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Puah Reservoir, Malaysia: A Preliminary Limnological Finding at the Newly Operated Hulu Terengganu Hydroelectric Project (HTHEP)

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Abstract

In this study we present a first limnological characterization of Puah Reservoir (surface area of 69.79km^2) since completion in 2014 and filling in 2015. The results obtained from seven sampling points shows the overall average values, standard deviation and range (min – max) of the physico-chemical parameters investigated in Puah Reservoir for twelve (12) months (Jan – Dec 2016) sampling. Puah Reservoir overall average surface water parameters recorded are water temperature (29.83 ± 1.78 ºC ; 24.10 – 33.70 ºC); dissolved oxygen (DO) (6.17 ± 0.95 mg/L ; 4.00 – 8.74 mg/L); chemical oxygen demand (COD) (17.67 ± 8.18 mg/L ; 2.00 – 39.00 mg/L), biological oxygen demand (BOD) (2.41 ± 1.38 mg/L ; 0.30 – 6.90 mg/L), pH (6.73 ± 0.47 ; 5.79 – 8.51), total suspended solid (TSS) (3.62 ± 2.23 mg/L ; 1.10 – 16.50 mg/L); nitrate (NO_3^-) (0.01 ± 0.01 mg/L ; 0.00 – 0.04 mg/L), nitrite (NO_2^-) (1.14 ± 0.88 mg/L; 0.00 – 4.00 mg/L); phosphorus (PO_4^-) (0.48 ± 0.28 mg/L ; 0.18 – 1.40 mg/L) and ammonia-N (NH4-N) (0.19 ± 0.15 mg/L ; 0.00 – 0.70 mg/L). Calculation of Water Quality Index (WQI) based on six (6) parameters shows that sampling stations at Puah Reservoir are in Class II with an average of 87.58 (Class II). Based on WQI for Class II, it has been proposed suitable for recreational activities involving the body contact, drinking water resources with conventional treatment and suitable for sensitive aquatic species. In summary, thermal stratification in Puah Reservoir was identified within range of 2 – 5 meter vertical depth.

Keywords: Puan reservoir, Stratification, Water quality.

1. Introduction

Lakes and reservoir are important sources of water in Malaysia and they formed part of storage basins for multipurpose functions for municipal and industrial water supply, agriculture and hydropower. There are only two natural lakes namely Tasik Chini and Tasik Bera with 90 man-made lakes are found in Malaysia (NAHRIM, 2009). Dam can be defined as a barrier constructed to hold back water and rise to the level that creates reservoir that can be used in the generation of electricity or other means such as irrigations, drinking water and flood mitigation. Hydropower in Malaysia contributed about 4.8% of the energy supply in year 2016 (Malaysia Energy Statistics Handbook, Energy Commission, 2018).

Lakes and reservoir all over the world experience different problem. Common problems include eutrophication, sedimentation and weed infestation. According to Zati and Salmah, (2008) eutrophication of lakes, which is known as a prevalent global concern in lakes and reservoir, is also a critical issue in Malaysia. Indiscriminate utilization of lakes and human activities in the catchment areas such as agriculture practices, public jetty, infrastructural development and unsustainable logging activities have resulted in various environmental problems. Consequently, to maintain the sustainability of lakes and reservoirs, regular monitoring is necessary for the establishment of a frame work for better management, restoration and conservation of this water bodies.

In a tropical reservoir, water column is usually divided into two major zones known as photic and aphotic (dark) zone. Photic zone is the layers that receive enough light penetration to perform photosynthetic activity whereas aphotic zone is the lower layers of water column that receive no light penetration (Lokman, 1992). Consequently, their ability to harvest light photosynthetically is impaired. APHA (2005) therefore suggested that since physical and chemical properties give a specific picture of water quality in fresh water at a point in time and biota (biological property) act as a continuous monitor and give more general pictures of water quality over a period, regular monitoring should be maintained to always meet water standard requirement.

