Assessment of water quality index of Puah Reservoir, Hulu Terengganu, Malaysia

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Abstract. Puah dam is located 50 km from Bandar Gua Musang – Hulu Terengganu roadway, and about 65km west of Kuala Terengganu. Puah Reservoir is used for macro-hydro power plant (capacity 250MW). The purpose of this study was to determine the water quality status of the reservoir. Based on water quality index grading, the reservoir water has been classified as poor according to WHO WQI rating with a calculated range of 11.52 – 485.71. Although, the result for the mean WQI for all the stations/locations (48.04 – 154.36) revealed that the water is fit for drinking purpose through any form of treatment. However, it’s relatively good for swimming, bathing, laundry, irrigation and industrial purposes. This condition showed that the activities of Tambat and Puah hydro-power generation had no negative effect on the water quality of upper and lower parts of Puah Reservoir respectively.

1. Introduction
Freshwater lakes are one of the most vulnerable ecosystems to environmental contamination and crucial aquatic inland ecosystems which play many ecological and environment roles including biodiversity protection, local climate regulation and groundwater resources replenishment [1]. Lakes and reservoirs are major resources as these holds about 90% of the world’s surface freshwater and are the key freshwater resources for agriculture, fisheries, domestic, industrial, recreational, landscape entertainment, and energy production. However, these utilizations depend on the desirable water quality that should be based on a well-balanced environment in terms of its physical and chemical characteristics. The lentic surface water quality in reservoirs, lakes, or ponds is severely affected by anthropogenic pollution, and many efforts have already been made to assess and manage their water quality [2].

Water ecosystem, especially freshwater ecosystem, are some of the most important resources in the replenishment and purification of water sources used by human. Unfortunately, the sustainability of a large amount of these ecosystems is being negatively affected by land development. Increased use of underground aquifers, creation of water division system, industrial and household wastewater contamination and the eradication of wetlands and marsh areas all pose a threat to these ecosystems that help to provide us with fresh water. Inland freshwater resources have gained great concern in the recent years which are highly affected by various kinds of anthropogenic activities. Thus, to review strategies for conservation and utilization of freshwater resources in a better way, a scientific study is required.

Water quality index (W.Q.I) provides a single number that expresses overall water quality at a certain location and time, based on several water quality parameters [3]. Water Quality is an important factor...
to judge environment changes, which are strongly associated with social and economic development. The objective of water quality index is to turn complex water quality data into information that is understandable and used by the public. A water quality index based on some very important parameters provides a single indicator of water quality. In general, water quality indices incorporate data from multiple water quality parameters into a mathematical equation that rates the health of a water system with number [4].

Freshwater reservoirs are important in Malaysia as there are few natural lakes in Malaysia. There are over 90 freshwater reservoirs that had been constructed to support the water supply and to maximize the collection and storage of rainwater harvested from catchments [5]. In addition, Malaysia’s reservoirs are also important for recreational, social and aesthetic values, as well as flood control. The quality and quantity of surface water bodies such as lakes depend upon the climate, catchments, geography of the area and the inputs and outputs both natural and manmade [2]. Puah reservoir could be a comprehensive case study site to better understand the changes that could occur after completion of a dam works since no study has been carried out on aspects of water quality in the reservoir. The water quality of lakes can be degraded due to microbiological and chemicals contaminants. The monitoring and assessment of water quality of freshwater lakes such as Puah Reservoir is therefore imperative because wildlife and aquatic life consume these water as well as energy production.

2. Materials and Methods

2.1. Area under Investigation
Puah dam is about 50 km from Bandar Gua Musang – Hulu Terengganu roadway, and about 65km west of Kuala Terengganu situated on geographical coordinates of 5 05 N 102 45E / 5.083N 102.750E with a total area of 134,690.54ha, an average depth of 20m and 296m from the sea level. This infrastructure is of type Hydro Power Plant constructed from 2011-2017 with a design capacity of 250MW. The locations and names of collection water samples are represented in (Figure 1 and Table 1).

