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Effects of Thermal Stratification on the Concentration of Iron and Manganese in a Tropical Water Supply Reservoir

(Kesan Perlintapan Haba ke atas Kepekatan Ferum dan Mangan di dalam Takungan Air Bekalan Tropika)

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ABSTRACT

Thermal stratification in lakes is an important natural process that can have a significant effect on the water resource quality. The potential changes in chemical contents in water resulting from stratification are the production of ammonia, sulphides and algal nutrients and the increasing concentrations of iron and manganese. One of the water supply reservoirs located in Johor, Malaysia facing with high iron and manganese concentrations associated with the period of stratifications. This study showed that the level of thermal stratification in the reservoir varied at different time of the year. During the strongest period of stratification, the dissolved oxygen content was found to diminish significantly with depth and iron and manganese were recorded at the highest concentrations. Although significant period of rainfalls contributed to the natural destratification of reservoir, lower concentrations of iron and manganese only remained for a shorter period before the concentrations continued to increase with the onset of the thermal stratification. A good understanding on the behaviour of the reservoir may help to identify several measures for the improvement of water quality.

Keywords: Iron; manganese; thermal stratification; water quality

ABSTRAK

Perlintapan haba yang berlaku di dalam tasik merupakan suatu proses semula jadi yang memainkan peranan penting terhadap kualiti air bekalan. Antara perubahan kimia yang berlaku di dalam air hasil daripada perlintapan haba adalah penghasilan ammonia, ion sulfida dan nutrisi alga serta peningkatan kepekatan ferum dan mangan. Sebuah tasik takungan tropika yang membekalkan air mentah kepada loji air minuman di Johor, Malaysia menghadapi masalah kepekatan ferum dan mangan yang tinggi disebabkan oleh perlintapan yang berlaku. Kajian ini menunjukkan tahap kewujudan perlintapan haba dalam tasik takungan tropika berubah-ubah sepanjang tahun. Pada tahap perlintapan haba yang tinggi, kandungan oksigen terlarut berkurangan mengikut kedalaman tasik menyebabkan kepekatan yang tinggi bagi ferum dan mangan. Walaupun musim hujan mempengaruhi penyahlintapan haba secara semula jadi di dalam tasik, bacaan kepekatan ferum dan mangan yang rendah hanya mampu bertahan dalam tempoh masa yang pendek dan akan kembali meningkat apabila perlintapan berlaku semula. Pemahaman yang baik terhadap keadaan tasik takungan tropika ini dapat digunakan untuk mengenalpasti beberapa kaedah yang boleh diambil bagi tujuan peningkatan kualiti air.

Kata kunci: Ferum; kualiti air; mangan; perlintapan haba

INTRODUCTION

Thermal stratification caused by solar heating plays a major role in determining water quality in reservoir. In tropical countries, lakes and impoundments will stratify during the drier season as a result of increasing temperature differences between warm upper (epilimnion) and cold lower (hypolimnion) layers of water (Lukatelich et al. 1991). With insufficient wind action which in turn decreases the extent of mixing between these two layers will result in significant dissolved oxygen reduction in the hypolimnion. For a water supply system, this anaerobic condition creates a chemical reducing environment which allows iron, manganese and other minerals and nutrients normally bound in the bottom sediments to go into solution, which then results in treatment difficulties (Wetzel 1983; Zaw & Chiswell 1999).

In this study, the existence of thermal stratification process in a tropical water supply reservoir was monitored for over 13-month. The concentration of iron and manganese throughout the water column were determined. The effects of thermal stratification on the water quality in the reservoir were appraised.

MATERIALS AND METHODS

The study area is a water supply reservoir located about 40 km north-east of Johor Bahru, in the state of Johor, Malaysia (Figure 1). The reservoir has a surface area of 6 km^2, with a maximum depth of 16 m. The capacity of the reservoir is 40 Mm^3 with a catchment area of 30 km^2. The residence time of the water in the reservoir is 6 months and it receives an average inflow of 60,000 m^3/day from another smaller reservoir (named as LOL Reservoir) as well as runoff from the catchment area which is estimated at 2.7 m/yr. Water from Sg. Johor is also pumped into the reservoir when needed to maintain the water level above 11 m in the reservoir.

Four water sampling sites were chosen randomly in the reservoir. Sites 1 and 2 are situated in the deeper section with depths of 16.5 m and 15.9 m, respectively at maximum storage capacity (elevation of 26.60 m). Sites 3 and 4 are situated some distance from the intake tower and are shallower than the first two sites with 10.5 m and 10.3 m, respectively. Site 3 is situated the closest to the primary tributary of reservoir whereas the tributary upstream of Site 4 is significantly smaller.

