory [1]. Nonpoint source (NPS) pollution is also called diffuse pollution and impacts over a wide area which is not attributed to a single source and associated with particular land uses [2]. Since point source pollutants are associated with point locations, therefore, they are more readily identifiable and measurable. Besides, nonpoint source pollutants are difficult to trace to a source, certainly uncontrollable meteorological events and existing geographic or geomorphologic conditions [3].

In Thailand, water pollution is largely associated with urbanization, industrialization, and agricultural activities [4]. Recent research in the Mun river which one of the largest tributaries of the Mekong River showed that excessive phosphorus is the main cause of water quality degradation in the upstream, Lam Takhong river which the agricultural land affected across the basin [5]. The pollutants for surface water quality problems are sediments, nutrients, and other chemical substances [6] in Lam Takhong river. In addition, the plays an important role in drainage, recreation, and environmental conservations in its basin. In the past, the water quality assessment of Lam Takhong River in 20 stations from 2008 to 2009 was in class three of surface water standard in Thailand, except ammonia-nitrogen (NH₃-N), phosphorus (P), and biochemical oxygen demand (BOD) [7].

In recent years, water quality is constantly deteriorating, especially in urbanization areas. Dissolved oxygen (DO) concentration in Lam Takhong river declines to zero value during dry season occasionally causing the inappropriate raw water quality for Nakhon Ratchasima [8]. There were many kinds of researches applied tools to assess, simulate, and predict water quality conducted in the world in general and in Thailand in particular by the different models including MIKE-11, Hydrological Simulation Program-Fortran (HSPF), QUAL2K, Soil and Water Assessment Tool (SWAT), Water Evaluation and Planning (WEAP), Water Quality Analysis Simulation Program (WASP) [9, 10].

The application of water quality modeling and dissolved oxygen control in the Tungabhadra river in India was conducted by Ranjith in 2019 [11]. This study concentrated on the simulation of flow, local oxygenation, and loads modification from point sources. Besides, Huy Bui Huy [12] integrated SWAT model and QUAL2K to calibrate and validate the model from 12 wastewater sources in the Cau River, Vietnam. Both of these new studies are focused on point sources and have not shown the factors that have the significant influence on river water quality in the region.

SWAT model was used to evaluate the streamflow, sediment, nitrate-nitrogen, and total phosphorus in Lam Takhong river basin in 2015 [13]. The simulation identified nine sub-basins and classified them as a high loading rate of total phosphorus. From the year 2008 to 2009, WASP model was successfully calibrated and validated to simulate the concentrations of dissolved oxygen for the Lam Takhong river system for Empowering Water Quality Management goal [14]. The result suggested that a substantial 50% reduction result in pollution would considerably improve the water quality of the river. Besides, QUAL2K was integrated WEAP models for water quality modelling in water bodies where receive wastewater from treatment plants in Distrito Federal, Brazil [15]. The main benefit of this integration gave better results for the QUAL2K simulations.

Although SWAT was widely applied to simulate streamflow and water quality in Thailand [16, 17], and the Lam Takhong river [18, 19]. In addition, regional studies also applied other water quality models such as WASP [14], WEAP [20], QUAL2K [21] others [22]. However, there has not been an attempt to combine SWAT and QUAL2K to simulate water quality in the river in Thailand, especially in Lam Takhong watershed.

Water quality models that simulate the impacts of diffuse sources is very limited. The primary objective of this research was to integrate SWAT and QUAL2K to simulate water quality from point sources and nonpoint sources discharge into the Lam Takhong river along the lower Lam Takhong. Scenarios of dissolved oxygen change in the river were simulated. The results could be a useful tool for water quality management and planning in the Lam Takhong river.

METHODS

The one-dimensional stream water quality model, QUAL2Kw was selected to simulate water quality in Lam Takhong river. Calibrations were performed for models the different climatic regions and this study focuses on the water quality simulation from point sources pollution and diffuse sources discharge into the river.

Water quality modelling method

With the new approach of water resources management in which it is required the management of pollution problems from both point sources and diffuse sources at river basin. Therefore, it is necessary to apply the water quality modelling method to assess and manage water quality in the river (**Figure 1**).

