Physico-chemical Characteristics in the Filling Phase of Bakun Hydroelectric Reservoir, Sarawak, Malaysia

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Abstract

Since the impoundment of the Bakun Hydroelectric Dam commenced, there have not been any studies on the water quality of the reservoir. As aquaculture is a potential industry to be developed, a study was conducted to determine the water quality of the reservoir fifteen months after the impoundment started at 12 stations. Results show that temperature in the reservoir decreased 5 °C from surface to 20 m depth. At the station nearest to the dam site, thermocline occurred at 5 m depth whereas further away, thermocline occurred at 4 m depth. In the reservoir, DO at the subsurface (5.49 - 8.51 mg/L) dropped drastically to anoxic level at 2 - 4 m. As the distance from the dam site increased, turbidity at the subsurface and at 20 m depth increased indicating the high suspended solids originating from upstream. The present study shows that the newly filled Bakun reservoir is not suitable for aquaculture due to the anoxic condition at such a shallow depth, low pH and high turbidity.

Keywords: hydroelectric dam, turbidity, dissolved oxygen, thermocline, inland aquaculture

1. Introduction

World-wide hydroelectric dams have been constructed to provide an alternative source of energy as petroleum reserve is not renewable and is depleting. The Sarawak Corridor of Renewable Energy (SCORE) which is the center piece of the Sarawak state's plans for economic growth and development (Sovacool and Bulan 2012) is a key development project of Malaysia situated on the Borneo Island. To meet the energy needs and security, dams are and will be constructed to generate hydroelectricity. Among them is the Bakun Hydroelectric Dam situated on the Balui River, a tributary of the Rajang River near the town of Belaga where construction started in 2002. The Bakun Hydroelectric dam is the largest hydropower project in Malaysia with an installed capacity of 2,400 MW of electricity (http//www.sarawak-hidro.com). It is the second highest concrete faced rockfill dam in the world with height of 207 metres (http//www.bakundam.com). The impoundment commended on 13th October 2010 and it reached its full supply level of 228 m above sea level on 9th March 2012 with an area of 695 square kilometers. Research related to Bakun Dam has been conducted on the aspect of energy security and hydropower development (Sovacool and Bulan 2012) and the analysis of the concept of sustainability assessment (Andre 2012). However, no studies have been conducted on the water quality of the newly filled reservoir.

Similar to the earlier developed Batang Ai Reservoir, tourism and aquaculture are the two main potential industries that could provide employment opportunities for the resettled population. According to Chapman (1996), reservoirs formed by a dam across the course of a river are intermediate type of water bodies between rivers and natural lakes as there is a control in the contained volume of water at the outlet.

Reservoirs formed by impoundment undergo great changes in water quality in the early stages of their formation (Chapman 1996) as observed in tropical reservoirs such as Lake Brokopondo in Surinam (Van der Heide 1978) and Feitsui Reservoir in Taiwan (Chang and Wen 1997) and temperate reservoirs such as Bureye Reservoir in Russia (Shesterkin 2008) and Butgenbuch Reservoir in Belgium (Lourantou *et al.* 2007). This is due to the impact of inundated soil and vegetation including the standing forest on the water quality such as dissolved oxygen (Van der Heide 1978; Shesterkin 2008) and acidity which are vital for the survival of aquatic life. Fifteen months after the commencement of the filling of Bakun Dam reservoir, we conducted a study on the water quality of the tropical reservoir formed in January 2012.

2. Materials and Methods

Water quality of the newly filled Bakun reservoir was carried out on 6 - 8th January 2012. Twelve sampling stations (St 1 – St 12) were selected in the reservoir and at the tributaries inflow as shown in Figure 1. Nine stations (St 1- St 9) were located in the reservoir and the remaining 3 stations (St 10 to St 12) were in the tributaries. St 1 was located near the dam site and St 8 was the farthest upstream. St 12 was located in the upstream of Kebhor River. *In-situ* parameters studied were temperature, dissolved oxygen (DO), pH, conductivity, total dissolved solids (TDS) and turbidity. These parameters were measured using YSI 650 Multiparameter Water Quality Monitoring Unit and data was recorded continuously as the probe was lowered at each station. At the time of sampling, the reservoir has been filled for duration of 15 months and it was about two months away from the full supply level. Two turbines were operating at that time and water intake was from the top. Statistical analysis were performed on data collected at subsurface (0 m), 2 m, 4 m, 6 m, 12 m and 18 m depths by using two way ANOVA and at each depth comparisons among stations were made using one-way ANOVA. Regression analysis of TDS on conductivity was performed. All analyses were carried out using the SPSS ver 19.0 package.

3. Results and Discussion

Water temperature of the eight stations in the Bakun Reservoir is shown in Figure 2a. Temperature in the reservoir ranged between 29.63 - 30.96 ^{o}C at the subsurface. Temperature decreases as depth increases for all stations. The decrease in temperature for stations St 1 - St 6 from the subsurface to 20 m depth was about 5 ^{o}C. At 6 m depth, there was a progressive change in temperature for the stations in the order of St1 > St2 > St3 > St4 > St5 > St6 > St7. St 6 and 7 showed lower temperature due to inflow from tributaries upstream. St 8 was the farthest upstream and therefore the total depth was 18.2 m only and the temperature was lower due to inflow from Bahau River and Balui River. St 12 has the lowest temperature of 22.9 ^{o}C as it is located upstream of Kebhor River (Table 1). Table 2 shows the temperature at selected depths of subsurface, 2, 4, 6, 12 and 18 m. Most of the stations showed significant difference except among three stations St 3 - St 5 in the reservoir where they did not show significant difference at 0, 2 and 4 m depths.