The water quality monitoring was conducted on a weekly basis for a 13-month period. *In-situ* monitoring for temperature and dissolved oxygen concentrations were measured at every 1.0 m depth, using YSI600 XL. Water samples for iron and manganese analysis were taken from the surface, middle and at the bottom layers (0.5 m above the sediment) using Hydro-Bios Water Sampler. Both metals were analysed following procedures in Standard Methods for the Examination of Water and Waste Water (APHA 1998). *On-site* monitoring for turbidity was conducted using a portable turbidimeter (HACH 2100P). As soon as the water sampler was brought to the surface, a sub sample was collected and analysed.

Results and Discussion

Reservoir Hydrology

A monthly summary of the rainfall event and water transfer from Sg. Johor and LOL Reservoir is presented in Figure 2. Rainfall occurred throughout the study period. The months of October to December represented the wettest period (monsoon season) of the year while March to July was considered to be the drier period. In total, 3218 mm fell was recorded during the study period, equivalent to 7.5 mm a day. The highest rainfall event was recorded in late July (142 mm fell in 48 h).

A total of 26.9 Mm^3 were transferred from Sg. Johor to the reservoir during the study period. Off-peak pumping was carried out between 10 pm and 8 am for the months of August to October as well as March. Continuous pumping was conducted during the months of November to February. There was no significant transfer undertaken from Sg. Johor during the remainder of the study period.

Temperature

Temperature variation on the surface and bottom waters at Sites 1 and 2 is shown in Figure 3. It is apparent that the behaviour of these two deeper sites in the reservoir was relatively uniform with respect to temperature. Although the vertical temperature variation was typically around 2°C, compared to the temperate climate reservoir which was about more than 6°C, thermal stratification does exhibit in the reservoir (Lawson & Anderson 2007).

Generally, thermal stratification in the reservoir tends to be permanent throughout the study period except during monsoon seasons. The strongest period of stratification occurred between March and July, as the bottom water temperature was initially at a minimum when the surface layer warms rapidly due to the increased solar radiation incident on the reservoir. Comparatively warmer water inflows into reservoir induced in establishing temperature difference between the surface and bottom water (Palancar et al. 2006).

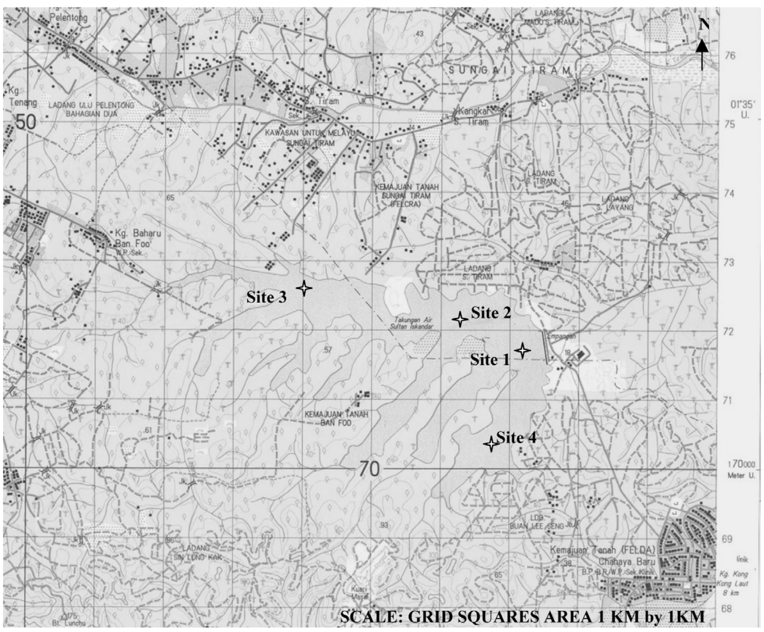

FIGURE 1. The sampling location of study area

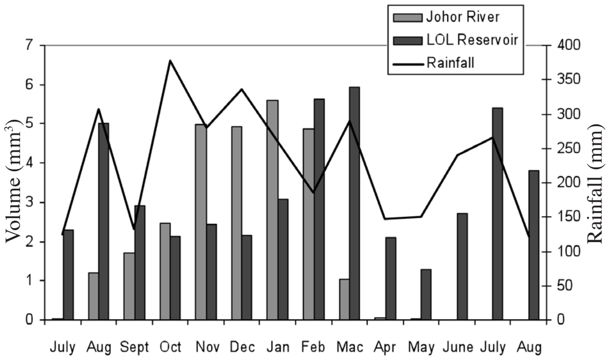

FIGURE 2. Rainfall and volume of water transferred to the reservoir during the study period

