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Development of water quality modelling using InfoWork river simulation in Malacca River, Malaysia and contribution towards Total Maximum Daily Load approach

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Abstract. Nowadays, development and urbanization have increase the pollutant loads in the river. As one of important water resource, river has been threatened by the increasing of pollutant loads in the river body. The water quality modelling is an important tool to simulate water quality analysis and river management by addition of pollutant loads. The needs of effective watershed management are crucial to ensure the river is well managing and regulated. In Malaysia, Malacca River has become one of the most popular place for tourism activities. Present work has developed water quality modelling by using InfoWork River Simulation version 10.5, to simulate the water quality condition by doing pollution reduction analysis. The modelling framework is developed to simulate the load reduction for Chemical Oxygen Demand (COD) as the pollutant controlled at the selected area. The simulation shows that, based on four scenarios created, Scenario 3 are selected as the best condition to achieved Class II water quality standard. As a conclusion, the development of water quality modelling by using InfoWork (RS) can improve the water quality condition at Malacca River by using pollution loading reduction analysis and suggested for future watershed management such as Total Maximum Daily Load (TMDL) implementation plan.

Keywords—InfoWork (RS), water quality simulation, total maximum daily load

Abbreviations. ArcGIS: Arc Geographic Information System; AutoCAD: Auto commercial computer-aided design; BOD: Biochemical Oxygen Demand; C1: Cheng 1; COD: Chemical Oxygen Demand; DO: Dissolved Oxygen; DT1: Durian Tunggal 1; GIS: Geographic Information System; GPS: Global Positioning System; InfoWork (RS): InfoWork River Simulation; LA: Load Allocation; M1: Malacca 1; M20: Malacca 20; MOS: Margin of safety; MO1: Malacca Outlet 1; NH₃-N: Ammoniacal Nitrogen; NWQS: National Water Quality



Standards; P1: Putat 1; PO_4^{3-} : Phosphate; QUAL2E: Enhanced Stream Water Quality Model with Uncertainty Analysis; SWAT: Soil and Water Assessment Tool; TMDL: Total Maximum Daily Load; TP: Total Phosphorus; TSS: Total Suspended Solid; WLA: Waste Load Allocation; WQI: Water Quality Index.

1. Introduction

River is one of natural resources that are important for sustainability of life. However, the increasing of urbanization development has destroyed the water quality of the river. The river pollutions are contributed from various sources which categorised as Point Sources (PO) and Nonpoint Sources (NPS) [3, 24]. The point sources can be describing as pollution from sources that can be identified, in contrast nonpoint sources is diffuse pollution which occur over a wide area and are not easily attributed to a single source [3, 14, 32]. Point and non-point sources of pollution has significantly deteriorated of river water quality. The increasing amount of waste discharged into river and the level of assimilative capacity has greater impact to the river water quality [18]. To have better understanding on the changes of the river, it is useful to develop a water quality model to simulate the pollutant loads into the river.

The water quality modelling is usually used as the water quality planning tools in managing the watershed [10]. The main purpose of developing the water quality model is analyse and forecast the observed effect of any changes occurs in river. The water quality model usually indicates the changes in river, significantly shows the relationship between pollution and river condition [33]. The analysis of the model can be used to create the scenarios analysis for decision-making process [9, 25, 36]. The scenarios of load reduction created are important for environmental impact assessment [30]. The prediction of water quality condition at the river is important to propose the defensive strategy for maintaining the health of the river. The modelling process helps to improve the water quality and water quality management.

Since, Malaysia has face many environmental challenges such as flooding, degradation of water quality, and management problems, the water quality modelling has become one of solution. There are few studies has been conducted such as low flow analysis by using QUAL2E model at Selangor River, and calculation of pollution loading at Tebrau River [18]. The InfoWork (RS) model has been used at Juru River, to study the types of pollution and the tidal influences on river water quality [27]. According to [17, 27, 28], the study of water quality modelling by using InfoWork (RS) are well establishing and known in Malaysia.