There was a significant drop in temperature as depth decreased from subsurface to 18 m ($P<0.05$) (Table 2). At St 1, thermocline occurred between 6 - 9 m and for St 2 it was 5 - 8 m (Figure 2a). Stations 3 - 6 behave in a similar way with thermocline occurring at about 3 - 4 m depth. For St 7, thermocline was not as distinct and for St 8, the temperature decreased more gradually. Thermocline decreases and became less distinct the further the station is located from the dam. This is likely due to tributary inflow and mixed flow from upstream. Figure 2b shows the temperature profile at the three tributaries. Temperature also decreased with depth. Among the tributaries stations, subsurface temperature increased in order of St 10 < St 9 < St 11. Station St 9, being located in the tributary between St 4 and 5 shows a slight thermocline at 3-5 m depth where temperature dropped 4 ^{o}C. At St 10, the drop in temperature was more constant. For St 11 which is located in the tributary between St 7 and St 8, temperature dropped about 3 ^{o}C between 3-5 m depth. Thermal stratification is common in reservoirs and it was reported to occur in two tropical reservoirs, the Lajes Reservoir which is located in a pristine area and the Funil Reservoir which is downstream of populated area in Brazil (Soares *et al.* 2008).

In the reservoir, DO at the subsurface was high ranging from 5.94 – 8.51 mg/L but dropped drastically to zero at 2- 4 m for all stations except St 8 Fig 2(c). With thermal stratification occurring as observed in Figure 2a, the suppression of vertical transport at the thermocline allows an oxygen gradient to occur which caused anoxic conditions to develop in the hypolimnion (Chapman 1996). At St 7, DO was zero between 2-15 m depth. However, at 15 m DO increased from zero to 1 mg/L at 18 m and after that decreased.

This is due to the undercurrent at that station as the Ba Long River flows into the reservoir at that station coupled with inflow from the main river. At St 8, DO was not zero for the 20 m depth measured. Instead, DO decreased drastically from 8.8 to 4.3 mg/L in 1 m depth and after that there was a further decrease but more gradual to to 1.7 mg/L at the depth of 8 m. At 10 m depth, DO increased to 2.5 mg/L. This is due to inflow from upstream of Balui River and Bahau River. At St 9, DO decreased from 9.27 mg/L at the subsurface to 5 mg/L at 2 m depth and increased to 7.6 mg/L at 6 m depth. This increase in DO below 2 m depth is due to the oxygenated cooler and denser water from Kebhor River. St 12, located in Kebhor River showed the highest DO (9.73 mg/L) due to the turbulent flow (Table 1). This shows the influence of the inflowing water on the DO trend. For the other two stations St 10 and St 11, DO dropped to anoxic level and did not increase as depth increases. St 1 subsurface DO was the lowest and significantly lower than all the other stations due to the stagnant water at the dam site and St 9-10 showed significantly higher DO values than the other stations except St 12 ($P<0.05$) (Table 3).

As depth increased from 0 m to 2 m, mean DO across all stations dropped significantly ($P<0.05$) with St 7, 9, and 11 not detectable (Table 3). The anoxic condition is due to the oxygen depletion by the decomposition of submerged vegetation as not all the trees were removed when the reservoir was impounded and being in the tropics, the rate of decomposition is faster compared with the temperate countries and thus deoxygenation is a particular problem at the first inundation of tropical impoundment (Chapman 1996). In fact the water was observed to be brownish in colour due to leaching of humic substances from the soil (Baxter 1977) and the decomposition of submerged vegetation. The observation that DO decreased quickly to undetectable levels for stations in the reservoir is similar to the report of the thin oxygen containing stratum during the filling phase of Lake Brokopondo in Surinam where DO was reported to decrease to zero between 1.5 - 4.5 m depth (Van der Heide 1978). Due to the drastic decrease in DO with depth, currently the reservoir is not suitable for cage culture as Lawson (1995) stated that 5 mg/L DO is required for healthy growth of fish. Compared with Batang Ai Reservoir, a mature reservoir of 26 years, the values of DO at subsurface in this study were comparable but at 14 m and 27 m DO at Batang Ai reservoir ranging from 3.94 to 5.46 mg/L were not anoxic as compared with the Bakun Reservoir in the filling phase (Paka 2009).

pH values of all stations were acidic, ranging from 5.17 to 5.92 for stations in the reservoir (Figure 2e). For the tributaries, pH increased according to St 11 < St 10 < St 9 (Figure 2f). The range of pH at St 9, St 10 and St 11 were 6.47-6.71, 5.95-6.29 and 5.31-5.72 respectively and St 9 and St 10 showed higher pH than all the other stations. In all stations, pH trend showed a decrease to a minimum followed by an increase. There was a drastic decrease in pH in the top 0.5 m for all stations especially those in the reservoir. The cooler water from the tributaries is denser and higher in pH and thus the higher pH observed in the deeper regions of the stations. Table 4 shows pH values at different stations at selected depths and their significant difference. Most of the stations show significant difference at each depth except among some stations of St 2 – St 5 where pH were not significantly different ($P > 0.05$). Comparing among depths, mean pH at subsurface was significantly higher than the other depths (Table 4). Chapman (1996) reported that pH of most natural waters is between 6.0 - 8.5. In this study, most of the stations showed pH values below 6.0 except St 9 and certain depths of St 10 (Figure 2f) and St 12 (Table 1). The overall trend is lowering of pH as we move from upstream toward the dam.

