Physicochemical Parameters of Bakun Reservoir in Belaga, Sarawak, Malaysia, 13 Months after Reaching Full Supply Level
(Parameter Fizikokimia Takungan Bakun di Belaga, Sarawak, Malaysia, 13 Bulan selepas Mencapai Tahap Bekalan Penuh)

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ABSTRACT

Determining the water quality of Bakun Reservoir 13 months after it operates at full supply level is crucial for better understanding of changes in the physicochemical parameters, which may enable the prediction of its effects on the survival of aquatic life in the reservoir. This study determined 13 physicochemical parameters at six stations within the reservoir at fixed depths. The results showed that the minimum 5 mg/L of dissolved oxygen (DO) required for sensitive aquatic organisms was recorded at 6 m depth. However, DO was not detectable at depths exceeding 7 m. The water was acidic at depths of more than 10 m. Turbidity and total suspended solids increased corresponding with depth. Inorganic nitrogen were predominantly in the form of ammonia-nitrogen, creating an unhealthy environment for aquatic life. Concentration of Chl-a was significantly higher at the subsurface water than 30 m depth in four out of six stations. The present study shows changes in water quality as compared to the pre-impounded period and 15 months after the filling phase, in particular, stratification of dissolved oxygen, thermocline conditions and alkalinity. The changes varied according to the distance from the dam and may have been influenced by existing land developments within the area such as the construction of the Murum Hydroelectric Dam, oil palm plantations and timber concessionares. Though the water quality might have deteriorated, further study is needed to determine if this condition will prolong.

Keywords: Impoundment; Murum; new reservoir; stratification; tropical reservoir

ABSTRAK

Menentukan kualiti air Empangan Bakun 13 bulan selepas ia beroperasi pada tahap bekalan penuh adalah penting untuk lebih memahami perubahan dalam parameter fizikokimia, yang membolehkan ramalan tentang kesannya terhadap kewujudan hidupan akuatik dalam takungan. Kajian ini menentukan 13 parameter fizikokimia di enam stesen dalam takungan pada kedalaman yang tetap. Keputusan menunjukkan bahawa minimum 5 mg/L bagi oksigen terlarut (DO) diperlukan oleh organisme akuatik sensitif dicatatkan pada kedalaman 6 m. Walau bagaimanapun, DO ini tidak dikesan pada kedalaman melebihi 7 m. Air adalah berasid pada kedalaman lebih daripada 10 m. Kekeruhan dan jumlah pepejal terampai meningkat sejajar dengan kedalaman. Nitrogen bukan organik yang kebanyakannya dalam bentuk ammonia-nitrogen, mewujudkan persekitaran yang tidak sihat untuk hidupan akuatik. Kepekatan Chl-a adalah lebih tinggi pada air subpermukaan daripada kedalaman 30 m di empat daripada enam stesen. Kajian ini menunjukkan perubahan dalam kualiti air berbanding dengan tempoh prapembendungan dan 15 bulan selepas fasa mengisi, khususnya, penstratuman oksigen terampai, keadaan termoklin dan alkalin. Perubahan ini berbeza mengikut jarak dari empangan dan mungkin dipengaruhi oleh pembangunan tanah sedia ada dalam kawasan seperti pembinaan Empangan Hidroelektrik Murum, ladang kelapa sawit dan konsesi perkayuan. Walaupun kualiti air mungkin semakin merosot, kajian tambahan diperlukan untuk menentukan jika keadaan ini akan berpanjangan.

Kata kunci: Murum; pembendungan; stratifikasi; takungan baru; takungan tropika

INTRODUCTION

Hydropower is an alternative source of energy to fossil fuel. It is considered a renewable source of energy which is reliable and efficient (USBR 2005). Therefore, many countries have constructed hydroelectric dams to meet the energy demands for use in economic development. The Malaysian government has also explored this resource due to the depleting oil and gas reserves (Choy 2005). In Sarawak, the resource is explored under the Sarawak Corridor of Renewable Energy (SCORE) to generate energy needed for development of the State (RECODA 2014). Of the twelve hydroelectric dams that have been planned in Sarawak (SEB 2013; SIWRM 2008), two had been fully commissioned, namely, the Batang Ai Hydroelectric Dam and Bakun Hydroelectric Dam with Bakun Dam being the largest, 695 km^2 in surface area and 44000 MCM in gross storage (SIWRM 2008). The dam impoundment commenced on 13th October 2010 and reached the full supply level on 9th March 2012 (Nyanti et al. 2012).

Water quality changes are inevitable with the construction of a dam across a river as the river ecosystem becomes lacustrine (Chapman 1996). In the 27 years old Batang Ai Reservoir, studies have shown that changes in water quality were significant and to some extent decreased to unhealthy levels for aquatic life (Ling et al. 2013b, 2012). Evidence of water temperature stratification have also been recorded for the reservoir, where the phenomenon was associated with the location within the reservoir and seasons. Anecdote evidence indicted that sudden changes in weather conditions might have resulted in large amount of fish killed in Batang Ai Reservoir (Patrick Luyong, Agriculture Officer, Personal communication 2008). This ecological phenomenon remains unknown due to little study being done in particular during the early impoundment stages. Indeed, the present study on water quality in Bakun Reservoir would be useful in explaining the ecological phenomenon if it were to occur in the dam. With 69640 ha of forest and soil submerged inclusive of 50 million m^3 of biomass (Choy 2005), a similar ecological phenomenon might occur in Bakun Reservoir. Submersion of forest and soil and subsequent microbial decay of such a large volume of organic matter would affect the water quality and the aquatic life. Study by Nyanti et al. (2012) during the filling phase showed that the DO level dropped rapidly to anoxic level at a shallow depth, whereas turbidity increased with depth. Monitoring the water quality is important to provide the baseline data needed for planning and management of fisheries, recreation and aquaculture activities. Therefore, the objective of this study was to determine the water quality at different depths which was conducted 13 months after the reservoir reached the full supply level.