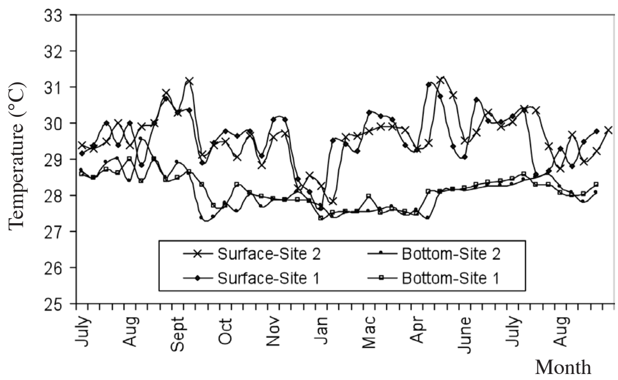

FIGURE 3. Data set from Sites 1 and 2 for surface and bottom water temperatures

An equivalent surface and bottom layer water temperatures were observed when the reservoir was naturally destratified in January and February. This period occurred primarily as a result of the monsoon seasons that fell between October and December. Significant large rainfall event recorded in late July which resulted in complete mixing of the water column. It is apparent that rainfall, while in total contributing less than the inter-basin transfers, has a comparatively more significant impact on the behaviour of the reservoir.

Further comparisons of the data from two shallower Sites 3 and 4 with Sites 1 and 2 indicate that there is greater variability in the temperature of the water column at Sites 3 and 4. This would in part be due to the shallow nature of these two sites. Pronounced stratification occurs between April and July at Sites 3 and 4, closely mimicking the two deeper sites. In addition, there is a period of relatively complete mixing that occurs in February, again, as already shown for deeper sites.

DISSOLVED OXYGEN

Figure 4 shows data collected in April that indicate a typical dissolved oxygen profile during a period of stratification while the data in February indicate the period of strong mixing within the reservoir. Once stratification became established the hypolimnion deoxygenated. The upper part of the dissolved oxygen gradient remained closely associated with thermocline layer (at 4.5 – 5.5 m) throughout the stratification period. As the thermal stratification in the reservoir reached a maximum (about 2°C), the difference in dissolved oxygen between the surface and bottom also reached a maximum, approximately 7 mg/L.

The increase partial mixing due to the natural destratification subsequently results in higher dissolved oxygen concentration in the bottom water. Obviously, a uniform dissolved oxygen (about 6 mg/L) through the entire water column was observed when mixing process occur in the reservoir (Figure 4). However, the bottom dissolved oxygen was completely depleted within two weeks of the onset of thermal stratification.

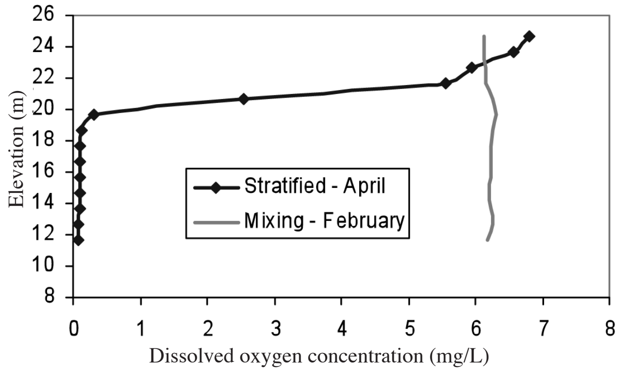

FIGURE 4. Typical dissolved oxygen concentration in water column during period of stratification and strong mixing

TURBIDITY

The turbidity of the study reservoir was low throughout the monitoring period, as can be expected for an impounded water body. Table 1 presents a summary of the turbidity data for the reservoir. It can be seen that the average turbidity for the surface of the reservoir was lower than for the bottom layer and exhibits less variation. The period of the monsoon (October to December) has been addressed separately in Table 1 for the bottom layer of the reservoir. It is evident that the average turbidity was higher in the bottom during the monsoon period. In particular, there was a significant increase in turbidity with a corresponding increase in variability at Site 3. This is due to the proximity of the site to the main tributary of the reservoir-rapid inflows resulting from rainfall events would induce elevated turbidity levels in the upper reaches of the reservoir. That the surface turbidity was consistently lower than the bottom indicates that rapid inflow events are typically entering, and moving through, the reservoir at depth rather than at the surface.

