Water Quality at Batang Ai Hydroelectric Reservoir (Sarawak, Malaysia) and Implications for Aquaculture

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Abstract

Batang Ai reservoir has been an inland aquaculture site. However, little is known about the water quality of the reservoir which is important for aquaculture expansion. Therefore, the objective of this study was to determine the level of dissolved oxygen (DO), biochemical oxygen demand (BOD_5) and sulfide in the reservoir. Samplings were conducted at 12 stations and at three different depths. Results show that pH and dissolved oxygen decreased as depth increased. Mean DO at 0.5 m, 14 m and 27 m were 6.4 mg/L, 3.9 mg/L and 2.95 mg/L respectively. BOD_5 were 3.9 mg/L, 8.7 mg/L and 8.3 mg/L at 0.5 m, 14 m and 27 m depth respectively. Total sulfide ranged from 0.33 to 32.0 µg/l and the mean at 27 m was significantly higher than 0.5 m depth. Multiple linear regression indicates that BOD_5 was the only significant predictor of total sulfide. This study shows that sulfide was much lower than the lethal level and it would only be unhealthy for the caged fish if there were upwelling or mixing where lower DO water with toxic sulfide at and below 14 m depth were to be brought to the culture zone.

Keywords: dissolved oxygen, biochemical oxygen demand, total sulfide, cage culture

1. *Introduction*

Cage aquaculture is getting increasingly important worldwide due to the increasing demand for fish protein but stagnant supply from wild catch. According to Petr (2007), by the year 2025, an additional 62 million tons of aquatic products will be required to maintain the present consumption of 19.1 kg/person and much of it will have to come from inland waters, including reservoirs.

The Batang Ai reservoir was created for hydroelectric generation when the Batang Ai River was dammed in 1984 and it is one of the most important sources of energy for the Sarawak Corridor of Renewable Energy (SCORE) which is aiming to achieve US$105 billion of investment (Sovacool and Bulan 2012). In addition to power generation, the government encouraged aquaculture and fisheries industry to be developed in the reservoir. As a result, cage culture with a low production of 3 tons in 1993 increased to 434 tons in 2003 and 744 tons in 2011 due to the great demand for its product throughout the year. Reports of fish kills due to unsustainable development of cage culture in reservoirs in other countries such as the Cirata Reservoir in Indonesia (Hayami *et al.* 2008; Abery *et al.* 2005; Costa-Pierce 1998) indicate that cage culture in our reservoir should be developed sustainably for social benefit and local market. Fish kills are frequently results of poor water quality due to nutrients enrichment that cause algal bloom and crush which leads to oxygen depletion and accumulation of toxic products such as hydrogen sulfide. However, information on water quality including sulfide concentration and their diurnal changes in the reservoir is scarce.

Batang Ai reservoir has been built with very little pre-clearing and is situated in a thick tropical forest area (Pusin 1995). Since the water column is thermally stratified, it inhibits deep water mixing with surface water (Pusin 1995; Luther *et al.* 2004). At the bottom, bacteria consume oxygen in the process of decomposition of organic matter such as dead trees depleting the oxygen and when oxygen is fully consumed, production of toxic hydrogen sulfide occurs (Luther *et al.* 2004). Through mixing and diffusion, hydrogen sulfide move into the overlying waters potentially affecting fish and aquatic organism. The net effect of hydrogen sulfide poisoning is acute oxygen deficiency (Lawson 1995). Toxicity study of hydrogen sulfide on freshwater fish, bluegill, showed that it affects eggs deposition, growth, food consumption and the most sensitive stage to acute toxicity was the feeding fry and to chronic toxicity was the spawning adult (Smith *et al.* 1976). Cultured milkfish and tilapia fish kills were frequently reported in the tropical country of the Philippines due to aquaculture intensification and sulfide toxicity study showed that it could be a causative factor in fish kills of milkfish and tilapia and that it aggravates mortality due to hypoxia or low pH (Bagarinao and Lantin-Olaguer 1999). Hydrogen sulfide appeared to be the primary reason for fish kills in Delaware inland bays (Luther *et al.* 2004). The irritating smell of hydrogen sulfide has been detected at the reservoir, at outflow and at a downstream town of Lubok Antu. However, there has not been any study on its level. Due to the toxicity of hydrogen sulfide to fish and the threat to fisheries and cage culture industries in Batang Ai, the objective of this study was to determine sulfide concentration at different depths at selected stations in the reservoir and its relationship with other parameters of water quality.