MATERIALS AND METHODS

Bakun Dam is located about 37 km upstream of Belaga town, in the central region of Sarawak. The reservoir covers approximately 1.5 million ha of catchment mainly the Balui River that is fed by three major tributaries, namely, Murum River, Linau River and Bahau River. The study was carried out on the 9th - 12th April 2013 at six stations (Figure 1); Station (St) 1 is located in the proximity of the dam, St 2 at Long Liko, St 3 at Linau River, St 4 at Murum River, St 5 at Upstream of Wat River and St 6 is located between St 4 and the Murum Dam.

In-situ variables of temperature, pH, turbidity, conductivity and dissolved oxygen (DO) were measured using a multiparameter sonde (YSI 6920). Transparency was measured using a secchi disc. Triplicate water samples were collected from three depths; subsurface (0.2 m), 15 m and 30 m using a Van Dorn water sampler. The samples were placed in 2 L acid-washed polyethylene bottles and transported on ice to the laboratory. Determination of total suspended solids (TSS) and chlorophyll-*a* (Chl-*a*) were conducted following the Standard Methods (APHA 1998). One litre of water sample was filtered and the filter (Whatman GF/C) was dried overnight in an oven at 105°C and the process was repeated until constant weight. The mass of suspended solids in a litre of water sample was determined as the difference between the initial and final weight of the filter. For Chl-*a* analysis, one litre of water sample was filtered (Whatman GF/F). Three mL of 90% aqueous acetone solution was added to each filter and grinded by pestle and mortar. After the sample was transferred into a capped centrifuge tube, 90% acetone was topped up to 10 mL and it was left in a refrigerator
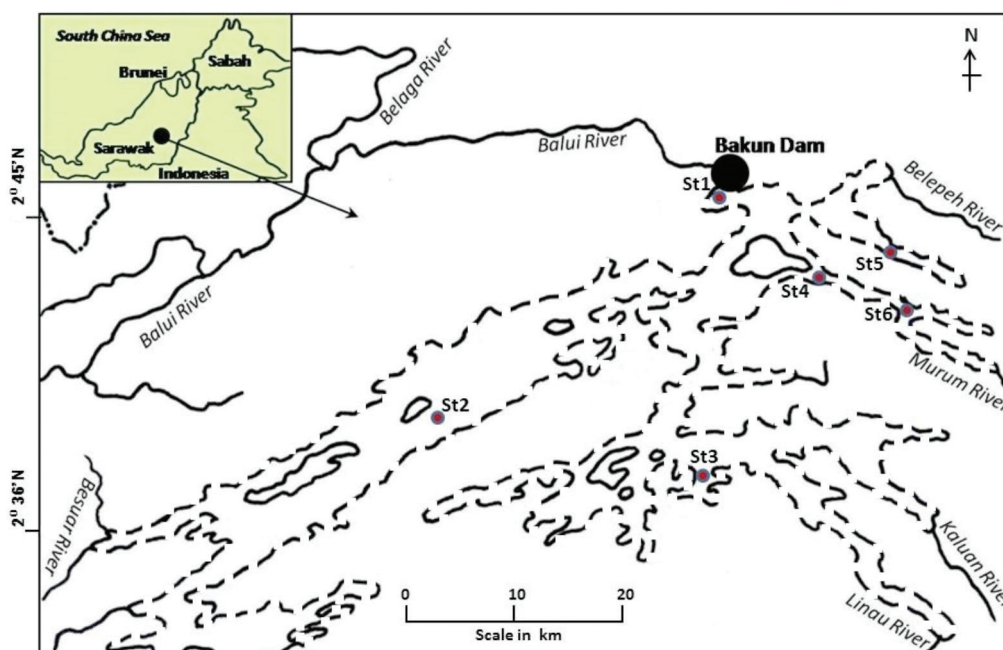

FIGURE 1. Five sampling stations in the Bakun Hydroelectric Reservoir with the reservoir boundary indicated by dotted line

for a minimum of 2 h. Subsequently, the sample was centrifuged for 20 min at 500 g. Chl-*a* was determined using the trichromatic method, where the optical density of the extract was measured at 630, 647, 664 and 750 nm using a spectrophotometer. Chl-*a* concentration in water sample was calculated based on (1).

$$\text{Chl-}a\ (\mu g/L) = [11.85\ (E_{664}\text{-}E_{750}) - 1.54\ (E_{647}\text{-}E_{750})$$
$$- 0.08\ (E_{630}\text{-}E_{750})]\ v\ /\ V$$

(1)

where E_{630}, E_{647}, E_{664} and E_{750} are optical densities at 630, 647, 664 and 750 nm, respectively, v is the volume of extract (L) and V is the volume of water sample filtered (m^3).

Chemical oxygen demand (COD), soluble reactive phosphorus (SRP), total ammonia-nitrogen (TAN), nitrate-nitrogen and nitrite-nitrogen in the filtered sample were determined using the colorimetric methods of Hach (2000). COD was analysed by following the reactor digestion method whereby water sample was heated for 2 h with potassium dichromate before the concentration was determined. The filtered sample was analysed for SRP according to ascorbic acid method. Nessler method was used for TAN analysis, cadmium reduction method for nitrate-nitrogen analysis whereas diazotization method was used for nitrite-nitrogen analysis. After the

reactions, the respective concentrations were determined using a spectrophotometer (DR2800). All analyses were conducted in triplicates. Comparison of water quality parameters among stations and depths were conducted using one-way ANOVA and Tukey's pairwise comparisons with 5% significance level. Bivariate correlation was used to investigate the relationship among the parameters. All analyses were performed using SPSS Statistics, v. 22.