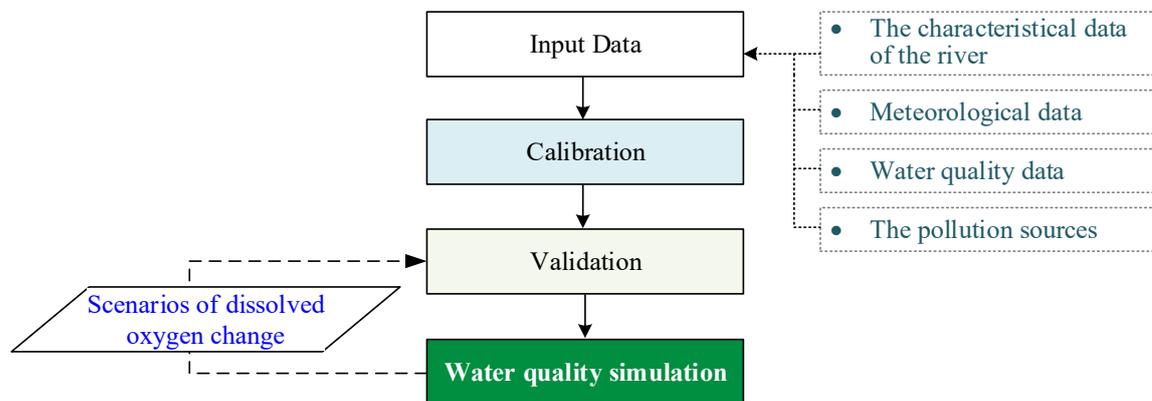


Figure 1 Research framework methodology

Firstly, the model was set up and run before be calibrated by dividing the river into segmentations and combining characteristic, meteorological, pollution sources, water quality data.

Model calibration is a critical step in achieving good model performance and is defined as the process of tuning the parameter values to attain optimal agreement between the simulated and observed data. Besides, model calibration should be supplied with the numerical parameter values as well as the initial condition of the state variables and boundary conditions. The process of parameter justification can be done automatically, by searching for an optimal value of a given criterion.

On the other hand, model validation entails assessing the degree of reliability of the calibrated model using one or more independent data sets, but not the same data that are utilized for model calibration. The model was validated by using observed water quality data at locations in the river.

After the model was successfully validated, simulated scenarios were carried out with load change of polluted sources discharging into the river. The results obtained from scenarios found out which polluted source affected the water quality in the river.

QUAL2Kw model description

QUAL2Kw is a modeling framework to represent a modernized version of the QUAL2E river water quality model by the U.S. Environmental Protection Agency (EPA) [23]. In addition, this model includes several newer features that allow shallow and upland streams to be simulated.

As QUAL2E, one-dimensional QUAL2Kw simulates the transport and fate of non-toxic pollutants. It can also be used for river water quality simulation when the streamflow is steady but non-uniform and the pollution loading into it remains roughly constant. The model considers the influence of both point source and non-point source pollution loads during the simulation. The model has a number of newer elements that make it usable for a shallow and small river beside a relatively large river. The QUAL2Kw model has a general mass balance equation for all constituent concentrations [23]. The model simulates changes within the daily cycle with a user-selected time step of less than one hour [24].

QUAL2Kw is deployed within Microsoft Excel and programmed in VBA which a model run is performed by a compiled Fortran 95 program. Excel is employed as a graphical interface for input, running, and output of the model.

A general mass balance for a constituent concentration (c_i) in the water column of a reach is shown as **Figure 2**.

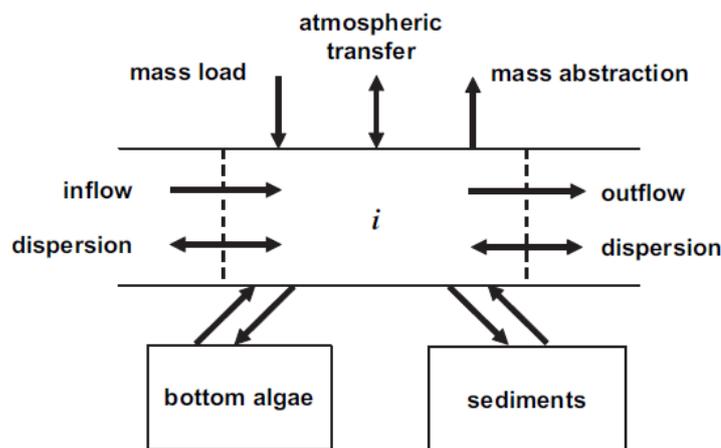


Figure 2 Mass balance for constituents in a reach segment “i”

The detailed description of the QUAL2Kw model in Version 5 and 6 is presented in the website of the Department of Ecology, State of Washington [25].

