Faculty of Resource Science and Technology

Water and Sediment Quality of Batang Ai Reservoir

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Declaration

I hereby declare that this report entitled "Water and Sediment Quality of Batang Ai Reservoir" is an original research work done by the undersigned candidate, as part of her Resource Chemistry studies. All information in this report has been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that, as required by these rules and ethical conduct, I have fully cited and referenced all materials and results that are not original to this work. This thesis is not submitted to any other university or institution for the award of any degree or published any time before.

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List of Abbreviations

BOD_5	Five-day Biochemical Oxygen Demand
BOD	Biochemical Oxygen Demand
NO_3^--N	Nitrate-nitrogen
NO_2^--N	Nitrite-nitrogen
TAN	Total Ammonia Nitrogen
TN	Total Nitrogen
SRP	Soluble Reactive Phosphorus
TP	Total Phosphorus
TS^{2-}	Total Sulfide
COD	Chemical Oxygen Demand
PSA	Particle Size Analysis
OM	Organic Matter
TOC	Total Organic Carbon
TKN	Total Kjeldahl Nitrogen
NH_3-N	Ammoniacal Nitrogen
DIW	Deionized Water
HDPE	High Density Polyethylene
HCl	Hydrochloric acid
NaOH	Sodium hydroxide
$NaNO_2$	Sodium nitrite
KH_2PO_4	Potassium dihydrogen phosphate
$Na_2S.9H_2O$	Sodium sulfide nonahydrate
H_2SO_4	Sulfuric acid
$(NH_4)_2S_2O_8$	Ammonium persulfate

$K_2Cr_2O_7$	Potassium dichromate
$FeSO_4 \cdot 7H_2O$	Ferrous sulfate heptahydrate
HNO_3	Nitric acid
$HClO_4$	Perchloric acid
M	Molarity
mg/L	milligram per litre
µg/L	microgram per litre
N	Nitrogen
P	Phosphorus
S^{2-}	Sulfide
±	plus and minus
µS/cm	microsiemens per centimetre
NTU	*Nephelometric Turbidity Units*
mg/m^3	milligram per cubic meter
g/kg	gram per kilogram
mg/kg	milligram per kilogram
L	litre
mL	millilitre
kg	kilogram
g	gram
mg	milligram
µg	microgram
km	kilometre
km^2	square kilometre
m	meter

mm	millimetre
µm	micrometre
nm	nanometre
°C	Degree Celsius
rpm	revolutions per minute
Mg/m^3	mega gram per cubic meter
mL/min	millilitre per minute
SPSS	Statistical Package for the Social Sciences
LCD	*Liquid-crystal Display*
GPS	Global Positioning System
WQI	Water Quality Index
TSI	Trophic State Index
NWQS	National Water Quality Standards of Malaysia

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Water and Sediment Quality of Batang Ai Reservoir

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ABSTRACT

Water and sediment quality can affect the aquatic organisms. Hence, this study was conducted to determine the water and sediment quality at two future aquaculture sites (C14 and D15), an abandoned aquaculture sites (B9) and at the confluence (A6) of Batang Ai River and Engkari River. This study was done in June 2014 and January 2015. The results show the dissolved oxygen falls into Class II of NWQS (5-7 mg/L) at 0.2-8 m depths. Thermocline happens at 8-13 m. Stations C14 and D15 recorded high five-day biochemical oxygen demand, total suspended solids, nitrate-nitrogen, nitrite-nitrogen, total ammonia nitrogen, total nitrogen in water and sediment, total phosphorus and total sulfide as well as the highest chlorophyll-*a* at 10 m. The highest soluble reactive phosphorus recorded at A6 at 10 m in both sampling months. B9 recorded the highest water content, organic matter, total organic carbon, clay and total phosphorus in sediment. Sediment texture of all stations was classed into clay. Overall, the water quality of these stations at 0.2 m and 10 m fall into Class II (76.5-92.7 mg/L) and III (51.9-76.5 mg/L) according to Water Quality Index, which are suitable for sensitive, common and tolerant aquatic species. Trophic state of this study was oligotrophic and mesotrophic. However, periodic management of the activities in Batang Ai Reservoir is required to sustain the development of aquaculture.