RESULTS

Figure 2 shows the temperature, DO, pH and turbidity profiles measured on the 10th April 2013 at St 2. Temperature at the subsurface was the highest (31.4°C) and it decreased with the depth (Figure 2(a)). There was a sudden drop of 4.4°C at the depth between 5.7 and 8.9 m after which the temperature decreased gradually to 24.8°C at 30 m depth.

The DO profile record shows that DO was the highest at the subsurface and the concentration started to decrease rapidly from 5 m to undetectable level at 7 m as depth increased (Figure 2(b)). It also showed that DO was above 5 mg/L only in the top 6.4 m of the water column. The trend of pH decrease as depth increased was similar to temperature whereby there was a rapid change in pH at the thermocline region (Figure 2(c)). On the other hand, turbidity profile shows an increase in turbidity with the
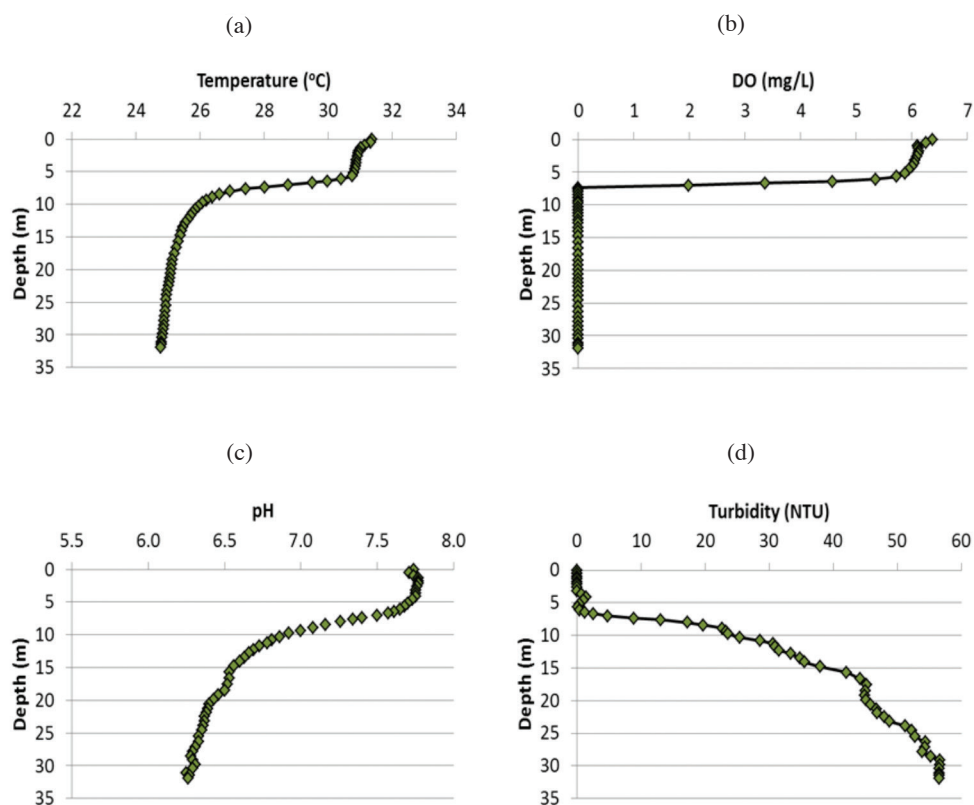
(a)

(b)

(c)

(d)

FIGURE 2. (a) Temperature, (b) dissolved oxygen (DO), (c) pH and (d) turbidity profiles
at St 2 in the Bakun Reservoir recorded on 10th April 2013

rapid change occurring in the thermocline region as well (Figure 2(d)).

Transparency was the very low at St 6 compared to the other stations (Figure 3). This corresponds to the highest TSS at that station (Figure 4(a)). TSS was the lowest at the subsurface and as depth increased, TSS increased at all stations. TSS at 30 m was significantly higher than TSS at 0.2 m (Table 1). Among the stations, St 6 shows significantly higher TSS than St 1, St 2 and St 3 at all depths.
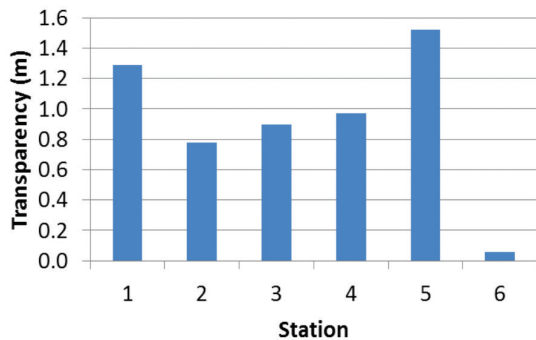

FIGURE 3: Transparency at the six stations

TABLE 1. Total suspended solids (mg/L) at three depths at the six sampling stations in Bakun Reservoir

St	Subsurface	15 m	30 m
1	85 ± 11^{a123}	93 ± 10^{ab1}	113 ± 9^{b1}
2	73 ± 8^{a12}	99 ± 10^{b1}	128 ± 9^{c1}
3	67 ± 11^{a1}	103 ± 16^{a1}	162 ± 17^{b23}
4	96 ± 6^{a234}	103 ± 12^{a1}	133 ± 3^{b12}
5	100 ± 7^{a34}	143 ± 16^{b2}	167 ± 16^{b3}
6	115 ± 8^{a4}	151 ± 11^{b2}	227 ± 10^{c4}

*Means in the same row with the same letters or column with the same numbers are not significantly different at 5% level

The electrical conductivity of most stations were low except at the deeper region of St 5 (Figure 4(b)). The conductivity decreased with depth at St 4 and 6, but the opposite trend was observed at the other stations (Figure 4(b)) and the differences were significant (Table 2). The lowest conductivity was recorded at St 6 at both 15 and 30 m. St 6 shows significantly lower electrical conductivity than all the other stations at all depths (Table 2).