This shows that the low pH does not originate from the inflow from tributaries as shown by higher pH of St 9 and St 12 but most likely generated in the inundated areas where submerged carbonaceous materials undergo decay and release acidic products. Lawson (1995) reported that decay of organic matter and oxidation of compounds in bottom sediments can alter the pH in water bodies. Rotten egg smell of hydrogen sulfide was detected during sampling and sulfide could be oxidized to sulfuric acid resulting in low pH values in the reservoir. For warm water pond fish, it has been reported that the daylight pH for best growth is 6.5-9.0, in 4-6 range there will be slow growth, and reproduction diminishes at pH below 6. As such, currently, Bakun reservoir is not favorable for fish aquaculture. The pH observed at the surface was lower than the medium values of 7.0 and 7.3 reported in two tropical reservoirs in Brazil (Soares *et al.* 2008). The pH in Bakun is much lower than those in Batang Ai Reservoir where the values of pH at 0.5 m, 14 m and 27 m ranged from 7.23-7.42, 7.00-7.18 and 6.94-7.18 respectively (Paka 2009). The low pH values observed in this study was also observed by Inverarity *et al*. (1983) where stations downstream of an impoundment showed pH 5.3-5.5 due to the water derived from the reservoir.

Conductivity of the stations in the reservoir falls between 27 and 66 µS/cm and in the tributary they fall between 46-66 µS/cm (Figure 3a, b).

At each station the range was 7-15 µS/cm with lowest range observed at St 10 (Figure 3b). In the reservoir, at the subsurface level, to about 2 m depth, St 1 near the dam site showed the lowest conductivity. Below 2 m depth, St 8 showed the lowest conductivity and it decreased as depth increased up to 6 m depth after which it remained constant. This shows that upstream of Balui and Bahau rivers were not the major contributors of conductivity. For the other stations in the reservoir, it was constant for the top 4 m depth followed by a sharp increase to a maximum at about 5-7 m depth before decreasing and finally not changing much for depths of more than 12 m. Below 4 m depth, St 11 showed high conductivity. The lowering of conductivity below 4 m depth at St 9 was contributed by flow from the Kebhor tributary where the conductivity was only 37 µS/cm as conductivity of St 12 was significantly lower than all the other stations (Table 5). The conductivity is due to internal loadings from submerged vegetation and soil in the flooded area as reported by Chang and Wen (1997) for a newly impounded reservoir in Taiwan. The conductivity observed in this study is in the range of the value of 23-47 µS/cm as reported by Van der Heide (1978) during the filling of Lake Brokopondo in Surinam but higher than Lajes Reservoir in Brazil (18.0-31.0 µS/cm) which is located in a preserved area with dense vegetation but lower than Funil Reservoir (64.6-107.6 µS/cm) which received inflow from populated area (Soares *et al.* 2008). Compared with nutrient rich Cruzeta reservoir with conductivity of 290-550 µS/cm (Chellappa *et al.* 2008), the values of Bakun Reservoir is much lower.

Total dissolved solids (TDS) in the reservoir fall between values of 24 and 40 mg/L with the maximum occurring at about 5-8 m from the surface. This trend of TDS was similar to conductivity. In the tributary, TDS at St 10 and St 11 fluctuated but the range was smaller than the reservoir. Below 4 m depth St 8 showed the lowest TDS and below 6 m depth St 2 showed the highest TDS in the reservoir. At 12 and 18 m depth, TDS of St 4-6 did not show any significant difference (Table 6). Regression analysis shows that TDS is 0.6265 times of conductivity and this value lies in the range of 0.55 and 0.75 reported by Chapman (1996). The conductivity and TDS most likely originates from the dissolved ions such as nutrients from the mineralization of organic materials which are mainly submerged vegetation and release from sediment. In addition as the bottom layers were anoxic, sulfide, ferrous and manganous ions were formed (Baxter 1977).

Turbidity increases as depth increases for all stations except St 10 (Figure 3e, f). In the reservoir, at all depths, St 8 showed the highest turbidity ranging from 33 NTU at the surface to 121 NTU at 20 m depth followed by St 7 (7-103 NTU) as shown in Figure 3e. This is due to high suspended solids from upstream. This inflow of high turbidity and greater density water explains the gradual decrease in the turbidity as we move from St 8 to St 7 and finally to the dam site. St 9 is downstream of St 12 which is a turbid tributary on the north side of the reservoir with a mean value of 93.7 NTU as shown in Table 1 and thus among the tributaries, St 9 showed second highest turbidity after St 12. St 10, situated on the south side of the reservoir showed the lowest turbidity. At subsurface, stations St 8 showed the significantly higher turbidity among stations in the reservoir and St 12 showed the significantly higher turbidity among stations sampled (Table 7) indicating their contributions to the turbidity in the reservoir. High turbidity of the water indicates high scattering or absorption of incident light by the particles (Chapman 1996) and in this study, the turbidity of the stations were predominantly due to suspended solids consisting of particles from the eroded soil transported through surface runoff from the logging in the watershed upstream especially on the north side of the reservoir. High turbidity will prevent sunlight penetration and low productivity. Productivity is important for fish as it provides phytoplankton as fish food. High turbidity caused by suspended solids is harmful for fish as it can clog the gills of small fish and invertebrates settle onto and smother fish eggs and shield food organisms (Lawson 1995).