MATERIALS AND INPUT DATA

Sampling sites and data collection

The study was conducted using the Lam Takhong River, located in the Northeastern of Thailand. The river is under degradation due to the industrialization and urbanization covered over 122 km length of the river from Lam Takhong Dam to the outlet as a distributary to the Mun River (**Figure 3**).

For this study seven monitoring stations were selected along the river namely: 1. Lam Ta Klong River Mouth (LT01); 2. Samakkhi Temple Community Bridge (LT02); 3. Ban Kutchan Bridge, Sikhio District (LT03); 4. Hair Dam, Chalerm Phrakiat District (LTK01); 5. Lam Ta Kong Bridge, Mueang District (LTK02); 6. Makham Tao Dam, Mueang District (LTK03); 7. Lam Ta Khong Bridge Kham Thale So District (LTK04) and Output Lam Takhong Dam (M38C). The detailed summary of the monitoring stations is shown in **Table 1** and locations are indicated in **Figure 4**.

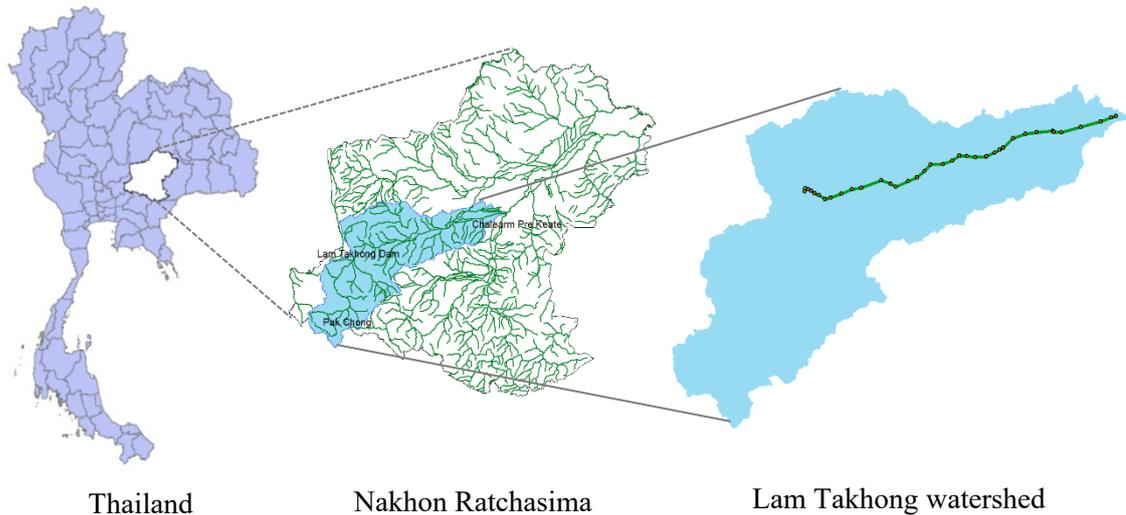


Figure 3 Location of Lam Takhong river

Table 1 Water quality monitoring stations in the Lam Takhong river

Station No.	Name of Stations	Distance from downstream (km)	Location
1	LT04	0	Outlet of Lam Takhong Dam
2	LT03	30.5	Ban Kutchan Bridge, Mittraphap Subdistrict, Sikhio District
3	LTK03	49.9	Makham Tao Dam, Ban Mai Sub-district, Mueang District
4	LTK04	82.9	Lam Ta Khong Bridge Kham Thale So, Kham Thale So Subdistrict, Kham Thale So District
5	LTK02	111.3	Lam Ta Kong Bridge, Ban Tha Krasang, Hua Thale Subdistrict, Mueang District
6	LT02	112.0	Samakkhi Temple Community Bridge, Nai Mueang Subdistrict, Mueang District
7	LTK01	120.0	Hair Dam, Phra Phut Subdistrict, Chalerm Phrakiat District
8	LT01	122.0	Lam Ta Khong River Mouth, Yongyang Co., Pha Nao Subdistrict, Mueang District

The water quality data were monitored four times per year in every March, May, August, and November by the Regional Environment Office 11. The observed water quality parameters were temperature, pH, electrical conductivity (EC), DO, 5 days BOD, nitrate-nitrogen (NO₃-N), nitrite-nitrogen (NO₂-N), ammonia nitrogen (NH₄-N), total phosphorus (TP), and total solids (TS).

