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To cite this article: Z M Munirah *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **711** 012006

Water quality characteristics and modeling of *Tasik Aman,* USM, Penang

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Abstract. *Tasik Aman* was constructed in 1990 as a flood retention pond in the Universiti Sains Malaysia, Main Campus, Penang, Malaysia. *Tasik Aman* has been experiencing accumulation of excess nutrients from the surrounding area mainly from Sungai Gambir, causing high algae population in the water body. Thus, a study was carried out in December 2019, focusing on the current water quality determination of *Tasik Aman*, to predict the future water quality condition of the lake. Four sites were designated to conduct water quality analysis comprising of water temperature, dissolved oxygen (DO), pH, transparency, biological oxygen demand (BOD), total dissolved solids, total suspended solids, conductivity, orthophosphate, chlorophyll-*a*, total phosphorus, ammonia, nitrite, and nitrate. Some physico-chemical parameters were measured *in-situ* while some were measured in the lab by analyzing the water samples collected in the field in accordance with APHA (2005). DO and BOD data were modeled using Water Quality Analysis Simulation Program (WASP). *Tasik Aman* showed high readings in temperature, TSS, TDS, conductivity, DO, BOD, chlorophyll-*a*, and nitrate-nitrogen. One-way ANOVA further revealed significant differences of DO, TDS, conductivity, transparency, orthophosphate, nitrate, and chlorophyll-*a* among the stations of *Tasik Aman* ($p<0.05$). Based on WASP analysis, simulated graphs produced for *Tasik Aman* showed a decrease in DO and an increase in BOD level proving that the lake contain high nutrient content that may exacerbate the eutrophication.

1. Introduction

Lentic ecosystem, or a standing water body has been experiencing water quality problems such as eutrophication which often caused by the surplus of nutrients in the aquatic ecosystem. Water quality contamination mainly contributed by the industrial effluents, agricultural runoff and domestic sewage

which negatively impacted the quality of the receiving waters. Excessive loading of nitrogen and phosphorus into the water bodies has resulted in the adverse impact of eutrophication and its occurrence has been established as the global water deterioration issues [1]. Water quality degradation might directly reduce oxygen level in the freshwater environment impacting the biodiversity of the aquatic animals and plants.

Since early 1970s, Universiti Sains Malaysia has been progressively constructed and transformed from a former army barrack into a new learning campus consist of multiple concrete buildings and lecture halls as well as fascinating green scenery around the campus. Unfortunately, by 1990, due to land conversion from a rural to an urban environment, surface runoff has increased, resulting in the infrequent flooding issues around the campus area. Thus, one of the flood retention ponds named as *Tasik Aman* was constructed mainly to temporarily hold the overflow runoff of heavy rain, thus reduce the degree of flooding. *Tasik Aman* are home to various aquatic and terrestrial plants and animals apart from serving as a key time-out spot for the campus community to relish their spare time. Various recreational activities were carried out here for instance, jogging, kayaking, and camping. Ever since the construction, *Tasik Aman* has occasionally accumulating excess nutrients from the surrounding campus areas for example phosphorus and nitrogen which subsequently increase the algae population. *Tasik Aman* is covered with algae bloom that gave its green colour and emits unpleasant smell. Dead algae settled at the sediment bed and contribute to internal loading of nutrients which exacerbate the eutrophic condition.

Eutrophication caused wide fluctuation of dissolved oxygen in the lake [2]. Henceforth, a study was carried outto determine the present water quality status in *Tasik Aman* to review the water quality deterioration, as well as to predict the water quality in *Tasik Aman* and the influence on the ecosystem. Water Quality Analysis Simulation Program (WASP) was introduced in the study to develop a mathematical model. WASP is frequently used by researchers especially in the analysis of water quality. Most WASP analysis were done aimed towards the study relating to the aquatic ecosystem, any water column as well as the underlying benthos. WASP focuses on the interpretation and the prediction of the responses of water quality towards the natural phenomenon. This model is able to structure the water bodies in one, two, and three-dimensional models [3]. In this study, WASP was introduced to simulate the prediction of DO and BOD level based upon the current water quality condition.