2. Materials and Methods

Batang Ai Hydroelectric Reservoir is located in Sri Aman, a distance of about 275 km from Universiti Malaysia Sarawak, Kota Samarahan, Sarawak, Malaysia. The reservoir has a water surface area of 84 km^2, a water volume of 750 million m^3, and a mean depth of 44 m. The depth ranged from 14 to 63 m. The main inflow of the reservoir are the Engkari River and the Batang Ai River. Data were collected at 12 stations at 3 different depths (0.5 m, 14 m and 27 m) on 16th April 2009, 19th November 2009, 20th and 21st May 2010. There were cage aquaculture near stations 1, 2, 4, 5, and 11 at the time of sample collection. The stations are shown in Figure 1.

Physico-chemical characteristics such as temperature, pH, dissolved oxygen (DO), five-day biochemical oxygen demand (BOD_5) and total sulfide were determined. Temperature, pH, and DO data were collected using *in situ* analyzer (YSI 6600 Multiparameter Water Monitor). Water samples were collected using a van dorn sampler and they were analyzed for BOD_5 and total sulfide. BOD_5 was determined in the field according to the Standard Methods (APHA 1998). Total sulfide concentrations were determined in the field using the Methylene Blue method described in DR2800 spectrophotometer procedures manual (Hach 2000). Reagents were added to 10 mL of water samples and the intensity of the blue colour is proportional to the sulfide concentration. The intensity was measured at 665 nm using the DR2800 spectrophotometer. All samples were analyzed in triplicates. Significant difference of each parameter among stations was analyzed using three-way ANOVA where the factors were depth, station and sampling date. Multiple linear regression by Backward Elimination Method with $F \geq 0.100$ as the criterion of rejection was performed to see the relationship between total sulfide concentrations and other parameters measured. All statistical analyses were performed using Univariate analysis of variance of SPSS 17.0.

3. Results and discussion

Temperature values of the subsurface, that is, 0.5 m depth were consistently higher than 14 and 27 m depths (Figure 2).

Temperature at 27 m depth was the lowest at all the stations and it did not fluctuate much among the stations. At 14 m of station 1, 2, 7, 10, and 11, the temperature was high because on 19th November 2009 it was dry season and the water was much shallower than the other three sampling days and at station 12, the water was less than 14 m deep. Overall, station 11 has significantly higher temperature ($P<0.05$) than the other stations (Table 1). Temperature decreased significantly with depth ($P<0.05$) (Table 2).

pH at 0.5 m at all the stations were above the value of 7 and were higher than 14 m and 27 m except station 11 (Figure 3) as they are influenced by photosynthesis process of phytoplankton with the energy from solar radiation. At both 14 m and 27 m depths, pH values were low, mostly below 7, the neutral value and low values were observed at station 7 where it was sheltered and thus less circulation (Figure 3). At station 8, the trend appears to be opposite of station 7 where higher pH were observed at 14 m and 27 m due the mixing caused by the withdrawal of water near the dam near the outflow site. At station 2, pH at 14 m and 27 m were low and they corresponded with low DO and high BOD_5 values (Figure 3-6). This is likely due to the oxygen consumption during the breakdown of organic matter from excess feed and fish waste as it was located near an aquaculture site. Station 12 has high pH and DO and low BOD_5 and total sulfide (Table 1) as it is a shallower station and thus has better aeration. pH decreased in the order of 0.5 m >14 m > 27 m (Table 2) and they were significantly different ($P<0.05$).