COD ranged from 7 to 119 mg/L with the highest value at 30 m of St 1 and the lowest occurring at subsurface of St 3 (Figure 4(c)) and those values were significantly different
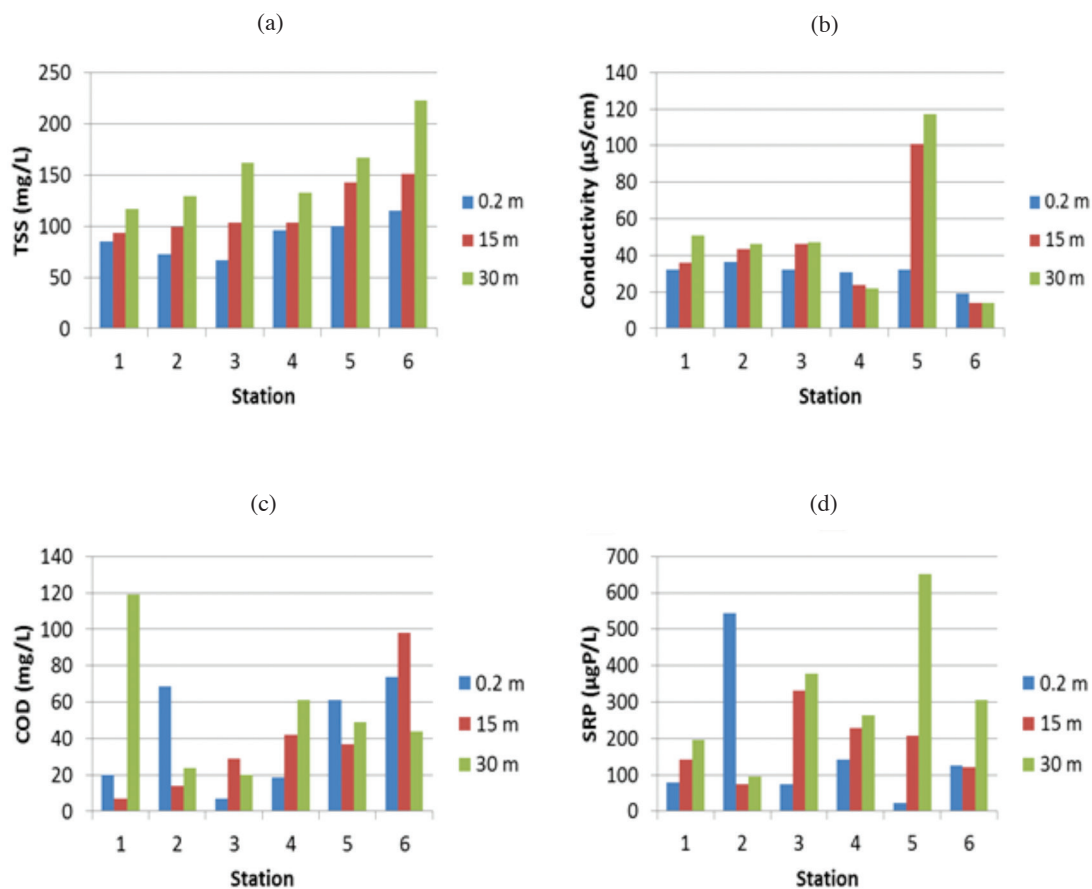
(a)

(b)

(c)

(d)

FIGURE 4. (a) Total suspended solids (TSS), (b) electrical conductivity, (c) chemical oxygen demand (COD) and (d) soluble reactive phosphorus (SRP) at the six stations

from the others (Table 3). The highest COD was observed at either 15 or 30 m at all stations except St 2 and St 5 where the highest occurred at subsurface. Overall mean of the three depths shows St 6 having the highest mean and the lowest was observed at St 3. The highest SRP was observed at St 5 at 30 m followed by subsurface of St 2. At all stations, among the three depths, SRP was the highest at 30 m depth except at St 2 where the highest was observed at the subsurface (Figure 4(d)). In all stations, SRP at 15 and 30 m were significantly different from subsurface (Table 4).

Nitrate-nitrogen at all stations were low, in the range of 0.003-0.027 mg/L (Figure 5(a)) and the only significant difference observed was between subsurface and 30 m

TABLE 3. Chemical oxygen demand (COD) (mg/L) at three depths at the six sampling stations in Bakun Reservoir

St	Subsurface	15 m	30 m
1	20.0 ± 4.0^{a1}	6.7 ± 1.2^{a1}	118.7 ± 8.5^{b1}
2	58.7 ± 5.1^{a2}	13.7 ± 3.5^{b1}	24.3 ± 5.5^{b2}
3	7.0 ± 1.7^{a3}	28.7 ± 6.4^{b2}	19.7 ± 3.1^{b2}
4	18.7 ± 3.2^{a1}	42.3 ± 5.5^{b2}	60.7 ± 4.9^{c3}
5	61.3 ± 5.1^{a2}	37.0 ± 5.2^{b2}	48.7 ± 5.9^{ab34}
6	74.0 ± 2.6^{a4}	98.0 ± 8.0^{b3}	43.7 ± 5.1^{c4}

*Means in the same row with the same letters or column with the same numbers are not significantly different at 5% level

TABLE 2. Electrical conductivity (µS/cm) at three depths at the six sampling stations in Bakun Reservoir

