

# Nutrient Concentration Distribution in Sediment and Overlying Water at Bukit Merah Reservoir, Perak

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**Abstract.** Bukit Merah Reservoir (BMR) is the oldest reservoir in Malaysia constructed to supply irrigation water to the Kerian Irrigation Scheme. Depletion of storage capacity due to sedimentation process is the most concerning issue of the reservoir recently. Sediment analysis is also very important when monitoring the substances that appear in the reservoir water. Environmental toxins, like heavy metals and hydrophobic organic components, as well as nutrients such as nitrogen and phosphorus are readily bond to the particulate matter. Factors in the reservoir that affect the particulate matter will aid the distribution of contaminants in the sediments. The contaminants in the sediments could have higher concentrations compared to those found in the overlying water. This means that the sediment plays an important role in the cycling of nutrients and distribution of contaminants in the ecosystem. The objectives of this research are to determine the relationship of nutrient and heavy metal content for sediment and overlying water. Nutrient profile information is provided from sediment sample analysis. Based on the data from the horizontal distribution of surface sediment phosphorus in BMR, it was apparent that the highest concentration occurred in the reservoir inlet from Sungai Kurau catchment area. Phosphorus and nitrogen in BMR have a similar trend of decreasing concentration from upstream to downstream. The phosphorus and nitrogen concentrations of surface sediment were in fact significantly correlated with phosphorus and nitrogen concentrations of surface water because of the high value of determination of correlation ( $R^2$ ). As a conclusion, the deposition of sediments was found to bring along external nutrients. Variability of phosphorus and nitrogen concentrations in the sediment directly affects the quality of water which is very important for irrigation and domestic uses.

## 1 Introduction

A reservoir is one of the key sources of water supply as it provides hydroelectric power and provides flood protection. However, reservoir storage is often affected by sedimentation due to soil erosion in the catchment area [1]. Reservoir sedimentation is a threat to the optimal use of water resources.

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Reservoir sedimentation is the process of sediment deposition that occurs after a dam construction [2]. Removal of vegetation and indiscriminate land development in the catchment area can increase the volume of stream flows. As a result of runoff from rainfall, soil particles on the surface of catchment area can be eroded and transported [3]. Erosion will decrease the soil water storage capacity and also reduce infiltration on the eroded sites. The eroded soil will then be transported along the water stream and deposited upon arriving at the reservoir. Repetition of transportation and deposition processes will result in the occurrence of reservoir sedimentation problems.

Sediment analysis is also very important when monitoring the substances that appear in the reservoir water. Environmental toxins, like heavy metals and hydrophobic organic components, as well as nutrients such as nitrogen and phosphorus are readily bond to the particulate matter. Factors in the reservoir that affect the particulate matter will aid the distribution of contaminants in the sediments. The contaminants in the sediments could have higher concentrations compared to those found in the overlying water. This means that the sediment plays an important role in the cycling of nutrients and distribution of contaminants in the ecosystem. Therefore, the objectives of this research are to determine the relationship of nutrient and heavy metal content for sediment and overlying water.

Phosphorus was chosen as it is a key nutrient. This is because phosphorus often functions as the limiting nutrient and thereby determines phytoplankton abundance [4]. Therefore, the availability of phosphorus is commonly considered as the most important factor for the overall environmental state of lakes. Iron indirectly has a strong influence on the nutrient yield in lake. This is due to the formation of compounds for example, iron hydroxids, which are important for inorganic binding of phosphorus in lake. Retention and availability of phosphorus are therefore closely linked with the capacity of iron to release or take up phosphorus.

Nitrogen is recognised to play an important role in some lake ecosystems [5]. This is true for most of the lake where nitrogen leaves the system through denitrification, while phosphorus remains [6]. However, the concentration of nitrogen is often strongly correlated with the phosphorus level, but the differentiation of impacts between these two substances may be difficult within the empirical context. However, all these sediment nutrient concentrations are high at the surface and fall to a more constant value about 20 cm below the sediment-water interface as explained by Fish and Andrew [7].