At 0.5 m depth, DO ranged from 4.7 to 8.7 mg/L and they were higher than 14 m and 27 m depths at all the stations (Figure 4). Out of the 12 stations, 7 stations have DO of below 5 mg/L, the level recommended for healthy growth of warm water fish (Lawson 1995) at some depths. At station 10, the rank of DO values at different depths was the opposite of BOD_5 indicating the influence of BOD_5 on DO values. The high DO of above 8 mg/L at 0.5 m of station 10 (Figure 4) was most likely from phytoplankton photosynthesis caused by dry season low flow and thus more concentrated organic matter inflow from household waste upstream as indicated by the highest BOD_5 at the same depth (Figure 5). Station 3 showed high DO at the 14 m and 27 m and the difference between DO of the three depths was the least as it was not located near any aquaculture site and it was not sheltered and thus better wind-induced re-aeration. The high DO at 14 m and 27 m of station 3 also corresponded with low BOD_5 when compared to stations 2 and 4. Station 2 has the lowest DO (below 5 mg/L) at all depths as there was cage aquaculture nearby that station throughout the sampling period and thus organic matter in the sediment below the cage area increases as reported by Jiwyam and Chareontesprasit (2001).

Similarly, DO at 14 m and 27 m of station 4 were low due to nearby cage aquaculture. The lower DO at some aquaculture sites is mainly caused by consumption of DO by microorganisms in decomposition of organic matter (Chapman, 1996). Other contributing factors could be the lowered re-aeration and water movement due to obstruction by the structures of cages. Overall, DO were significantly different among the three depths with DO decreasing as depth increased (Table 2). Compared with other studies, DO in the present study was not as low as reported by Hayami *et al*. (2008) where the thickness of oxygenated water at Cirata Reservoir with dense net cages and high production were only 5-7 m whereas the anoxic water mass was more than 70 m deep. Low DO water from the reservoir was also reported by Schouten (1998) where DO values of a river which received outflow from a dam in Vietnam were more frequently observed to be below 5 mg/L than above 5 mg/L.

Mean BOD_5 at the stations ranged from 2.2 mg/L at 0.5 m depth to 14.8 mg/L at 14 m depth the values at 0.5 m was the lowest at all stations (Figure 5). At 14 m and 27 m, the means were higher than 0.5 m depth and between 14 m and 27 m, the means were not significantly different ($P>0.05$) (Table 2). At 27 m, BOD_5 was the highest at station 10 (Figure 5). This high BOD_5 corresponds with high temperature (Figure 2) and low DO (Figure 4). Station 10 is located nearer to the inflow of the reservoir but it is also submerged and the high 27 m depth BOD_5 observed was mainly due to the value observed on 19 November 2009 which occurred during dry season with high temperature, little precipitation and thus more concentrated organic matter. As for station 11, at 14 m depth BOD_5 was the highest as it was near the bottom of a cage aquaculture site where nutrients and organic matter from the fish excess feed and waste accumulated that resulted in high oxygen demand and in dry season when water temperature increases, the rate of decomposition increases (Chapman 1996). High organic loading from the fish cages was reported to be the major source of organic matter and rapid decomposition in the tropics resulted in high oxygen consumption rate (Hayami *et al*. 2008). According to a study by Jiwyam and Chareontesprasit (2001) in Thailand, organic matter of bottom sediments of the reservoir under tilapia cage culture area increased with time during the cage culture period in most cases. That explains the higher BOD_5 observed near some cage culture sites.

Total sulfide was detected at all the stations in the reservoir and the concentrations ranged from 0.33 µg/L to 32.0 µg/L as shown in Figure 6. The ranges for 0.5 m, 14 m and 27 m depths are 0.33-12.67 µg/L, 3.00-14.67 µg/L and 1.33-32.00 µg/L respectively. At almost all the stations, mean total sulfide concentrations at 14 m or 27 m depths were higher than the 0.5 m depth. At the 0.5 m depth, station 10 showed the highest total sulfide. At 14 m, station 6 showed the highest and at 27 m station 7 showed the highest values. Even though stations 6 and 10 are located near inflow of the reservoir, they are also at the submerged areas and thus showed relatively high total sulfide concentrations. Station 7 is located at a sheltered and deep station and thus it showed high total sulfide at all depths with the values increasing with depth. In fact, the highest maximum concentration of sulfide was observed at that station during dry season (19 November 2009) when the reservoir water level was lower and temperature at the 14 m and 20 m depths were about 2 ^{o}C higher than the other trips and DO was only 0.57 mg/L indicating the formation of sulfide under anoxic condition. For station 8, there was very little difference in total sulfide between the three depths as it is located near the outflow of the reservoir and the dam water intake creates mixing of the surrounding water.

