# Water quality modelling using QUAL2K at Likas River, Sabah

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**ABSTRACT** Assessing water quality through modeling has the advantage of simplifying the tedious and complicated on-field investigations while reducing potential on-site risks, costs, and time. A combination of manual observation and simulation can predict water quality along the river, as the computer program can instantly generate reliable data based on the desired parameters. This technique also facilitates the river's data collection management for the selected points along the monitored river for any time and duration required. This work utilized the Digital Elevation Model (DEM) from geospatial and satellite maps for obtaining the hydraulic parameters. Then the cross-section of the river has been generated based on the elevation data. The study collected samples from the Likas River and was characterized in the civil engineering environmental laboratory. The represented water quality data from 22nd December 2019 to 22nd February 2020, during the critical dry season, were used as input in the QUAL2K program to predict the selected Likas River's water quality model. The study found that the Likas River is possibly affected by effluent discharges from both the point and non-point sources of pollution from nearby commercial or residential areas and exceeds the Class-III river's BOD properties. Recommendation on utilizing stormwater filtration as on-site prevention is also highlighted in this work.

**KEYWORDS:** Digital elevation model (DEM); QUAL2K; Water quality modelling; Likas River; Pollutants
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## INTRODUCTION

One of the main contributors to water quality degradation in the Likas River is the inappropriate waste disposal, including domestic litter, trace metals, and other chemicals from the local industries polluting the coastal area of Kota Kinabalu. The lack of awareness and law enforcement from the public, private sector, and the authorities may have led irresponsibility to occur arbitrarily. Before the Kota Kinabalu Industrial Park (KKIP) was developed, all the industries were concentrated within the Likas / Kolombong area. As the Likas River flows across the highly populated industrialized zone, the river's potential to be polluted increases and would disrupt the water supply. The industrial area discharges its wastewater to the river flow, which reduces the dissolved oxygen (DO) concentration and other water quality parameters, causing heavy river pollution. Thus, maintaining the water quality's minimum standard and having efficient river management is significant.

River quality can be measured by examining the resultant data analyzed from the field and laboratory work and through simulation of the river's water quality model based on the desired parameters. Water quality can be modeled using the QUAL2K program, a one-dimensional water quality model modified from the previous version of QUAL2E (Zhang *et al.*, 2012). It is widely used for various applications in water quality prediction. The new modification includes additional water quality parameters such as DO and biochemical oxygen demand (BOD) due to algae and river plants' interaction and denitrification rates. QUAL2K requires input data of the hydraulic parameter such as flow, velocity, and length of the river, and up to 16 water quality parameters, including temperature, pH, total suspended solids (TSS), total phosphorus (TP), and total nitrate (TN) (Elsayed, 2014). For instance, the QUAL2K model has been used to predict the water quality in

Pamba River, India, and it was demonstrated that the simulated profile of each sample for BOD, TN, TP, TSS, and alkalinity are comparable to the observed data (Ashwani *et al.*, 2017).

Likas River is a small stream without any tributary. Pollutants may enter from a wide range of economic activities nearby, including industrial, agricultural plantations, urbanizations, and construction activities (Ladoni, 2009). This research aims to simulate and validate the QUAL2K model with the water quality parameters obtained in the field. Data sampling and analysis for the hydraulic and water quality parameters such as Chemical Oxygen Demand (COD), BOD, DO, pH, temperature, conductivity, ammoniacal nitrogen (AN), and Total Suspended Solid (TSS), were carried out. The paper also highlighted the potential application of stormwater filtration for on-site prevention in the later section.

## METHODOLOGY

*Study Area*

Kota Kinabalu Likas River, one of the main Inanam River tributaries, is located at the centre of the Kolombong industrial zone and residential area of Kota Kinabalu, Sabah. The water quality assessment for Likas River was modeled using the QUAL2K at two selected boundaries. Boundaries include the river flows from close to the roundabout at the upstream until the downstream at Taman Kemajuan near the main coastal area. The river's length, measured using the Google map tool, is approximately 9.1km. Water sampling was conducted at four monitoring stations. Figure 1 shows the location of the study area along the Likas River.


**Figure 1.** Study area at Likas River.

*Monitoring and Data Collection: River Segmentation*

The developed QUAL2K model for Likas River is divided into 12 segments (as shown in Figure 2), which equals 0.78km length and uses uniform hydraulic characteristics to simulate the water quality. This model requires several data inputs—first, the geographical attributes such as the river's location and elevation. Second is the water quality parameters, including BOD, DO, temperature, pH, TSS, AN, and the river's conductivity. The third part is the hydraulic characteristics such as Manning value, the river's cross-section, the river's flow, and the identified on-site pollution source. Five nodes of point locations were made in river segmentation as the monitoring stations for hydraulic and water quality data collection.