The water quality model is integral part of development of TMDL implementation plan. The modelling process provide the decision support system for TMDL development, in terms of loads reduction analysis. The TMDL can be define as total maximum daily loads, where the maximum amount of pollutant allowed to enter the water body without violating the water quality standard [21]. The approach of TMDL implementation plan are important to improve and protect the water quality of Malacca River. The process of TMDL can be simplified based on the equation below [7]:

$$\text{TMDL} = \sum \text{WLA} + \sum \text{LA} + \text{MOS} \quad (1)$$

TMDL is derived from WLA (waste load allocation of point sources), LA (load allocation of nonpoint sources), and MOS (margin of safety for future development [34]. The TMDL program usually helps to improve the river water quality by improve the pollution sources in river. The mathematical modelling are important tools for developing TMDL implementation plan [30].

In Malaysia, there are 321 river basin all over the country [6]. The evaluation of water quality status in Malaysia using Water Quality Index system (WQI), based on six parameter which is $\text{NH}_3\text{-N}$ (Ammoniacal Nitrogen), BOD (Biochemical Oxygen Demand), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), pH, and TSS (Total Suspended Solid Total Suspended Solid), categorized as clean, slightly polluted and polluted [5]. Malacca River is one of important and attractive river in Malaysia. It has become attraction for tourism activity due to historical place, unique building and

boating activities near the river. The high density of activity and population occurs around the Malacca River, has increase the pollution sources and pollute the river. Therefore, Malacca River are selected as target area to study the impact of reducing the pollution sources into river by using water quality modelling towards the TMDL approach. In this study InfoWork (RS) version 10.5 model are used as water quality planning tools and is calibrated with the observed data. The objective of the study is (1) to calibrate the InfoWork (RS) model with water quality data of Malacca River and (2) to simulate scenarios for river pollution reduction conditions for better watershed management which produce TMDL implementation plan.

2. Water Quality Model

2.1. Study area

The Malacca watershed consist of five main river which is Putat River, Cheng River, Durian Tunggal River, Tampin River and Batang Malacca River. Malacca River has been selected for TMDL program because water quality problem which lead to fish kills incident, smelly river, and low dissolved oxygen. The fish kills incident and the impairment of river prove the river has been over-utilization due to the rapid development [26]. The Durian Tunggal River, Cheng River and Putat River are the main tributaries for Malacca River. The observation during sample collection shows the Malacca River are located at develop area.

2.2 Samples collection

At Malacca River, twenty sites have been selected (M1-M20), and three tributaries which is Durian Tunggal River, Cheng River, and Putat River for samples collection. The samples are collected between August until November 2014 (four times). The in-situ parameter was collected using EUTECH Instrument PCD650 such as water temperature, salinity, pH, Dissolved Oxygen (DO) and conductivity. The latitude and longitude recorded by using Global Positioning System (GPS). There are 23 water quality samples from the sampling location were analysed triplicate. The following parameters has been tested according to the [2]: BOD, NH₃-N, COD, TN (Total Nitrogen), TP (Total Phosphorus), and PO₄³⁻ (Phosphate).

2.3 Water quality model development

The water quality modelling was develop using InfoWorks (RS) version 10.5 which is a one-dimensional hydrodynamic simulation program by solving the fully dynamic de Saint-Venant equations developed by the Wellingford, United Kingdom, capable of performing steady and unsteady flow water surface profile calculations [1, 28]. The governing equation in for InfoWork (RS) is [22]:

1Dimensional (1-D) continuity equation;

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0 \quad (2)$$

There are few assumptions for St. Venant Equations which is the flow is one-dimensional, the hydrostatic pressure prevails, and vertical accelerations are negligible, the streamline curvature is small, the bottom slope of the channel is small, the Manning's equation is used to describe resistance effects, and the fluid is incompressible [22]. The methodology for water quality model development was referred based on River Hydrodynamic Modelling-The Practical Approach manual [27]. InfoWorks Water Quality is a computer program used to model water quality in open channels. There is separate simulation, which is hydraulic model and hydrological model as shown in Figure 1. The hydraulic model consists of network data which is the physical component that do not change with time, whereas the hydrological model is part of event data such as initial condition, boundary condition, and simple control data.