Comparing cage culture stations of 1, 2, 4, 5, and 11 with the other stations, only station 2 ranked fourth for the 27 m depth and fifth for the 0.5 m depth in sulfide concentrations (Figure 6) and low DO concentrations (Figure 4). Among the aquaculture stations, station 4 showed the lowest sulfide values (Table 1). Station 1, 4 and 11 are relatively shallower stations and thus less accumulations of sulfide occurred. Furthermore, station 11 cage culture operations was only a few months old at the time of sampling and thus not as much organic matter accumulated. Even though overall sulfide concentrations at aquaculture stations did not rank the top three, it was observed that total sulfide values at three (stations 1, 4 and 5) out of the five stations were the highest at 14 m depth; at station 11, the 0.5 m depth total sulfide was higher than the 14 m depth and at station 2 the 0.5 m and 14 m depths total sulfide were almost of the same values (Figure 6). Oxygen demand by decomposition of fish feed, fish excretion and dead phytoplankton at those stations resulted in less oxygen availability at those stations for the oxidation of sulfide diffused to the shallower depths leading to its accumulation.

The mean total sulfide value at 27 m was 8.75 µg/L and it was significantly higher than mean value of 4.56 µg/L at 0.5 m depth ($P<0.05$) (Table 2). Among the stations, Station 7 and 10 were the highest and they were significantly higher than station 4 and 12 ($P<0.05$). Total sulfide was significantly higher on 19 Nov 2009 (11.77 µg/L) when the water level was much lower and temperature higher compared to the other three dates (20 May 2010, 4.73 µg/L; 21 May 2010, 5.18 µg/L; and 16 April 2009, 6.22 µg/L) ($P<0.001$). Multiple regression analysis ($N = 66$) showed that there was significant regression ($P<0.0005$). BOD_5 was the only significant predictor of total sulfide with beta value of 0.608, *t* value of 6.129 and *p*-values of less than 0.0005 and it explained 37.0 % of the variations in total sulfides. The prediction equation is expressed as Equation [1].

$$\text{Total sulfide} = 0.675 + 0.973{*}BOD_5 \qquad [1]$$

Total sulfide was the highest 27 m depth because in the absence of oxygen, anaerobic bacteria use sulfate as terminal electron acceptor in sediments with production of toxic hydrogen sulfide (Luther *et al.* 2004). The presence of sulfide has been reported in other reservoirs in literature; Schouten (1998) reported that during the months of August and September the rotten egg smell of hydrogen sulfide has been reported at the dam site in Vietnam and Lourantou *et al.* (2007) reported an irritating odour observed during the bottom water sampling in the summer in Belgium attributed to hydrogen sulfide. However, both studies did not include concentrations of sulfide. Sulfide was detected at all stations studied as most of the standing trees were submerged during the impoundment due to little pre-clearing of the forest, organic materials decomposition led to anoxic condition and with the stagnant water mass, accumulation of reduced substances such as sulfide occurred (Baxter 1977). In addition, waste from human settlement upstream and from fish cage culture in the reservoir are also sources of organic matter. Higher concentrations of total sulfide were observed during dry season as there was less dilution and flushing of water since there was less inflow from the rivers and thus more concentrated organic matter. In addition, during dry season, the temperature was higher than the wet season and thus the rate of sulfide production was also higher. Weiland and Kuhl (2000) reported that sulfide production increased strongly with temperature from 25^{o}C to 40^{o}C in both dark and light conditions.

The values of hydrogen sulfide (converted from total sulfide) observed in the present study (Table 3) were much less than the high levels of hydrogen sulfide ranging from 0.3-2.0 mg/L at 2 m to 8 m depth with temperature of 30.5-31.0 ^{o}C in Lake Cirata in Indonesia attributed to excessive density of cages and fish (Effendie *et al.* 2005).