Hydraulic characteristics are determined using spatial map analysis where the DEM was obtained from Open Topography and Alaska Satellite Facility website. DEM is widely used, mainly when the study area is ungauged, has low accessibility, and consists of a lengthy dynamic river dimension (Clark *et al.,* 2015). The water level's depth is determined from the water level's recent width. In contrast, the river's vertical depth to the bottom channel is determined by comparing the surface water level's cross-section and width. From this observation, other hydraulic characteristics such as the area of the wetted cross-section, hydraulic radius, velocity, and flow discharges can be computed with the hydraulic formula (Kim & Kang, 2017).

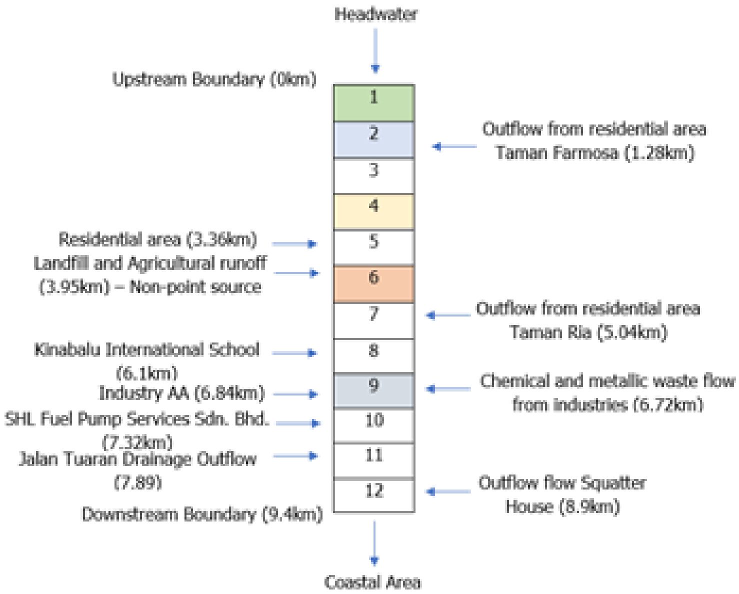


**Figure 2.** QUAL2K segmentation scheme for Likas River.

The water quality sampling was done on-site in one seasonal of critical dry conditions from December 2019 to February 2020. Two liters of water bottle sampling are used for data collection. For BOD, 300ml of a black bottle is used to collect the water sample before storing it inside an incubator. The temperature of the river was measured on-site using a temperature meter. The water's acidity and alkalinity are determined in the laboratory with other chemical and biological parameters of BOD, DO, TSS, and AN. The water analysis experimental works referred to APHA procedures and DOE Malaysian standards.

*Model Setup and Data Input*

Several data inputs of hydraulic characteristics and water quality parameters for both mainstream and the point and non-point source data are provided in each of the software's worksheets. The worksheets' tables have different colors for headwater, every reach, hydraulic, point source, diffuse, and water quality data to signify whether the column or row is for input by the user or the calculated output. The colors used are blue and yellow for user input, green for output values, and dark colors for labels. Table 1 shows the a) calculated hydraulic input data, including the discharge flow and velocity, whereas b) simplified Manning values and elevation measured from geospatial map analysis of DEM on ArcMap GIS software.

**Table 1.** -a) Hydraulic input for each station

| Station / Reach | Discharges ($m^3/s$) | Velocity (m/s) |
|---|---|---|
| **1 (Downstream)** | 94.59 | 1.25 |
| **2** | 86.06 | 1.32 |
| **3** | 7.37 | 1.23 |
| **4** | 20.49 | 1.86 |
| **5 (Headwater)** | 19 | 1.64 |