Key words: Water quality, sediment, aquaculture, Water Quality Index, trophic state.

ABSTRAK

Kualiti air dan sedimen membawa kesan kepada organisma akuatik. Oleh itu, kajian ini dijalankan untuk menentukan kualiti air dan sedimen pada dua tapak akuakultur masa depan (C14 dan D15), tapak akuakultur ditinggalkan (B9) dan pertemuan (A6) di Batang Ai dan Batang Engkari. Kajian ini telah dijalankan pada Jun 2014 dan Januari 2015. Hasil kajian menunjukkan DO dikelaskan kepada Kelas II NWQS (5-7 mg/L) pada 0.2-8 m. Thermocline berlaku di 8-13 m. C14 dan D15 menunjukkan tinggi BOD_5, *TSS,* NO_3^-*-N,* NO_2^-*-N, TAN, TN dalam air dan sedimen, TP dan* TS^{2-} *dan juga yang paling tinggi klorofil-a pada 10 m. A6 menunjukkan SRP tertinggi pada 10 m dalam kedua-dua bulan persampelan. B9 direkodkan kandungan air, OM, TOC, tanah liat dan TP yang paling tinggi dalam sedimen. Tekstur sedimen telah digolongkan ke dalam tanah liat. Secara keseluruhan, kualiti air stesen-stesen ini pada 0.2 m dan 10 m dikelaskan kepada Kelas II (76.5-92.7 mg/L) dan III (51.9-76.5 mg/L) mengikut Indeks Kualiti Air, yang sesuai untuk sensitif, biasa dan bertolak ansur spesies akuatik. Keadaan trofik kajian ini adalah oligotrof dan mesotrophic.Walau bagaimanapun, pengurusan aktiviti di Batang Ai Empangan diperlukan untuk mengekalkan pembangunan akuakultur.*

Kata kunci: *Kualiti air, sedimen, akuakultur, Indeks Kualiti Air, keadaan trofik.*

1.0 Introduction

Wurbs (1996) stated that the concerns of management of the reservoir and river system were water quality, sedimentation, and improvement of fish, wildlife as well as other environmental resources. Water and sediment quality has the potential to affect aquatic organisms as the toxic metal in water and sediment will be consumed by the fish (Shilling *et al.*, 2004). Therefore, monitoring water and sediment quality of an area is important to sustain the natural environment and the aquatic life.

Batang Ai Hydroelectric dam, the first dam built in Sarawak, Malaysia was completely constructed in 1985 (China Institute of Water Resources [CIWR], 2008). The purpose of Batang Ai Hydroelectric Reservoir was to produce hydroelectric power which was the main source of energy for the Sarawak Corridor of Renewable Energy (Sovacool & Bulan, 2012). Other than energy production, Department of Agriculture encouraged the development of aquaculture and fisheries industry in the reservoir in 1993 (Ling *et al*., 2012b; Ling *et al*., 2013a; Nyanti *et al*., 2012) in order to meet the high demand of fish protein (Food and Agriculture Organization [FAO], 2014; Ling *et al*., 2012b; Nyanti *et al*., 2012). A study of Nyanti *et al*. (2012) stated that about 2,696 cages of fish cage culture in the reservoir and 500 fishes were stocked in each cage. FAO (2014) reported the supply of per capita aquatic product from aquaculture increased from 0.7 kg to 7.8 kg in 1970 and 2006 respectively, with a growth rate of 6.9% per annum on average.