Compared with the hydrogen sulfide profile reported by Pusin (1995) of a study done 23 years ago at one station in Batang Ai Reservoir, the results of the present study at 14 m was comparable but at 27 m depths, the values in this study were much less than her report (Table 3). The trend of drastic increase in concentration as depth increases as reported by Pusin (1995) was also not observed at every station we studied as in the present study sulfide at 14 m of 5 stations were higher than values at 27 m depth. This indicates that over the years, hydrogen sulfide have decreased in concentration in the deeper region of the reservoir as decomposition of the un-removed vegetation occurred all these years.

In terms of toxicity of sulfide, Bagarinao and Lantin-Olaguer (1999) reported that when the sulfide tolerance of 2-5 g milkfish and 5–8 g O. mossambicus was determined in 25-liter aquaria with flow-through sea water (100 ml min^{-1}) at 26–30 °C, pH 8 – 8.5, about 313 µg/L hydrogen sulfide was lethal to 50% of the fish in 4–8 h, and 128 µg/L in 24–96 h. However, the experiment done by lowering pH using sulfuric acid and lowering oxygen showed that milkfish was less tolerant to sulfide levels and that sulfide, hypoxia and low pH aggravate each other's toxicity. Exposure of freshwater channel catfish to 3.2 µg/L and 32 µg/L hydrogen sulfide resulted in 18% and 64% *in vitro* inhibition of brain cytochrome oxidase activity (Torrans and Clemens 1982). In the present study, the calculated hydrogen sulfide ranging from 0.07 to 27.0 µg/L are much lower than the lethal concentrations reported by Bagarinao and Lantin-Olaguer (1999) but in the range of brain cytochrome oxidase activity inhibition of catfish as reported by (Torrans and Clemens 1982). Compared with the recommended value of 2 µg/L proposed by USEPA (1986) for fish and aquatic life, 58% (10% at 0.5 m; 24% at 14 m; and 24% at 27 m) of the sample hydrogen sulfide concentrations in the present study exceeded that recommended value.

4. Conclusions

Temperature, pH and DO decreased as depth increased. Total sulfide was detected at all stations studied. The concentration of BOD_5 and sulfide were the lowest at 0.5 m and there was no significant difference between 14 m and 27 m. DO at 0.5 m of all stations were above 5 mg/L except at one aquaculture site. The highest maximum total sulfide value occurred at low DO of 0.57 mg/L at the deepest, sheltered station during dry season. For aquaculture stations, there appear to be high sulfide at 14 m and/or 0.5 m depth. Multiple linear regression showed that BOD_5 was the only significant predictors of total sulfide. 58% of hydrogen sulfide concentrations observed exceeded USEPA recommended value of 2 µg/L. Therefore, it would only be unhealthy for the cage fish if there is upwelling or mixing where the high sulfide level is brought to the culture zone together with anoxic water. Selection of site for cage culture is important for successful aquaculture activities.

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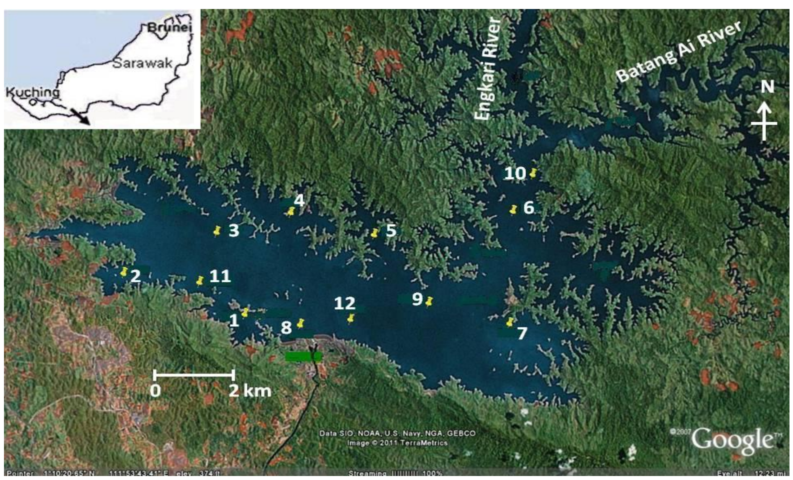

Figure 1: Sampling stations in Batang Ai Reservoir.

