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Water quality assessment of Bukit Merah Reservoir, Malaysia using mathematical modeling

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Abstract. Bukit Merah Reservoir (BMR), Perak is the oldest man-made reservoir in Malaysia, situated in Kerian District, northern part of Perak, Malaysia, purposely to provide irrigation water to Kerian Irrigation Scheme (KIS) for rice cultivation. Thus, a study focuses on the determination of the current water quality status of the reservoir was conducted in November 2018 and February 2019 as a representative for the wet and dry season, respectively, in order to assist the prediction of the water quality in BMR and its impact towards the ecosystem. Five sampling stations were chosen to provide a general overview of physico-chemical profile in BMR. Physico-chemical parameters (i.e.: temperature, dissolved oxygen, conductivity, total dissolved solids, pH, and water transparency) were measured in situ whereas in the laboratory, total suspended solids, chlorophyll-a, and nutrient analysis were done in accordance to APHA (2005). The concentration of dissolved oxygen (DO) and biological oxygen demand (BOD) were simulated in a graph using Water Quality Analysis Simulation Program (WASP). Based on the analysis conducted throughout the study, the result indicated that the temperature, pH, chlorophyll-a, orthophosphate, and nitrate-nitrogen were higher in November 2018 compared to February 2019 which is 31.3°C, 6.8, 0.0533 µg/L, 0.0158 mg/L, and 0.1731 mg/L, respectively. One-way ANOVA showed that temperature and pH were significantly different between stations ($p<0.05$). WASP was used to validate the calculation to make sure that other parameters including DO saturation level, BOD loading, BOD decay rate, and reaeration rate values are reflected in the simulation graph. As for the initial study, this model reflects the current condition of DO and BOD level in the reservoir, but in future the reservoir should be divided into segments in order to obtain a more realistic prediction. The accuracy of the predictions can be improved with more input of water quality data.

1. Introduction

Freshwater lakes and reservoirs are one of the main sources of water supply that function as hydroelectric power generator, storage basins mainly for domestic water supply, industrial water supply, municipals, agriculture, and irrigation purposes. Lake and reservoirs are best known for their importance in supporting the repository of biodiversity and the ecosystem especially for the endemic, rare and endangered species [1]. Some reservoirs were built as a flood control detention storage especially for flood mitigation to buffer the flow of water during wet and dry seasons.

Water quality status in most water resources, however, is deteriorating from natural and anthropogenic activities. External inputs, for instance, the organic and inorganic pollutants, and nutrient loading entered the water bodies, thus deteriorating the water quality [2]. Due to the growth of the human population and urbanization in the watersheds, it has finally triggered the land use activities surrounding the water bodies. Unrestrained land-use could impact the lakes and reservoirs through the runoff from any anthropogenic activities. According to Sharip and Zakaria [1], Akinbile *et al* [3], and Qin *et al* [4], the most common deterioration in water quality is sedimentation, eutrophication and weed infestation. Eutrophication occurs due to the substantial increase of fertilizer needed by plants which usually contains nutrients, for instance, nitrogen and phosphorus, which increase the productivity of aquatic microorganisms.

Bukit Merah Reservoir (BMR) is facing a major threat to its water quality due to sand mining, land clearing and multiple land conversions including oil palm plantation. Hence, this study focuses on the determination of the current water quality status of the reservoir in order to assist in the prediction of the water quality in BMR and its impact towards the ecosystem. A mathematical model using Water Quality Analysis Stimulation program (WASP) based upon data collected during the research conducted in the lake was developed to assess the nature of the water quality degradation by simulating the graphs of DO and BOD concentrations.

2. Methodology

2.1 Study sites

Bukit Merah Reservoir (BMR) is a well-known oldest man-made lake in Malaysia and was built as a modified homogenous embankment, situated in Kerian District, northern part of Perak State, Peninsula Malaysia. Built in 1902 for the Kerian Irrigation Scheme (KIS) and was operated since 1906, BMR has the capacity of 70 million m^3, with the length of 13.8 km and the width of 4.5 km [5]. According to Drainage and Irrigation Department [6], the maximum depth of the lake is 5.3 m while the mean depth is 2.5 m. The water sources that flow into the reservoir came from two main catchment areas specifically, Kurau River Basin and Merah River Basin including some tributaries that link up with the reservoir.

The main purpose of BMR is for the irrigation to KIS especially for rice cultivation that covers approximately 23,560 hectares of paddy field and to channel water supply for Kerian and Larut Matang District and for the sanctuary of *Scleropages formosus*, a commercially valuable freshwater fish also known as Arowana Malayan gold [6]. BMR is divided into 2 sections which are the northern part and the southern part of the reservoir by a 4 km railway-line that is constructed across the reservoir, by Keretapi Tanah Melayu Berhad (KTMB). Bukit Merah Dam consisted of a main dam, 2 saddle dams, a gated service spillway, a gated auxiliary spillway, and an intake structure. Land use of BMR was mainly made up of the virgin and primary forests (46.29%), agriculture (palm oil plantation), and a breeding farming industry (national boar breeding centre) for economical purposes (48.80%) [7, 8]. Five sampling stations (ST1, ST2, ST3, ST4, and ST5) around BMR were established (figure 1). The description of the surrounding areas of each sampling site is shown in table 1.