St	Subsurface	15 m	30 m
1	32.0 ± 0.0^{a1}	36.0 ± 1.7^{b1}	50.7 ± 0.6^{c1}
2	36.3 ± 0.6^{a2}	43.3 ± 0.6^{b2}	46.3 ± 1.5^{c2}
3	32.0 ± 0.0^{a1}	46.3 ± 0.6^{b2}	47.3 ± 1.2^{b2}
4	31.0 ± 0.0^{a1}	23.7 ± 1.2^{b3}	22.0 ± 0.0^{c3}
5	32.0 ± 0.0^{a1}	101.0 ± 2.0^{b4}	117.0 ± 0.0^{c4}
6†	19.0 ± 0.0^{4}	14.0 ± 0.0^{5}	14.0 ± 0.0^{5}

*Means in the same row with the same letters or column with the same numbers are not significantly different at 5% level.†The three replicates of each depth are equal in value

TABLE 4. Soluble reactive phosphorus (SRP) (µg/L) at three depths at the six sampling stations in Bakun Reservoir

St	Subsurface	15 m	30 m
1	78.3 ± 5.6^{a14}	143.5 ± 19.8^{b123}	195.7 ± 26.7^{c12}
2	544.6 ± 25.9^{a2}	75.0 ± 8.6^{b1}	94.6 ± 5.6^{b1}
3	75.0 ± 11.8^{a14}	332.6 ± 56.6^{b4}	378.3 ± 57.3^{b3}
4	143.5 ± 22.8^{a3}	228.3 ± 28.9^{b3}	264.1 ± 40.1^{b23}
5	22.8 ± 3.3^{a1}	208.7 ± 48.2^{b23}	652.2 ± 69.7^{c4}
6	127.2 ± 33.9^{a34}	120.7 ± 19.8^{b12}	306.5 ± 37.6^{b23}

*Means in the same row with the same letters or column with the same numbers are not significantly different at 5% level
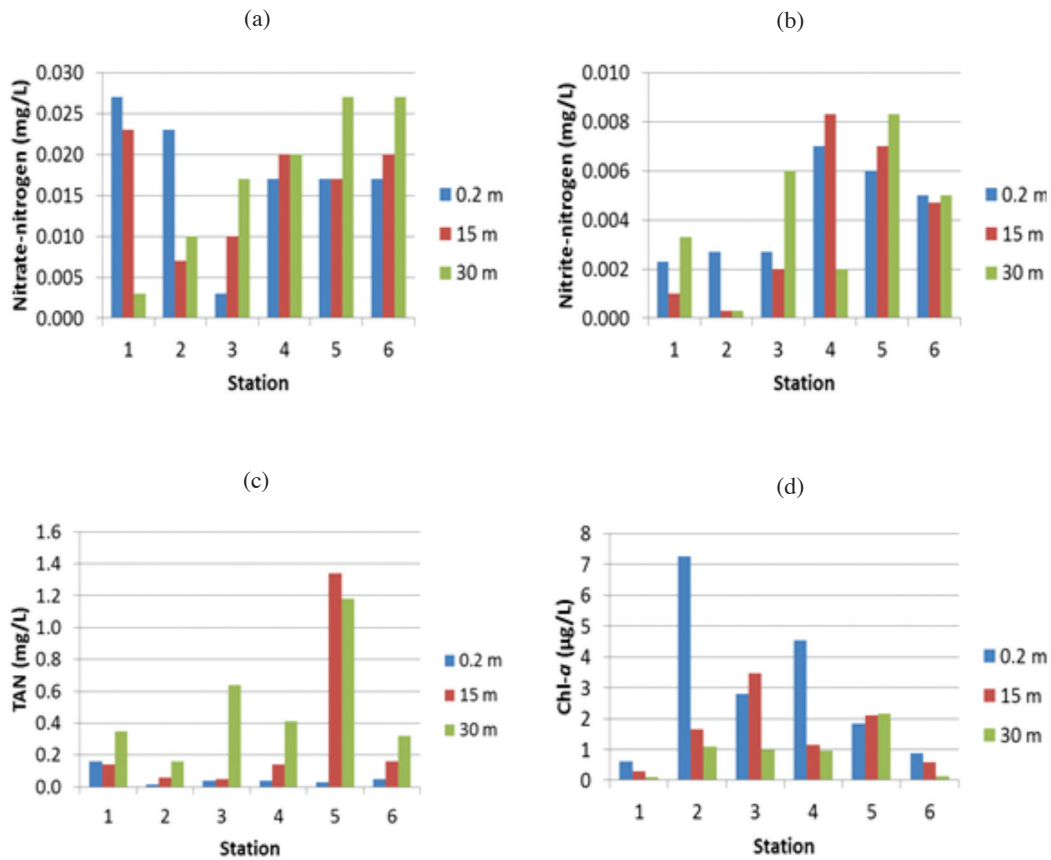
(a)

(b)

(c)

(d)

FIGURE 5. (a) Nitrate-nitrogen, (b) nitrite-nitrogen, (c) total ammonia-nitrogen (TAN) and (d) chlorophyll-*a* (Chl-*a*) at the six stations

depth of St 3 (Table 5). Similarly, nitrite-nitrogen at all stations were low, 0.0003-0.0083 mg/L (Figure 5(b)). In St 2, 3 and 6, nitrite-nitrogen was not significantly different among the three depths (Table 6). For TAN, the means at the stations ranged from 0.02-1.34 mg/L, where the lowest value was observed at St 2 at the subsurface, whereas the highest was at 15 m of St 5 (Figure 5(c)). TAN at 30 m were higher than those at the subsurface and 15 m depths except St 5 where 15 and 30 m values were not significantly different (Table 7). At 15 and 30 m depths, St 5 showed significantly higher TAN than the other stations. Overall, the highest and second highest values of Chl-*a* were observed at subsurface of St 2 and 4 (Figure 5(d)). At St 1, 2, 4 and 6, concentrations of Chl-*a* at 0.2 m were significantly higher than 15 and 30 m (Table 8). However, at St 3, Chl-*a* at 15 m was the highest and all three depths showed significantly different concentrations and at St 5 the means were not significantly different among the three depths.