Figure 1. Locations of the sampling stations at Puah Dam site, Hulu Terengganu.
2.2. Physical and Chemical Analyses

In-situ measured were taken from the subsurface (about 30 cm) at nine stations to cover the whole Reservoir area from March 2019 to February 2020. Sample collection and analysis spanned across two consecutive successful seasons (March 2019–February 2020) and sampling was done monthly. According to [6], wet and dry seasons alternate on an average of six months each in Peninsular Malaysia hence, samples was collected for at least 12 months (Wet season included March – August 2019 while dry season September 2019–February 2020). In addition to, water samples were also collected with cleaned/sterilized glass bottles with capacity of 2L for chemical analysis in the laboratory. Thirteen water quality parameters were studied at nine sampling stations in Puah Reservoir. Physical and chemical analyses of water samples were done according to the methods described in American Public Health Association [7]. Water temperature (°C), water pH, Conductivity (EC, mS/cm), total suspended solid (TSS) and Dissolved oxygen were in-situ measured using calibrated multi meters YSI Professional Plus handheld multi-probe and a DO meter (YSI Pro DSS Water Quality Digital Meter) respectively. Transparency and depth were measured using a white/black Secchi Disk (20 cm in diameter) and an echo-sounder (Model 710679, Speedtech Instruments) respectively. Biological oxygen demand (BOD) was determined by using the 5 days incubation method. Chemical oxygen demand (COD) was carried out using the potassium permanganate method. Ammonia was determined by the phenate method. Total Nitrogen was determined using a colorimetric method with formation of a reddish-purple azo dye. Total phosphorus (TP) was estimated by using the ascorbic acid-molybdate method.

2.3. Water Quality Index

Water quality index (WQI) is defined as a technique of rating that provides the composite influence of individual water quality parameter on the overall quality of water [8]. The calculation method of WQI was developed by [9], which has been widely used by many scientists [10,11,12,13,14&15]. The mathematical formula of this WQI method is given by:

\[ WQI = \frac{\sum_{i=1}^{n} Q_i W_i}{\sum_{i=1}^{n} W_i} \]

Where \( Q_i \) is the sub quality index of \( i^{th} \) parameter (or \( Q_i \) is the quality rating scale of each parameter). \( W = \) weight unit of each parameter, \( n = \) number of parameters.

2.3.1. Calculation for water quality index. For the calculation of water quality index in this study, eight important parameters were chosen. The WQI has been calculated by using the standard drinking water quality recommended by World Health Organization (WHO). The process of calculation is as follows; i. Selection of water quality index parameters: Parameters were selected based on their importance. ii. Relative weight (Wi): This was calculated using the equation:

\[ W_i = \frac{w_i}{\sum_{i-1}^{n} w_i} \]

Where, \( W_i = \) relative weight, \( w_i = \) is the weight of each parameter \( n = \) number of parameters

iii. Quality rating scale (q): This was calculated by dividing the concentration of each water sample by its respective standard and the result multiplied by 100.

### Table 1. Longitude, Latitude and names of sampling stations in Puah Reservoir.

| Code of stations | Name of stations            | Longitude   | Latitude      |
|------------------|-----------------------------|-------------|---------------|
| P1               | Terengganu Mati             | 5°12'30.75"N| 102°32'17.01"E|
| P2               | Limbing Besar               | 5°10'10.50"N| 102°34'29.11"E|
| P3               | Tambat Outlet              | 5°12'33.09"N| 102°34'56.17"E|
| P4               | Pelagong                    | 5° 9'3.67"N | 102°33'1.19"E |
| P5               | Sireh                       | 5° 8'44.54"N| 102°33'47.21"E|
| P6               | Centre Dam                  | 5° 9'31.93"N| 102°35'12.24"E|
| P7               | Power Intake                | 5° 9'1.77"N | 102°35'50.62"E|
| P8               | Puah Env. Flow (Downstream) | 5° 9'58.36"N| 102°36'14.87"E|
| P9               | Tailrace (Puah Outlet)      | 5° 8'54.05"N| 102°36'47.66"E|
Where \( C_i \) = Concentration of each chemical parameter in each water sample, \( S_i \) = WHO standard for each chemical parameter.

However, for the purpose of getting quality rating of pH and dissolved oxygen, the expression below was used.

\[
Q_i = \frac{(V_i-V_0)}{(S_i-V_{10})} \times 100
\]

Where;
- \( Q_i \) = quality rating for the ith water parameter
- \( V_i \) = Estimated value of the ith parameter at a given station (that is, the concentration)
- \( S_i \) = Standard permissible value of the ith parameter
- \( V_{10} \) = Ideal value of ith parameter in a pure water.

Note: Ideal value in most cases \( V_{10} = 0 \) except in certain parameters like pH and dissolved oxygen.