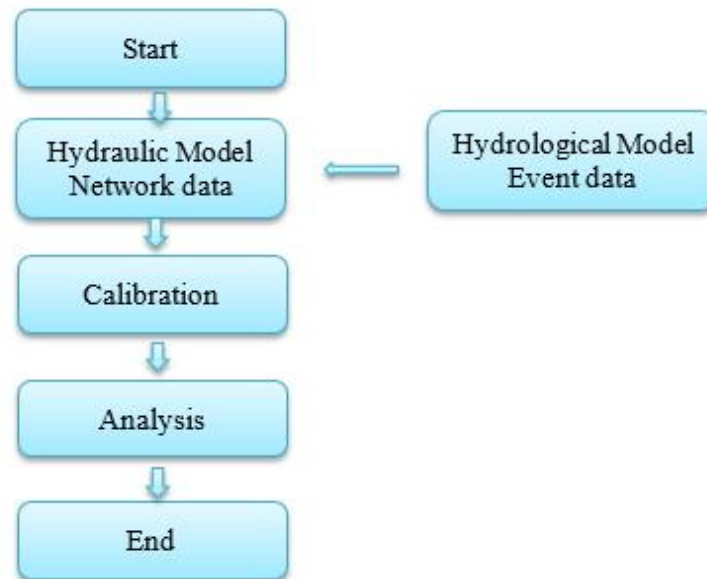


Figure 1. Model of development process for water quality modelling using InfoWork (RS)

2.4 Water quality model preparation

The model was developed using InfoWork (RS) version 10.5. The model has two separate simulation engines: a hydraulic engine and a water quality engine. The hydraulic engine provides hydrodynamic data, which is used in the water quality simulation. The model uses a finite differences approximation to the advection-diffusion equation, where the SMART algorithm developed by [8] is used to approximate the advection term. This model consists of three main characteristics: network, event, and water quality. There are 72 nodes of cross-section along the 40 km long river. The network of the river was integrated with Arc Geographic Information System (ArcGIS) and Auto commercial computer-aided design (AutoCAD). The event section was used to build the boundary condition for the model. The upstream boundary node uses the flow-time event type, while the downstream of Malacca River uses stage-time as the event type. The water quality group was created for water quality analysis. Two run groups were created: one for hydraulic analysis and one for water quality analysis. The hydraulic analysis was carried out for steady and unsteady events, while water quality analysis was used for creating scenarios.

2.5 Model Calibration

Model calibration is a fundamental process in developing water quality modelling to ensure the model can produce suitable results for specific interests and purposes [19]. Model calibration usually considers three main elements: the target of the model, available information, and selected parameters used in calibration, and the model calibration process [4]. The water quality model development needs to ensure that observed and simulated data are well compared during the calibration process. Model calibration is a process where the model is adjusted so that the model prediction better represents the water quality modelling process and conditions. The model is successfully calibrated when it replicates observed data within an adequate level of accuracy and precision [4]. However, the calibration process is subjective to be judged, because it depends on the purpose of model development, the point of view of the modeller, the available data and information, and the quality of data provided. Several locations were used to calibrate the model from August to October 2014 for two parameters: COD and DO. The location of calibration point sources is shown in Figure 2. Figure 2 was drawn using the ArcGIS application.