Water quality of a reservoir can affect the aquatic organisms and wildlife habitat (Martin *et al*., 2007). According to Varol *et al*. (2012), anthropogenic activities or natural processes affect the water quality, harming its future use and also protection of aquatic life, and thus deterioration of reservoirs. A study reported in Cirata Reservoir, Indonesia, the development of aquaculture in the reservoir was unmanageable and caused the excess fish foods released into the water body and deteriorates water quality (Hayami *et al.*, 2008). In addition, degradation of the water quality and loss of aquatic biodiversity had been identified in the dam of Tasik Chini (Gasim *et al*., 2006). Therefore, it is important to monitor the water quality of a reservoir in order to sustain the health of the river and reservoir water as well as to provide good quality of aquatic food.

According to NIWA Taihoro Nukurangi [NIWA] (2013), amount of sediment that entered the freshwater ecosystem increased due to human activities around the stream. Excess sediments would reduce light penetration, thereby prevents the process of photosynthesis in aquatic plants and algae, and decrease the visibility for fish to search for food (NIWA, 2013). Excess sediments that settled down on the stream bed influenced the flow and depth of the stream over time (NIWA, 2013). Jiwym and Chareontesprasit (2001) stated that the amount of nutrients in the sediment increased caused by the cage fish culture.

Previous studies of water quality that had been conducted in Batang Ai reservoir only focused on the water quality of cage culture site, inflow and outflow of the reservoir (Ling *et al*., 2012b; Ling *et al*., 2013a; Paka *et al*., 2009). However, there is a lack of study about the sediment quality and the suitability of water quality for future new aquacultures in Batang Ai Reservoir. Therefore, the objectives of this study were to determine water quality at three different depths and sediment quality of future cage culture sites, an abandoned cage culture and confluence of Batang Ai River and Engkari River as well as to classify water quality of Batang Ai Reservoir according to the Water Quality Index and National Water Quality Standards of Malaysia, and trophic state based on Trophic State Index.

2.0 Literature Review

2.1 Background of Study Area

Batang Ai Hydroelectric dam, the first dam in Sarawak, Malaysia was completely constructed in 1985 (CIWR, 2008). In 1993, aquaculture and fisheries industry had been introduced to the reservoir by Department of Agriculture (Ling *et al*., 2012b; Ling *et al*., 2013a; Nyanti *et al*., 2012) in order to meet the high demand for fish protein (FAO, 2014; Ling *et al*., 2012b; Nyanti *et al*., 2012).

2.2 Water Quality Analysis

Water quality can be measured based on various parameters which are *in-situ* parameters and *ex-situ* parameters (Gasim *et al.,* 2006; Islam *et al.*, 2012). According to Department of Environment [DOE] (2010), Water Quality Index is used to classify water quality of the river. Besides, the health of the water body can be classified based on Trophic State Index (Devi Prasad & Siddaraju, 2012; United States Environmental Protection Agency [USEPA], 2012c).

2.2.1 *In-situ* Parameters

In-situ water quality parameters such as temperature, pH, dissolved oxygen, electrical conductivity, turbidity and transparency are widely measured as these parameters could change physically, chemically or biologically during transport (Bartram *et al*., 1996).

2.2.1.1 Temperature

Temperature of water influences the rates of metabolism and physiological response of the aquatic biota as well as chemical rates, biochemical rates, and biogeochemical reaction in the reservoir (Wurbs, 1996). Temperature is measured throughout the depth of the water in order to understand the biological and chemical processes in the water bodies (Chapman & Kimstach, 1996). Ling *et al*. (2012b) reported the temperature of water at Batang Ai Hydroelectric Reservoir decreased as the depth increased. Said *et al*. (2004) stated that cold water could hold more oxygen. A range of 27.5 °C to 31.2 °C was obtained by Ling *et al*. (2013a) in Batang Ai Reservoir.

2.2.1.2 pH

pH affects biological and chemical processes in the water body and all water supply as well as treatment processes, therefore, it is a vital variable in the assessment of water quality (Chapman & Kimstach, 1996). Ling *et al*. (2012b) and Nyanti *et al.* (2012) stated that pH of Batang Ai Hydroelectric Reservoir decreased as the depth of water increased in the site where aquaculture was nearby. The water of cage culture sites in Batang Ai Reservoir was acidic with mean pH value of 6.42 and 6.97 at depth of 20 m and 0.2 m respectively (Nyanti *et al*., 2012). Ling *et al*. (2010a) stated that high nutrients contributed from the anthropogenic activities lead to growth of algae and thus higher pH value.