## 2 Methodology

### 2.1 Description of study area

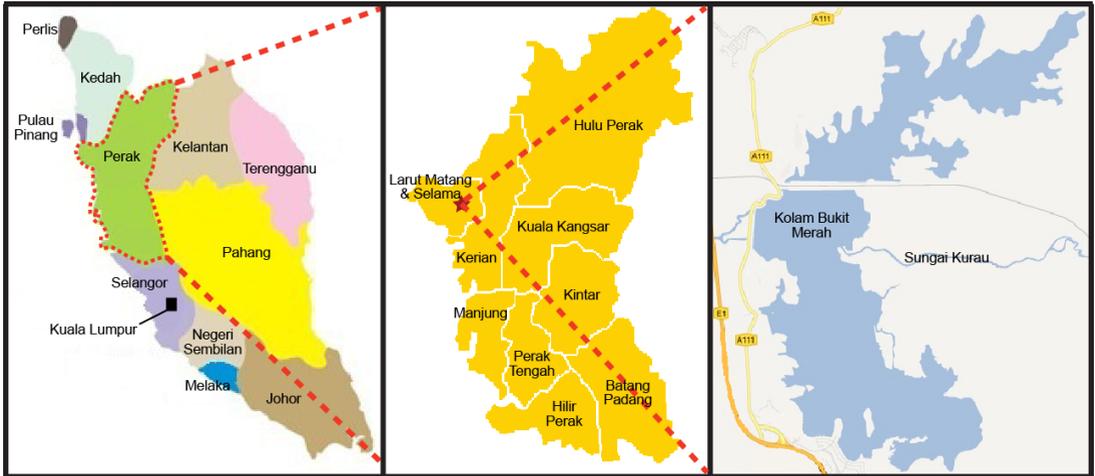
BMR is the oldest artificial lake in Malaysia. It is located at the north-western corner of Perak state in Peninsular Malaysia, which is between longitude of  $04^{\circ} 48'$  and  $05^{\circ} 13'$  and latitude  $100^{\circ} 33'$  and  $101^{\circ} 40'$ . Figure 1 shows the location of BMR. BMR was constructed in 1906 on Sungai Kurau and located at the upstream of Kerian Irrigation area in order to supply water to the Kerian Irrigation scheme.

BMR has a distinctive unique shape compared with other manmade lake. Typically, shape of the reservoir tends to be narrow and elongated as it is formed in the river valley. The current shape of BMR is in crescent shape, where width longer than the length. The measurement of BMR is about 13.88km long running from north to south direction and a width of 4.5km from east to west. Its operation level is 8.5m above sea level with a maximum depth of 5.3m. The uniqueness of this shape tends to cause different types of flow and may reduce the retention time. Due to this factor BMR was chosen as the study area for this research.

Bukit Merah dam is an earth filled embankment constructed at the upstream of Sungai Kurau and Sungai Merah confluences in 1906. As reported by Anwar (2010), the embankment level is at reference level (RL) 8.08 m above the mean sea level and it is further improved to RL 10.67 m under the 2nd Malaysian Plan (1961-1965). In 1984, under Kerian-Sg.Manik Intergrated Agricultural Development Project (IADP KSM), the embankment level was again raised to the present level of

11.28 m. At present level, water can be stored to a maximum level of RL 9.14 m to enhance the double cropping planting intensity to Kerian Irrigation Scheme.

BMR functions as an irrigation supply to the Kerian Agricultural Scheme. Approximately 10,000 farmers rely on rice cultivation industry. In addition to the irrigation supply, it also provides fresh water to meet the domestic and industrial demands of Kerian District as well as Larut Matang District.



**Figure 1.** Reservoir Location of Bukit Merah.

## 2.2 Sampling equipment

Due to difficulty of existing corer, an attempt was made to preserve the best qualities of the existing corers while reducing the overall weight and size of the device. Newly invented gravity corer using transparent acrylic tubes with 5.0cm outer diameter was used to take out the sediment cores [8]. Each of these tubes is 0.5m long. During sampling activities, the tubes were covered with stainless steel casing which is fitted snug to the tubes. It was used to avoid any damage to the tubes and samples. This casing can go up to 6.5m length (length can be adjusted according to the water depth) with attached weights of up to 5kg. It was also equipped with a serrated edge to facilitate the penetration process.

The design consists of a corer covered with casing that uses the attached weight sink into the sediment when released from the surface. From the surface, a weight then was dropped and hammered to the steel casing. The corer was hammered into the sediment as deep as possible until it could not go any further. Once the corer reaches above the water, the tube was immediately taken out from its casing and then a cork was placed at the bottom of the tube.