Calculation of quality rating for pH is 7 while dissolved oxygen is 14.6mg/l

iv. WQI: The overall WQI is calculated by the equation:

\[
WQI = \frac{\sum_{i=1}^{n} Q_i W_i}{\sum_{i=1}^{n} W_i}
\]

In this study, the WQI level was categories based on permissibility for human consumption or uses. WQI has been classified into 5 classes according to WHO, the water quality is rated excellent, good, poor, very poor and unfit when the value of the index lies between <50, 50-100, 100-200, 200-300 and >300 respectively as shown in Table 2.

| Water quality index levels | Description          |
|---------------------------|----------------------|
| <50                       | Excellent            |
| 50-100                    | Good water           |
| 100-200                   | Poor water           |
| 200-300                   | Very poor (bad) water|
| >300                      | Unsuitable (unfit) for drinking |

Source: [16]

3. Results and Discussion

The values of eight physico-chemical parameters of Puah Reservoir were used for calculating the water quality index (WQI) for twelve months are presented in Tables 3-12. The WQI of the reservoir is established from the important physic-chemical parameters studied. The calculation of WQI was monthly in the nine different sampling stations to investigate the suitability of the reservoir for different purposes. The physico-chemical results indicate that higher values were observed in Stations 1, 2, 4, 5, 6 and 7 while lower values were observed in Stations 3, 8 and 9 throughout the study. In general, the results of physico-chemical parameters across stations indicated that most parameters like pH and BOD in stations 1 to 7 were beyond the permissible limits as prescribed by world health organization (WHO) standards for drinking water. But other stations (8 and 9) showed lower concentrations within the desirable limits except for pH. However, increases in values were obtained more in the rainy season months (March to August) than the dry season months of October to February. Although, September been a transitional month experience the pick in pH.
### Table 3. Physiochemical parameter values for all sampling stations in March 2019.

| Parameters  | P1   | P2   | P3   | P4   | P5   | P6   | P7   | P8   | P9   |
|------------|------|------|------|------|------|------|------|------|------|
| Temp (°C)  | 27.9 | 28.4 | 28.6 | 29.8 | 27.3 | 29.9 | 25.7 | 27.9 | 32.2 |
| pH         | 7.22 | 7.22 | 9.15 | 8.56 | 9.21 | 8.81 | 8.83 | 8.44 | 8.35 |
| Cond. (μS/cm) | 21.5 | 20.8 | 31.2 | 30.9 | 23.9 | 24   | 22.7 | 33.7 | 26.8 |
| TSS (mg/l) | 4.7  | 1.1  | 1.7  | 1.3  | 3    | 1    | 1.1  | 1.4  | 3.9  |
| DO (mg/l)  | 0.60 | 0.54 | 0.54 | 0.61 | 0.58 | 0.54 | 0.55 | 5.85 | 4.61 |
| Transp. (cm) | 1.82 | 3.34 | 3.1  | 2.89 | 3.94 | 3.74 | 3.79 | 0    | 0    |
| BOD (mg/l) | 1.4  | 6.1  | 5.5  | 5.6  | 3    | 3.2  | 3.1  | 4    | 1.5  |
| COD (mg/l) | 18   | 18   | 18   | 13   | 17   | 18   | 8    | 9    | 13   |
| Nitrite (mg/l) | 0   | 0    | 0.017| 0.004| 0    | 0.003| 0    | 0    | 0    |
| Nitrate (mg/l) | 0  | 0    | 0.22 | 0.51 | 0.27 | 0.31 | 0    | 0    | 0    |
| TP (mg/l)  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| Depth (m)  | 8.7  | 19   | 11.7 | 9.8  | 45   | 33   | 14.5 | 0.5  | 2    |

### Table 4. Physiochemical parameter values for all sampling stations in May 2019.

| Parameters  | P1   | P2   | P3   | P4   | P5   | P6   | P7   | P8   | P9   |
|------------|------|------|------|------|------|------|------|------|------|
| Temp (°C)  | 30.5 | 30.7 | 31.4 | 31.2 | 31.3 | 31.8 | 31.9 | 28.9 | 32.1 |
| pH         | 9.01 | 8.04 | 7.93 | 8.4  | 7.95 | 7.92 | 7.9  | 10.13| 9.53 |
| Cond. (μS/cm) | 0.022| 0.021| 0.031| 0.029| 0.026| 0.024| 0.023| 41.2 | 34   |
| TSS (mg/l) | 2.2  | 0.9  | 1.7  | 2.2  | 0.9  | 0.9  | 1.7  | 1.6  | 1    |
| DO (mg/l)  | 6.54 | 6.40 | 7.81 | 6.30 | 7.54 | 7.86 | 6.30 | 3.40 | 7.63 |
| Transp. (cm) | 2.46 | 3.3  | 2.3  | 2.6  | 3.1  | 4.1  | 3.4  | 0    | 0    |
| BOD (mg/l) | 2.6  | 6.6  | 3    | 5.5  | 1.4  | 2.6  | 2    | 1.8  | 1.7  |
| COD (mg/l) | 18   | 15   | 18   | 23   | 15   | 15   | 12   | 17   | 16   |
| Nitrite (mg/l) | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| Nitrate (mg/l) | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| TP (mg/l)  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| Depth (m)  | 9    | 17   | 10.5 | 11   | 18.5 | 48   | 13.2 | 0.52 | 2    |