Since the actual freshwater environment would be too complicated to be described wholly, water quality model would be beneficial to observe the ecological occurrence happened in the water bodies as well as to model the future forecast on the specific environmental situation. Any threats happened in the aquatic environment which would alter the water quality situation of the research areas can be simulated and predicted with the help of the modeling. In this study, Water Quality Analysis Simulation Program (WASP) version 7.3 was used to as a prediction instrument to signify the existing condition and to forecast the DO and BOD level in the water bodies.

2. Materials and Methods

A one-off sampling was performed at *Tasik Aman* on 20th December 2019. Four sampling stations (TA1, TA2, TA3, TA4) around *Tasik Aman* were accomplished (Figure 1). The depiction of the nearby area of each station is presented in Table 1.

Temperature, pH, dissolved oxygen (DO), total dissolved solids (TDS), conductivity, and turbidity were measured *in-situ* at the sampling sites. Temperature, conductivity, and TDS were assessed using the YSI ProPlus. DO concentration values were assessed using the YSI Model 550 handheld Dissolved Oxygen Meter while the pH was measured by using YSI pH meter. All water quality parameters were assessed slightly below the water surface. Water transparency was measured by lowering the Secchi disc into the water in order to obtain the information of the underwater light condition. Locations of the sampling points were recorded using a handheld GPS.

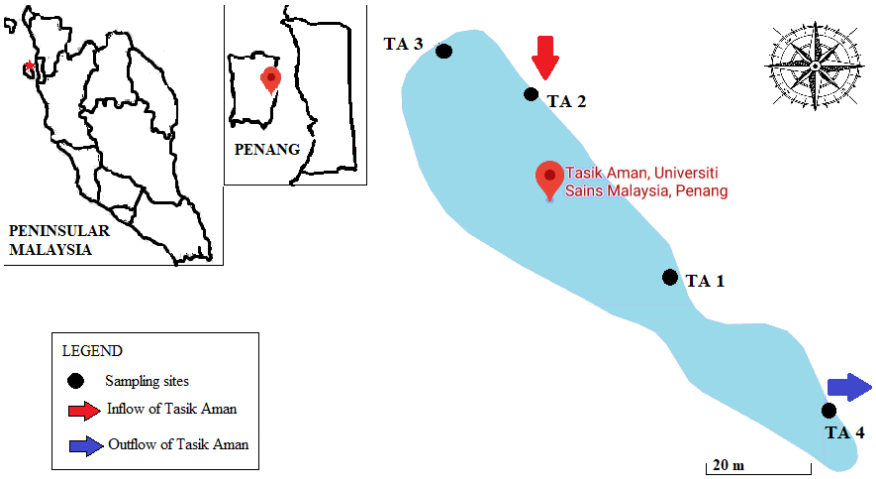

Figure 1. Study site and sampling area. (TA: *Tasik Aman*).

Table 1. GPS coordinates of each sampling sites in *Tasik Aman*.

Sampling stations	GPS Coordinates	Description of stations
TA 1	N 05°21'15.2" E 100°17'54.2"	Area where bamboo trees present densely nearby the sampling station
TA 2	N 05°21'16.6" E 100°17'54.2"	Inlet of the lake where water intrusion occurs from Sungai Gambir into the lake
TA 3	N 05°21'16.9" E 100°17'56.4"	Situated at the embayment area of the lake which most part of it is exposed to the wind turbulent directly
TA 4	N 05°21'14.0" E100°17'56.4"	Outlet of the lake where water flows out of the lake