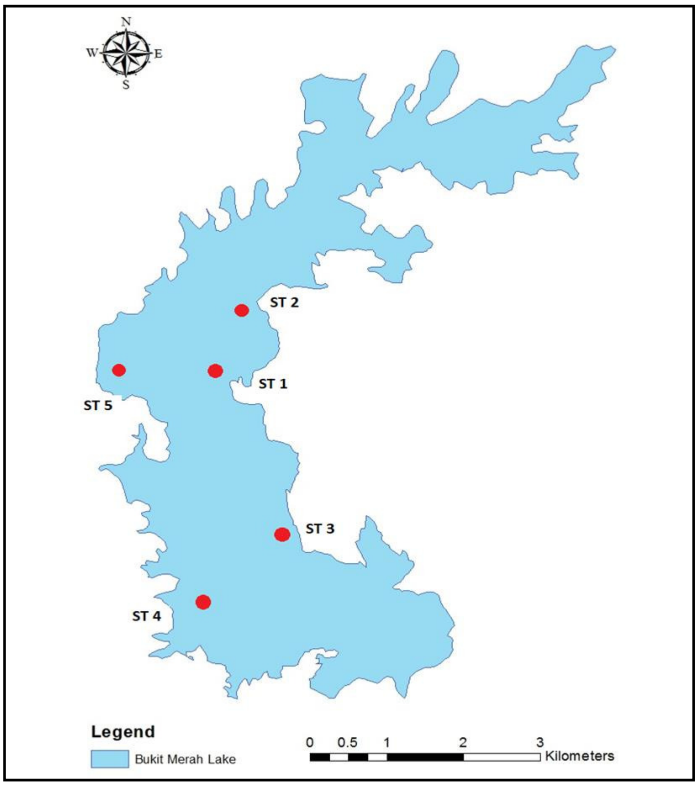

Figure 1. Location of five sampling stations (Station 1 – Station 5) in Bukit Merah Reservoir (BMR)

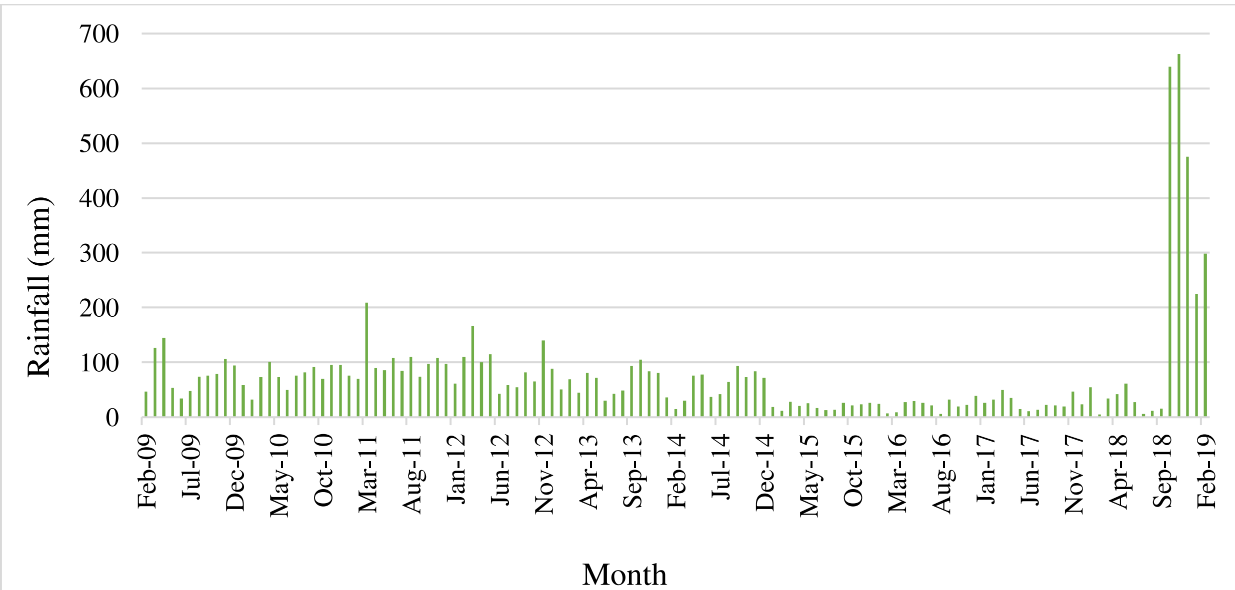

Figure 2. Monthly variation of average rainfall at Bukit Merah Reservoir (BMR) station from February 2009 to February 2019 in 10 years period.

Table 1. GPS coordinate and description of each sampling stations in Bukit Merah Reservoir

Stations	Coordinate	Description of station
ST1	N 05° 01’ 56.8” E 100° 39’ 54.9”	Located near to the inlet of Sungai Kurau Basin.
ST2	N 05° 02’ 20.6” E 100° 40’ 10.3”	Considered as the upper northern area and located near to the new railway line of Bukit Merah Reservoir.
ST3	N 05° 00’ 39.9” E 100° 40’ 26.3”	Located near to the Orang Utan Island and considered as the southern part of the reservoir.
ST4	N 04° 59’ 59.5” E 100° 39’ 51.3”	Located in between the Orang Utan Island and the lakefront resort and waterpark.
ST5	N 05° 02’ 08.0” E 100° 39’ 10.6”	Located near to the spillway of Bukit Merah Reservoir.