## 2.3 Laboratory test

### 2.3.1 Sediment digestion

The sliced core sections were digested using USEPA Method 3050B (Acid Digestion for Sediments, Sludge and Soils) for Total Phosphorus (TP) and Total Nitrogen (TN) determination. The purpose of acid digestion process was to crush and dilute the sediment. At the end of the process, it turned the sediment into liquid phase. There are three chemical solutions needed in this process which are Nitrate Acid ( $\text{HNO}_3$ ), Hydrogen Peroxide Solution ( $\text{H}_2\text{O}_2$ ) and Hydrochloric Acid (HCl).

### 2.3.2 Total phosphorus and total nitrogen

Chemical analysis was carried out according to the method outlined in the Standard Method for the Examination of Water and Wastewater [9]. Total phosphorus was determined using Method 10127 Molybdovanadate Method with Acid Persulfate Digestion while, total nitrogen was measured according to Method 10072 Persulfate Digestion Method and were tested using DR 2010 Spectrophotometer by adding certain reagents to the samples. A spectrophotometer was used to measure the amount of light transmitted or absorbed by the solutions. The detection limits for total phosphorus and total nitrogen methods were 0.0 to 100.0 mg/L  $\text{PO}_4^{3-}$  and 10.0 to 150.0 mg/L N respectively.

## 3 Results and Discussion

Analyses of total nitrogen and total phosphorus concentration for surface sediment and water samples across the reservoir are shown in Figure 2 and Figure 3 respectively.

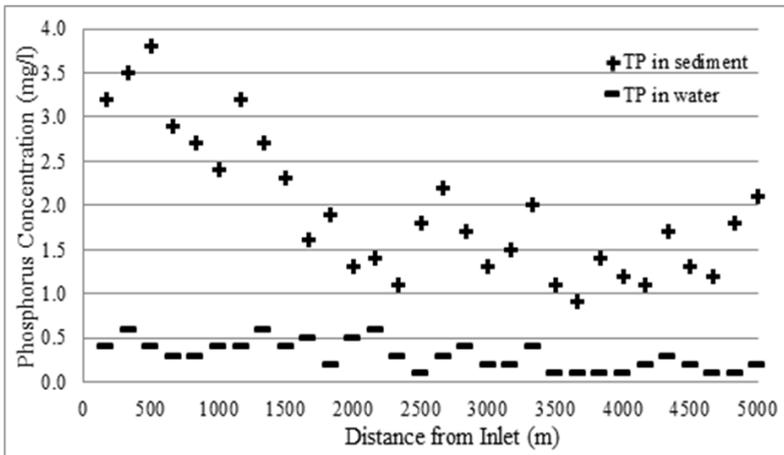


Figure 2. Total phosphorus concentration in surface sediment and water for 30 sampling points.

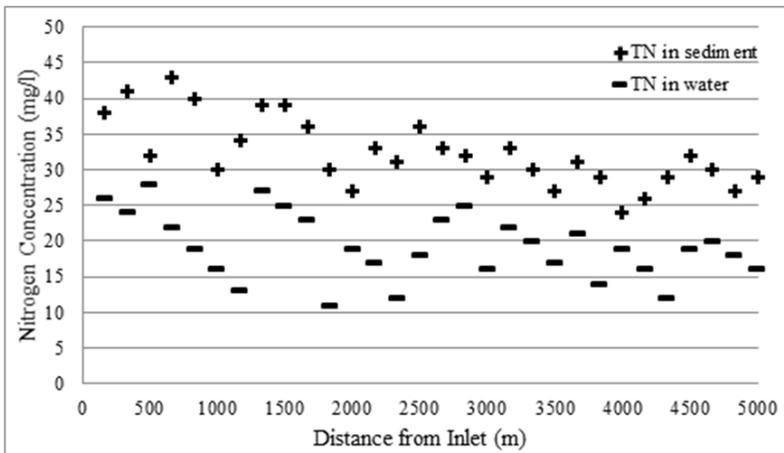


Figure 3. Total nitrogen concentration in surface sediment and water for 30 sampling points.