Water samples were gathered from the sites in triplicate to perform nutrient analyses, total suspended solids (TSS) and chlorophyll-*a* analysis. BOD bottles covered with aluminium foil were used to collect water samples for biological oxygen demand (BOD_5) analysis. Low indophenol method was used to identify the concentration of NH_4-N where ammonium, phenol reagent and hypochlorite solution yielded blue indophenol colour [4]. To determine NO_2-N concentration, nitrite, sulphanilamide and N-(1-naphthyl)-ethylenediamine dihydrochloride were used in the diazotization method which formed a pink colour compound [4]. Boyd and Tucker [5] method was used to assess the orthophosphate concentration where blue colouration was formed when reaction occur between sulphuric acid, ammonium molybdate, ascorbic acid and potassium antimonyl tartrate [6]. BOD_5 analysis was carried out by incubating the water samples in an incubation chamber at 20°C for 5 days. Initial and final DO levels were measured. The values of initial and final DO were compared to obtain the value of BOD concentration. One-way ANOVA test and Tukey's HSD was carried out using SPSS version 24 to clarify the significant difference of the parameters among all sampling sites.

To calibrate and validate the WASP model, physical parameters of *Tasik Aman* (surface area, mean depth, volume of the lakes and maximum depth) were obtained. An analytical model created by Streeter and Phelps was applied as a basic steady-state equation to calculate the DO and BOD simulation [7].

Hence, the equation:
BOD (mg/L):

$$dl/dt = -al + \gamma$$

DO (mg/L):

$$dc/dt = - al + \beta (Cs - C) + \delta \sin (\sigma t - \frac{7\pi}{12})$$

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
a = BOD decay rate, day"¹

3. Results and Discussion

Water temperature controls the physical, biological, and chemical characteristic in aquatic ecosystems [8]. In the present study, the mean water temperature in *Tasik Aman* recorded the lowest value of 33.2 ± 0.38°C in TA2 to the highest value of 34.0 ± 0.2 °C in TA4. The mean showed no significant difference among stations (One-way ANOVA, $p > 0.05$). The water temperature in TA4 was slightly greater than TA2 since TA4 is located at the area where it was exposed to the sunlight compared to TA2 which is located at a shady area. The mean temperature increased linearly with the stations due to the time factor of the sampling since it was done at noon onwards.

The mean value of pH ranged from 9.82 ± 0.16 (TA1) to 10.16 ± 0.03 (TA4). The mean showed no significant difference among stations (One-way ANOVA, $p > 0.05$). The pH of *Tasik Aman* was relatively high which round up to the value of 10, fairly high in alkalinity due to high photosynthetic rate by the blooming of algae. According to [9], fishes are tolerable to the pH of 6.5 to 9.0, thus, explained why there is very few fish population dominating the lake.

Water transparency is an important limiting factor in the distribution of flora and fauna of a water body. The mean water transparency was the highest at TA2 (0.39 ± 0.018 m) and the lowest at TA1 (0.23 ± 0.015 m). The mean showed significant difference among stations (One-way ANOVA, $p < 0.05$). The water in *Tasik Aman* is green in colour thus, low water transparency of *Tasik Aman* was due to high suspended solids exacerbated by dense algae population that make it more turbid [10].

The DO reading of *Tasik Aman* recorded the lowest concentration of 4.9 ± 0.31 mg/L (TA4) to the highest concentration of 9.23 ± 0.41 mg/L (TA1). The mean showed significant difference among stations (One-way ANOVA, $p < 0.05$). TA1 situated at an open area that facilitates the microalgae photosynthetic activity which contribute oxygen into the water column. Sampling was done before noon. During that time, the light intensity received was in the range optimum for photosynthesis by bloom of algae that increase the oxygen level in a eutrophic water body [11, 12].

The total dissolved solids (TDS) reading for *Tasik Aman* recorded the lowest of 73.9 ppm ± 1.6 ppm (TA1) to the highest of 79.3 ± 1.0 ppm (TA4). TA4 which is located at the outlet of the lake, recorded the highest TDS reading during the study. The high mean TDS reading of the lake isdue to high non-point source pollution and runoff carried from Sungai Gambir into the lakes, before flowing out into the nearest shoreline. This occurrence could change the water balance due to the increasing of precipitation and limited outflow from the lake, thus increased the TDS concentration in *Tasik Aman* [13]. The mean showed significant difference among stations (One-way ANOVA, $p < 0.05$). Meanwhile, mean TSS recorded the lowest concentration of 24.67 ± 1.02 mg/L in TA3 to the highest concentration of 28 ± 1.16 mg/L in TA2. The mean showed no significant difference among stations (One-way ANOVA, $p > 0.05$).