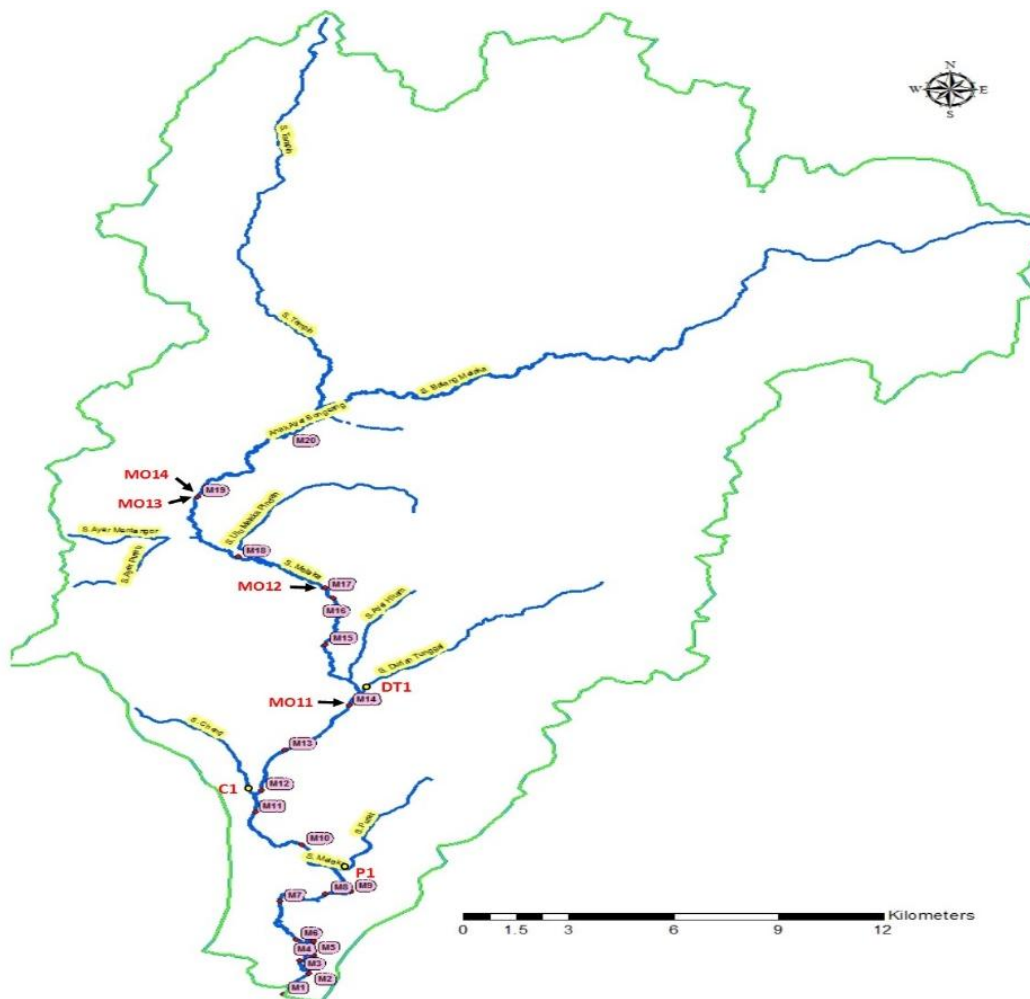


Figure 2. Location of point sources pollution using during the calibration process along Malacca River

3. Result

3.1 Hydrodynamic Simulation and Calibration

The model was calibrated using two main water quality parameters, to fulfil the need of the study. The results are shown in Figure 3. The COD parameter was our interest parameter for TMDL development, therefore it is important to ensure the simulated data of COD are well-fitted with the observation data. While DO is chosen as one of the parameter for calibration analysis, based on the concept of sequence of model: 'which one feeding another' [15]. To study the health of the river, the concentration of DO parameter is the most important aspect, whereas the concentration of COD will eventually have affected. Hence, these two parameters are chosen for calibration analysis. The calibration of water quality model is important to ensure the model can simulate the real condition of river, as well as provides the reactions towards the pollution loading [23]. Well calibrated model is able to reproduce the observed water quality results of river. The calibration analysis was done to find the condition that best fit the water quality observation data. Based on the calibration analysis done, the predicted COD parameter fits with the observation data shows the model was calibrated successfully. It shows the develop water quality model is suitable to use for generating the scenarios for reduction of pollution loading analysis at Malacca River.