Input data

Input data were collected on 20 November 2017 and used to calibrate the QUAL2K. There were 36 collected cross-sections and the Lam Takhong river was divided into 35 reaches, which vary in length. Besides, downstream coordination, length of reaches, element number, and others of reach were also collected. Locations of point sources and nonpoint sources are shown in [Figure 5](#).

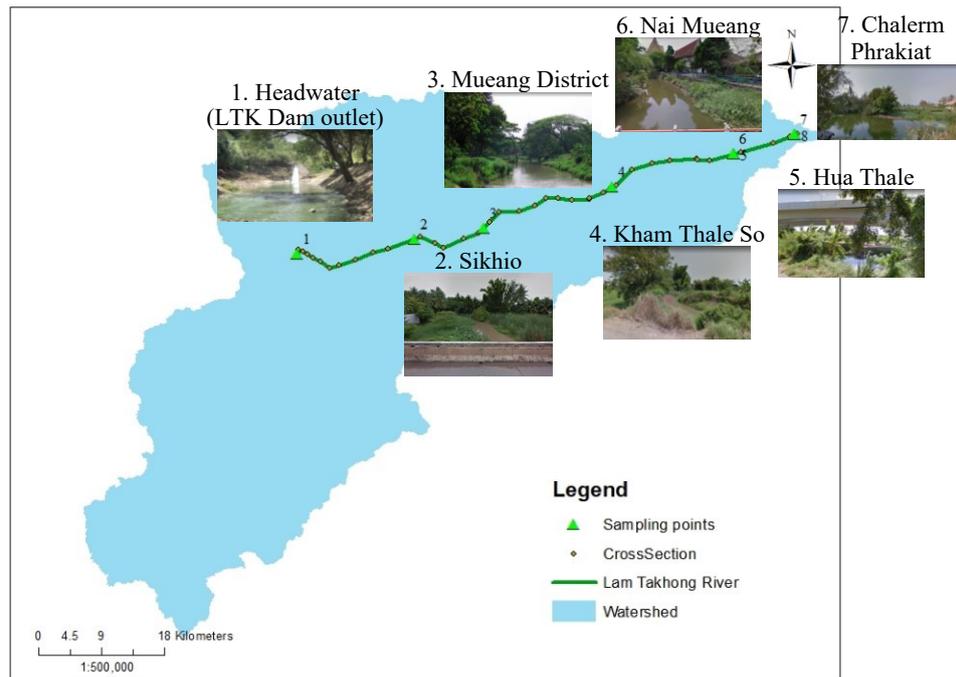


Figure 4 Cross section and sampling sites in Lam Takhong river

The meteorological data input of QUAL2K including air temperature, dew point temperature, wind speed, cloud cover, and shade condition was monitored on an hourly basis. Light and heat dates were calibrated from QUAL2K and radiation, evaporation, air convection, sediment heat, and others were also adjusted.

The input data of water quality parameters were flow, temperature, EC, pH, DO, BOD, NH₄-N, NO₃-N, TP, TS. The data were collected on a daily basis of each three months which are usually February, May, August, and November. The bottom plants were assumed to be 40% and the hyporheic zone thickness was assumed to be 10 cm.

The diffuse sources data calculated by the SWAT model were calibrated and validated, the output of SWAT was used as the input data for the QUAL2Kw model to simulate water quality in the Lam Takhong River. Land use along the Lam Takhong River is mainly agricultural land for rice, cassava, and other crops that requires a significant amount of fertilizers. Therefore, diffuse sources continuously released high nutrient loading into the river.

RESULTS AND DISCUSSION

The main results achieved in the study performed for QUAL2K calibration and scenarios of dissolved oxygen change are presented below, highlighting that the outflow discharge of point sources has a major impact on the water quality in Lam Takhong river.

Calibration of modelling

The exponential model was selected for oxygen inhibition of the fast carbon biochemical oxygen demand (CBOD) oxidation and nitrification; also for oxygen enhance of the de-nitrification and bottom algae respiration. The fast CBOD oxidation rate was assumed as 0–5 1/day, the other parameters were set up as default value in QUAL2Kw. The calculation step was set at 5.625 min while Euler’s method was chosen for the solution of integration, and Newton–Raphson method was applied for the pH simulation. The model was run for a population size of 100 with 50 generations in the

evolution as suggested by Pelletier [26] that the population size of 100 was better than smaller numbers. The calibrated physicochemical parameter values in the model are presented in Table 2.