The BOD of *Tasik Aman* recorded the lowest concentration of 3.27 ± 0.067 mg/L (TA 1) to the highest concentration of 3.47 ± 0.033 mg/L (TA4). Plant decaying processes resulted in the increases of the BOD level within the lake [14]. The abundance of algae in the water ecosystem caused high volume of algae

decomposition which arises the oxygen level in the process [15]. Presence of aquatic organisms that inhibit this lake ecosystem may impact the excess of nutrient loading from their excretions. Their wastes increased the organic level in the lake which further translated into high BOD. The mean showed no significant difference among stations (One-way ANOVA, $p > 0.05$).

Electrical conductivity indicates the purity of water [16]. The conductivity of *Tasik Aman* recorded the lowest concentration of 132.93 ± 0.56 µS/cm (TA3) to the highest concentration of 143.17 ± 1.6 µS/cm (TA 4). TA4 which is the outflow of *Tasik Aman* had higher conductivity since it carries dissolved salt from the whole lake to the outflow. The mean showed significant difference among stations (One-way ANOVA, $p<0.05$).

Chlorophyll is an important component in the absorption of sunlight for photosynthesis. The chlorophyll-*a* of *Tasik Aman* recorded the lowest concentration of 0.024 ± 0.002 mg/L (TA4) to the highest concentration of 0.069 ± 0.006mg/L (TA2). TA2 of *Tasik Aman* recorded its highest chlorophyll-*a* concentration where the water flows into the water bodies. According to Robertson et al. [17], chlorophyll-*a* concentration ranging from 0.026 to 0.075 mg/L are considered eutrophic due to high density of algae. However, chlorophyll-*a* concentration in *Tasik Aman* is fairly high as bloom of algae covered the whole lake. The mean showed significant difference among stations (One-way ANOVA, $p<0.05$). Tukey post-hoc revealed that TA4 and TA1 were significantly different from other stations and TA2 was significantly different from TA3.

The orthophosphate of *Tasik Aman* recorded the lowest value of 0.018 ± 0.006 mg/L (TA 2) to the highest value of 0.122 ± 0.019 mg/L (TA3). According to Balali et al. [18] and Talib et al. [19], phosphate enters the reservoir from direct deposition in the sediment into organic matter by primary producers which finally settles in the water. Wastewater that carried high volume of nutrient stimulates the growth of algae, thus reducing the oxygen available from the algae decomposition [20]. Total phosphorus recorded higher value in TA3 (0.141 ± 0.036 mg/L) compared to TA2 (0.036 ± 0.012 mg/L). The orthophosphate showed significant difference among stations (One-way ANOVA, $p < 0.05$) while there was no significant difference of total phosphorus among stations (One-way ANOVA, $p>0.05$). Orthophosphate at TA2 was significantly different from TA3 based on the Tukey post-hoc.

Ammonia-nitrogen of *Tasik Aman* recorded the lowest value of 0.121 ± 0.013 mg/L (TA1) to the highest value of 0.144 ± 0.067 mg/L (T 2). *Tasik Aman* contain vaguely lower concentrations of ammonia-nitrogen due to the abundance of algae as it may have absorbed the ammonia, which decreased the ammonia level in the lake and raised the pH at the same time [21]. The ANOVA showed no significant difference among stations (One-way ANOVA, $p > 0.05$). Nitrite-nitrogen concentration of *Tasik Aman* showed the lowest value of 0.0169 ± 0.0049 mg/L (TA1) to the highest value of 0.0534 ± 0.0008 mg/L (TA2). According to Ismail and Najib [22], vegetation, denitrification and sedimentation will increase increase the nitrite-nitrogen especially at TA2 which is situated at the inlet of Tasik Harapan where sediments might enter the lake from Sungai Gambir. The ANOVA showed no significant difference among stations (One-way ANOVA, $p > 0.05$).