The nitrogen and phosphorus concentrations at surface sediment represented by the first discrete horizontal sediment sample slice (0 to 2cm) from each sediment core varied between 900 and 380 mg P kg<sup>-1</sup> and 2400 and 4300 mg N kg<sup>-1</sup> dry weight, respectively. The horizontal distribution of annual mean phosphorus and nitrogen concentrations in the surface water varied from 0.1 to 0.6 mg P l<sup>-1</sup> and 11 to 28 mg N l<sup>-1</sup>, respectively. The phosphorus relative variation across the lake tended to be higher for surface sediment than for surface water.

Phosphorus and nitrogen concentrations in both surface sediment and surface water are significantly correlated (Table 1). The sediment phosphorus were significantly correlated with surface water phosphorus ( $r = 0.517$ ,  $p < 0.003$ ,  $n = 30$ ) as well as nitrogen ( $r = 0.448$ ,  $p < 0.013$ ,  $n = 30$ ).

For the sediment, there was a clear incline of increasing nitrogen towards the outlet area of the reservoir, similar to the surface water phosphorus concentrations (Figure 2 and Figure 3). Due to that, there was high correlation coefficient between nitrogen and phosphorus concentration in surface sediment ( $r = 0.93$ ,  $p < 0.001$ ,  $n = 32$ ). The ratios of N:P in surface water is 30. This suggests P is more limiting than N for primary production in BMR. The average N:P mass ratio in water of 64.2:1 during the survey. By contrast, the N:P mass ratio in the surface sediments was only 16.6:1.

**Table 1.** Correlation coefficients of phosphorus and nitrogen in sediment and water.

	N water	P water	N sediment	P sediment
P sediment	0.448	0.517	0.648	-
N sediment	0.517	0.503	-	
P water	0.403	-		
N water	-			

**\*\*All significant at  $p < 0.05$ ;  $n = 30$**

It has been shown above that the horizontal nutrient concentration gradients can be presented in surface sediments of lakes, induced by high external nutrient loadings and often associated with elevated sediment nutrient concentrations near river mouths [10]. Therefore, it is reasonable to assume that the horizontal distributions of sediment and water variables presented in Figure 1 and 2 gave a realistic representation of the actual horizontal distributions. Based on data from the horizontal distributions of surface sediment phosphorus, it was apparent that the highest concentration occurred in the reservoir inlet from Sungai Kurau catchment area. This area has the major inflows and sources of external phosphorus entered the reservoir. The phosphorus concentrations in the surface water were also high in this area.

Nitrogen concentrations tended to be higher in sediments of BMR. However, compared with other studies, including shallow eutrophic lakes in northern Europe [11-13], New Zealand [14] and Estonia and Russia [15], phosphorus and nitrogen in sediments are still low. This may be caused by the large surface area of BMR. Trolle et al. [16] found that in large surface areas, regardless of wind direction, energy is available for mixing and resuspension. Therefore, fine organic particles, which have high phosphorus and nitrogen contents, may be resuspended most of the time, and partly mineralised in the water rather than buried in the sediments.

The average N:P ratios in the surface water were higher than the N:P ratios found in the surface sediment (Table 1). The difference between the N:P ratios of surface water and sediment suggest that up to 70% of the nitrogen that was absorbed by the sediment vanished through denitrification. During denitrification, nitrate converts to ammonium or free nitrogen (N<sub>2</sub>) that may diffuse into the water phase and the atmosphere. Thus, it is lost from the system. Furthermore, a BMR nutrient budget for year 2008 [17], reported that over 60 % and 30% of nitrate and nitrite respectively that entered the reservoir were retained and permanently buried in the sediment, while the rest are estimated to be removed via denitrification. In Denmark, Jensen et al. [18] found that nitrogen retention was indeed

caused by denitrification. Akinbile et al. [19] also did a study on addition to the analysis of phosphorus and nitrogen contents of the sediment in BMR and found out that the water was slightly polluted (Class III according to Malaysia Water Quality Index) at the highest concentration of nitrogen and phosphorus. And it decreases to Class I when the concentration decrease.