TNB has just recently developed a new hydropower station in fulfilling increasing electricity demand, and the station starts its operation since 2016. Hulu Terengganu Hydroelectric Project (HTHEP) is located in Tembat Forest Reserve and Petuang Forest Reserve in Hulu Terengganu district covering two (2) hydropower stations (Puah and Tembat). Puah Hydropower Station construction works started in 2009 and completed in 2014 provide electric supply of 250MW. Puah Reservoir full supply level is 296m above the sea level and currently there is no water spill recorded in present. Generally, when a dam is constructed, changes will occur resulting in transformation of a free-flowing river ecosystem to a reservoir habitat (Wetzel, 1983). It is the first hydropower station in Malaysia that subjected to Environmental Quality Act 1974 (requires a DEIA study). Based on DEIA study, the newly operated hydropower station is predicted to experience a change of terrestrial habitat to turn into aquatic and lotic habitat turns into lentic with significant hydrological changes such as water flow, water volume and depth. Thus, the biodiversity of the aquatic system may also be altered due to changes in physical forces (Bunn and Arthington, 2002).

However, currently there are limited data for Puah Reservoir in operational phase for reference to support and understand such situations. Therefore, a preliminary limnological study was conducted to address the water quality status of Puah Reservoir which will serve as baseline data for fundamental reference for future research and sustainability management of HTHEP.

2. Materials and Methods

2.1 Study Sites

The study area is located within Hulu Terengganu catchment, at the north of existing Kenyir Dam in Kuala Berang, Daerah Hulu Terengganu, Negeri Terengganu Darul Iman, Malaysia. It is about 50 km from Bandar Gua Musang – Hulu Terengganu roadway, and about 65km west of Kuala Terengganu in a geographical location of 5°09'04.9"N 102°36'32.8"E with a total catchment area of 405.55 km^2 and surface are of 69.79km^2. HTHEP located at upstream of Sultan Mahmud Kenyir Hydropower Station. Seven (7) sampling locations (P1, P2, P3, P4, P5, P6 and P7) were selected as shown in Figure. 1. Table 1 summarised the major changes based on physical structure of the existing environment due to the development of hydropower station effects. Sampling been carried out once a month started Jan 2016 to December 2016.