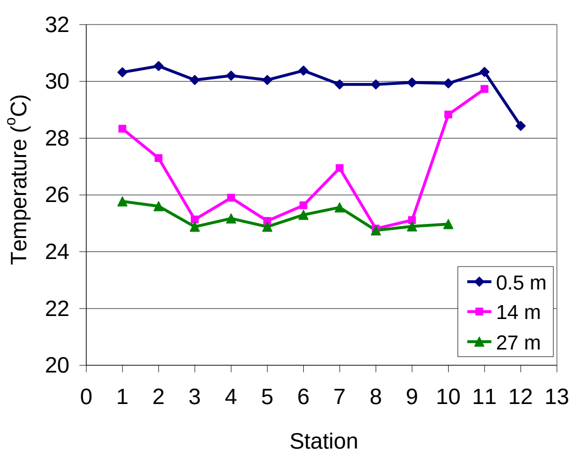

Figure 2: Temperature at the three different depths (0.5 m, 14 m, 27 m) at the 12 sampling stations.

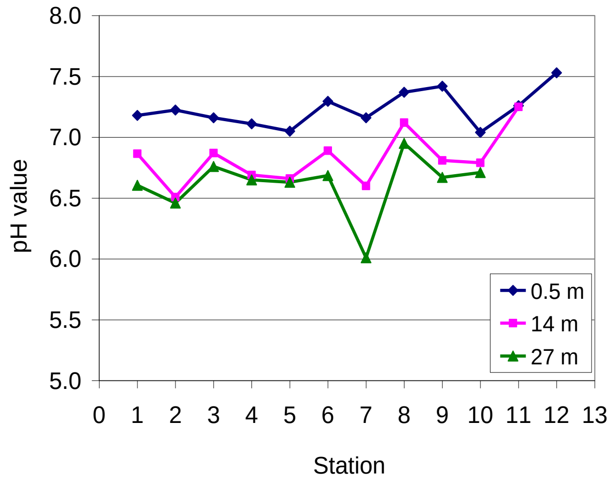

Figure 3: pH at the three different depths (0.5 m, 14 m, 27 m) at the 12 sampling stations.

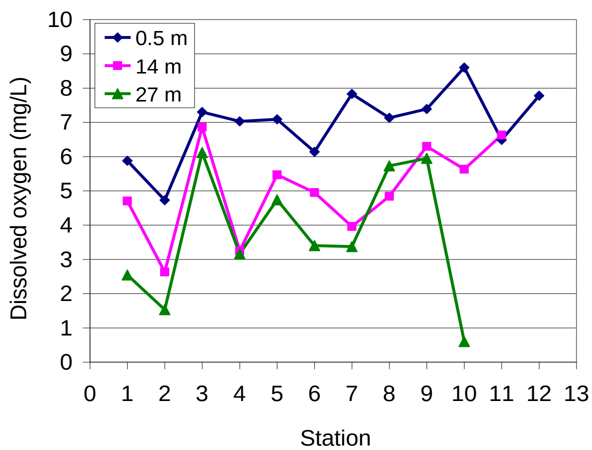

Figure 4: Dissolved oxygen (DO) at the three different depths (0.5 m, 14 m, 27 m) at the 12 sampling stations.

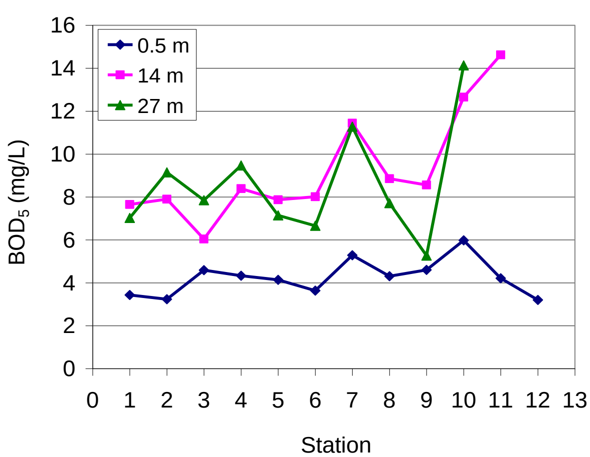

Figure 5: Biochemical oxygen demand (BOD_5) at the three different depths (0.5 m, 14 m, 27 m) at the 12 sampling stations.