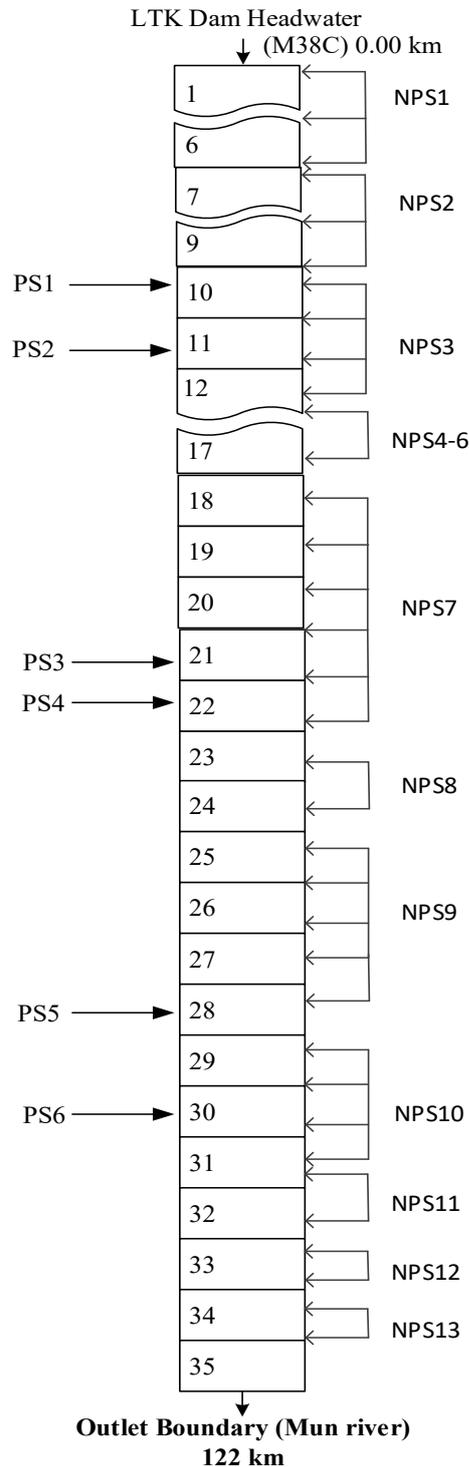


Figure 5 QUAL2K segmentation scheme with the location of polluted sources

The calibration results for the water quality in Lam Takhong River at six monitoring locations are presented in Figure 6 and compared to the calibrated parameters by Huy Bui [12], the simulated results are presented as continuous lines and the observed data as symbols. The model calibration results are in well fit with the measured data with the

relative mean error values of temperature, pH, flow, DO, and BOD are 6.46%, 3.07%, 11.49%, 6.51%, and 11.85% respectively.

Meanwhile, results of nitrate and nitrite, and total phosphorus calibration show more discrepant fit, however, the calibration of nitrate is much better than total phosphorus. The cause is a few data sets for the surface water quality in the Lam Takhong river were used to calibrate the QUAL2K model. Furthermore, the water quality would vary between daytime and nighttime, by which only daytime data were available. These reasons have affected the calibration results, which is the basic study for further research to improve the simulation results and find out the location where water quality deteriorates more accurately in the future.

Table 2 Parameters were calibrated by QUAL2Kw

Parameters	Values	Units	Auto-calibration	Min. value	Max. value
Carbon	40	gC	No	30	50
Nitrogen	7.2	gN	No	3	9
Phosphorus	1	gP	No	0	4.2
Dry weight	100	gD	No	100	100
Chlorophyll	1	gA	No	0.4	2
ISS settling velocity	0.259	m/day	Yes	0	2
O ₂ reaeration model	Internal		No		
Fast CBOD oxidation rate	0.760	1/day	Yes	0	5
Organic N hydrolysis	2.27	1/day	Yes	0	5
Organic N settling velocity	1.67	m/day	Yes	0	2
Ammonium nitrification	1.694	1/day	Yes	0	10
Nitrate denitrification	2	1/day	Yes	0	2
Sed. denitrification transfer coefficient	0.131	m/day	Yes	0	1
Organic P hydrolysis	1.200	1/day	Yes	0	5
Organic P settling velocity	0.117	m/day	Yes	0	2
Inorganic P settling velocity	0.048	m/day	Yes	0	2
Sed. P oxygen attenuation half sat constant	1.718	mgO ₂ /L	Yes	0	2

Figure 6 presents the simulation result in comparison with the observed data at stations along the mainstream of the Lam Takhong River when calibration was conducted on parameters including flow, temperature, pH, DO, CBOD, NO₃-N+NO₂-N, and TP. The results showed that the calibration results were a very good agreement between simulated and observed values for flow, temperature, pH, DO, CBOD (**Figure 6a** to **Figure 6e**). As for experiments, the NO₃-N+NO₂-N calibration results (**Figure 6f**) in downstream are not as good as upstream locations, in contrast to total NO₃-N and NO₂-N, total phosphorus is calibrated better downstream locations (**Figure 6g**).