### Table 5. Physiochemical parameter values for all sampling stations in June 2019.

| Parameters  | P1   | P2   | P3   | P4   | P5   | P6   | P7   | P8   | P9   |
|------------|------|------|------|------|------|------|------|------|------|
| Temp (°C)  | 30.8 | 30.9 | 32   | 31.9 | 31.5 | 31.6 | 31.8 | 29.9 | 32.1 |
| pH         | 8.44 | 8.89 | 7.81 | 7.91 | 7.19 | 7.38 | 7.65 | 9.13 | 9.02 |
| Cond. (μS/cm) | 19.62| 19.895| 19.905| 19.905| 19.345| 19.49 | 19.725| 56.3 | 43.2 |
| TSS (mg/l) | 3.1  | 0.7  | 1.1  | 0.8  | 0.8  | 0.9  | 0.7  | 1.6  | 1    |
| DO (mg/l)  | 0.46 | 0.49 | 0.55 | 0.48 | 0.50 | 0.68 | 0.48 | 7.63 | 7.05 |
| Transp. (cm) | 2.46 | 4.3  | 3.24 | 3.12 | 3.33 | 2.89 | 2.2  | 0    | 0    |
| BOD (mg/l) | 1.7  | 3.8  | 2    | 4.4  | 3.8  | 4    | 4.1  | 1.7  | 3.9  |
| COD (mg/l) | 18   | 24   | 15   | 23   | 15   | 15   | 12   | 17   | 16   |
| Nitrite (mg/l) | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| Nitrate (mg/l) | 0  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| TP (mg/l)  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| Depth (m)  | 8.7  | 18   | 10.2 | 8    | 29   | 34   | 3.4  | 0.52 | 3    |

Cond = conductivity, TSS = total suspended solutes, DO = dissolve oxygen, Transp = transparency, BOD = biochemical oxygen demand, COD = chemical oxygen demand, TP = total phosphorous.
### Table 6. Physiochemical parameter values for all sampling stations in July 2019.

| Parameters | P1     | P2     | P3     | P4     | P5     | P6     | P7     | P8     | P9     |
|------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Temp (°C)  | 31     | 30.7   | 31.3   | 31.6   | 31.7   | 31.4   | 31.7   | 29.8   | 32     |
| pH         | 11.89  | 12.63  | 7.8    | 7.81   | 7.2    | 7.37   | 12.93  | 12.96  | 12.99  |
| Cond (µS/cm) | 0.023  | 0.022  | 0.029  | 0.029  | 0.027  | 0.024  | 0.024  | 21.38  | 22.495 |
| TSS (mg/l) | 1.8    | 1.6    | 2      | 1      | 0.7    | 0.5    | 0.2    | 2.9    | 4.4    |
| DO (mg/l)  | 0.71   | 0.66   | 0.50   | 0.48   | 0.50   | 0.53   | 0.66   | 7.19   | 6.77   |
| Transp. (cm) | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      |
| BOD (mg/l) | 2.6    | 3.3    | 2.2    | 1.5    | 2.5    | 4      | 2.9    | 3.3    | 0.3    |
| COD (mg/l) | 27     | 31     | 16     | 26     | 20     | 11     | 17     | 16     | 18     |
| Nitrite (mg/l) | 0     | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      |
| Nitrate (mg/l) | 0    | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      |
| TP (mg/l)  | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      |
| Depth (m)  | 8.7    | 18     | 9.6    | 9      | 24.5   | 31.5   | 5.75   | 0.53   | 3      |