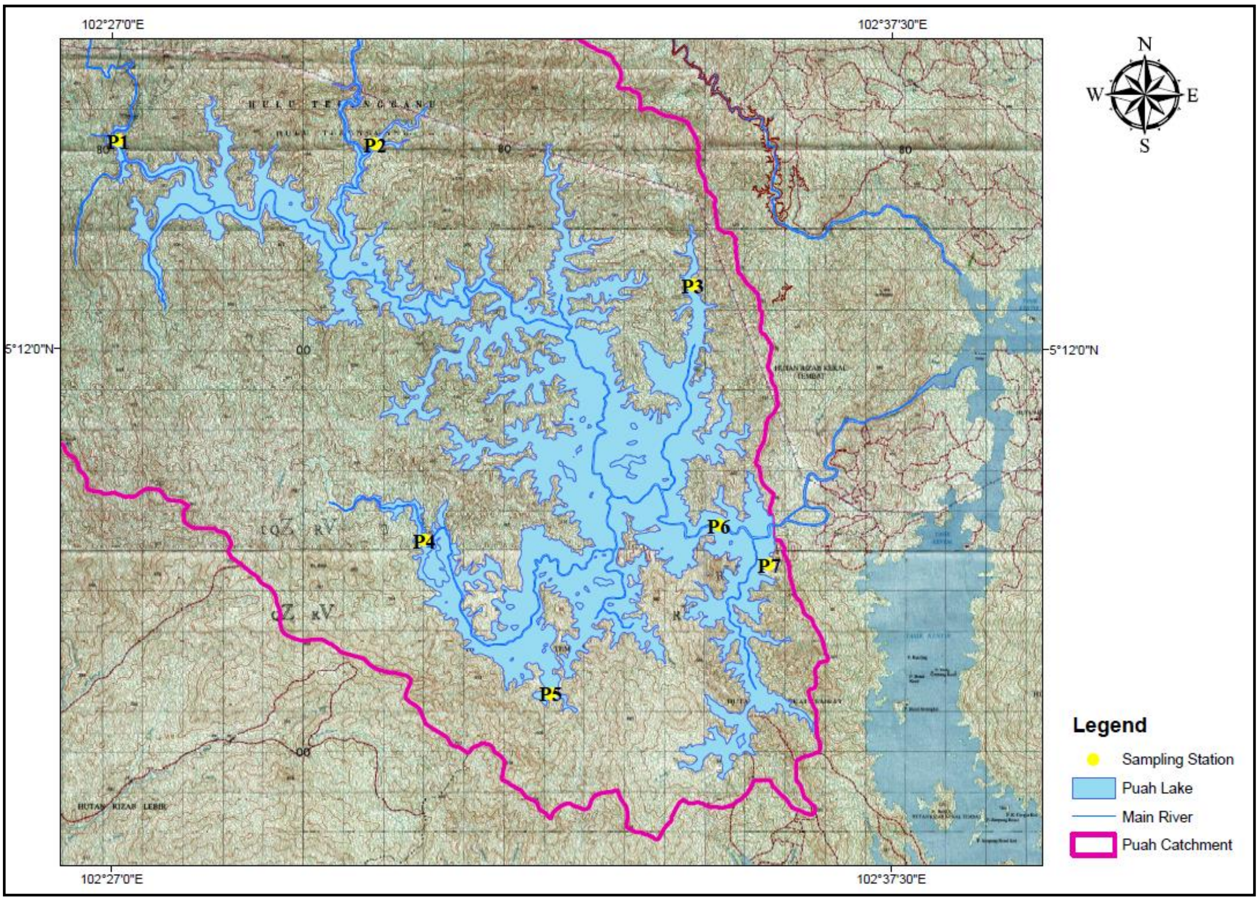


Figure 1. The location of the study location with sampling stations (P1, P2, P3, P4, P5, P6 and P7).

Table 1. Locations and characteristic of samplings station in Puah Reservoir study.

Station	River	Characteristic
P1	Sg. Terengganu Mati	Lotic to lentic ecosystem
P2	Sg. Limbang	Lotic to lentic ecosystem
P3	Sg. Jalang	Lotic to lentic ecosystem
P4	Sg. Pelagong	Lotic to lentic ecosystem
P5	Sg. Sireh	Lotic to lentic ecosystem
P6	Center Dam Puah	Lotic to lentic ecosystem
P7	Power Intake Puah	Lotic to lentic ecosystem

*Notes: Sg = River

2.2 Analysis

Water temperature, pH and DO were determined *in-situ* using calibrated multi meters YSI Professional Plus handheld multi-probe from the surface to 10 m depth with 1 m interval. Nitrate, nitrite, COD, BOD, phosphorus, total suspended solid (TSS) and ammonia-N were analysed using Hach DR/2000 5 portable water analysis kit in the laboratory according to APHA 1992 and HACH 2003 procedures. All parameters especially at the surface later will be analysis using Water Quality Index (WQI) to determine water quality status of this newly operation reservoir.

3. Results and Discussion

Results of surface water quality parameters at seven sampling locations were recorded as shown in Table 2. The result obtained shows the overall average values, standard deviation and range (min – max) of the physico-chemical parameters investigated in Puah Reservoir. Based on the results recorded, water temperature (29.83 ± 1.78 ºC ; 24.10 – 33.70 ºC); dissolved oxygen (DO) (6.17 ± 0.95 mg/L ; 4.00 – 8.74 mg/L); chemical oxygen demand (COD) (17.67 ± 8.18 mg/L ; 2.00 – 39.00 mg/L), biological oxygen demand (BOD) (2.41 ± 1.38 mg/L ; 0.30 – 6.90 mg/L), pH (6.73 ± 0.47 ; 5.79 – 8.51), total suspended solid (TSS) (3.62 ± 2.23 mg/L ; 1.10 – 16.50 mg/L); nitrate (NO_3^-) (0.01 ± 0.01 mg/L ; 0.00 – 0.04 mg/L), nitrite (NO_2^-) (1.14 ± 0.88 mg/L; 0.00 – 4.00 mg/L); phosphorus (PO_4^-) (0.48 ± 0.28 mg/L ; 0.18 – 1.40 mg/L) and ammonia-N (NH_4-N) (0.19 ± 0.15 mg/L ; 0.00 – 0.70 mg/L).(Table 2).