2.2 Sampling design of Bukit Merah Reservoir
The measurement of the water quality parameters *in-situ* and the water samples collection were done in November 2018 (663.1 mm) and February 2019 (298.3 mm) as the representative of the wet and dry season, respectively. Figure 2 showed the monthly variation of rainfall at Bukit Merah Reservoir (BMR) station from February 2009 to February 2019 in 10 years period. The sampling stations were chosen based on their vicinities to human activities and land use nearby in order to provide an overview of the physico-chemical profile of the water. Therefore, five sampling points in Bukit Merah Reservoir (BMR) were chosen and the coordinate of each sampling point were marked by using a handheld GPS (table 1). Station 1 was chosen based upon its location which situated at the river mouth of Kurau River where the water source came from the river into the reservoir. Station 2 is considered as the upper northern area of the reservoir and it is located near to the railway line of BMR. There was less water movement in this area since it is shaded with the railway line. Station 3 is situated at the southern part of the reservoir, near to the Orang Utan Island. Station 4 is located in between the Orang Utan Island and just 200 m away from the Bukit Merah Laketown and Bukit Merah Laketown Resort. Riparian vegetation consists of Rasau tree, *Hanguana malayana* and bushes, present nearby the station while station 5 is located near to the spillway of Bukit Merah Reservoir. Station 3 and 4 were also chosen as it is situated in the embayment area. Embayment areas are classified by a large diameter of surface water which is exposed to the wind turbulence directly. Station 1 is located near to the riverine zone whereas Station 2, Station 3, Station 4 and Station 5 are located in the transition zone.

2.3 Measurement of physico-chemical parameters and nutrient analysis
Temperature (°C), dissolved oxygen (DO, mg/L), pH, electrical conductivity (S/m) and total dissolved solids (TDS) were recorded *in-situ* using a multi-probe meter (YSI 6,600 MPS). Measurement of the parameters was carried out slightly under the water surface. Water transparency provides information on the underwater light condition and was measured by using a Secchi disc and a measuring tape. In triplicate, 250 ml of water samples were collected at the sampling sites to carry out nutrient analyses, chlorophyll-*a* (chl-*a*) and total suspended solids (TSS) while another triplicate of water samples were collected using BOD bottles and were covered with aluminum foil to prevent the penetration of sunlight for biological oxygen demand determination (BOD_5). The concentration of NH^4-N was determined by using the low indophenol method where the reaction between ammonium with the phenol reagent and hypochlorite solution produced blue indophenol colour [9]. Diazotization method was used to determine the NO^2-N concentration in which a pink colour compound was formed during the reaction of nitrite, sulphanilamide reagent and N-(1-naphthyl)-ethylenediamine dihydrochloride [9]. Additionally, the

NO^3-N concentration was determined by the cadmium-reduction method using a cadmium column system [9]. In order to determine the ortho-phosphate concentration, Boyd and Tucker [10] method was used. A blue colour solution formation was observed when a reaction occurs between sulfuric acid, potassium antimonyl tartrate, ammonium molybdate and ascorbic acid [11]. As for the BOD determination, BOD_5 was done in which the DO level of the water samples that were stored in the dark place inside the wood box to avoid sunlight penetration and were checked using DO meter after 5 days. The reading of DO after 5 days were compared to the initial DO to find the value of BOD.

2.4 Statistical analysis
Prior to analysis, parametric univariate analyses (One-Way ANOVA test, Tukey's HSD) using SPPS version 22 were used to determine the significant difference of water quality parameters among stations.

2.5 Water Quality Analysis Simulation Program (WASP)
Water quality modeling is a tool used to observe the natural phenomenon of water bodies and to simulate a model to represent the environmental situation since the whole actual environment is too complex to be described fully. With the help of modeling, any threats or pollutant intrusion which would transform the water quality condition in the aquatic environments could be predicted and simulated. Water Quality Analysis Simulation Program (WASP) is constructed by the eutrophication model which was implemented in WASP 7.3 [12]. In this study, DO and BOD were taken into consideration to be simulated using this model. Simulation of the BOD and DO parameters using WASP can be used as a prediction tool in order to reflect the current condition and to predict the future condition of the DO and BOD levels in the reservoir [12]. Physical parameters of BMR data for instance reservoir surface area (km^2), mean depth (m), reservoir volume (mil m^3) and the maximum depth (m^3) were obtained from the Department of Irrigation and Drainage for the calibration and validation purposes. An analytical model which involved basic steady-state equation developed by Streeter and Phelps was used for dissolved oxygen (DO) and biological oxygen demand (BOD) simulation [13].

The equation was as follows:

BOD (mg/L)
$$dl / dt = -\alpha l + \gamma$$

DO (mg/L)
$$dc / dt = -\alpha l + \beta (Cs - C)$$
where,

l = BOD mean concentration, mg/L
C = DO mean concentration, mg/L
Cs = DO saturation level, mg/L
t = time, day
β = reaeration rate, day^{-1}
γ = BOD loading, mg/L/day
α = BOD decay rate, day^{-1}

3. Results and Discussion
3.1 Water quality parameters
Mean water temperature was ranged between 29.3 ± 0.94°C and 31.3 ± 0.94°C during sampling on November 2018 and February 2019. The lowest temperature was recorded at Station 2 whereas the highest temperature was recorded at Station 3 and 4. There was a significant difference between the mean of water temperature among sampling stations (One-way ANOVA, $p<0.05$). Tukey's HSD proved that the temperature at Station 4 and 5 were significantly higher than other stations ($p<0.05$). In BMR, the temperature was consistent during the sampling events although there was a drop in temperature

observed at certain stations especially Stations 1 and 2 due to the time factors in which the samplings were carried out before noon. The water temperature reading shows the highest at Station 5 as the collection of samples were carried out during the higher radiation adsorption and degree of exposure to sunlight.