TABLE 5. Nitrate-nitrogen (mg/L) at three depths at the six sampling stations in Bakun Reservoir

St	Subsurface	15 m	30 m
1	0.027 ± 0.012^{a1}	0.023 ± 0.012^{a1}	0.003 ± 0.006^{a1}
2	0.023 ± 0.015^{a1}	0.007 ± 0.006^{a1}	0.010 ± 0.010^{a1}
3	0.003 ± 0.006^{a1}	0.010 ± 0.000^{ab1}	0.017 ± 0.006^{b1}
4	0.017 ± 0.006^{a1}	0.020 ± 0.010^{a1}	0.020 ± 0.010^{a1}
5	0.017 ± 0.006^{a1}	0.017 ± 0.012^{a1}	0.027 ± 0.015^{a1}
6	0.017 ± 0.006^{a1}	0.020 ± 0.010^{a1}	0.027 ± 0.012^{a1}

*Means in the same row with the same letters or column with the same numbers are not significantly different at 5% level

TABLE 6. Nitrite-nitrogen (mg/L) at three depths at the six sampling stations in Bakun Reservoir

St	Subsurface	15 m	30 m
1	0.002 ± 0.001^{ab1}	0.001 ± 0.000^{a1}	0.003 ± 0.001^{b23}
2	0.003 ± 0.002^{a12}	0.000 ± 0.000^{a1}	0.000 ± 0.000^{a1}
3	0.003 ± 0.001^{a12}	0.002 ± 0.001^{a1}	0.006 ± 0.006^{b34}
4	0.007 ± 0.001^{a3}	0.008 ± 0.003^{a2}	0.002 ± 0.001^{b12}
5	0.006 ± 0.001^{a23}	0.007 ± 0.002^{a2}	0.008 ± 0.001^{a4}
6	0.005 ± 0.002^{a123}	0.005 ± 0.002^{a12}	0.005 ± 0.002^{a3}

*Means in the same row with the same letters or column with the same numbers are not significantly different at 5% level

TABLE 7. Total ammonia nitrogen (TAN) (mg/L) at three depths at the six sampling stations in Bakun Reservoir

St	Subsurface	15 m	30 m
1	0.016 ± 0.05^{a1}	0.14 ± 0.05^{a1}	0.35 ± 0.05^{b12}
2	0.02 ± 0.01^{a2}	0.06 ± 0.04^{a1}	0.16 ± 0.04^{b1}
3	0.04 ± 0.02^{a2}	0.05 ± 0.02^{a1}	0.64 ± 0.16^{b2}
4	0.04 ± 0.02^{a2}	0.14 ± 0.03^{a1}	0.41 ± 0.06^{b12}
5	0.03 ± 0.01^{a2}	1.34 ± 0.27^{b2}	1.18 ± 0.23^{b3}
6	0.05 ± 0.01^{a2}	0.16 ± 0.05^{a1}	0.32 ± 0.07^{b12}

*Means in the same row with the same letters or column with the same numbers are not significantly different at 5% level

TABLE 8. Chlorophyll-*a* (μg/L) at three depths at the six sampling stations in Bakun Reservoir

St	Subsurface	15 m	30 m
1	0.62 ± 0.02^{a1}	0.28 ± 0.02^{b1}	0.10 ± 0.01^{c1}
2	7.25 ± 0.96^{a2}	1.64 ± 0.05^{b3}	1.10 ± 0.18^{b2}
3	2.80 ± 0.25^{a3}	3.48 ± 0.32^{b4}	0.99 ± 0.10^{c2}
4	4.53 ± 0.45^{a4}	1.14 ± 0.18^{b2}	0.89 ± 0.06^{b2}
5	1.84 ± 0.18^{a13}	2.10 ± 0.08^{a3}	2.16 ± 0.14^{a3}
6	0.87 ± 0.04^{a1}	0.60 ± 0.16^{b1}	0.14 ± 0.02^{c1}

*Means in the same row with the same letters or column with the same numbers are not significantly different at 5% level

DISCUSSION

As a river changes from lotic to lentic system, the water body stratifies as indicated by the temperature profile. It was observed that the surface layer which is exposed to solar radiation showed the highest temperature, exceeding 30°C. Thermocline temperature occurred at the depth of 6-9 m and the decrease was 4.4°C whereas previous study only recorded a 2°C drop (Nyanti et al. 2012). Additionally, the present thermocline curve was relatively sharper and more distinct with a greater temperature contrast between subsurface and 20 m depth (Nyanti et al. 2012). The present water temperature was higher than 15 months before (Table 9). All these differences might have been due to the larger amount of stagnant water in the reservoir in the present study in coincidence with the warmer season of the year. Comparing with pre-impoundment temperature (Mohamed et al. 1997) as shown in Table 9, there was an increase in the present study whereby the surface layer of 13.5 m showed temperature of 25.5-31.3°C. The temperature profile obtained in the present study is comparable to that of the 27 years old Batang Ai Hydroelectric Reservoir despite the difference in depth of occurrence of thermocline that was reported at 8-11 m in the same month of the year (Ling et al. 2013b).