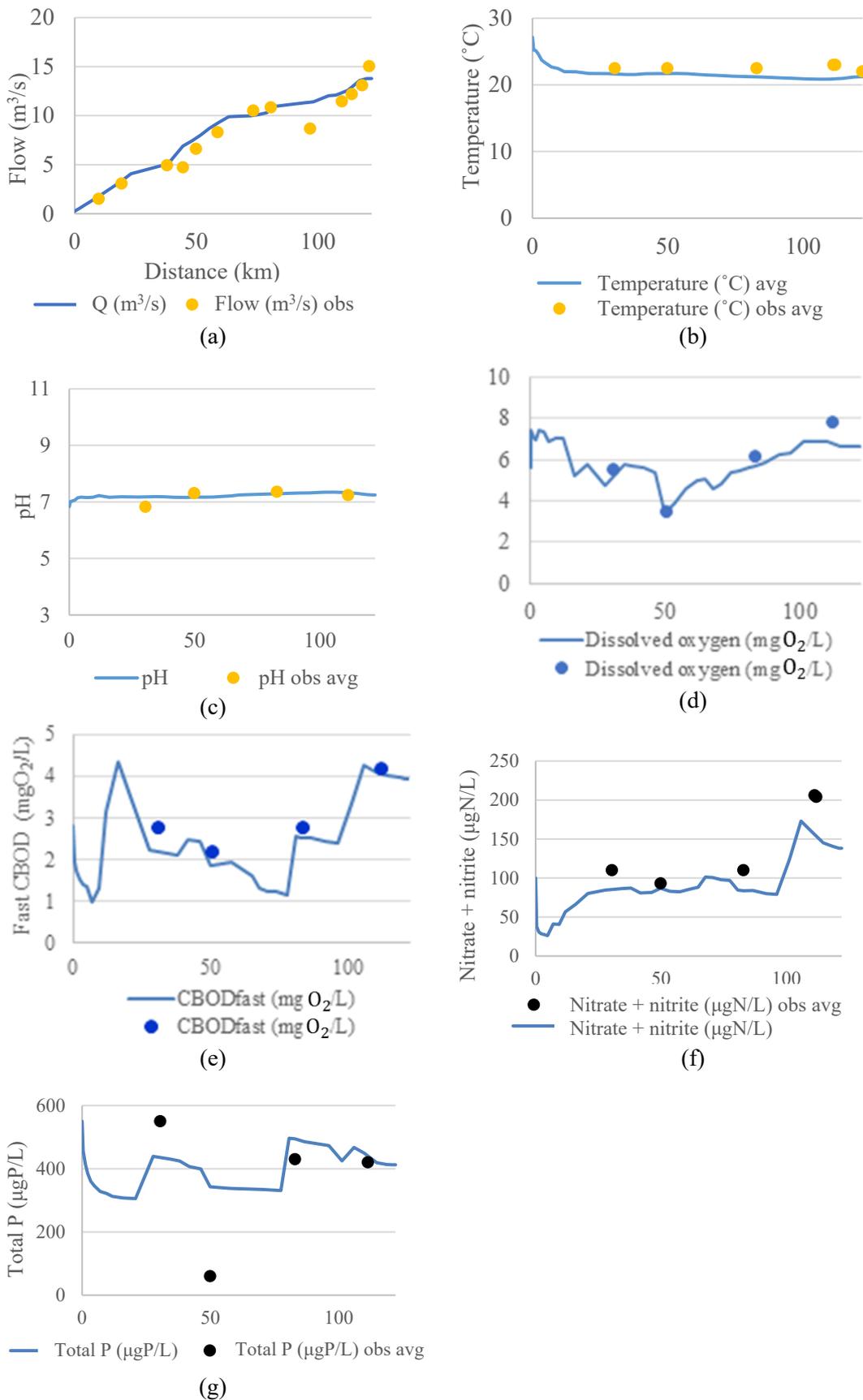


Figure 6 Calibration results: calibration graph of discharge (a); calibration graph of temperature (b); calibration graph of pH (c); calibration graph of DO (d); calibration graph of BOD5 (e); calibration graph of NO₃-N+NO₂-N (f); calibration graph of TP (g)

Scenarios of dissolved oxygen change

This study focuses on the simulation of water quality from diffuse sources discharge into the river. From simulation results of the calibration during the critical period (low flow), it can be concluded that the river water is less appropriate for fisheries survival in which the minimum DO concentration is 4 mg/L (class three standard in Thailand) and BOD₅ concentration in rivers should not exceed 4 mg/L (class four standard). Therefore, the examination also includes different scenarios of point sources that they are allocated along the river to assess the change of the DO concentration in downstream as follows.