Based on table 2, Station 2 showed the lowest reading of dissolved oxygen with the value of 5.3 ± 0.688 mg/L in November 2018 whereas the highest reading of 15.2 ± 3.159 mg/L was recorded at Station 5 on February 2019. Based on one-way ANOVA test, there was no significant difference of DO among the stations ($p>0.05$). The mean concentration of DO was higher in February 2019 compared to November 2018 (table 2). This could be due to the algal productivity level that carries out more photosynthesis and produced more oxygen which causes the high DO in water. According to Mollah *et al* [14], photosynthetic activity, respiration, and decomposition of aquatic organism and process of oxygen diffusion from the atmosphere are some of the factors that could influence the DO concentration in water. Boyd [11] noticed that whenever any water bodies were covered with shade or situated at any shady area, it can experience a huge drop in DO during the phases of warm weather thus explained the lowest reading of dissolved oxygen at Station 2 which were located near to the railway line. Station 2 recorded the lowest (26.8 ± 0.559 S/m) and the highest (30.2 ± 0.750 S/m) mean conductivity reading in November 2018 and February 2019, respectively. Ismail and Najib [5] identifies that higher water conductivity could be due to the water discharges from Kurau River that carried along with sediments and a high level of inorganic pollutants based on non-point sources. There was an insignificant difference in the mean conductivity among the sampling stations ($p>0.05$).

From table 2, the result indicated the range of mean TDS reading between 16.26 ± 0.98 to 18.2 ± 0.98 mg/L in November 2018 and 18.2 ± 0.58 to 19.5 ± 0.58 mg/L in February 2019. The highest mean TDS was recorded at Station 1, 2, 3 and 5 in February 2019 whilst the lowest was found at Station 5. The higher mean of TDS reading obtained from the study could be due to the non-point sources pollution which includes industrial effluent and wastewater transported along Kurau River changed the water balance due to the limiting inflow or increased precipitation which can cause changes in TDS concentration [15]. Based on one-way ANOVA test, no significant difference in the TDS concentration among sampling stations ($p>0.05$). From the data in table 2, it is apparent that February 2019 recorded the lowest pH reading in Station 2 while November 2018 showed the highest reading in Station 1. Verma and Singh [16] suggested that due to acid rains or any surface run-off discharged from nearby industries or agriculture as well as sewage tends to change the pH of the water bodies. From the study, the pH mean was significantly different among stations (One-way ANOVA, $p<0.05$). Tukey's HSD indicate that Station 2 have significant differences with Station 1, 3 and 4 while Station 3 has a significant difference with Station 5.

One-way ANOVA confirmed that there was no significant difference of water transparency between stations ($p>0.05$). The mean of water transparency was ranged between 31.0 ± 16.2 and 95.7 ± 13.55 cm. The highest mean of water transparency was recorded at Station 4 in February 2019 whereas the lowest reading was recorded at Station 1 in November 2018. Run-off from the surrounding areas near BMR including residential areas and urban development causing the increase of organic and inorganic suspended solids, sediments, debris and silts in water bodies, thus contributed to the low water transparency [17]. Thus, Station 1 recorded the lowest reading of water transparency as it was located at the inlet of Kurau River carrying the inflow of run-off water. A study finding proves that Kurau River is the major contributor of large sediment and nitrogen loading as it is the largest catchment area compared to the other three river inlets [5].

The mean TSS analyzed was ranged between 14.4 ± 2.12 to 43.73 ± 2.41 mg/L and 35.33 ± 2.81 to 71.73 ± 5.22 mg/L in November 2018 and February 2019, respectively. Station 3 in November 2018 recorded the lowest mean TSS while Station 2 in February 2019 recorded the highest mean TSS. This could be probably due to the nearby development planning that causes high total suspended solids in domestic discharges. There was no significant difference of TSS mean among sampling stations ($p>0.05$). From table 2, Station 1 showed the lowest reading of mean chlorophyll-a concentration with the value of 0.0003 ± 0.0003 µg/L while the highest was recorded at Station 2 with the value of 2018

0.0544 ± 0.0937 μg/L, both in November 2018. There was an insignificant difference of the mean chlorophyll-a concentration among the sampling stations (p>0.05). Artificial lakes received more sediment loading due to increased shore erosion caused by higher fluctuations of water level [18, 19]. Consequently, lake turbidity was increased which then influenced the light penetration, Secchi depth reading, and chlorophyll-*a* concentration. Thus, it explained the highest reading of mean chlorophyll-a concentration in Station 2 as it located nearby to the development planning area. There is a significant correlation between chlorophyll-*a* and phytoplankton density [20]. Eutrophication is related to high productivity while nutrients especially nitrogen and phosphorus promote algal growth which causes high chlorophyll concentration [21].