At the time of sampling, water was still entering the reservoir from the tributaries and upstream river and they were of lower temperature, and lower content of dissolved and higher content of suspended solids and consequently of higher density. This resulted in the patterns of maximum conductivity and TDS and minimum of pH at certain depths as observed in this study as the incoming water did not mix immediately with the reservoir water (Baxter 1997). Strong rotten egg smell indicating of hydrogen sulfide was detected at the sampling stations. This observation was also reported by Lourantou *et al.* (2007) where irritating odour attributed to hydrogen sulfide was detected during bottom water sampling of a recently filled reservoir in Belgium. This contribute to the low pH condition observed.

4. Conclusions

This study shows that the reservoir is stratified and thermocline occurred at a shallow depth of about 5 m. pH of stations in the reservoir subsurface were all below 6 and at 5-6 m depth the pH was the lowest ranging between 5.1-5.5 indicating acidic conditions. Turbidity in the reservoir increased with depth and was high in the inflow from upstream and tributaries due to suspended solids. DO at subsurface dropped to anoxic conditions rapidly at 1 m to 4 m depths. Decomposition of submerged carbonaceous materials is the predominant factor in the acidic condition and low DO observed. Due to low DO and low pH, the reservoir is not yet suitable for cage culture activities.

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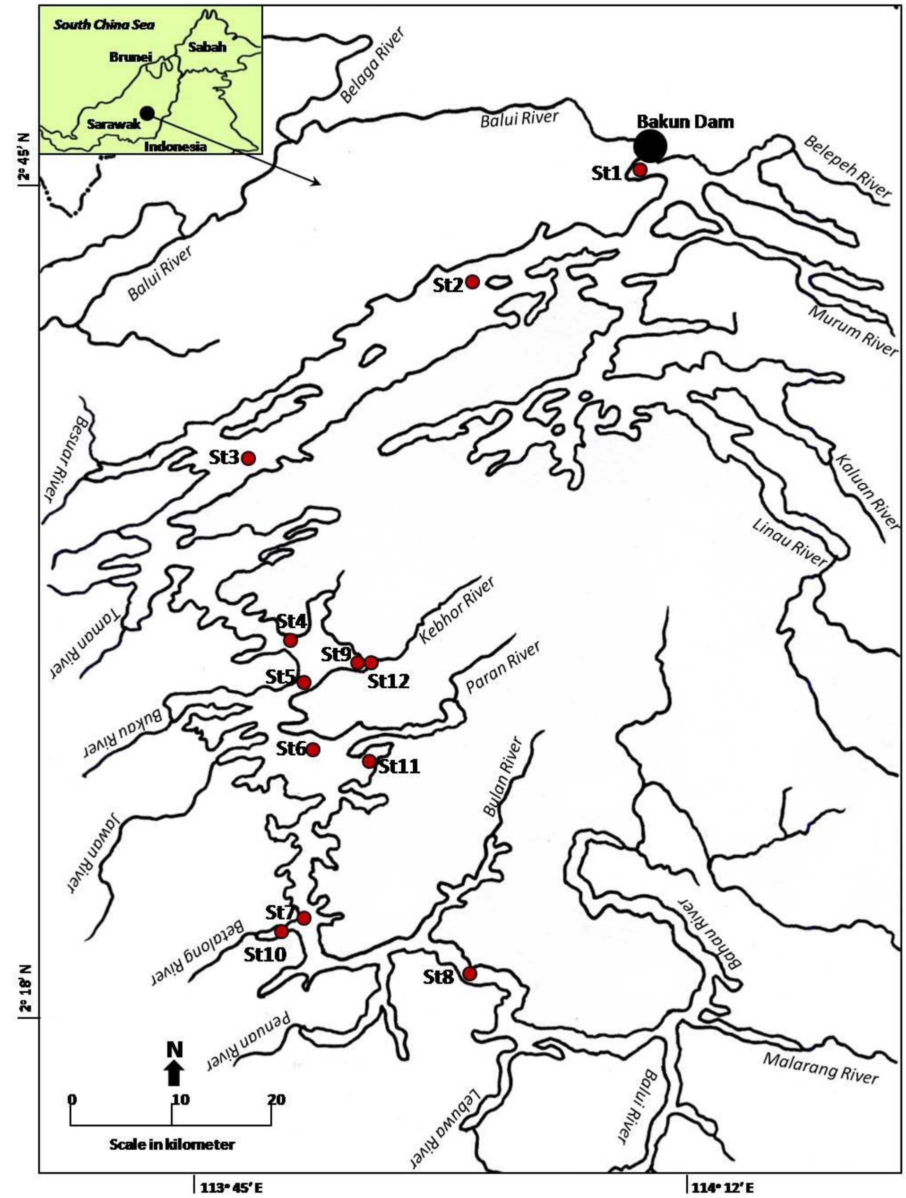