### Table 7. Physiochemical parameter values for all sampling stations in Sept 2019.

| Parameters | P1     | P2     | P3     | P4     | P5     | P6     | P7     | P8     | P9     |
|------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Temp (°C)  | 30.3   | 30.6   | 31.4   | 31.7   | 22.3   | 31.6   | 32     | 30.1   | 27.3   |
| pH         | 14.51  | 15.23  | 13.89  | 15.21  | 15.4   | 13.4   | 14.72  | 13.48  | 15.54  |
| Cond (µS/cm) | 0.021  | 0.021  | 0.029  | 0.028  | 0.025  | 0.024  | 0.024  | 0.037  | 0.042  |
| TSS (mg/l) | 0.9    | 1.2    | 1.1    | 1      | 0.4    | 1.2    | 1.2    | 17.9   | 0.6    |
| DO (mg/l)  | 0.62   | 0.55   | 0.54   | 0.52   | 0.53   | 0.52   | 0.52   | 6.48   | 7.31   |
| Transp. (cm) | 2.34   | 4.2    | 3.05   | 3.65   | 4.4    | 4.05   | 3.05   | 0      | 0      |
| BOD (mg/l) | 1.6    | 0.4    | 1.4    | 0.9    | 2.6    | 2.6    | 0.1    | 5.2    | 1      |
| COD (mg/l) | 7      | 15     | 5      | 19     | 12     | 25     | 39     | 33     | 8      |
| Nitrite (mg/l) | 0.006 | 0.004  | 0.001  | 0.001  | 0.004  | 0.006  | 0.003  | 0.011  | 0.007  |
| Nitrate (mg/l) | 0.03  | 0.05   | 0.01   | 0.02   | 0      | 0      | 0      | 0.01   | 0      |
| TP (mg/l)  | 0.21   | 0.3    | 0.43   | 0.04   | 0.39   | 0.23   | 0.29   | 0.67   | 0.2    |
| Depth (m)  | 8.7    | 18     | 9      | 10     | 20     | 29     | 8.1    | 0.54   | 3      |

### Table 8. Physiochemical parameter values for all sampling stations in Oct 2019.

| Parameters | P1     | P2     | P3     | P4     | P5     | P6     | P7     | P8     | P9     |
|------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Temp (°C)  | 28.9   | 30.1   | 32     | 31.3   | 31.5   | 31     | 30.7   | 29.6   | 27.1   |
| pH         | 6.82   | 7.1    | 6.8    | 7.4    | 7.36   | 7.4    | 7.38   | 7.54   | 6.5    |
| Cond (µS/cm) | 28.6   | 24.9   | 35.1   | 32     | 28.3   | 27.9   | 27     | 45.3   | 60.6   |
| TSS (mg/l) | 3      | 1.3    | 1      | 0.7    | 0.8    | 0.8    | 0.8    | 7.3    | 14.2   |
| DO (mg/l)  | 0.56   | 0.51   | 0.50   | 0.52   | 0.53   | 0.50   | 0.50   | 7.38   | 4.17   |
| Transp. (cm) | 8.2    | 2.4    | 2.8    | 2.7    | 2.7    | 2.5    | 3.3    | 0.5    | 1      |
| BOD (mg/l) | 3.7    | 2.7    | 2.2    | 2.2    | 2.4    | 0.4    | 0.5    | 7.8    | 0.3    |
| COD (mg/l) | 20     | 19     | 20     | 8      | 1      | 1      | 1      | 8      | 1      |
| Nitrite (mg/l) | 0.009 | 0.005  | 0.007  | 0.005  | 0.009  | 0.007  | 0.006  | 0.007  | 0.007  |
| Nitrate (mg/l) | 0.02  | 0.02   | 0.02   | 0.02   | 0.02   | 0.02   | 0.02   | 0.04   | 0      |
| TP (mg/l)  | 0.15   | 0.14   | 0.19   | 0.1    | 0.4    | 0.2    | 1.3    | 0.49   | 0.1    |
Table 9. Physiochemical parameter values for all sampling stations in Nov 2019.

| Parameters | P1  | P2  | P3  | P4  | P5  | P6  | P7  | P8  | P9  |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Temp (°C)  | 27.8| 28.4| 29.1| 29  | 28.8| 28.8| 28.9| 27.4| 25.8|
| pH         | 6.6 | 6.6 | 6.59| 6.9 | 6.6 | 6.64| 6.6 | 6.9 | 6.98|
| Cond (μS/cm)| 22.8| 23  | 29.1| 28.7| 25.1| 24.7| 23.7| 84.2| 87.2|
| TSS (mg/l) | 1.1 | 1.4 | 0.9 | 0.7 | 1.5 | 1.4 | 1.4 | 13  | 3.1 |
| DO (mg/l)  | 0.62| 0.51| 0.51| 0.54| 0.51| 0.52| 0.52| 5.22 | 1.76|
| Transp. (cm)| 5.4 | 3.12| 2.97| 3.11| 1.8 | 3.15| 3.44|     |     |
| BOD (mg/l) | 4.2 | 5.2 | 4.59| 4.83| 3.975| 5.4 |     | 15.4| 4.7 |
| COD (mg/l) | 9   | 5   | 9   | 9   | 0   | 4   | 11  | 7   | 1   |
| Nitrite (mg/l) | 0.006| 0.007| 0.007| 0.003| 0  | 0.006| 0.008| 0.1 | 0.004|
| Nitrate (mg/l) | 0.02 | 0.02| 0.03| 0.05| 0.02| 0.01| 0.01| 0.02| 0.01|
| TP (mg/l)  | 0.57| 0.44| 0.3  | 0.4 | 0.38| 0.58| 0.4  | 0.29| 0.37|
| Depth (m)  | 7   | 23  | 9.5 | 6   | 30  | 30  | 15  | 0.49| 4.5 |