The mean orthophosphate concentration analyzed from the water collected in each station were calculated and was ranged between 0.0132 ± 0.0007 mg/L to 0.0158 ± 0.0009 mg/L. Station 1 in February 2019 recorded the lowest reading of mean orthophosphate concentration while Station 1 in November 2018 showed the highest reading of mean orthophosphate concentration. Based on one-way ANOVA test, there was no significant difference between the mean orthophosphate concentration among sampling stations (p>0.05). Phosphate can enter the reservoir either being directly deposited in the sediment as particulate form or integrated into organic matter by primary producers as dissolved phosphate that eventually subsides into the water [22, 23]. Thus, explain the higher reading of mean orthophosphate concentration in November 2018 due to the rainfall during the sampling period and causing phosphate to enter the reservoir from the Kurau River inlet.

The mean of ammonia-nitrogen concentration in November 2018 ranged between 0.0042 ± 0.0065 to 0.3054 ± 0.2276 mg/L while in February 2019 ranged between 0.0158 ± 0.0085 to 0.3108 ± 0.4099 mg/L with the lowest mean of ammonia-nitrogen was recorded at Station 5 in November 2018 while the highest reading was recorded at Station 4 in February 2019. Ammonia-nitrogen can enter the water body through the residential sewage, industrial sewage, and animal wastes. Moreover, through the process of denitrification, nitrate is converted to ammonium or free nitrogen (N_2) by bacterial activity that may diffuse into the water phase and to the atmosphere and thus varnished from the system [23]. The amount of ammonia in BMR is lower compared to the amount of nitrite and nitrate. In that study, the observation showed that nitrite and nitrate remained in the reservoir while ammonia was removed from the reservoir through the process of nitrification where bacteria present in the water break down the ammonia thus, release the nitrogen gas into the atmosphere [5]. There was an insignificant difference of the mean ammonia-nitrogen concentration among the sampling stations (One-way ANOVA; p>0.05).

Station 1 in February 2019 showed that the lowest mean of nitrite-nitrogen concentration recorded reading which is 0.0169 ± 0.0003 mg/L and Station 4 showed the highest reading of 0.0373 ± 0.0314 mg/L in February 2019. As suggested by Ismail and Najib [5], the uptake by vegetation, denitrification process and sedimentation are among the factors that lead to the increase amount of nitrite-nitrogen especially in Station 4 where it is situated near to the Bukit Merah Laketown where sedimentation activities due to soil erosion transported by the water from the laketown. Based on one-way ANOVA test, there was no significant difference of nitrite-nitrogen concentration among the stations (p>0.05). The mean of nitrate-nitrogen concentration in November 2018 ranged between 0.1235 ± 0.0157 to 0.1731 ± 0.0053 mg/L while in February 2019, mean of nitrate-nitrogen concentration ranged between 0.0943 ± 0.0060 to 0.1224 ± 0.0044 mg/L. Station 1 in February 2019 indicated the lowest mean concentration of nitrate-nitrogen whilst the highest mean of nitrate-nitrogen concentration was recorded at Station 1 in November 2018. In this study, the concentration of nitrate-nitrogen was the highest at all sampling stations in November 2018. The variations in nitrate concentration were due to human activities nearby the reservoir and its watershed which results from the leaching and run-off from the nearby agricultural area and oil palm plantations near BMR [17]. This study showed that the rainy season is the peak of agricultural activities near BMR also leads to an increase in the concentration of nitrate. During the rainy season, the nitrate is soluble enough to get carried away by surface run-off, thus increasing the concentration of nitrate in water bodies. Based on One-way ANOVA test, there was a significant difference between the nitrate-nitrogen concentration among sampling stations (p<0.05).

The mean of biological oxygen demand was ranged between 2.88 ± 0.60 mg/L and 11.27 ± 0.15 mg/L. The highest mean of biological oxygen demand was recorded at Station 5 in February 2019 while the lowest mean concentration of BOD was recorded at Station 3 in November 2018. A study by Akinbile *et al* [3] showed the concentration of BOD was in the range of 6 to 12 mg/L in the water samples from Merah River and Jelutong River which also nearly similar in range with this recent study in BMR. High BOD indicates a high number of microorganisms which suggest a high level of pollution in the area. Thus, suggesting that Station 5 recorded a high mean of biological oxygen demand due to its location at the outlet of the reservoir. It indicates that the water was rich with nutrients, mainly nitrates and phosphates, before being outflowed from the reservoir. One-way ANOVA test indicated that there was no significant difference between the BOD concentration among sampling stations ($p>0.05$).

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Table 2. The mean reading of all measured parameters during wet (November 2018) and dry season (February 2019)