Figure 1: Location of the twelve sampling stations at Bakun Reservoir

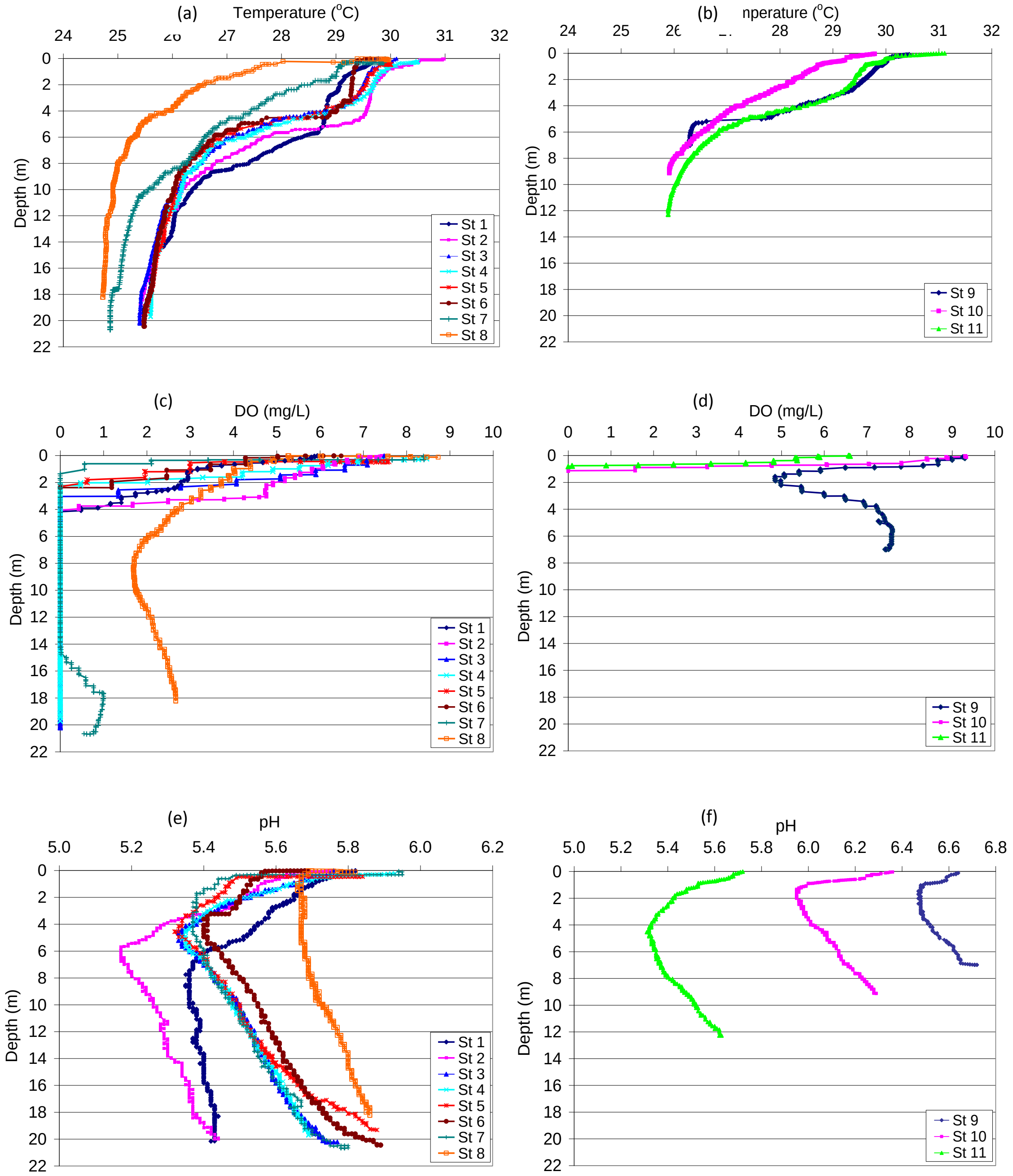

Figure 2: Temperature, dissolved oxygen (DO), and pH of Bakun Reservoir (a, c, e) and its tributaries (b, d, f).

Table 1: Depth and water quality at Station 12, upstream of Kebho River.

Parameter	Values
Depth (m)	0.262 ± 0.001
Temperature (°C)	22.94 ±0.004
DO (mg/L)	9.34 ±0.35
pH	6.41 ±0.01
Conductivity (µS/cm)	37.0 ± 1.0
TDS (mg/L)	25.0 ± 0.3
Turbidity (NTU)	93.69 ± 1.94