Nitrate-nitrogen of *Tasik Aman* recorded the lowest concentration of 0.733 ± 0.013 mg/L (TA 2) to the highest concentration of 0.975 ± 0.025 mg/L (TA1). *Tasik Aman* contain high nitrate levels exceeding the 0.5 mg/L mark, which was classified as eutrophic based on water quality classification by DOE [23]. The lake takes in manure, plant litter, garbage and nitrate sources carried from Sungai Gambir.in the campus. The ANOVA revealed a significant difference among stations (One-way ANOVA, $p < 0.05$). Tukey post-hoc revealed that NO_3-N at TA3 and TA4 were significantly different from the other two stations.

Table 2 shows the parameters of *Tasik Aman* which is essential in the adjustment purposes of WASP model. A basic steady-state calculation proposed by Streeter and Phelp [7] was introduced to calculate the lake's BOD loading and decay rate by replacing the value of BOD mean, DO saturation level, and DO mean concentration into the Streeter-Phelp equation. The simulation was modelled up to one-month period to forecast the DO and BOD concentration and the graph for both parameters were simulated.

Table 2. The range (highest and lowest mean and standard deviation) of all measured parameters in *Tasik Aman*, USM, Penang.

Parameters	Range (Mean ± standard deviation)
Temperature (°C)	33.2 ± 0.38 to 34.0 ± 0.2
pH	9.82 ± 0.16 to 10.16 ± 0.03
Transparency (m)	0.23 ± 0.015 to 0.39 ± 0.018
Dissolved Oxygen (mg/L)	4.90 ± 0.31 to 9.23 ± 0.41
Total dissolve solids (ppm)	73.9 ± 1.6 to 79.3 ± 1.0
Total suspended solids (mg/L)	24.67 ± 1.02 to 28 ± 1.16
Biological oxygen demand (mg/L)	3.27 ± 0.067 to 3.47 ± 0.033
Conductivity (μS/cm)	132.93 ± 0.56 to 143.17 ± 1.6
Orthophosphate (mg/L)	0.018 ± 0.006 to 0.122 ± 0.019
Total Phosphorus (mg/L)	0.036 ± 0.012 to 0.141 ± 0.036
Ammnonia-nitrogen (mg/L)	0.121 ± 0.013 to 0.144 ± 0.067
Nitrite-nitrogen (mg/L)	0.0169 ± 0.0049 to 0.0534 ± 0.0008
Nitrate-nitrogen (mg/L)	0.733 ± 0.013 to 0.975 ± 0.025
Chlorophyll *a* (mg/L)	0.024 ± 0.002 to 0.069 ± 0.006

Table 3. Brief technical data of *Tasik Aman*, USM, Penang, Malaysia

	Tasik Aman
Surface area of lake (km^2)	0.006
Lake volume (mil m^3)	0.03
Maximum depth (m)	1.5

Based on the Streeter-Phelp equation, the value of the parameters needed in the DO and BOD simulation were obtained and are presented in Table 4. DO saturation level and BOD decay rate are constant value. DO and BOD concentrations were obtained from records collected from field (Table 2). Based on the calculation, the values of the reaeration rate and BOD loading were calculated.

Table 4. Selected water quality parameters for *Tasik Aman*

	Tasik Aman
BOD mean concentration, mg/L (l)	3.38
DO mean concentration, mg/L (C)	6.98
DO saturation level, mg/L (Cs)	7.12
Reaeration rate, day^{-1} (β)	1.09
BOD loading, mg/L/day (γ)	0.098
BOD decay rate, day^{-1} (α)	0.029

The data illustrated in Table 4 were applied accordingly into the WASP model. The model was executed, and the postprocessor was accessed. Graphs of x/y plots were generated for DO and BOD for the simulated lake which spans for a period of one month. Results were revealed in the form of x/y plot graph. The forecasted values of DO and BOD in one segment of *Tasik Aman* were presented. Validation in WASP using the values of DO saturation level, BOD loading, BOD decay rate and reaeration rate need to be done in order to get the actual data gained from the site. WASP simulated and predict the data to one-month period. The graph showed that the DO level decreased to 5.0 mg/L and congregated to the mean value of 4.75 mg/L (**Figure 2**) while the BOD level increased to 5.72 mg/L and congregated to the mean value of 5.75 mg/L (**Figure 3**). The calculation and the values simulated from WASP for DO saturation rate, BOD

loading, BOD decay rate and reaeration rate is proven accurate as it reflected the exact data acquired from the field.