Parameters	November 2018	February 2019
Temperature (°C)	29.3 ± 0.94 to 31.3 ± 0.94	29.7 ± 0.34 to 30.5 ± 0.34
Dissolved Oxygen (mg/L)	5.3 ± 0.69 to 7.1 ± 0.69	7.1 ± 3.16 to 15.2 ± 3.16
Conductivity (S/m)	26.8 ± 0.56 to 28.1 ± 0.56	28.3 ± 0.75 to 30.2 ± 0.75
Total Dissolve Solid (ppm)	16.26 ± 0.98 to 18.2 ± 0.98	18.2 ± 0.58 to 19.5 ± 0.58
pH	5.99 ± 0.36 to 6.8 ± 0.36	5.89 ± 0.26 to 6.52 ± 0.26
Water transparency	31.0 ± 16.2 to 69.0 ± 16.2	61.8 ± 13.55 to 95.7 ± 13.55
Total Suspended Solid (mg/L)	14.4 ± 2.12 to 43.73 ± 2.41	35.33 ± 2.81 to 71.73 ± 5.22
Chlorophyll-a (µg/L)	0.0003 ± 0.0003 to 0.0544 ± 0.0937	0.0050 ± 0.0029 to 0.0230 ± 0.0172
Orthophosphate (mg/L)	0.0140 ± 0.0015 to 0.0158 ± 0.0009	0.0132 ± 0.0007 to 0.0137 ± 0.0007
Ammonia-nitrogen (mg/L)	0.0042 ± 0.0065 to 0.3054 ± 0.2276	0.0158 ± 0.0085 to 0.3108 ± 0.4099
Nitrite-nitrogen (mg/L)	0.0171 ± 0.0019 to 0.0318 ± 0.0187	0.0171 ± 0.0019 to 0.0318 ± 0.0187
Nitrate-nitrogen (mg/L)	0.1235 ± 0.0157 to 0.1731 ± 0.0053	0.0943 ± 0.0060 to 0.1224 ± 0.0044
Biological Oxygen Demand (mg/L)	2.88 ± 0.60 to 4.19 ± 0.46	3.87 ± 0.30 to 11.27 ± 0.15

3.2 Water Quality Analysis Simulation Program (WASP)

Table 3 showed the physical parameters of BMR including reservoir surface area (km^2), mean depth (m), reservoir volume (mil m^3) and maximum depth (m^3) which were obtained from DID [6] for the calibration and validation purposes. An analytical model which involved basic steady-state equation developed by Streeter and Phelps [13] was used for dissolved oxygen (DO) and biological oxygen demand (BOD). The value of reaeration rate, BOD loading, and BOD decay rate were obtained by substituting BOD mean concentration, DO mean concentration and DO saturation level in the steady-state equations for data input in the eutrophication model. By using the eutrophication model in WASP, the graph of DO and BOD concentration were simulated. Although the sampling was done for one day, the simulation was run to one-month period to predict DO and BOD variation for a longer time by adjusting the time range for the start date and end date in the data set.

Table 3. Brief information and technical data of Bukit Merah Reservoir, Perak, Malaysia [6]

Reservoir surface area (km^2)	41
Mean depth (m)	2.5
Reservoir volume (mil m^3)	83
Maximum depth (m)	5.3

Table 4 shows all the value of parameters for dry and wet seasons which need to be input in the appropriate section in WASP model. DO saturation level and BOD decay rate are constant value while DO and BOD mean concentrations were taken from the field data. The value of the reaeration rate and BOD loading were obtained from the calculation.

Table 4. Value of parameters for the dry and wet season

	Value (wet season)	Value (dry season)
BOD mean concentration, mg/L (l)	3.33	8.11
DO mean concentration, mg/L (C)	6.3	11.48
DO saturation level, mg/L (Cs)	6.3	7.54
Reaeration rate, day^{-1} (β)	1.0742	-0.8223
BOD loading, mg/L/day (γ)	1.332	3.24
BOD decay rate, day^{-1} (α)	0.4	0.4

Data were obtained when the WASP model was executed, and the results were displayed in the form of graph (x/y plots). The graph configuration menu which creates an x/y plot was obtained along with the data that is being plotted in x/y window. In the x/y plot, the predicted values of DO and BOD in November 2018 and February 2019 in one segment were presented in BMR.

The DO and BOD mean concentrations in BMR were input into the model and the output for the daily concentrations of the DO and BOD were provided by the model for one segmentation in November 2018 and February 2019 which represented the wet and dry seasons, respectively. In order to make the predicted value equal to the actual value, the parameters were adjusted.

Figure 3 shows that in November 2018, the mean DO concentration increased to 6.35 mg/L and converged to the mean value of 6.31 mg/L. Figure 4 shows that in November 2018, BOD concentration increased and converged to the mean value of 3.33 mg/L. Figure 5 shows that in March 2018 the mean DO concentration increased and converged to the mean value of 11.48 mg/L. Figure 6 shows that in February 2019, BOD concentration decreased and converged to 3.33 mg/L.

WASP was used to validate the calculation to make sure that other parameters including DO saturation level, BOD loading, BOD decay rate and reaeration rate values are reflected in the simulation graph. In the wet season, which is represented by figure 3 shows that the mean DO concentration increased to 6.35 mg/L and converged to the mean value of 6.31 mg/L; while, according to figure 4, BOD concentration increased and converged to the mean value of 3.33 mg/L. Hence, it is proven that the calculation and the values obtained for DO saturation rate, BOD loading, BOD decay rate and reaeration rate of this study in table 4 are correct as it reflects the exact data obtained from the field. Although the sampling was done for one day, the simulation was run to one-month period to predict DO and BOD variation for a longer time.