Oxygen in the deeper regions is utilized for the decomposition of organic matter and ecologically is irreplaceble due to stratification that reduces the efficiency of water circulation. Thus, DO dropped rapidly from 6 m to undetectable level at 7 m. The DO profile shows that the values were lower than the values of 7-8 mg/L measured before impoundment as shown in Table 9 (Mohamed et al. 1997). However, at St 6 where it was reported that DO were 7.05-7.67 mg/L as it was influenced by the fast flowing Murum River (Nyanti et al. 2015). Other than DO variable, pH and turbidity at thermocline region were also affected by stratification evidenced by rapid changes in their values as depth increases.

The impact of the on-going Murum Dam construction was evident at St 6. Logging activities to remove vegetation in preparation for dam filling led to exposed land surface and disturbed soil resulting in soil erosion; thus, there was high TSS (at 30 m), low transparency, low Chl-*a* and high COD (at subsurface and 15 m) at St 6. In addition, the influence of the flowing Murum river led to low and more

TABLE 9. A comparison of water quality of stations in the present study with pre-impoundment condition
(Mohamed et al. 1997) and 15 months before (Nyanti et al. 2012)

Parameter	Pre-impoundment (Mohamed et al. 1997)	January 2012 (Nyanti et al. 2012)		The present study†	
		Depth (m)	Values	Depth (m)	Values
Temperature (°C)	24.7-25.5	0.2	29.69-30.53	0.2	31.28-31.34
		15	25.66-25.69	15	25.24-25.60
		20	25.40-25.48	30	24.74-25.79
DO (mg/L)	7.0-8.0	0.2	5.80-6.94	0.2	6.25-6.64
		15	0.00	15	0.00
		20	0.00	30	0.00
pH	6.0-7.9	0.2	5.65-5.79	0-31.9	6.25-7.77
		15	5.34-5.40		
		20	5.43-5.44		
Electrical conductivity (μS/cm)	12-50	0.2	43-51	0.2	32-36
		15	51-56	15	33-101
		20	47-56	30	47-117
TSS (mg/L)	170-300		NA	0.2	66.7-100.0
	290-1400			15	93.0-143.0
				30	117.0-167.0
COD (mg/L)	2-19		NA	0.2	7.0-68.7
	90-171			15	7.0-37.0
				30	20.0-119.0
NO_3-N (mg/L)	0.047		NA	0.2	0.003-0.027
				15	0.007-0.023
				30	0.003-0.027
TAN (mg/L)	0.009		NA	0.2	0.017-0.183
				15	0.050-1.340
				30	0.160-1.180

NA: Not available; †St 4 and St 6 were not included in this comparisons due to the influence of Murum Dam

even distribution of conductivity, nitrite and nitrate among the three depths with more impact at St 6 than St 4. High turbidity ranging from 611-1141 NTU at that station was reported by Nyanti et al. (2015). Similar observation of increasing suspended sediment was reported by Beschta (1978) as a result of logging activities in two watersheds in Oregon.

DO profile at St 2 shows that DO was above 5 mg/L, the minimum level required for healthy aquatic organisms (Chapman 1996), up to the depth of 6.4 m and it dropped to undetectable level at 7 m. In contrast, measurements made on 6th January 2012 showed that DO was above 5 mg/L up to the depth of less than 2 m only and it was undetectable at the depth of 4.1 m (Nyanti et al. 2012). This shows that DO in the water column has improved and become more favorable for sensitive aquatic organisms compared with 15 months earlier.

The subsurface water was alkaline in contrast to the acidic condition (pH below 6) of the previous study (Nyanti et al. 2012) as shown in Table 9. The improvement in water quality from Class III (pH5-9) to Class I (pH6.5-8.5) according to the National Water Quality Standard of Malaysia (NWQS) (Table 10) may also indicate a favorable environment for aquatic life. pH at subsurface were comparable to that reported in Batang Ai Reservoir (Ling et al. 2012). pH in the present study fall in the range of the pre-impoundment value (Table 9) (Mohamed et al. 1997).

Electrical conductivity of most stations and depths fall in the range before impoundment as reported by Mohamed et al. (1997) except for the depth of 30 m at St 1 and 5 and 15 m at St 5 (Table 9). Similarly, the results were comparable to those measured in January 2012 (Nyanti et al. 2012), except 15 and 30 m depths of St 5. Electrical conductivity of most of the stations were higher at 30 m depth due to the inorganic dissolved solids from the decaying submerged biomass and sediment. A significant positive correlation with BOD_5 (Nyanti et al. 2015), SRP and ammonia-nitrogen concentrations was deduced (r=0.663, 0.560, 0.830; 0.000 $\leq p \leq$ 0.016). All the values of conductivity fall in Class I of NWQS (Table 10).

Turbidity and TSS increased with depth due to the sedimentation of inorganic solid particles. The increase was likewise observed in January 2012 (Nyanti et al. 2012); however, the trend of rapid increase in turbidity at thermocline region was not observed in the earlier study likely due to unstable condition as filling of the dam was still on-going. Turbidity profile shows that turbidity of the surface 7 m column fall in Class I whereas those deeper than 23 m exceeded Class II limit of NWQS .

TABLE 10. Classification of water quality according to National Water
Quality Standards for Malaysia

Station	Depth (m)	EC (μS/cm)	TSS (mg/L)	TAN (mg/L)	COD (mg/L)
	0.2	I	III	II	II
1	15	I	III	II	I
	30	I	III	III	V
	0.2	I	III	I	IV
2	15	I	III	I	II
	30	I	III	II	II
	0.2	I	III	I	I
3	15	I	III	I	III
	30	I	IV	III	II
	0.2	I	III	I	II
4	15	I	III	II	III
	30	I	III	III	IV
	0.2	I	III	I	IV
5	15	I	III	IV	III
	30	I	IV	IV	III
	0.2	I	III	I	IV
6	15	I	III	II	IV
	30	I	IV	III	III

EC: Electrical conductivity

TSS values obtained in the present study were higher than the values (1.3-11.00 mg/L) observed at the Batang Ai Reservoir at 0, 10 and 20 m depths (Ling et al. 2013b). Compared with the values prior to impoundment during a low and high flow condition as shown in Table 9 (Mohamed et al. 1997), the concentrations in the present study showed a decrease due to stagnant water which allowed particles to settle as opposed to the turbulent river with suspended solids from logging activities. TSS of all stations exceeded the Class II limit of 50 mg/L with most of the stations categorised in Class III or IV of NWQS (Table 10).