Table 2: Temperature (^{o}C) at the sampling stations at selected depths

St	0 m	2 m	4 m	6 m	12 m	18 m
1	29.77 ± 0.01a*	29.06 ± 0.01a	28.81 ± 0.00a	28.35 ± 0.05a	26.04 ± 0.01a	25.58 ± 0.00a
2	30.96 ± 0.01b	29.69 ± 0.01b	29.55 ± 0.01b	27.68 ± 0.03b	25.89 ± 0.00b	25.46 ± 0.01b
3	30.00 ± 0.10c	29.51 ± 0.01c	28.77 ± 0.10a	27.04 ± 0.06c	25.81 ± 0.00c	25.43 ± 0.00c
4	30.50 ± 0.00d	29.69 ± 0.01b	28.88 ± 0.10ac	27.28 ± 0.05d	25.88 ± 0.00b	25.61 ± 0.00d
5	30.00 ± 0.01c	29.55 ± 0.02cd	28.82 ± 0.16ac	26.88 ± 0.09e	25.95 ± 0.01d	25.58 ± 0.01a
6	29.63 ± 0.00e	29.29 ± 0.01e	28.98 ± 0.04c	26.75 ± 0.03f	25.86 ± 0.00e	25.59 ± 0.01a
7	29.89 ± 0.01f	28.48 ± 0.08f	27.48 ± 0.05d	26.60 ± 0.02g	25.26 ± 0.02f	24.90 ± 0.01e
8	29.95 ± 0.01cf	26.54 ± 0.04g	25.96 ± 0.02e	25.30 ± 0.02h	24.83 ± 0.01g	24.73 ± 0.00f
9	30.37 ± 0.05g	29.58 ± 0.02d	28.33 ± 0.08f	26.31 ± 0.01i		
10	29.73 ± 0.06a	28.26 ± 0.01h	27.29 ± 0.02g	26.55 ± 0.02g		
11	31.00 ± 0.08b	29.41 ± 0.01i	28.45 ± 0.08f	26.82 ± 0.01cf	25.89 ± 0.00b	
12	22.94 0.00h					
Mean†	29.56 ± 2.06a	29.01 ± 0.91b	28.30 ± 0.98c	26.87 ± 0.75d	25.71 ± 0.38e	25.36 ± 0.33f

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

Table 3: Dissolved oxygen at the sampling stations at selected depths

St	0 m	2 m	4 m	6 m	12 m	18 m
1	5.94 ± 0.00a*	2.79 ± 0.00a	0.56 ± 0.17a	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
2	7.42 ± 0.00b	4.91 ± 0.00b	0.09 ± 0.19b	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
3	7.41 ± 0.19b	4.07 ± 0.00c	0.00 ± 0.00b	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
4	8.46 ± 0.00c	1.09 ± 0.85d	0.00 ± 0.00b	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
5	7.56 ± 0.02b	0.50 ± 0.28e	0.00 ± 0.00b	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
6	6.35 ± 0.08d	1.44 ± 0.57d	0.00 ± 0.00b	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
7	8.40 ± 0.00c	0.00 ± 0.00f	0.00 ± 0.00b	0.00 ± 0.00a	0.00 ± 0.00a	0.99 ± 0.01b
8	8.51 ± 0.12c	3.72 ± 0.00c	2.73 ± 0.07c	2.06 ± 0.04b	2.09 ± 0.05b	2.67 ± 0.00c
9	9.27 ± 0.02e	4.98 ± 0.00b	7.26 ± 0.02d	7.58 ± 0.00c		
10	9.22 ± 0.20e	0.00 ± 0.00f	0.00 ± 0.00b	0.00 ± 0.00a		
11	6.59 ± 0.02f	0.00 ± 0.00f	0.00 ± 0.00b	0.00 ± 0.00a	0.00 ± 0.00a	
12	9.73 ± 0.32g					
Mean†	7.91 ± 1.18a	2.14 ± 1.96b	0.97 ± 2.16c	0.88 ± 2.22c	0.24 ± 0.67d	0.46 ± 0.91e

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

Table 4: pH at the sampling stations at selected depths

St	0 m	2 m	4 m	6 m	12 m	18 m
1	5.82 ± 0.00a*	5.65 ± 0.00a	5.55 ± 0.00a	5.41 ± 0.01a	5.38 ± 0.00a	5.43 ± 0.00a
2	5.74 ± 0.01b	5.51 ± 0.01bd	5.29 ± 0.00b	5.17 ± 0.00b	5.29 ± 0.01b	5.37 ± 0.00b
3	5.75 ± 0.02b	5.52 ± 0.01b	5.37 ± 0.01c	5.37 ± 0.01c	5.54 ± 0.01c	5.66 ± 0.01c
4	5.92 ± 0.01c	5.52 ± 0.01b	5.37 ± 0.01c	5.36 ± 0.01c	5.53 ± 0.00ce	5.65 ± 0.01c
5	5.83 ± 0.01a	5.44 ± 0.01c	5.34 ± 0.00d	5.39 ± 0.01d	5.53 ± 0.00ce	5.81 ± 0.01d
6	5.68 ± 0.01d	5.50 ± 0.00d	5.40 ± 0.01e	5.45 ± 0.01e	5.59 ± 0.00d	5.73 ± 0.00e
7	5.94 ± 0.01e	5.38 ± 0.00e	5.37 ± 0.00c	5.40 ± 0.00ab	5.52 ± 0.01e	5.65 ± 0.00c
8	5.81 ± 0.01f	5.67 ± 0.00f	5.67 ± 0.00f	5.68 ± 0.00f	5.77 ± 0.00f	5.86 ± 0.00f
9	6.63 ± 0.01g	6.48 ± 0.01g	6.52 ± 0.01g	6.63 ± 0.01g		
10	6.35 ± 0.01h	5.95 ± 0.00h	6.01 ± 0.00h	6.13 ± 0.00h		
11	5.72 ± 0.00i	5.42 ± 0.01c	5.33 ± 0.00d	5.35 ± 0.00i	5.62 ± 0.00g	
12	6.43 0.01j					
Mean†	5.97 ± 0.31a	5.64 ± 0.31b	5.57 ± 0.37c	5.58 ± 0.41c	5.54 ± 0.13d	5.64 ± 0.16b