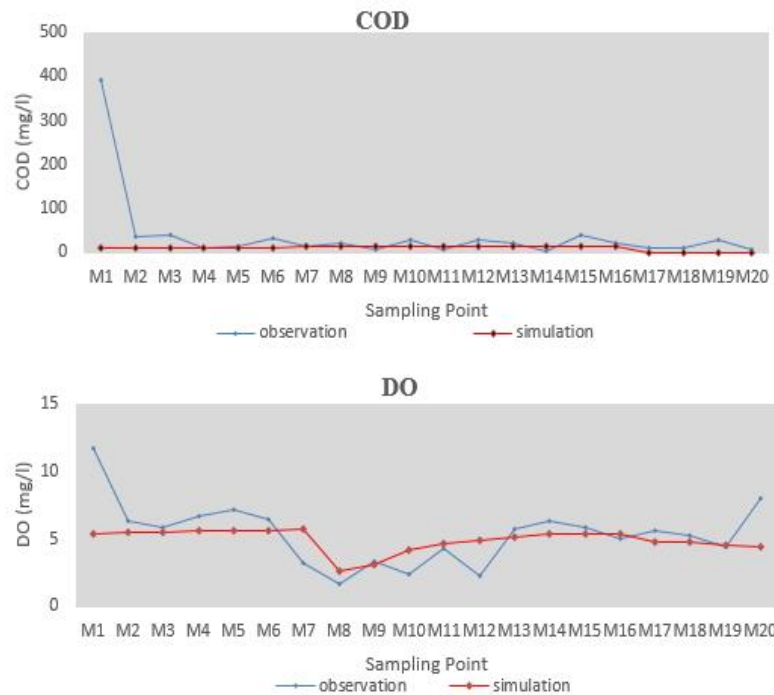


Figure 3. Calibrated simulation for COD and DO parameters using InfoWork (RS) version 10.5 for M1 until M20

3.2 Load Reduction Analysis

The water quality parameter, COD, has been chosen as the highest contribution of pollutant at Malacca River to analyses. The condition of load reduction analysis of COD is shown in Table 1. The target of water quality is set at Class II, referring on Department of Environmental (DOE) Water Quality Index (WQI) in Malaysia, where the COD value must be 25 mg/L. By achieving Class II, Malacca River are suitable to carry out few activities such as supplying water (need of conventional treatment), fisheries activities, and recreational activities [20]. It is important for Malacca River to achieved Class II especially at downstream area, because there a lot of recreational activities occurs and tourism attraction. There are three types of criteria was created which is pollution reduction at point sources upstream, downstream and combination of both with tributaries. Scenario_1 describes the pollution reduction at upstream with 30% of COD reduction at point sources MO11, MO12, MO13, and MO14. Scenario_2 describes the pollution reduction at downstream with 30% of COD reduction at point sources MO1-MO10. The Scenario_3 shows the pollution reduction 30% of COD, at P1, C1 and DT1 which is the tributaries of Malacca River. While Scenario_4 are the combination of Scenario_1 and 30% reduction at tributaries, and Scenario_5 are combination of Scenario_2 and 30% reduction at tributaries. All these scenarios were analysing to study the impact to the water quality of Malacca River towards the pollution reduction condition. The pollution loading from LA and WLA are describes in detail as shown in Table 2. The calculation of pollution loading are obtains by using formula below.

$$\text{Loading (kg/d)} = \text{Flow rate (m}^3\text{/d)} \times \text{Average COD concentration (mg/L)} \quad (3)$$

The load reduction scenario analysis for TMDL approach are very important components to ensure the simulated and predicted analysis achieved the desired target water quality standard [30]. Based on scenarios created as shown in Figure 4, all the scenario shows the improvement of COD parameter. However, the Scenario_3, which reduction of COD at tributaries does not improve the COD water quality at M1, which is the mouth of Malacca River. The Scenario_5 has chosen as the suitable

scenario for TMDL development, which is 30% reduction of COD at the downstream and 30% reduction COD at tributaries. This selected scenario has chosen as the target pollution reduction for TMDL approach, due to the possible pollution reduction to be done and achieving the Class II water quality standard. It is suggested the load reduction at the urban areas has the highest impact of water quality improvement [11]. Since the downstream part of Malacca River is the urban and developing areas, it is important to control the pollution loading into the river.

Table 1. Description from reduction analysis based on criteria and scenario

Criteria	Scenario	Description
Pollution reduction of point sources at upstream	Scenario_1	30% pollution reduction at upstream (M20, MO11, MO12, MO13, MO14)
Pollution reduction of point sources at downstream	Scenario_2	30% pollution reduction at downstream (MO1-MO10)
Pollution reduction of point sources at tributaries	Scenario_3	30% % pollution reduction at tributaries (P1, C1, DT1)
Combination of pollution reduction of point sources at upstream/ downstream and tributaries	Scenario_4	Scenario 1 + 30% pollution reduction at tributaries
	Scenario_5	Scenario 2 + 30% pollution reduction at tributaries