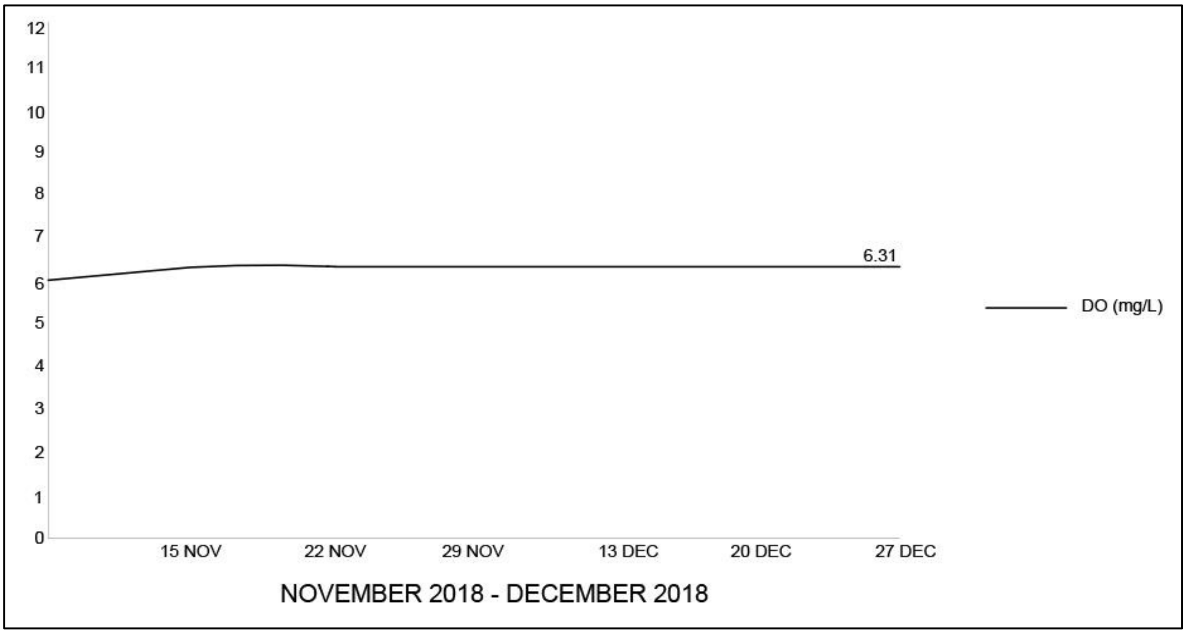

Figure 3. The x/y plot of the concentration of DO (mg/L) in BMR from November 2018 to December 2018 (wet season).

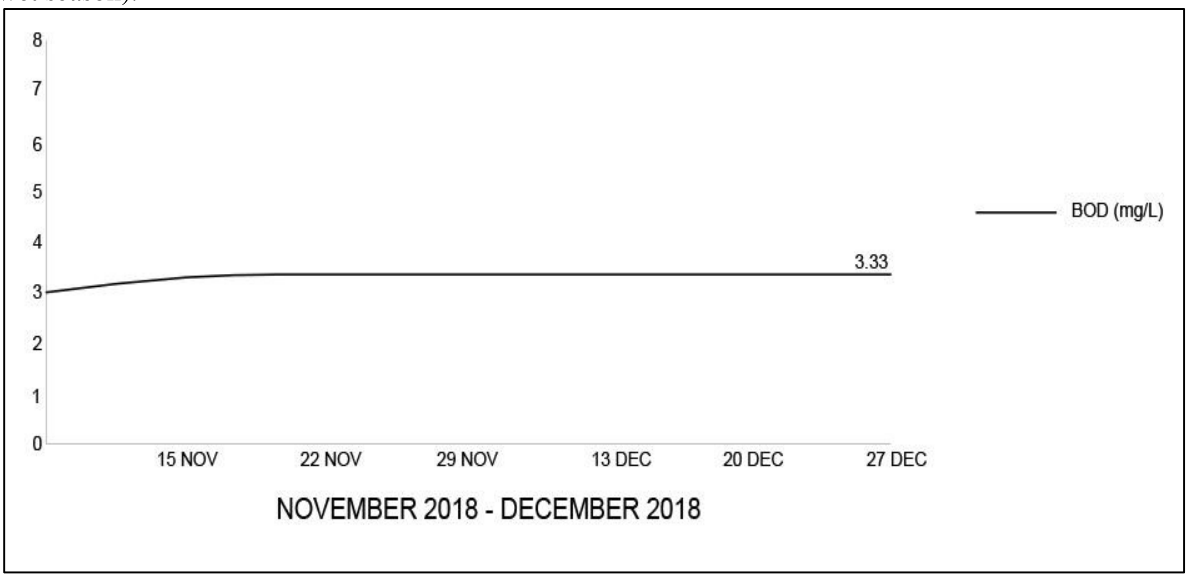

Figure 4. The x/y plot of the concentration of BOD (mg/L) in BMR from November 2018 to December 2018 (wet season)

As for the dry season, which is represented by figure 5 shows that the mean DO concentration increased and converged to the mean value of 11.48 mg/L, while according to figure 6, BOD concentration decreased and converged to 3.33 mg/L. The high value of DO and BOD may be affected due to the high rate of photosynthetic activity by algae productivity during the dry season because present study shows that the chlorophyll-*a* concentration was higher in February 2019 compared to November 2018.