Table 2. Mean reading of surface water quality parameters of Puah Reservoir study (Jan – Dec 2016)

Parameter	Mean		Standard deviation	Range
Temperature (ºC)	28.83	±	1.78	24.10–33.70
Dissolved Oxygen, DO (mg/L)	6.17	±	0.95	4.00 – 8.74
Chemical Oxygen Demand, COD (mg/L)	17.69	±	8.13	2.00 – 39.00
pH	6.73	±	0.47	5.79 – 8.51
Biological Oxygen Demand, BOD (mg/L)	2.41	±	1.38	0.30 – 6.90
Total Suspended Solid, TSS (mg/L)	3.62	±	2.23	1.10 – 16.50
Nitrate, NO_3- (mg/L)	0.01	±	0.01	0.00 – 0.04
Nitrite, NO_2- (mg/L)	1.14	±	0.88	0.00 – 4.00
Phosphorus, PO_4- (mg/L)	0.48	±	0.28	0.18 – 1.40
Ammonia-N, NH^3-N (mg/L)	0.19	±	0.15	0.00 – 0.70
WQI	87.58	±	5.49	70.14– 6.36

The water quality parameters of Puah Reservoir showed variation in values at different sampling stations as shown in Table 3. The average of water temperature was recorded at surface water in this study is higher at all sampling stations with ranging 24.10 – 33.70 ºC. This could be attributed to direct heating from solar radiation. Water temperature in the tropical region was strongly impacted by solar radiation and air temperature (Van Vliet et al., 2013). Variations of temperature in tropical reservoir was relatively small compared to the temperate reservoir (Ali, 1996; Boulton et al., 2014). The highest average water temperature been recorded at P5 with 30.72 ºC while for DO at P5 (6.66 mg/L), TSS at P4 (5.43 mg/L); pH at P5 (6.99), BOD at P4 (4.27 mg/L), COD at P4 (21.25 mg/L), NH3-N at P4 (0.39 mg/L and PO_4^- at P1 (0.74 mg/l) (Table 3). Overall, Puah Reservoir surface water can be classified as Class II based on WQI with reading ranging 83.15-90.74 (Table 3) and suitable for sensitive aquatic species.

However, most tropical reservoirs with no apparent of flushing flow showed two thermal stratifications (epilimnion and hypolimnion). Thermal stratification is common and an important natural process occur in tropical water reservoir that can have a significant effect on the water resource quality (Baharim et al., 2011). Deep man-made lakes especially created for hydropower generation are experiencing stratification problem. Puah Reservoir average water temperature range (24.44 - 29.85ºC) from the surface up to 10 m depth was a slight thermocline where temperature dropped more gradually at 2m to 5m depth (Figure. 2).

Table 3. Mean reading of surface water quality parameters of Puah Reservoir during the study (Jan – Dec 2016)

Parameters	Sampling Station						
	P1	P2	P3	P4	P5	P6	P7
Temperature (ºC)	28.68	29.73	29.66	29.70	30.72	29.98	30.38
Dissolved Oxygen, DO (mg/L)	6.33	6.42	6.07	6.07	6.66	5.94	5.72
Chemical Oxygen Demand, COD (mg/L)	16.83	12.42	17.67	21.25	18.42	21.83	15.42
Biological Oxygen Demand, BOD (mg/L)	1.69	1.91	2.84	4.27	2.13	2.09	1.97
pH	6.70	6.78	6.67	6.70	6.99	6.67	6.61
Total Suspended Solid, TSS (mg/L)	3.33	2.90	3.04	5.43	4.21	3.64	2.78
Nitrate, NO_3- (mg/L)	0.01	0.01	0.02	0.01	0.01	0.19	0.01
Nitrite, NO_2- (mg/L)	1.02	0.99	1.22	1.36	0.61	1.63	1.13
Phosphorus, PO_4- (mg/L)	0.74	0.39	0.42	0.41	0.45	0.31	0.67
Ammonia-N, NH^3-N (mg/L)	0.18	0.14	0.12	0.39	0.17	0.19	0.16
WQI	89.04	90.74	88.17	83.15	89.30	86.55	87.52
Class	II	II	II	II	II	II	II