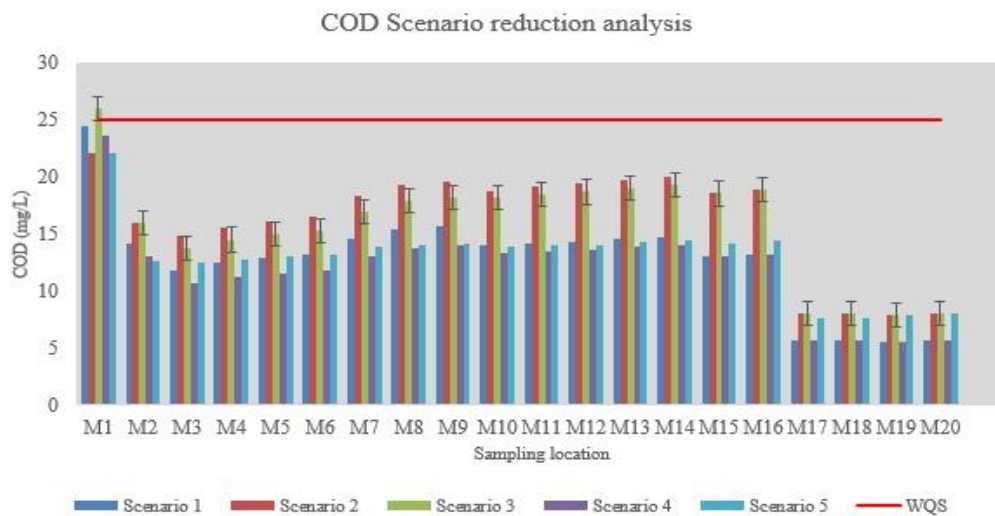


Figure 4. COD pollution reduction analysis for different scenarios.

The selected Scenario_5 as the target pollution reduction for TMDL implementation plan, need to be organized properly according to the WLA and LA sources. The centralized wastewater treatment plant can control the inclusion of pollutant load from the sewage plant for pollution loading reduction [35]. The centralized sewage plant can be treated with suitable wastewater treatment plant at the upstream of Malacca river. The study by Zhang et al., 2015, shows the pollution reduction analysis based on reducing sanitary sewage using wastewater treatment rate of sub-basin. While the nonpoint sources pollution can be controlled by implementing Best Management Practices (BMPs) and public education [12, 16, 31]. The TMDL implementation strategies for Malacca River need to be revised and modified from time to time by using monitoring programs to monitor whether the TMDL objectives have been met or vice-versa. The MOS can be expressed either implicitly or explicitly where implicit MOS is function by doing the conservative assumptions in the TMDL, while explicit MOS are

reserving a part of TMDL without allocate it [29]. In this study, the MOS has been assuming to be implicit.

Table 2. The COD pollution loading reduction for point sources at point sources at upstream/downstream and tributaries.

	Scenario_1	Scenario_2	Scenario_3	Scenario_4	Scenario_5
Current loading (kg/day)			29519.28		
LA (kg/day)	177.68	5526.93	1597.49	1775.18	7124.42
WLA(kg/day)	2576.18	10785.22	0.00	2576.18	10785.22
MOS(kg/day)	implicit	implicit	implicit	implicit	implicit
TMDL	2753.86	16312.15	1597.49	4351.35	17909.64

4.0 Conclusion

TMDL implementation plan is one of the suitable management plan to control the pollution loading into the river. The suitable water quality model as planning tools was used in this study by using InfoWork (RS) version 10.5 at Malacca River. As the highest pollutant contribution into the river, COD has been selected as the target parameter for TMDL program, to achieved Class II water quality. This study developed a water quality model for Malacca River, Malaysia by using InfoWork (RS) version 10.5. From five scenarios created, Scenario_5, has selected as the condition for improvement of water quality at Malacca River, by doing 30% of COD loading reduction at downstream and 30% of COD loading reduction at tributaries. The TMDL implementation plan suggested the construction of centralized wastewater treatment plan and BMPs practices can be carried out for other rivers in Malaysia. The more comprehensive study for watershed management can be done.

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