**Table 1.**-b) Elevation and Manning Likas River.

| Reach | Elevation | | Manning Formula | | | | |
|---|---|---|---|---|---|---|---|
| | **Upstream** (m) | **Downstream** (m) | **Channel** Slope | **Manning** n | **Width** (m) | **Side slope** Left | **Side slope** Right |
| **1** | 11.582 | 8.839 | 0.000647 | 0.0150 | 6.00 | 0.000010 | 0.000010 |
| **2** | 8.839 | 8.839 | 0.000836 | 0.0150 | 10.00 | 0.000010 | 0.000010 |
| **3** | 8.839 | 14.63 | 0.000745 | 0.0150 | 12.00 | 0.000010 | 0.000010 |
| **4** | 10.363 | 14.63 | 0.000947 | 0.0150 | 10.50 | 0.000010 | 0.000010 |
| **5** | 10.363 | 9.144 | 0.000418 | 0.0150 | 13.00 | 0.000010 | 0.000010 |
| **6** | 9.144 | 12.192 | 0.000147 | 0.0150 | 13.00 | 0.000010 | 0.000010 |
| **7** | 13.411 | 9.144 | 0.000145 | 0.0150 | 13.00 | 0.000010 | 0.000010 |
| **8** | 9.144 | 6.706 | 0.000139 | 0.0150 | 25.00 | 0.000010 | 0.000010 |
| **9** | 6.706 | 5.486 | 0.000112 | 0.0150 | 26.00 | 0.000010 | 0.000010 |
| **10** | 5.486 | 7.925 | 0.000106 | 0.0150 | 29.00 | 0.000010 | 0.000010 |
| **11** | 7.925 | 3.658 | 0.000090 | 0.0150 | 29.00 | 0.000010 | 0.000010 |
| **12** | 3.658 | 8.230 | 0.000089 | 0.0150 | 20.00 | 0.000010 | 0.000010 |

Ten days of water level is obtained through data processing from the Sentinel 3-A satellite image, directly built-in within the DEM. This remote sensing technique was similarly applied by a previous study (Bogning *et al.*, 2018) and proved its viability for the data's reliability and availability. Minimal data sampling was carried out during rainy days due to safety risks. Hence alternative data adapted from Sarda and Sadgir (2015) (Table 2) under low flow velocity or critical condition for each station was used so that the results could be fit to the steady flow as suggested by the QUAL2K model. The practical justification is essential to ensure that the QUAL2K model can simulate the output result.

The QUAL2K program is written using Visual Basic for Applications (VBA) with Excel (xl.exe) as the interface. It solves the governing equation using a finite-difference (implicit backward method) and is set up as a one-dimensional steady-state with a completely mixed system (Mustafa *et al.*, 2016). The observed data is calibrated with post-monsoon season data from the previous literature. However, some of the properties need to be adjusted to provide the best-fit relation and minimize the possible errors (Al-Dulaimi, 2017). At the final stage of trial and error, the difference between observed and simulated data is recorded, whereby the percentage of errors is determined.

**Table 2.** Alternative data for water quality in Likas River.

| Headwater water quality | Units | Alternative if data is not available |
|---|---|---|
| **Organic Nitrogen** | ugN/L | Dissolved Org. Nitrogen (DON) |
| **Dissolved Inorg. Nitrogen (DIN)** | ugN/L | NH4+NO3+NO2 |
| **Inorganic Solids** | MgD/L | 50% of Total Solids* |
| **NH4-Nitrogen** | ugN/L | Ammonia Nitrogen |
| **NO3-Nitrogen** | ugN/L | Nitrate Nitrogen |
| **Organic Phosphorus** | ugP/L | 35% of Total Phosphorus (P-Tot) ** |
| **Inorganic Phosphorus (SRP)** | ugP/L | 65% of Total Phosphorus** |
| **Phytoplankton** | ugA/L | Put as zero |
| **Detritus (POM)** | MgD/L | 20% of Suspended Solids ** |
| **Generic Constituent** | user-defined | Consider as COD |

## RESULT AND DISCUSSION

Figure 3 (a-b) shows the output result from the QUAL2K model for the predicted DO and BOD along the Likas River that exceeds the national water quality standards (NWQS) requirements. Being in Type Class III and below, the DO and BOD5 should not exceed 5mg/l and 6mg/l, respectively. The simulated DO in Figure 3a) ranges between 1.3 mg/l to 5.9 mg/l, whereas the simulated BOD5 in Figure 3b) ranged from 5mg/l to 7mg/l within two months prediction period. The first two reach shows a decrease in DO and increases in BOD5 concentration as the headwater for Likas River combines with several outflows, including from nearby Industrial centers along the river. Then, there is a sudden spike of DO value and a downfall BOD5 at the third reach of approximately 7.4km from the downstream of Likas River, where there is less contamination that might be due to self-purifying of the streams. However, at the fifth reach, DO concentration decrease, and BOD5 increases again. Potentially, due to the high loading of organic matter from polluted point source discharges from neighboring residential areas, reseller/store, and landfill areas for development.