Notes:
WQI = Water Quality Index; Class I (≥ 91.76); Class II (75.36 – 91.75); Class III (51.68 – 75.35); Class IV (29.61), and Class V (≤ 29.60).

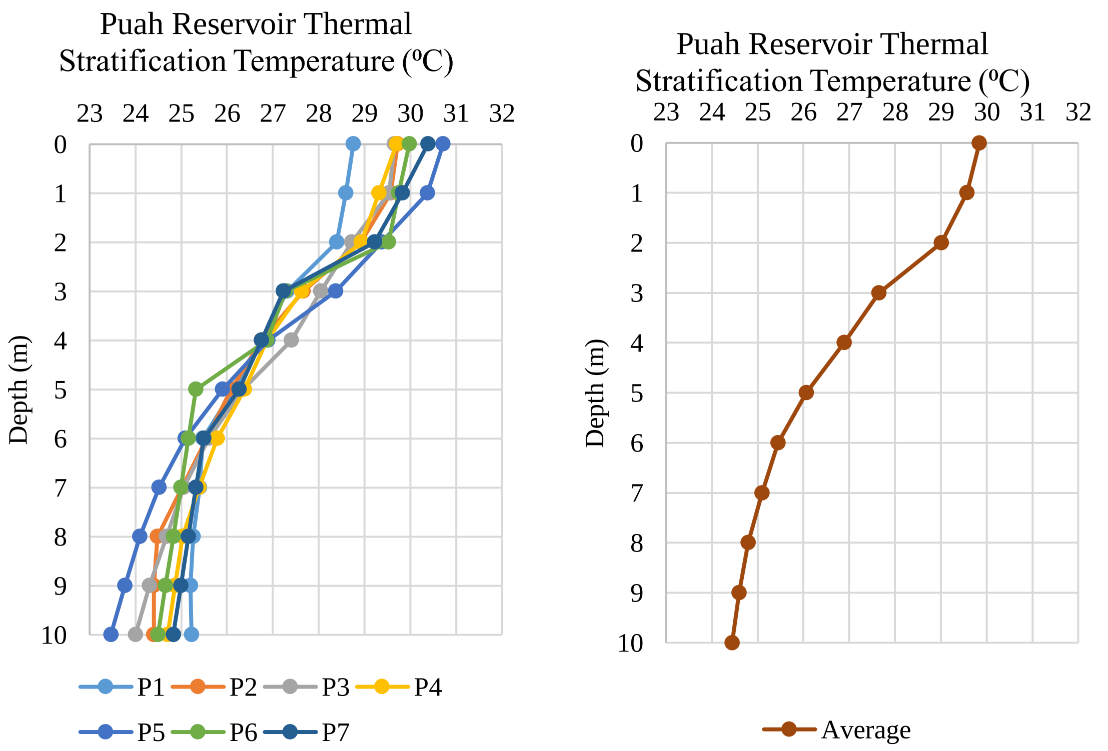
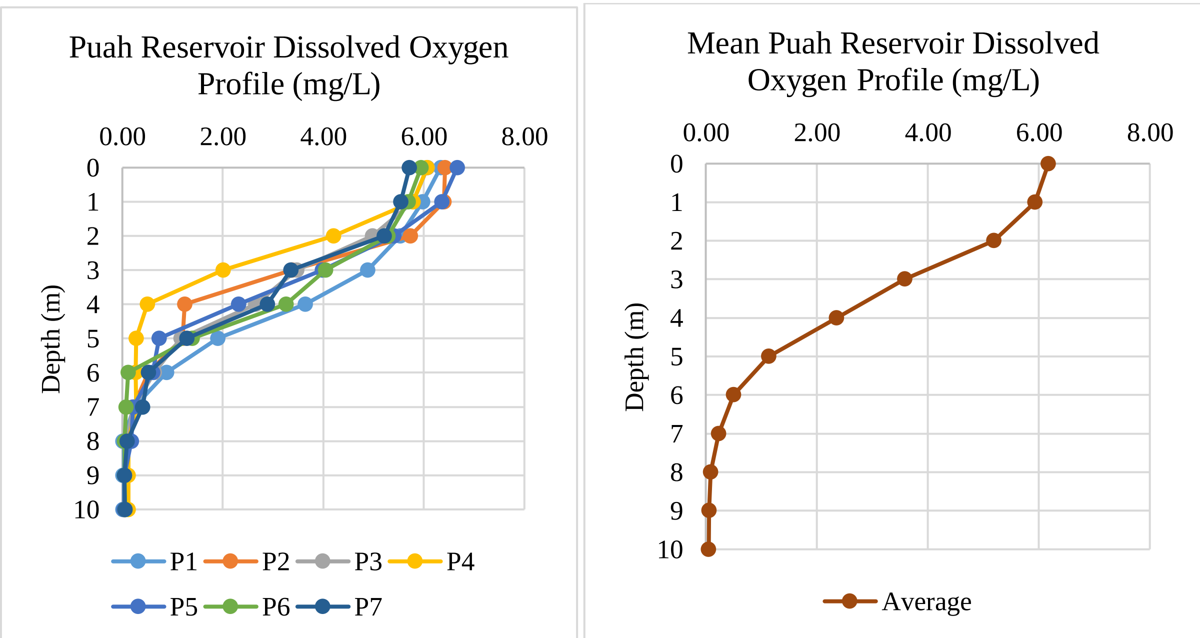