Pollution loads modification. It was assumed that the BOD₅ concentration reduction of point sources pollution is sequentially 50, 30, 20, and 10 mg/L along the lower reach of Lam Takhong river. The first scenario result, as shown in Figure 7, it can be noticed that the pollution load modification is the major cause of the decrease in DO levels.

When the BOD₅ concentration of point sources pollution increase to 50 mg/L along the lower reach of Lam Takhong River is DO concentration decline to under class four standard at Mueang district and the majority of sites have DO concentrations in class three of the surface water standard in Thailand.

However, this is a minor change, but when the outflow discharge from point sources increases from 0.01 to 0.5 m³/s, the DO concentration in the Lam Takhong river suddenly falls below the class four standard. Therefore, it is concluded that the BOD discharge concentration does not significantly impact the water quality but the BOD load discharge will significantly affect the water quality in the Lam Takhong river.

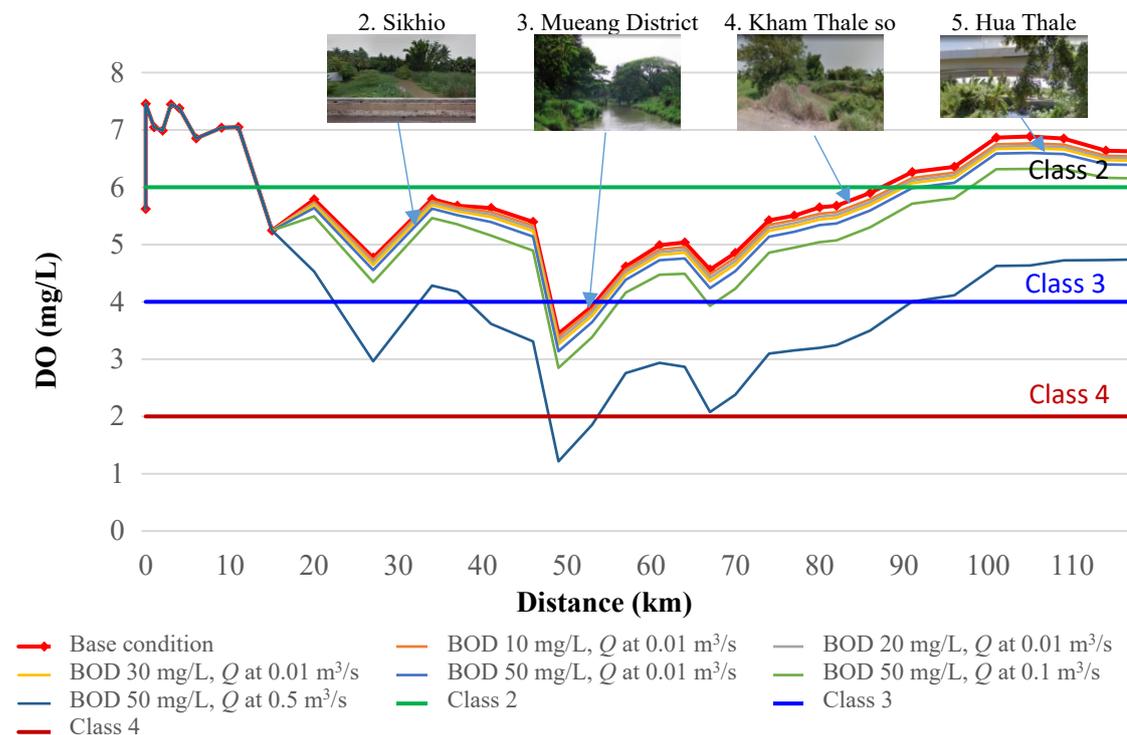


Figure 7 DO concentrations along with the downstream of Lam Takhong River

Nutrient load from diffuse sources. It was assumed that the same values of BOD₅ are 50 mg/L for point sources with outflow 0.01 m³/s at points along the river integrate the increase of nitrate concentration 10%, 30%, and 50% from diffuse sources. From Figure 8, it can be seen that scenario 2 does not give significant results of DO value change in

Lam Takhong river. Similarly, the scenario above when the outflow increases from point sources to 0.5 m³/s, the DO concentration in the Lam Takhong river also significantly decreases below the class four standard.