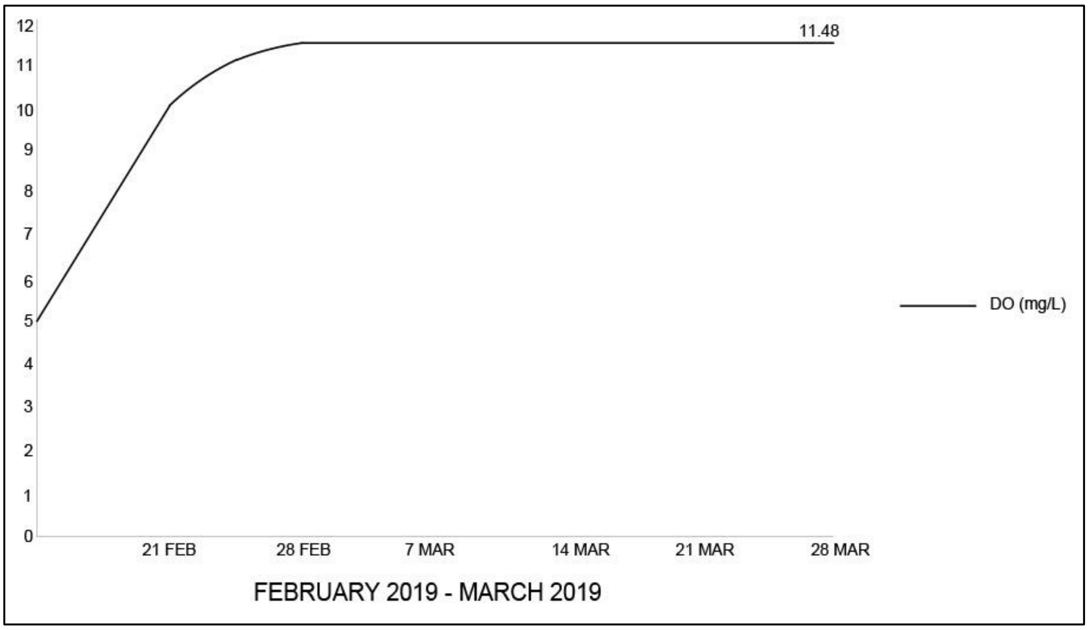

Figure 5. The x/y plot of the concentration of DO (mg/L) in BMR from February 2019 to March 2019 (dry season)

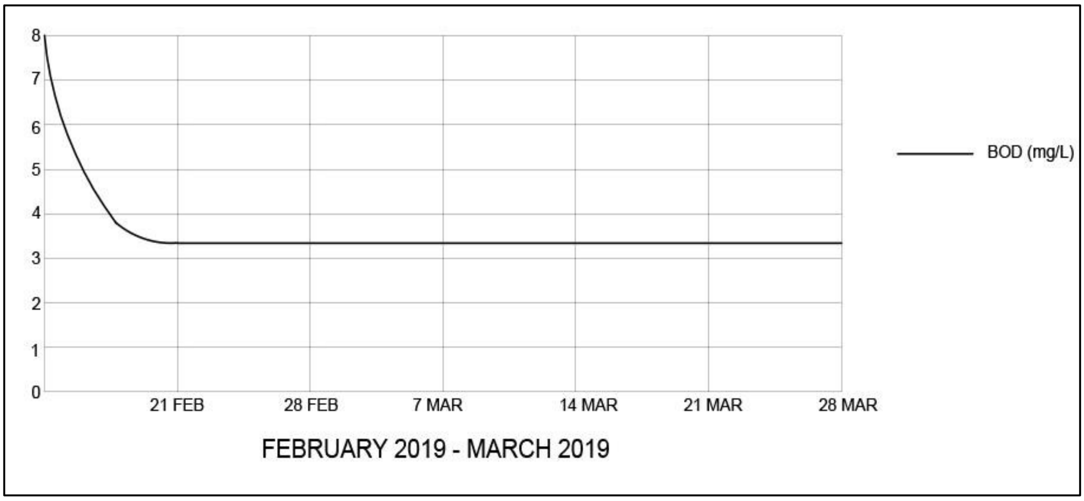

Figure 6. The x/y plot of the concentration of BOD (mg/L) in BMR from February 2019 to March 2019 (dry season)

In this study, only the values of DO and BOD were used to simulate data. For the simulation of chlorophyll-*a* and other parameters including phosphorus and nitrogen, longer period are required and more samplings are needed to be done in order to interpret and predict the long term water quality responses towards the natural phenomena that take place along with manmade pollution and it is beyond the scope of this project.

Moreover, the limitation of the model is that it discretizes the lake system into a specific number of segments in which it depends on the location of sampling sites followed by the prediction of the variations in the parameters on a segment-wise basis [12]. Different categories of data must be collected separately including the water volume in different segments, inflow and boundary characteristics, and environmental constants [12]. Therefore, only one segment is simulated in this study because the data for DO and BOD are almost constant throughout different locations in the reservoir for the initial study. In addition, only a limited number of water quality parameters which are orthophosphate, dissolved oxygen and nitrate can be predicted by WASP. This model reflects the current condition of DO and BOD level in the reservoir, but in the future there is a need to divide the reservoir into segments in order to obtain a more realistic and accurate prediction of the Bukit Merah Reservoir.

4. Conclusion

All the physico-chemical parameters measured showed variations among the sampling stations. BMR provides many essential functions to the surrounding areas including domestic water supply and support big-scale agriculture activities. However, human activities and urbanization that occur surrounding BMR could contribute to the degradation of water quality in BMR. Thus, it is important to have regular water quality monitoring to make sure that the water quality is safe enough to continue providing services.

In the present study, WASP was used to validate the calculation to make sure that other parameters including DO saturation level, BOD loading, BOD decay rate and reaeration rate values are reflected in the simulation graph. This model reflects the current condition of DO and BOD level in the reservoir, but in future there is a need to divide the reservoir into segments in order to obtain a more realistic prediction. The accuracy of the prediction can be improved with more input of water quality data.

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