Table 10. Physiochemical parameter values for all sampling stations in Dec 2019.

| Parameters | P1  | P2  | P3  | P4  | P5  | P6  | P7  | P8  | P9  |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Temp (°C)  | 22.8| 26  | 26.4| 26.5| 26.4| 26.4| 26.4| 26.1| 25.2|
| pH         | 4.5 | 66.4| 6.45| 6.2 | 6.4 | 6.1 | 6.5 | 6.8 | 6.91|
| Cond (μS/cm)| 9.3 | 21  | 30  | 30.4| 25.8| 25.5| 23  | 85.3| 88.3|
| TSS (mg/l) | 180.5| 3.7 | 0.9 | 3   | 2.5 | 2.2 | 2.7 | 33.9| 2   |
| DO (mg/l)  | 0.53| 0.55| 0.61| 0.61| 0.51| 0.51| 0.60 | 6.33| 1.91|
| Transp. (cm)| 0.1 | 2.86| 2.21| 1.7 | 1   | 0.1 | 0.18|     |     |
| BOD (mg/l) | 1.7 | 1.5 | 1.4 | 7.6 | 2.8 | 2.2 | 2.2 | 10.4| 0.2 |
| COD (mg/l) | 25  | 31  | 28  | 25  | 30  | 20  | 6   | 61  | 7   |
| Nitrite (mg/l) | 0.014| 0.003| 0.002| 0.001| 0.004| 0.002| 0.005| 0.001| 0.004|
| Nitrate (mg/l) | 0.02 | 0.01| 0.02| 0.01| 0.01| 0.03| 0.01 | 0.01| 0.01|
| TP (mg/l)  | 0.79| 0.4  | 0.37| 0.33| 1.04| 1.24| 0.54 | 0.24| 0.19|
| Depth (m)  | 13  | 21.5| 10.7| 8.5 | 18.5| 43  | 10.1| 0.49| 4   |

Table 11. Physiochemical parameter values for all sampling stations in Jan 2020.

| Parameters | P1  | P2  | P3  | P4  | P5  | P6  | P7  | P8  | P9  |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Temp (°C)  | 28.3| 27.7| 28.6| 28.8| 27.9| 27.4| 28.2| 26.3| 27.7|
| pH         | 6.2 | 6.3 | 6.6 | 7   | 6.7 | 6.59| 6.8 | 12.42| 7.1 |
| Cond (μS/cm)| 23.4| 21  | 32.1| 32.7| 26.2| 26.2| 25.3| 48.1| 31.6|
| TSS (mg/l) | 2.5 | 1.9 | 2.2 | 1.8 | 1.9 | 0.8 | 1.4 | 2.7  | 1.5 |
| DO (mg/l)  | 0.52| 0.43| 0.45| 0.42| 0.45| 0.45| 0.48| 0.80 | 0.68|
| Transp. (cm)| 1.88| 2.59| 2.18| 2.2 | 3.1 | 3   | 2.4 | 0    | 0    |
| BOD (mg/l) | 0   | 0   | 0   | 0   | 1.2 | 3   | 0   | 1.2  | 1.1  |
| COD (mg/l) | 1   | 3   | 3   | 3   | 1   | 4   | 2   | 5    | 1    |
| Nitrite (mg/l) | 0.006| 0.005| 0.002| 0.003| 0.004| 0.003| 0.006| 0.001| 0.002|

Temp = temperature, pH = hydrogen ion concentration, Cond = conductivity, TSS = total suspended solutes, DO = dissolve oxygen, Transp = transparency, BOD = biochemical oxygen demand, COD = chemical oxygen demand, TP = total phosphorus.
The WQI of water at stations 4 and 7 was $Wi Qi = 0.12406 = 34.68$, as an example for the method of calculating WQI by applying the values of the basic elements of; actual measured value ($Vi$) water quality standard value ($Si$), weight, relative (unit) weight ($Wi$), Quality rating ($Qi$) and the weighted values in the corresponded equations.

$$WQI = \frac{\sum_{i=1}^{n} Wi Qi}{\sum_{i=1}^{n} Wi} = \frac{4.302102}{0.12406} = 34.68$$