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

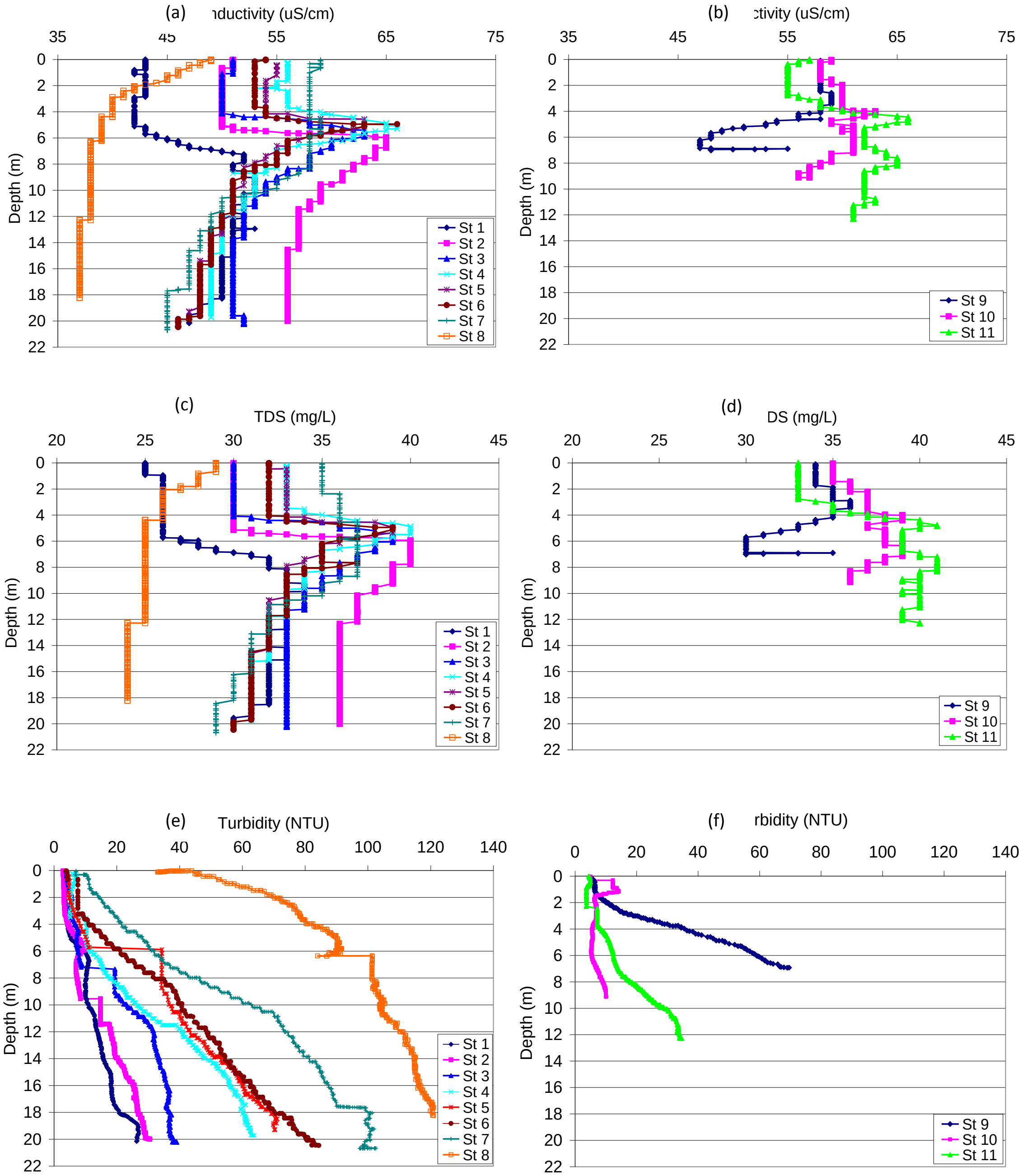

Figure 3: Conductivity, total dissolved solids (TDS), and turbidity of Bakun Reservoir (a, c, e) and its tributaries (b, d, f).

Table 5: Conductivity (µS/cm) at the sampling stations at selected depths

St	0 m	2 m	4 m	6 m	12 m	18 m
1	43.0 ± 0.0a*	43.0 ± 0.0a	42.0 ± 0.0a	44.6 ± 0.5a	52.0 ± 0.0a	50.0 ± 0.0a
2	51.0 ± 0.0b	50.0 ± 0.0b	50.0 ± 0.0b	65.0 ± 0.0b	57.0 ± 0.0b	56.0 ± 0.0b
3	51.0 ± 0.0b	50.0 ± 0.0b	50.0 ± 0.0b	61.6 ± 1.1c	52.0 ± 0.0a	51.0 ± 0.0c
4	56.0 ± 0.0c	55.0 ± 0.0c	58.6 ± 1.1c	62.0 ± 0.0c	50.4 ± 0.5cd	49.0 ± 0.0d
5	55.0 ± 0.0d	54.0 ± 0.0d	54.4 ± 0.9d	57.2 ± 0.8d	50.8 ± 0.4c	48.0 ± 0.0e
6	54.0 ± 0.0e	53.0 ± 0.0e	54.0 ± 0.0d	56.8 ± 1.1d	50.0 ± 0.0d	48.0 ± 0.0e
7	59.0 ± 0.0f	58.0 ± 0.0f	58.0 ± 0.0c	58.0 ± 0.07	49.0 ± 0.0e	45.0 ± 0.0f
8	49.0 ± 0.0g	42.2 ± 0.4g	40.0 ± 0.0e	39.0 ± 0.0e	38.0 ± 0.0f	37.0 ± 0.0g
9	58.0 ± 0.0h	58.0 ± 0.0f	57.4 ± 0.9c	48.0 ± 0.0f		
10	59.0 ± 0.0f	60.0 ± 0.0h	61.6 ± 0.9f	61.0 ± 0.0c		
11	57.0 ± 0.0j	55.0 ± 0.0c	60.4 ± 0.5f	62.0 ± 0.0c	61.0 ± 0.0g	
12	37.0 ± 0.0k					
Mean†	52.4 ± 6.5ad	52.6 ± 5.6abd	53.3 ± 6.9abcd	55.9 ± 8.1c	51.0 ± 6.0d	48.0 ± 5.2e