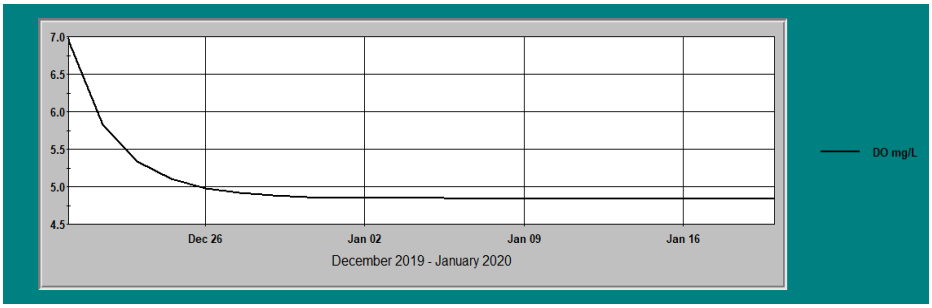

Figure 2. x/y plot of DO concentration in *Tasik Aman* from December 2019 to January 2020.

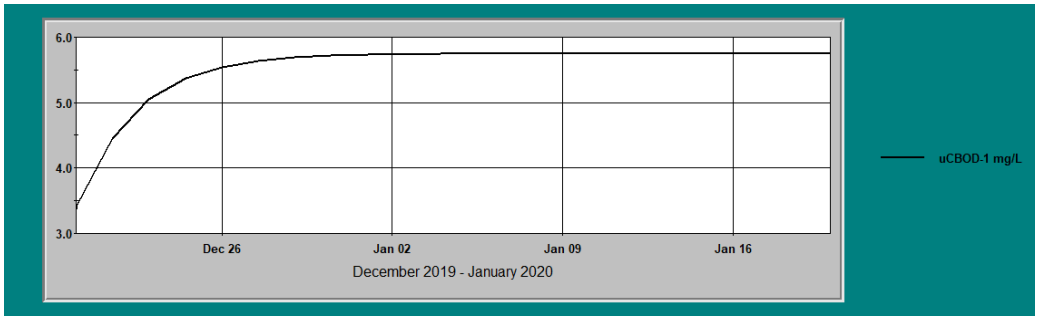

Figure 3. x/y plot of BOD concentration in *Tasik Aman* from December 2019 to January 2020.

The rather high temperature may decrease the solubility of the oxygen in the lake where the DO concentration continued to decrease. High BOD level in the water bodies showed that abundance of photosynthetic activities might affect the oxygen levels with decaying process or organic matter consume more oxygen in the water [15]. This study only focused on the data simulation based on the current status of DO and BOD levels in *Tasik Aman*. Simulation and prediction of the parameters might require longer and more sampling to predict the long-term water quality reactions on the phenomenon happened in the lake.

4. Conclusions

Tasik Aman as a closed lake system is expected to attain its greatest contamination level after years. This study found that many of the water parameters measured were rather higher than the standard values recommended by DOE. The lake is considered nutrient-rich with high TSS, nitrate and chlorophyll *a* concentration. WASP was applied to briefly simulate the graphs representing the lakes' current DO and BOD levels and the trends in a period of one month as these two parameters circulating around the oxygen levels of the water. Simulated graphs of *Tasik Aman* showed a decrease in DO and an increase in BOD level proving that the lake contain high level of nutrients and algal population. *Tasik Aman* was modelled based on one segment. It is advisable in future studies to separate the lake into few segmentations to acquire a more precise forecast besides the improvement of having more input of data from the sites.

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