Table 13 presents the result of WQI of station 4 for October 2019. This result of 34.68 has been calculated as an example for the method of calculating WQI by applying the values of the basic elements of; actual measured value ($Vi$) water quality standard value ($Si$), weight, relative (unit) weight ($Wi$), Quality rating ($Qi$) and the weighted values in the corresponded equations.

$$WQI = \frac{\sum_{i=1}^{n} Wi Qi}{\sum_{i=1}^{n} Wi} = \frac{4.302102}{0.12406} = 34.68$$

Table 19 reveals the WQI values and means for all sampling stations during the period of study. The index values shows that stations 1,2,4,5,6 and 7 fell under the poor water condition (100-200) while station 3, 8 and 9 is in the range of good water (50-100) except in July and September were the water sligts into very bad water (200-300). Stations 4 and 7 indicated pollution as they fell into very bad water (200-300) and unsuitable for drinking (>300) categories during the transitional month from wet to dry season. Therefore, the quality of water at stations 4 and 7 was unfit for human uses during September.

Table 12. Physiochemical parameter values for all sampling stations in Feb 2020.

| Parameters | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 |
|------------|----|----|----|----|----|----|----|----|----|
| Temp (°C)  | 29.2 | 28.7 | 29.3 | 28.9 | 28.4 | 28.1 | 28.2 | 25.7 | 28.8 |
| pH         | 5.7 | 5.57 | 5.9 | 6.17 | 5.98 | 6.17 | 6.05 | 6.34 | 6.54 |
| Cond (μS/cm) | 83.8 | 22.8 | 34.5 | 33.4 | 27.4 | 24.7 | 25.4 | 43.3 | 43.7 |
| TSS (mg/l) | 2.6 | 2 | 1.2 | 1 | 1.1 | 4.4 | 1.7 | 1.6 | 8.7 |
| DO (mg/l)  | 0.56 | 0.43 | 0.53 | 0.57 | 0.53 | 0.59 | 0.55 | 7.55 | 7.02 |
| Transp. (cm) | 1.98 | 2.75 | 2.52 | 2.4 | 2.95 | 2.5 | 2.3 | 0 | 0 |
| BOD (mg/l) | 4.9 | 2.5 | 3.8 | 2.6 | 2.8 | 4.5 | 3.6 | 1.5 | 1.3 |
| COD (mg/l) | 23 | 82 | 136 | 167 | 111 | 28 | 57 | 4 | 45 |
| Nitrate (mg/l) | 13.95 | 42.25 | 69.9 | 84.8 | 56.9 | 16.25 | 30.3 | 2.75 | 23.15 |
| Nitrate (mg/l) | 18.475 | 62.125 | 102.95 | 125.9 | 83.95 | 22.125 | 43.65 | 3.375 | 34.075 |
| TP (mg/l)   | 9.5 | 0.26 | 0.69 | 0.53 | 0.26 | 0.28 | 0.46 | 0.92 | 0.85 |
| Depth (m)  | 8.85 | 15.5 | 13.5 | 10.5 | 10.5 | 30 | 33 | 9.5 | 0.54 |

Cond = conductivity, TSS = total suspended solutes, DO = dissolve oxygen, Transp = transparency, BOD = biochemical oxygen demand, COD = chemical oxygen demand, TP = total phosphorous.

Table 13. An example of WQI for P4 Oct 2019.

| Parameters | Observed Value ($Vi$) | Standard Value ($Si$) | Unit Weight ($Wi$) | Quality Rating ($Qi$) | Wi Qi |
|------------|-----------------------|-----------------------|-------------------|----------------------|------|
| pH         | 7.4 | 8.5 | 0.02 | 26.67 | 0.533 |
| Cond (μS/cm) | 32 | 300 | 0.088 | 10.67 | 0.939 |
| TSS (mg/l) | 0.7 | 500 | 0.002 | 0.14 | 0.0003 |
| DO (mg/l)  | 0.52 | 5 | 0.001 | 149.89 | 0.1498 |
| Transp. (cm) | 2.7 | 0.5 | 0.007 | 5.4 | 0.038 |
| BOD (mg/l) | 2.2 | 5 | 0.006 | 440 | 2.64 |
| Nitrate (mg/l) | 0.005 | 0.003 | 0.00001 | 16.67 | 0.002 |
| Nitrate (mg/l) | 0.02 | 45 | 0.00005 | 0.044 | 0.000002 |