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

Table 6: Total dissolved solids, TDS (mg/L) at the sampling stations at selected depths

St	0 m	2 m	4 m	6 m	12 m	18 m
1	25.0 ± 0.0a*	26.0 ± 0.0a	26.0 ± 0.0a	27.2 ± 0.4a	33.0 ± 0.0a	32.0 ± 0.0a
2	30.0 ± 0.0b	30.0 ± 0.0b	30.0 ± 0.0b	40.0 ± 0.0b	37.0 ± 0.0b	36.0 ± 0.0b
3	30.0 ± 0.0b	30.0 ± 0.0b	30.0 ± 0.0b	38.4 ± 0.5d	33.0 ± 0.0c	33.0 ± 0.0c
4	33.0 ± 0.0c	33.0 ± 0.0c	35.2 ± 0.8c	38.0 ± 0.0d	32.0 ± 0.0d	31.0 ± 0.0d
5	32.0 ± 0.0d	33.0 ± 0.0c	33.2 ± 0.4d	35.8 ± 0.4e	32.0 ± 0.0d	31.0 ± 0.0d
6	32.0 ± 0.0d	32.0 ± 0.0d	32.0 ± 0.0e	35.4 ± 0.5e	32.0 ± 0.0d	31.0 ± 0.0d
7	35.0 ± 0.0e	35.0 ± 0.0e	36.0 ± 0.0f	37.0 ± 0.0f	32.0 ± 0.0d	30.0 ± 0.0e
8	29.0 ± 0.0f	26.8 ± 0.4f	26.0 ± 0.0a	25.0 ± 0.0g	25.0 ± 0.0e	24.0 ± 0.0f
9	34.0 ± 0.0g	35.0 ± 0.0e	35.0 ± 0.0c	30.0 ± 0.0h		
10	35.0 ± 0.0e	36.0 ± 0.0g	38.2 ± 0.4g	38.0 ± 0.0d		
11	33.0 ± 0.0c	33.0 ± 0.0c	37.0 ± 0.0h	39.0 ± 0.0c	39.2 ± 0.4f	
12	25.0 0.0a					
Mean†	31.1 ± 3.3ac	31.8 ± 3.2a	32.6 ± 4.0a	34.9 ± 4.9b	32.7 ± 3.7a	31.0 ± 3.2c

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

Table 7: Turbidity (NTU) at the sampling stations at selected depths

St	0 m	2 m	4 m	6 m	12 m	18 m
1	3.18 ± 0.04a*	3.50 ± 0.00a	4.24 ± 0.05a	9.66 ± 0.27a	13.76 ± 0.18a	20.92 ± 0.24a
2	2.90 ± 0.00a	3.20 ± 0.00a	4.60 ± 0.10a	8.98 ± 0.29ab	18.05 ± 0.06b	26.80 ± 0.10b
3	3.90 ± 0.07b	5.70 ± 0.07b	6.72 ± 0.19b	7.74 ± 0.13ab	31.68 ± 0.08c	36.90 ± 0.21c
4	5.86 ± 0.05c	5.30 ± 0.00bc	10.30 ± 0.00c	11.74 ± 0.21ab	40.88 ± 0.16d	60.10 ± 0.32d
5	4.28 ± 0.04d	4.92 ± 0.13c	7.98 ± 0.47d	29.74 ± 10.31c	43.10 ± 0.35e	69.80 ± 0.49e
6	3.82 ± 0.04b	7.60 ± 0.00d	11.56 ± 0.49e	21.36 ± 0.55d	48.84 ± 0.29f	71.28 ± 0.88f
7	7.00 ± 0.00e	14.30 ± 0.38e	21.16 ± 0.43f	31.44 ± 0.38c	73.70 ± 0.56g	100.80 ± 0.39g
8	33.38 ± 0.30f	70.92 ± 0.90f	80.94 ± 0.55g	90.10 ± 0.41e	111.00 ± 0.76h	120.48 ± 0.36h
9	5.26 ± 0.11g	10.66 ± 0.46h	36.38 ± 1.47h	59.04 ± 0.70f		
10	5.00 ± 0.00g	6.58 ± 0.08g	5.64 ± 0.05i	5.40 ± 0.07a		
11	4.48 ± 0.04d	3.72 ± 0.04a	8.36 ± 0.30d	12.50 ± 0.00b	33.86 ± 0.09i	
12	94.92 0.44h					
Mean†	14.50 ± 25.75a	12.40 ± 18.95a	17.99 ± 22.06a	26.15 ± 25.55b	46.73 ± 28.63c	63.39 ± 33.24d

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