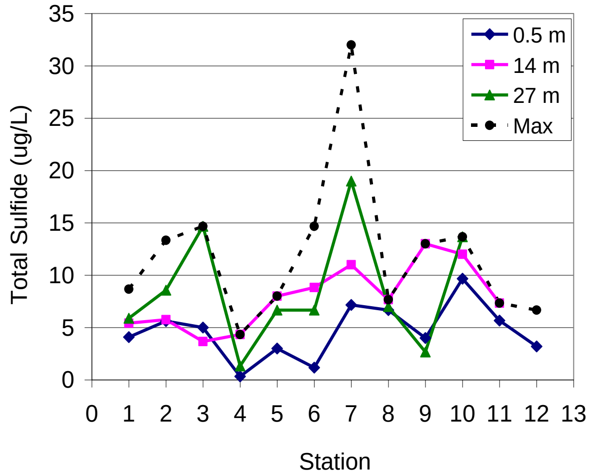

Figure 6: Total sulfide concentrations at the three different depths (0.5 m, 14 m, 27 m) at the 12 sampling stations.

Table 1: Mean temperature, pH, dissolved oxygen (DO), biochemical oxygen demand (BOD_5) and total sulfide at 12 sampling stations.

Station	Temperature (°C)	pH	DO (mg/L)	BOD_5 (mg/L)	Total Sulfide (µg/L)
1	28.35±1.96ab	6.85±0.39ab	4.19±2.14ab	5.48±2.84ab	5.06±2.39ab
2	27.81±2.18ab	6.73±0.40ab	2.96±1.72a	6.76±3.44abc	6.65±3.41ab
3	26.69±2.92a	6.93±0.21ab	6.76±0.60bc	6.16±1.63abc	7.78±6.00ab
4	27.09±2.72a	6.82±0.25ab	4.48±2.21ab	7.40±2.71bcd	2.00±2.08a
5	26.67±2.93a	6.78±0.23ab	5.77±1.20abc	6.38±1.98abc	5.89±2.59ab
6	27.40±2.74a	6.97±0.41abc	4.81±1.98abc	5.72±2.07abc	6.07±6.23ab
7	27.47±2.40a	6.59±0.58a	5.06±3.27abc	9.33±4.32cd	12.39±10.45b
8	26.48±2.95a	7.15±0.21abc	5.90±1.15abc	6.96±2.36abc	7.11±0.51ab
9	26.65±2.57a	6.97±0.40ab	6.55±0.75bc	6.14±2.11abc	6.56±5.62ab
10	27.91±2.60ab	6.85±0.17ab	4.94±4.01abc	10.92±4.34d	11.78±2.01bc
11	30.03±0.42b	7.26±0.01bc	6.56±0.10bc	9.42±7.36cd	6.50±1.17ab
12	28.43±1.91ab	7.53±0.31c	7.78±0.57c	3.20±0.02a	2.44±1.54a

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

Table 2: Mean temperature, pH, dissolved oxygen (DO), biochemical oxygen demand (BOD_5) and total sulfide at different depths.

Parameter	0.5 m	14 m	27 m
Temperature (°C)	30.05±0.88a	27.07±1.58b	25.39±0.61c
pH	7.25±0.21a	6.73±0.30b	6.51±0.27c
DO (mg/L)	6.44±1.59a	3.92±1.87b	2.95±2.04c
BOD_5 (mg/L)	3.93±1.14a	8.69±1.87b	8.33±2.04b
Total sulfide (µg/L)	4.56±3.60a	7.37±3.40ab	8.75±6.66b

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

Table 3: Maximum, minimum and mean values of hydrogen sulfide at different depths of the 12 sampling stations and comparisons with literature.

Depth (m)	N	Hydrogen Sulfide (µg/L)			
		Minimum	Maximum	Mean	Pusin (1995)
0.5	28	0.07	4.57	1.57±1.34	NA
14	24	0.83	9.96	3.89±2.33	12
27	24	0.87	29.97	5.43±5.22	125

NA: Not available.