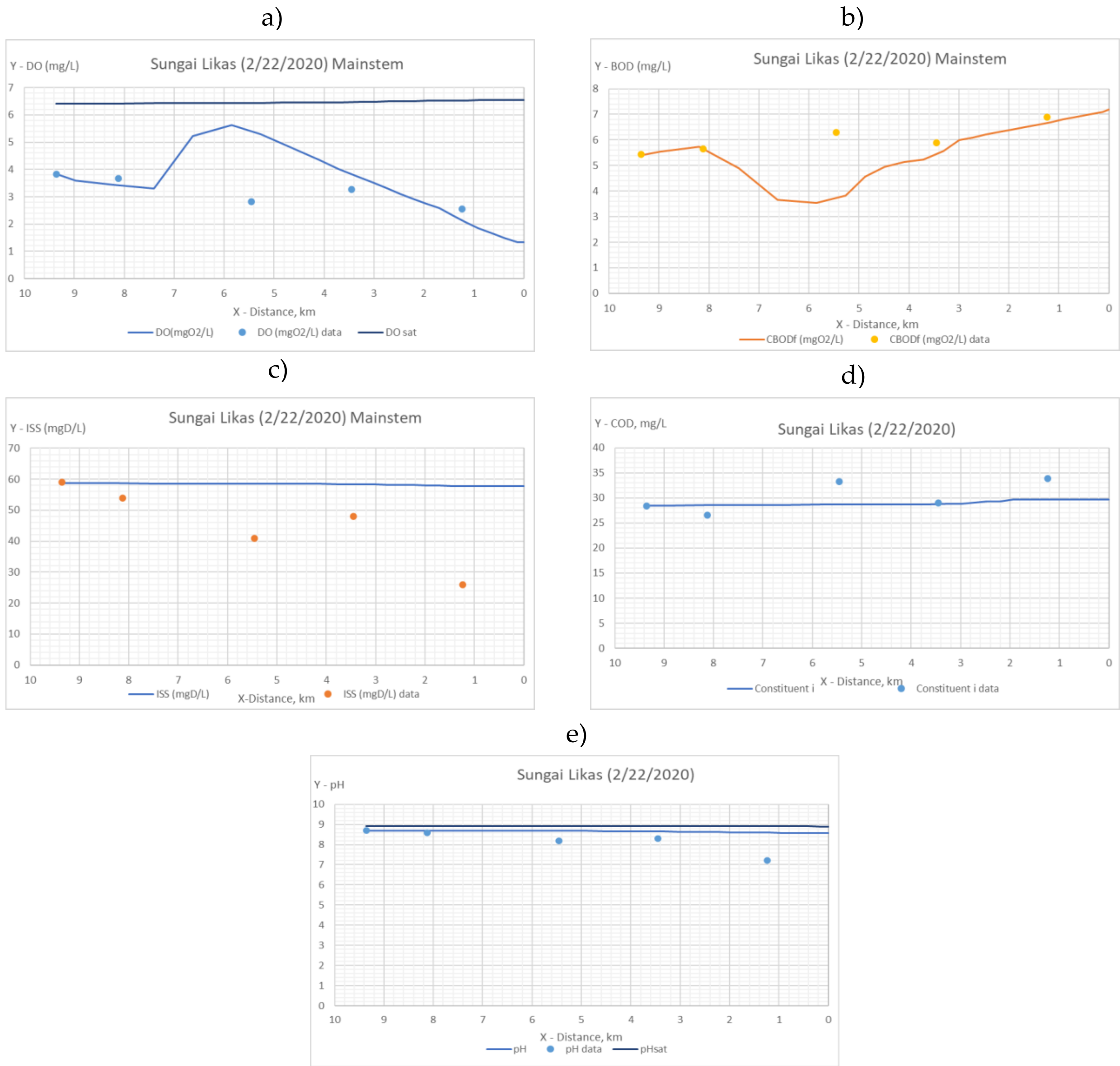


**Figure 3.** The observed and simulated graph for selected water quality parameters along the X-distance (km) of the Likas River. a) DO; b) $BOD_5$; c) TSS; d) COD; e) pH