$$\text{Water Quality Index } = \sum Wi Q_i / \sum Wi = 34.68$$
The results of this investigation revealed many remarkable features about the pollution status of Puah Reservoir. Notably is that none of the nine stations sampled have WQI of <50 during the wet season except station 1 and 2 (June) and station 8 and 9 (March - October) which implies that the water in all the mentioned stations and months were fit for human consumption directly without treatment. At station 1, the WQI ranged from 363.07 in September to 17.06 in October 2019 with a mean of 107.423. At station 2, the highest WQI was in the month of September (485.71) and lowest in the month of October (17.22) with a mean of 154.358. Station 3 WQI varied between 33.45 in January 2020 and 132.18 in September 2019 with a mean of 78.556. The fluctuation in the WQI in stations 1 and 2 indicated that the water of the Puah Reservoir at these stations remained slightly polluted for only September of the year as stations 1 and 2 are similar. Station 3 shows cleaner water throughout the year as it was devoid of any direct source of pollution unlike stations 1 and 2 being the first point of contact with the water from the main source (River Terengganu). Increased load of pollution as reflected in WQI values was observed during the raining months of March to October in all stations studied. This is not unconnected with the flooding brought about by rainfall which brings in organic materials from the surrounding watershed that led to increase in some physiochemical parameters. These inputs are however reduced in the dry season. Water of Puah Reservoir of stations 4 to 7 remained very poor during the wet season. In station 4, highest WQI value 405.84 was observed in September while lowest value of 34.68 was observed in October with a mean of 135.04. In station 5, highest value of WQI was 244.49 in the month of September and lowest of 23.99 in month of October with a mean of 103.523. Increase in pollution levels of these brackish stations may be as a result of a high level of pH, BOD and nitrates present in the physiochemical analysis. Station 8 and 9 shows cleaner water throughout the year as it was devoid of any direct source of pollution unlike other stations. In station 8 and 9, highest WQI values 149.12 and 125.86 were observed in September and July respectively while lowest values of 28.96 and 11.52 were observed in December and January 2020 with a means of 66.54 and 48.04 respectively. WQI mean ranged from 485.71 to 125.86 indicates that all stations are good. Therefore, based on this study it was observed that none of the water in the stations is fit for direct human consumption except at station 9. All stations were observed to be relatively clean and may be used for swimming, bathing, laundry, irrigation and other industrial purposes.

### Table 14. WQI and mean values for all stations from March 2019-February 2020.

| Months/year | P1   | P2   | P3   | P4   | P5   | P6   | P7   | P8   | P9   |
|-------------|------|------|------|------|------|------|------|------|------|
| March 2019  | 45.80| 34.94| 92.91| 72.10| 118.15| 104.16| 44.87| 33.49| 33.67|
| May 2019    | 135.54| 299.59| 99.52| 98.72| 143.85| 193.13| 158.96| 38.99| 42.65|
| June 2019   | 41.24| 138.40| 80.32| 314.13| 77.20| 68.10| 49.96| 47.52| 27.27|
| July 2019   | 107.97| 305.93| 113.40| 200.56| 222.59| 218.20| 351.82| 41.22| 125.86|
| Sept 2019   | 363.07| 485.71| 132.18| 405.84| 244.49| 266.93| 392.15| 149.12| 66.27|
| Oct 2019    | 17.06| 17.22| 40.26| 34.68| 23.99| 22.34| 22.03| 27.96| 22.93|
| Nov 2019    | 150.06| 90.71| 64.18| 58.58| 47.23| 73.07| 86.69| 61.88| 32.78|
| Dec 2019    | 45.86| 65.80| 51.92| 60.23| 36.47| 35.89| 35.84| 28.96| 29.72|
| Jan 2020    | 67.89| 71.02| 33.45| 44.78| 63.62| 55.16| 37.48| 144.15| 11.52|
| Feb 2020    | 99.74| 34.26| 77.42| 60.78| 57.64| 54.01| 53.29| 92.06| 87.71|
| WQI Mean values | 107.423| 154.358| 78.556| 135.04| 103.523| 109.099| 123.309| 66.535| 48.038|

### 4. Conclusion

In conclusion the various parameters viz. water temperature, transparency, pH value, electrical conductivity, TSS, BOD, COD, DO, phosphate and nitrogen were tested of Puah Reservoir water which were found between the range of WHO permissible limit. Based on water quality index grading, the reservoir water has been classified as poor due to water from the rock (embedded with nutrients), rainfall, intrusion from reserved animals and consequential alga bloom. However, there are some locations that were unfit for drinking such as P1 (September 2019), P2 (July and September 2019), P4 (June and September 2019) and P7 (July and September 2019). Although, the result for the mean WQI for all the stations/locations revealed that the water is fit for drinking purpose by any form of treatment.
However, it’s relatively good for swimming, bathing, laundry, irrigation and industrial purposes. This condition showed that the activities of Tambat and Puah hydro-power generation had no negative effect on the water quality of upper and lower parts of Puah Reservoir respectively.

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