Figure 2. Vertical water temperature profile at all sampling stations of Puah Reservoir study (Jan - Dec 2016).

Similar result as Shah et al (2009) reported in Muda Reservoir, thermocline decreases and less distinct compared to the Pedu Reservoir. Pedu Reservoir has larger surface area and exposure to physical and wind disturbances that the temperature has not become stratified. Thermocline increases and become more distinct the closest station is located from the dam. Compared with the report of Fatimah et al., (2002) in Kenyir Reservoir, reported a strong thermal stratification was observed with an anoxic hypolimnion during both dry and wet seasons. The epilimnetic layer is determined thinner in hot dry months (2 – 7m) compared to the wet season (14 – 15m) (Fatimah et. al., 2007). The mean water temperature for Puah Reservoir (30.7ºC) corresponds with temperature of Tasik Kenyir (30 to 32ºC) as reported by Siti-Zahrah et al., (2005).

Dissolved oxygen (DO) is a sensitive tracer of the physical and chemical processes occurring in an aquatic system. Adequate DO available at all depths of the reservoir is fundamental to ensure all areas in lake can sustenance biotic life. Healthy aquatic lentic environment usually describes as orthograde oxygen profile (oligotrophy) (Wetzel, 1983).

Besides, the presence of adequate DO in reservoir also can determine the water physical and chemical properties. Decrease of DO (consumption) at various depths naturally effects from oxidation process of particulate organic material settling into the aphotic zone. Temperature is the major factor of oxygen solubility under oligotrophic condition with 100% DO saturation increasing in depth.



(a) (b)

Figure 3. Vertical DO profile at all sampling stations of Puah Reservoir study (Jan - Dec 2016).