2.2.1.3 Dissolved Oxygen

Dissolved oxygen (DO) is important to the aquatic life and natural processes (Gordon & Higgins, 2007). The concentration of dissolved oxygen of the reservoir water influences aquatic biota in their respiration system and the physiological responses (Wurbs, 1996). Furthermore, the quantity and rate of chemical and biochemical nutrients release from the sediment into the water column are affected by the DO (Wurbs, 1996). Ling *et al*. (2012b) reported DO of Batang Ai Hydroelectric Reservoir decreased as depth of water increased and recorded a range of 2.95 mg/L to 6.4 mg/L at three different depths. In addition, higher

DO at the confluence of the two rivers in Batang Ai Reservoir was due to higher oxygenated water input from the upstream of the river (Ling *et al*., 2013a).

2.2.1.4 Electrical Conductivity

Chapman and Kimstach (1996) stated that measurement of the electrical conductivity (EC) is useful to manage temporal variations in total dissolved solids and major ions in rivers. Generally, EC increased as the water gets deeper. It was shown that the dissolved solids concentration increased due to excess feeds and wastes contributed by fishes (Boyd, 2004). Gassama *et al*. (2012) reported high EC in Bicaz Reservoir, Romania which was ranged from 151-338 μS/cm due to large organic loaded from the river. Nyanti *et al.* (2012) reported a range of 33-89 μS/cm EC in Batang Ai Reservoir. There was significantly higher conductivity at cage culture and depth of 20 m in Batang Ai Reservoir (Ling *et al*., 2013a; Nyanti *et al*., 2012).

2.2.1.5 Turbidity

Turbidity results from the light being scattered and absorbed by the suspended solids (Chapman & Kimstach, 1996; Wurbs, 1996). Said *et al*. (2004) stated that the habitats of aquatic organisms are damaged by high concentrations of particles. Turbidity showed significantly higher value at depth of 20 m in Batang Ai Reservoir (Nyanti *et al*., 2012). Ling *et al.* (2013a) reported the turbidity of water was increasing with depth at the station of confluence of Batang Ai River and Engkari River because of turbulence and lower chlorophyll-*a* was observed in the confluence. High turbidity level reduces the penetration of light through the water and limited the growth of aquatic plant and thus lower chlorophyll-*a* (Balali *et al*., 2013; Ling *et al*., 2013a).

2.2.1.6 Transparency

Transparency is the limit of visibility in the water (Chapman & Kimstach, 1996). In the study of Ling *et al*. (2012c), a significantly lower transparency in water was observed at the discharge station nearby a shrimp farm as a result of the suspended solids such as sediment, detritus and phytoplankton were discharged from the shrimp ponds in Selang Sibu River, Telaga Air, Sarawak (Ling *et al*., 2012c).

2.2.1.7 Depth

In a study conducted by Makela and Meybeck (1996) in Smir Reservoir, northern Morocco, 5 m to 7 m below the water surface was identified as a thermocline. In addition, there was a significant difference for pH value and concentration of DO above and below the thermocline (Makela & Meybeck, 1996). When the depth of water increased, the temperature, pH and DO were lower, while the concentration of BOD_5 and total sulfide were higher in Batang Ai Reservoir (Ling *et al*., 2012b).