Therefore, the nutrient discharge from the diffuse source does not affect the water quality in the Lam Takhong river, however, the outflow from the point source has a significant effect on water quality.

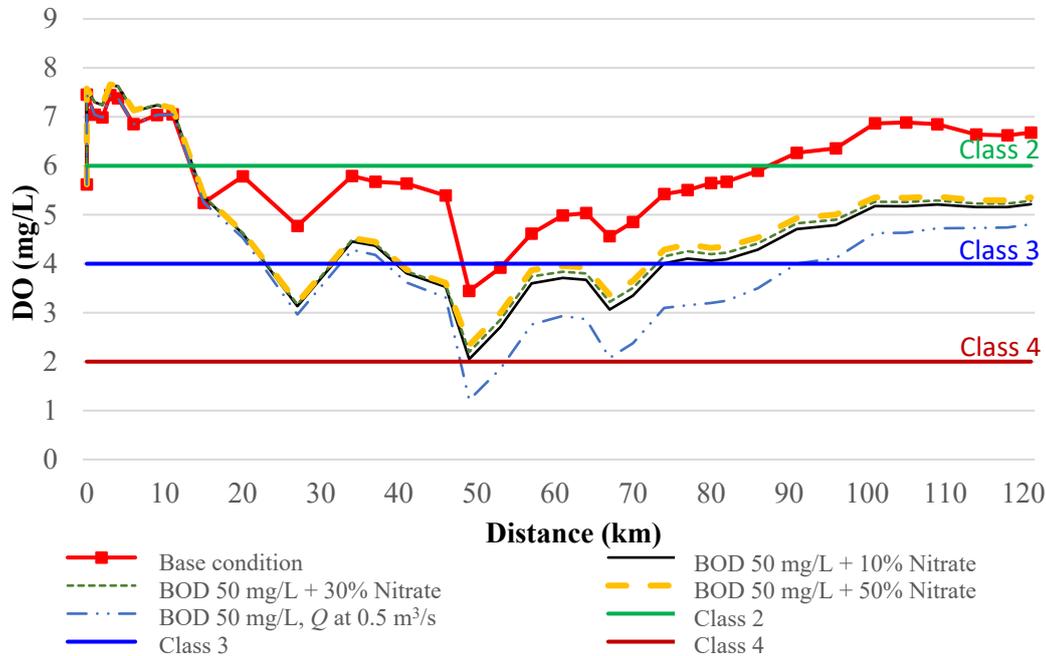


Figure 8 DO concentrations along with the downstream of Lam Takhong River with different BOD5 concentrations for point sources and nutrient augmentation

CONCLUSIONS

A water quality model, QUAL2K was calibrated for the Lam Takhong River using the collected water quality data in 2017. The simulation results are calculated completely in accordance with the observed water quality data. In calibration, the relative mean error values between the simulated and observed data for temperature, pH, streamflow, DO, and BOD were 6.46%, 3.07%, 11.49%, 6.51%, and 11.85% respectively.

The concentration level of DO in upstream and downstream was in class 2 of the surface water quality standard in Thailand, which is more favorable (very clean used for consumption, aquatic organism conservation, fisheries, and recreation). However, the DO concentration decreases significantly from 50 km downstream, resulting in the drop of water quality of Lam Takhong to class four standard (fair quality, requires special treatment process) since this location is an urban area. Thus, the water quality in this area is less appropriate for preserving the ecology of the river.

From the results of the scenarios, it can be concluded that the BOD₅ concentration modification from point sources does not significantly affect the water quality in the Lam Takhong river, however, the outflow discharge has a major impact on the water quality in the River. While nutrient input scenarios from diffuse sources neither significantly impact on DO concentration change in the Lam Takhong river. In summary, the outflow from point sources is the main factor affecting water quality in the Lam Takhong river.

Finally, results from the simulation of QUAL2K can be used to calculate the pollutant loading in Lam Takhong River and allocate the nutrient loading in Lam Takhong

watershed. The calculated results could be used for the water quality management estimate to cut down point sources and nonpoint sources to meet the surface water quality standard in Thailand.

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