The water quality parameters are evaluated based on the dry season scenario. The river flowing at a range of 19 $m^3/s$ to 98 $m^3/s$ is considered a medium size. Also, the sampling was done during the post-monsoon season between November and February. There is no sign of a decrease in pollutants level when the water flows from upstream to downstream (shown in Figure 3 as X-distance with '0' for downstream). There is a constant high value of TSS along the river ranging from 55 mg/l to 60 mg/l shown in Figure 3c). From the observed data, there was a declination of TSS when flowing from headwater to the downstream. This may have resulted from the constant output of both the point and non-point source along the river that contaminated the water by a wide variety of pollutants, including silt, decaying plants, animal droppings, industrial wastes, and sewage. However, there is an insignificant change to COD concentration and pH, as shown in Figures 3d) and 3e). From this simulation and observation, the DO, BOD, and TSS exceed the permitted limits for maintaining the river quality of Class III. Thus, to improve the river water quality, the values in terms of DO, BOD, and TSS may require further attention with room for potential improvements. Table 3 tabulated the root-mean-square-error (RMSE) analysis that compares both the observed and simulated data for model calibration and validation. Based on the result obtained, the simulated data has almost similar validity to the experimental data, which falls between 0.9–1.0 or more than 90%. Hence, acceptable (Zhang *et al.*, 2012). Except for the TSS, the observed and simulated value is less than 90% due to the physical properties primarily affected by the hydraulic input and elevation and roughness of the river channel.

**Table 3.** Root Mean Square Error between observed and simulated data.

| Parameters | Root Mean Square Error |
|---|---|
| **DO (mg/L)** | 0.952 |
| **BOD (mg/L)** | 0.937 |
| **COD (mg/L)** | 0.965 |

## RECOMMENDATION FOR RIVER QUALITY IMPROVEMENT

Several techniques for river quality improvement can be adopted from the best management practices (BMPs) as outlined in the Urban Stormwater Management Manual (USMM) (USMM, 2012). This includes permanent facilities such as infiltration, ponding, wetland retention systems, and erosion and sediment control structures. These can be applied to control pollutant loads from the point and non-point source at the highly polluted area and enforce stricter law, particularly for the industrial sector (Uddin *et al.*, 2018). Urban drainage practices, as described by Zakaria *et al.* (2011), can also be implemented to minimize the pollution factors through turfing, mulching, and trenching to promote solid-liquid separation and allow for cleaner effluent to enter the river directly.

Typically, granular sand media (Ahn *et al.*, 2017) and gravel are widely used in water filtration facilities. For instance, sand filter basins allow for settling, filtration, and adsorption in treating discharge flow. It requires less land usage, applicable in arid climates, provides high TSS removal, and easy to inspect. However, it has inadequate dissolved pollutant removal, high maintenance, clogging and aesthetic issues, and poor safety performance (SARA, 2019). This is similar to a vegetated filter strip and grassed swales that performed better in removing particulate bound such as TSS than dissolved pollutants, including metal and nutrients (Boger *et al.*, 2018). Since stormwater pollutants, especially heavy metals, and nutrients (Segismundo *et al.*, 2017), are majorly attached to TSS (Kandra *et al.*, 2014), the TSS parameter is essential for removing various pollutants from the stormwater. High TSS diffuses daylight and decelerates photosynthesis. It causes a reduction in DO concentration and affecting aquatic life. Hence controlling TSS would reduce the BOD by maintaining high DO concentration in the river flow.

Recent findings on using alternative materials as single media or in combination with other materials have also attracted interest from various researchers (Farizoglu *et al.*, 2003; Budari *et al.*, 2013). Each filtration material is separately useful for a particular parameter (Abdullah *et al.*, 2015) in removing pollutants. Since there is a need for these alternatives, investigation on other potential sustainable sources is significant. For example, agro-wastes such as rice husk, ficus tree, cottonwood, almond shell, sunflower stalk, and sugarcane stalk in the filtration applications have shown favoring potential (Bismarck *et al.*, 2002; Awang Ali & Bolong, 2019). These agro-wastes can be considered renewable sources, inexpensive, readily available, environmental-friendly, and may become income sources for the agriculture sector (Yahya *et al.*, 2018).

## CONCLUSION

Based on the observed and simulation results, it was concluded that the pollutant concentrations in the Likas River increased due to the effluents discharges from nearby residential areas and industries. The Dissolved Oxygen (DO) concentration ranges from 4mg/l to 6 mg/L at the upstream and 1mg/l to 2mg/L at the downstream. The concentration of COD, pH, and TSS was predicted to have a constant rate along the river with minimum changes as compared to observed data. The pollutants, particularly the TSS has rapidly discharge into the river, affecting the values that differ from the observed data. The predicted data for DO and BOD values are slightly different from the experimental data. The predicted values are affected by the river's self-purification action, and the different types of pollutants discharge with various DO values. In summary, the calibration and validation between the observed and predicted values measured using the RSME analysis or coefficient of determination $R^2$ shows that the QUAL2K model can generate a reliable simulation of more than 90% to represent the water quality parameters for each reach and station.

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