For most of the stations, the highest value of COD occurred at either 15 or 30 m depth as the submerged living organisms were at the bottom with some vegetation still standing. The difference among the stations could be due to the difference in the depth of stations and dispersion rate as some stations may have experienced more input from larger rivers than the others. Most of the COD values exceeded Class II of NWQS with the highest value at 30 m depth of St 1 classified as Class V (Table 10). Compared with the values of 2-19 mg/L during low flows and 90-171 mg/L during high flows prior to impoundment (Mohamed et al. 1997), most of the values observed exceeded the low flow range. Sources of phosphorus in the reservoir are sediment and living things at the bottom where decomposition was occurring which explains the highest SRP observed at 30 m depths of most of the stations.

The values of nitrate–nitrogen observed were far lower than the Class II limit of NWQS of 1.58 mg/L. In addition, they are also lower than the value of pre-impoundment condition (Table 9). This shows that as the raging river became still, dissolved oxygen decreased, thus lower nitrate and nitrite were observed. Inorganic nitrogen at the stations are predominately in the form of TAN due to the conversion of organic nitrogen from submerged biomass to ammonia, but insufficient DO is available to oxidize it to nitrate especially in the deeper regions. This explains the higher TAN in the deeper region than the subsurface and also the increase in TAN in the present study compared to pre-dam condition (Table 9). The high ammonia accumulated at 15 and 30 m at St 5 was most probably due to the decomposition of organic materials; the accumulation was further encouraged due to the reduced flushing by the smaller river and also the depth being shallower than other stations. The organic matter and TAN association is supported by the significant correlations between TAN and BOD_5 ($r=0.611$, $p=0.007$) where BOD_5 values were reported by Nyanti et al. (2015). Furthermore, TAN is significantly correlated with SRP ($r=0.540$, $p=0.021$) and SRP is significantly correlated to TSS ($r=0.591$, $p=0.010$) indicating the common sources of nutrients from the decaying living things and sediment at deeper regions. SRP observed in Bakun Reservoir were much higher than the Batang Ai Reservoir (Ling et al. 2013a) likely due to the release from the organically-bound phosphorus from flooded vegetation, excreta and soil (Chapman, 1996) in the young reservoir. All subsurface TAN and 15 m depths complied with Class II except St 5 which falls in Class IV and at 30 m depth, the values fall in Class III or IV (Table 10).

Chl-a concentrations are influenced by light and nutrient availability (Prairie et al. 1989). At subsurface depth of St 2, the second highest SRP and nitrate coupled with second lowest TSS explains the highest Chl-a observed there. On the other hand, the turbidity resulting from high suspended solids prevented light penetration

resulting in the low Chl-*a* at St 6. However, at St 4, as the water became more transparent, coupled with available nutrients, Chl-*a* at the subsurface was the second highest among the stations. Sobolev et al. (2009) also proposed that significant inorganic turbidity and the resulting low transparency resulted in rapid extinction of light within the water column and thus limiting the potential for algal blooms at the Ross Barnett Reservoir. Compared to Batang Ai Reservoir, the present study results are close to the range reported, which is 0.38-6.02 μg/L (Ling et al. 2013b). In addition, the range of Chl-*a* observed in the present study is also close to the range of 0.62-8.88 mg/m^3 in the Demirdoven Dam Reservoir in Turkey (Kivrak & Hasan 2005). The observation that Chl-*a* values were decreasing in trend as depth increases especially for turbid stations is in contrast to the older Batang Ai Reservoir whereby the highest occurrence of Chl-*a* was at 10 m depth which was 46.7% and even at 20 m depth, the occurence was 20%; this difference is attributed to the clarity of the water in the Batang Ai Reservoir where turbidity values were very much lower, which is 15 NTU and below (Ling et al. 2013b). The observation of highest Chl-*a* at 15 m instead of subsurface at St 3 is not surprising as it has the lowest subsurface TSS and Kivrak and Hasan (2005) also reported that maximum Chl-*a* was found near metalimnion of the Demirdoven Dam.

CONCLUSION

This study shows that water quality at the reservoir was influenced by the stagnant condition of the reservoir and decomposition of organic matter and inflow from tributaries such as the Murum River. The stagnant condition of the reservoir gave rise to thermal stratification with distinct thermocline occurring at 6-9 m depth. With decomposition of submerged vegetation and other living things, DO is only suitable for sensitive aquatic organism in the top 6 m water column. In addition, higher SRP, COD, TSS and TAN were observed in the deeper region with inorganic nitrogen predominantly in the form of TAN. High turbidity limited light peneration that influenced the depth of occurrence of highest Chl-*a*. Downstream of the Murum Dam under construction resulted in high TSS. Compared to pre-impoundment condition, water temperature of the top layers, TAN and SRP increased but DO, TSS and nitrate decreased. In comparison to 15 months before, the present study shows that DO and pH increase in the subsurface water column led to more favorable condition for sensitive aquatic organism. However, COD of most stations exceeded Class II and TSS were still high; therefore, there is a need to continue monitoring the water quality of the reservoir.

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