In this study, the vertical DO profiles of all sampling stations during the study period are shown in Figure 3. Average DO (Figure 3 (b)) recorded was eventually depleted at 2 – 5 m depth. The DO at the subsurface for average reading in Puah Reservoir was within the range of 5.72 to 6.66 mg/L and decreased with depths. Compared with Kenyir Reservoir DO concentration was in the range of 7.2 – 7.8 mg/L (Suratman et. al., 2019). In the Bakun Dam Reservoir, DO at the subsurface was high ranging from 5.94 – 8.51 mg/L but dropped drastically to zero at 2 – 4m (Lee et. al., 2012). In contrast for Muda Reservoir, the DO stratification was also observed to be almost anoxic at 10 m depth (Shah et. al., 2009). The DO of Kenyir Reservoir and Bakun Dam are higher probably due to larger surface area (369 km^2 and 695 km^2 respectively) which can be a factor for oxygen dissolution in water, compared to 69 km^2 surface area for Puah Reservoir. Generally, the value of DO remained high at surface water while the water column remained anoxic at 2 m depth. The high concentration of DO at surface layer recorded in this study was probably due to photosynthesis process by algae which released oxygen in the water column. The suppression of vertical transport at the thermocline allows an oxygen gradient to occur which caused anoxic condition to develop in the hypolimnion (Chapman 1996). Anoxic condition is due to depletion of oxygen by the decomposition of submerged vegetation as not all the trees were removed in the reservoir when impoundment phase. It was assumed that decomposition rate was increased due to the enhancement of metabolism. This could be attributed to higher nutrient inputs which might be because of chemical from the construction materials since the dam is new. This explained that the use of DO for both biological and chemical processes was high in hypolimnion layer (Dortch, 1997). DO concentration also can change from the top to the bottom due to underwater current especially at the river mouth, where cold river water with high DO flows into the lower portion of reservoir (Hamid, 1987; Ismail, 1995). However, this phenomenon was not observed in this study as sampling activities were concentrated from the surface to only 10 m depth. All DO readings at the surface were all within the class IIA (5 – 7mg/L) of National Water Quality Standards for Malaysia (NWQSM, 2006).

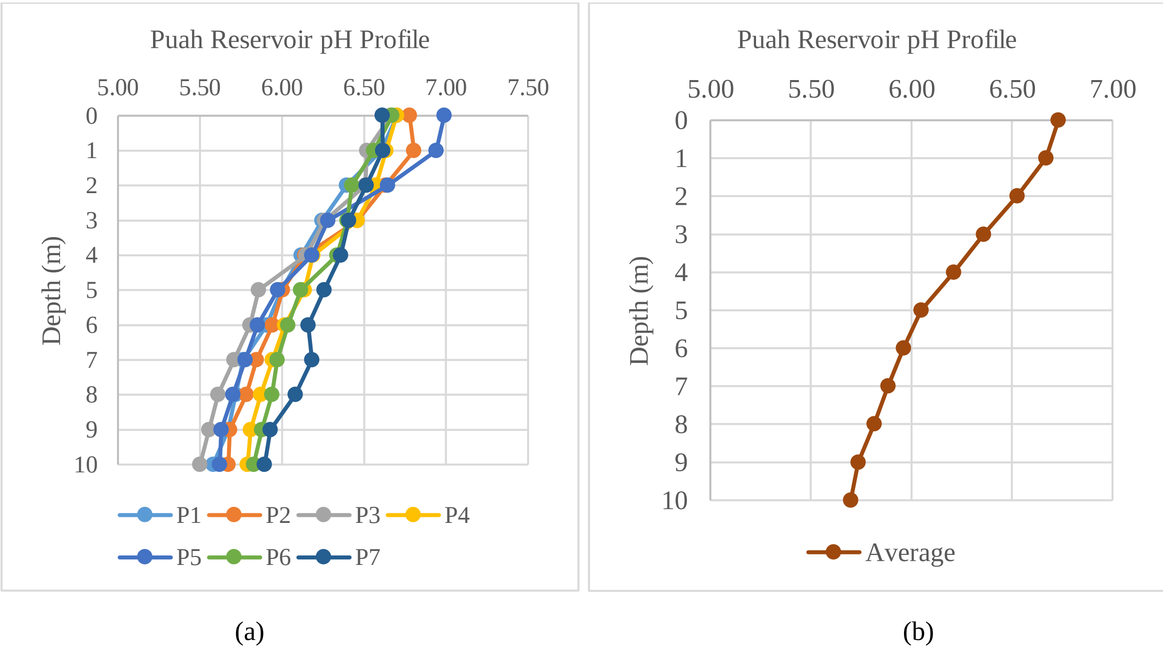


Figure 4. Vertical pH profile at all sampling stations of Puah Reservoir study (Jan - Dec 2016)