Phosphorus and nitrogen in BMR have a similar trend of decreasing concentration from upstream to downstream. Figure 4 and Figure 5 show the percentage of total nitrogen and total phosphorus reductions in both surface sediment and water, respectively. The phosphorus and nitrogen concentrations of surface sediment were in fact significantly correlated with phosphorus and nitrogen concentrations of surface water because of the high value of determination of correlation ( $R^2$ ). Previous study by Trolle et al. [16], showed that the nutrient concentrations of surface sediment were generally not significantly correlated with lake water quality (represented by surface water concentrations of phosphorus and nitrogen). However, this study shows otherwise.

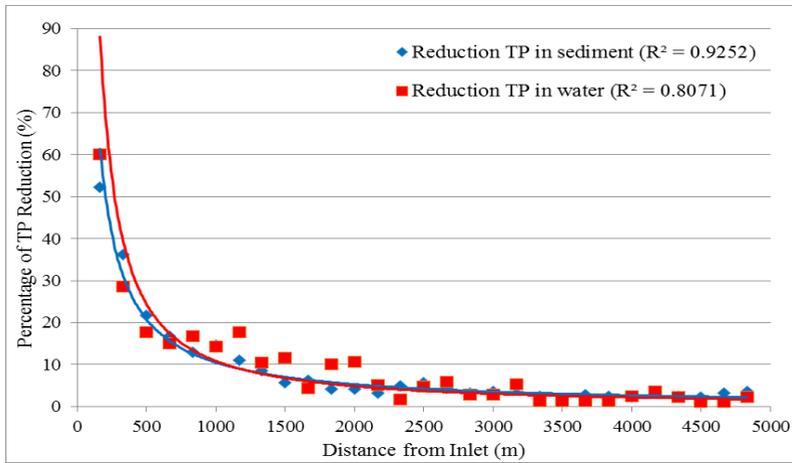


Figure 4. Relationship between phosphorus concentration in water and sediment with distance from inlet.

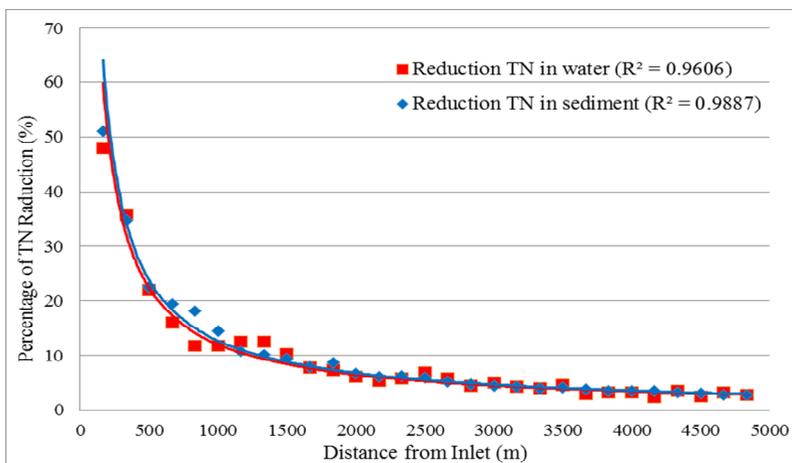


Figure 5. Relationship between nitrogen concentration in water and sediment with distance from inlet.

## 4 Conclusion

Interrelations between spatial variability in phosphorus and nitrogen concentrations of water and sediment were examined for 30 different sampling locations in Bukit Merah reservoir. Noticeable horizontal phosphorus and nitrogen concentrations in water have been shown to occur. It is apparent that the highest concentrations occurred in the reservoir inlet from Sungai Kurau catchment area. However, phosphorus and nitrogen concentration in surface sediment gave higher magnitude than the concentration in water. The phosphorus and nitrogen concentrations of surface sediment were in fact significantly correlated with phosphorus and nitrogen concentrations of surface water because of the high value of determination of correlation ( $R^2$ ). As a conclusion, the deposition of sediments was found to bring along external nutrients. Variability of phosphorus and nitrogen concentrations in the sediment directly affects the quality of water which is very important for irrigation and domestic uses..