2.2.2 *Ex-situ* Parameters

2.2.2.1 Five-day Biochemical Oxygen Demand

Biochemical oxygen demand (BOD) measures the amount of oxygen used up by microbes when decaying organic material in stream water (USEPA, 2012b). The greater the BOD, the more rapidly oxygen is depleted in the stream and thus less oxygen is available to aquatic life (USEPA, 2012b). Ling *et al*. (2012b) stated that the concentration of BOD_5 increased as the depth of water increased in Batang Ai Reservoir, and high BOD_5 corresponds with high temperature and low DO. Nutrients and organic matter from the fish excess feeds and waste accumulated near the bottom of cage aquaculture site resulted in high BOD_5 (Ling *et al*., 2012b). Ling *et al.* (2012b) reported the range of BOD_5 in Batang

Ai Reservoir was 3.9-8.7 mg/L. According to Chapman (1996), the standard of European Union of BOD_5 for fisheries and aquatic life ranged from 3.0-6.0 mg/L. The standard of BOD for sensitive aquatic species, and common and tolerant species in Malaysia was 1-3 mg/L and 3-6 mg/L respectively (DOE, 2010).

2.2.2.2 Chemical Oxygen Demand

Chemical oxygen demand (COD) is identified as the amount of organic and inorganic oxidisable compounds in water which is useful in water quality analysis (Water Resources Management *et al*., 2009). COD in Sampadi River, Malaysia was high near shrimp farm discharge (Ling *et al*., 2011). Nyanti *et al*. (2010) also reported high COD (about 150 mg/L) of shrimp farm harvest discharge in Telaga Air, Matang. High pollution in Pushkar Lake where the COD value ranged from 31.7-39.1 mg/L was due to the input of local drainage system and the use of soap and cleansing agent for washing and bathing (Mathur *et al*., 2007).

2.2.2.3 Total Suspended Solids

Total suspended solids (TSS) indicate the particles in water retained by a filter (American Public Health Association [APHA], 1998). Aquatic life is endangered as TSS could be attached with the toxic heavy metals. The suspended solids reduce the penetration of light into the water (Water Resources Management *et al*., 2009). Nyanti *et al*. (2012) stated that there was an insignificant difference in TSS among the depths due to the downward movement of the solid excess feeds and wastes. Ling *et al*. (2013a) reported TSS concentration in Batang Ai Reservoir ranged from 1.3-11.0 mg/L at depth of 0 m and 20 m and TSS was significantly correlated with turbidity. According to Chapman (1996), European Union standard of TSS concentration for fisheries and aquatic life is below 25 mg/L.

2.2.2.4 Chlorophyll-*a*

Determination of the presence of the photosynthetic chlorophyll pigment in aquatic algae is to evaluate the amount of algae present in the water sample (Ballance, 1996). Chlorophyll-*a* (Chl-*a*) is also a trophic index in aquatic ecosystem (Balali *et al*., 2013). Chapman and Kimstach (1996) stated that the concentration of Chl-*a* depends on the seasons, water depth or environmental conditions. Busman *et al*. (2002) stated that high levels of algae reduce clarity of water and the decomposition of algae leads to reduce the availability of dissolved oxygen. High concentration of Chl-*a* means there are high nutrients presence in water body (Chapman & Kimstach, 1996). Nyanti *et al*. (2012) reported the mean values of Chl-*a* (1.50-4.58 mg/m^3) was significantly higher at cage culture site in Batang Ai Reservoir due to nutrient from the excess feeds and wastes from fish, thus it may cause algal bloom. However, the limitation level for algal bloom is 40 mg/m^3 (Havens & Walker, 2002). Furthermore, the concentration of Chl-*a* in Batang Ai Reservoir that was obtained by Ling *et al*. (2013a) ranged from 0.38-6.02 mg/m^3 and the highest concentration of Chl-*a* showed at the depth of 10 m which was in the range of thermocline of 7 m to 11 m. There was a negative correlation between Chl-*a* and turbidity (Ling *et al*., 2013a). However, a study conducted by Balali *et al.* (2013) in Wetland, Iran stated that there was no significant correlation between Chl-*a* and turbidity.

2.2.2.5 Nitrate-nitrogen

Nitrate is an essential macronutrient in aquatic environments. It is used to determine the oxidized form of nitrogen (Davis & McCuen, 2005). Ballance (1996) stated that plants