The Puah Reservoir average pH recorded at subsurface water was ranged between 6.6 - 7.2 which is lower than Temengor Reservoir (7.82 – 8.76) and Ahning Reservoir (7.16 – 7.56) but within same range with Chenderoh Reservoir (6.10 to 6.84) (Meor *et al.*, 2002) and Pedu Reservoir (6.64 to 7.18) (Shah *et al.*, 2012). The pH was slightly acidic (mean 6.87 ± 0.7) except at station P4 which was slightly alkaline (7.2) (Table 3 and Figure 4). The vertical profiles at all sampling stations were quite similar. The vertical distribution of pH is strongly influenced various biologically mediated reactions (Wetzel, 1995). The presence of a lot of decaying stumps at 3 m below the water and photosynthesis process which took up dissolved carbon dioxide could be contributed to the decrease in pH. Consequently, high carbon dioxide level caused high dissociation of H^+ and therefore decreased the pH level (Boulton *et al.*, 2014). Hence, the gradual decrease of pH at Puah Reservoir was probably due to higher respiration and anaerobic decomposition rate in the deeper water layer since it received no light penetration for photosynthesis. All pH values were within the acceptable limit (6.5-8.5) recommended by WHO (1996) and USEPA (1979).

Nitrate and phosphate are essential nutrient as phytoplankton growth is limited by nutrients availability (Stent, 1981). Since there were no human activities around Puah Reservoir, the naturally occurring nitrate and phosphate may be the major contributing sources. According to Dortch (1997), even though there could be no man-made pollution sources upstream, a large quantity of organic substances from surface run-off plus decomposition of submerged trees could cause high nutrients concentration. This study recorded nitrate and phosphate ranges of 0.00-0.04 mg/L and 0.18-1.40mg/L respectively. According to EPA (1976), phosphate-phosphorus concentration higher that 0.28 mg/L could promote the development of algae and other aquatic plants that can interfere with the balance of the lake ecosystem.

Calculation of water quality index (WQI) based on 6 parameters shows that sampling stations at Puah Reservoir are in Class II with an average of 87.52 (Class II). Based on WQI for Class II, it has been proposed suitable for recreational activities involving the body contact, drinking water resources with conventional treatment and suitable for sensitive aquatic species (Omar, 2015). Although, significant difference occurred between the wet and dry season values of temperature, COD, BOD and TSS ($p < 0.01$). However, no significant difference was found between the seasons in terms of pH, nitrate. nitrite, phosphorous and ammonia-N ($p > 0.05$).

4. Conclusion

In general, the water column in Puah Reservoir is characterized as nutrient rich, high DO and a relatively stable pH slightly acidic hence, Puah Reservoir water quality is classified as within Class II. Puah Reservoir is a unique aquatic ecosystem due to irregular water releases. This ecosystem tends to accumulate high level of nutrients, sediment and other minerals brought into the system by surface run-off and inflowing rivers and streams. Extended storage time resulted in stratification of temperature and DO at various locations in Puah Reservoir. Major aquatic organisms are concentrated from the surface to the 2 m depth since DO depletion occurred at greater depth. However, an intensive study should be carried out to get more detailed information before any concrete conclusion can be made especially in terms of lake primary productivity. To achieve environmental sustainability of the hydropower operation, it is essential to continue the research with the aim to address the environmental impacts towards aquatic resources and lake management of the operational of Hulu Terengganu Hydroelectric Station, which will be functional as a fundamental reference and guidance for any hydroelectric projects to be developed in the future. This includes the development of Fish and Fishery Resource Management Plan and Community-based Tourism (CBT) that will help local community to generate source of income and help to recover the population of important fish species.

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