## References

- [1] S.H.A. Talib, M.S. Yusoff and Z.A. Hasan, Modeling of sedimentation pattern in Bukit Merah Reservoir, Perak, Malaysia, *Procedia Engineering*, **50**, 201-210, (2012).
- [2] G.L. Mamede, Reservoir sedimentation in dryland catchments: Modelling and management, Doctoral Thesis, Universitätsbibliothek, (2008).
- [3] W. Saenyi and H. Holzmann, An integrated approach of water erosion, sediment transport, and reservoir sedimentation, *ERB and Northern European FRIEND Project 5 Conf.*, Slovakia, (2002).
- [4] P.J. Dillon and F.H. Rigler, The phosphorus-chlorophyll relationship in lakes, *Limnol. Oceanogr.*, **19**(5), 767-773, (1974).
- [5] S.C. Maberly, L. King, M.M. Dent, R.I. Jones and C.E. Gibson,. Nutrient limitation of phytoplankton and periphyton growth in upland lakes, *Freshwater Biology*, **47**(11), 2136-2152. (2002).
- [6] W. Ripl, *Restoration of Eutrophic Lakes by Sediment Treatment, Restoration of Lakes, Streams, Floodplains and Bogs in Europe*, Springer, Netherlands, 77-84, (2010).
- [7] G.R. Fish and I.A. Andrew, Nitrogen and phosphorus in the sediments of Lake Rotorua, New Zealand *J. of Marine and Freshwater Research*, **14**(2), 121-128, (1980).
- [8] S.H.A. Talib, Sedimentation modelling and nutrient profile at Bukit Merah Reservoir, Perak, Malaysia. PhD Thesis, Universiti Sains Malaysia, Penang, (2014).
- [9] APHA, Standard Methods for the Examination of Water and Wastewater, American Public Health Association, Washington, (2012).
- [10] B. Qin, Z. Liu and K. Havens, *Eutrophication of Shallow Lakes with Special Reference to Lake Taihu, China*, Springer, Netherlands, (2007).
- [11] L. Håkanson, On the relationship between lake trophic level and lake sediments, *Water Research*, **18**(3), 303-314, (1984).
- [12] E. Jeppesen, M. Sändergaard, N. Mazzeo, M. Meerhoff, C. Branco, V. Huszar and F. Scasso, Lake restoration and biomanipulation in temperate lakes: relevance for subtropical and tropical lakes, *Restoration and Management of Tropical Eutrophic Lakes*, 331-349, (2005).
- [13] G.A. Weyhenmeyer, E. Jeppesen, R. Adrian, L. Arvola, T. Blenckner, T. Jankowski, E. Jennings, P. Nöges, T. Nöges and D. Straile, Nitrate depleted conditions on the increase in shallow northern European lakes, *Limnology and Oceanography*, **52**(4), 1346-1353, (2007).
- [14] D. Hamilton, and S. Mitchell, Waves induced shear stresses, plant nutrients and chlorophyll in seven shallow lakes, *Freshwater Biology*, **38**, 159-168, (2003).
- [15] T. Nöges, A. Järvet, A. Kisand, R. Laugaste, E. Loigu, B. Skakalski and P. Nöges, Reaction of large and shallow lakes Peipsi and Võrtsjärv to the changes of nutrient loading, *Shallow Lakes in a Changing World*, Springer, Netherlands, 253-264, (2007).
- [16] D. Trolle, G. Zhu, D. Hamilton, L. Luo, C. McBride and L. Zhang, The influence of water quality and sediment geochemistry on the horizontal and vertical distribution of phosphorus and nitrogen in sediments of a large, shallow lake, *Hydrobiologia*, **627**, 31-44. (2009).

- [17] W.R. Ismail and S.A.M. Najib, Sediment and nutrients balance of Bukit Merah Reservoir, Perak, Malaysia, *Lakes and Reservoirs: Research and Management*, **16**, 179-184, (2011).
- [18] J.P. Jensen, E. Jeppesen, P. Kristensen, P.B. Christensen and M. Søndergaard, Nitrogen loss and denitrification as studied in relation to reductions in nitrogen loading in a shallow, hypertrophic lake (Lake Sølbygård, Denmark). *Internationale Revue der gesamten Hydrobiologie und Hydrographie*, **77**, 29-42. (2007).
- [19] C.O. Akinbile, M.S. Yusoff, S.H. Abu Talib, Z. Abu Hasan, W.R. Ismail and U. Sansudin, Qualitative analysis and classification of surface water in Bukit Merah Reservoir in Malaysia, *Water Science and Technology Water Supply*, **13**(4), 1138-1145, (2013).