IRON AND MANGANESE

Iron and manganese concentrations were related to the dissolved oxygen characteristics of the reservoir. During

TABLE 1. Turbidity measurements from the reservoir

Location	Average turbidity for study period (NTU)	σ	Average turbidity for monsoon period (Oct – Dec) (NTU)	σ
Site 1 surface	2.9	0.8	-	-
Site 2 surface	2.9	0.7	-	-
Site 3 surface	3.6	0.8	-	-
Site 4 surface	2.9	0.7	-	-
Site 1 bottom	5.4	3.8	8.9	4.3
Site 2 bottom	8.0	7.2	12.4	5.5
Site 3 bottom	10.2	8.5	18.5	12.8
Site 4 bottom	4.8	3.0	5.5	2.3

σ = standard deviation

stratification, the development of the thermocline layer prevents the circulation of oxygen from the epilimnion to the hypolimnion layer. The decreasing dissolved oxygen concentration induces an anoxic condition and thus, deteriorates the quality of the bottom water.

The iron and manganese concentrations at Site 2 were found to increase significantly with depth, as indicated in Figure 5(a) and 5(b). During the strongest stratification period (between March and July), the total iron and manganese in the bottom water increased to the highest concentration of approximately 13 mg/L and 0.11 mg/L. More than 90% of the total concentrations of iron and manganese were dominated by the dissolved constituents.

As the monsoon results in complete mixing of the reservoir between January and February, the iron and manganese concentrations within the water column reduced to less than 1 mg/L and 0.02 mg/L. An immediate impact of heavy rainfall event on the metals can be observed by the decrease in total iron and manganese concentrations to approximately 5 mg/L and 0.04 mg/L in July. However, the oxidation rate of manganese was much slower as compared to the dissolved iron during this period. This is indicated in Figure 5(b) where only 64% of the total manganese concentrations in July were dominated by the dissolved manganese. Thermodynamically, manganese acquires higher oxidation condition as compared to iron (Davidson 1993). Although this rainfall event is able to reduce the metals concentration in the reservoir, this lower concentrations only remained for about two days. The iron and manganese concentrations in the reservoir continue to increase with the onset of the thermal stratification.

The metal concentration in the water column of shallower Sites 3 and 4 behave quite similarly as Site 2 except for certain periods. Figure 6(a) and 6(b) reveal the total iron and manganese concentrations on the surface and bottom, including the dissolved concentration in the bottom water for Site 3. The large

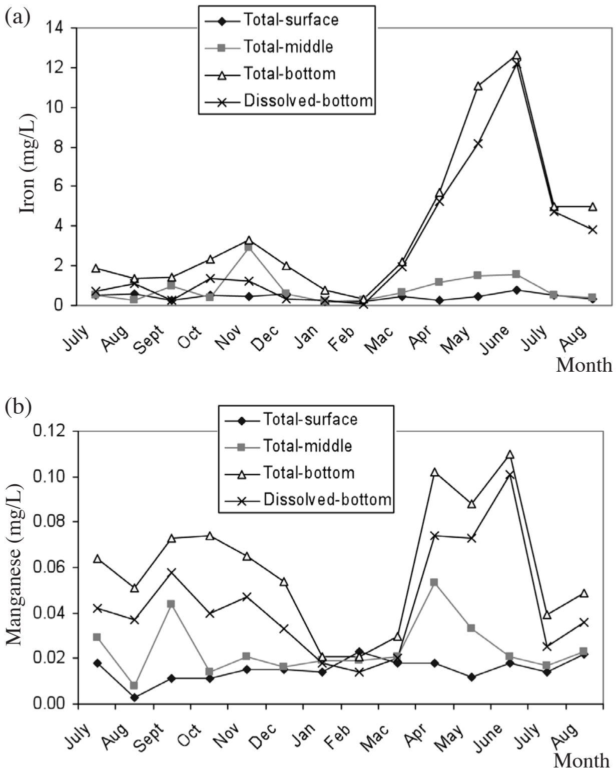

FIGURE 5. (a) Iron; (b) Manganese concentrations at Site 2 (surface-0.5 m from surface, middle-4.5 m from surface, bottom-0.5 m from bottom)

increase of the iron and manganese concentration in the bottom water was observed during the strongest period of stratification between March to June. More than 50 % of total iron and 80 % of total manganese in the bottom water consist of the dissolved components. Iron and manganese within the water column decreased to less than 1 mg/L and 0.02 mg/L during mixing period. The impact of monsoon season event and together with the rapid inflow from the tributaries results in significant differences in the metals distribution within the water column of Site 3 as compared to the deeper sites.

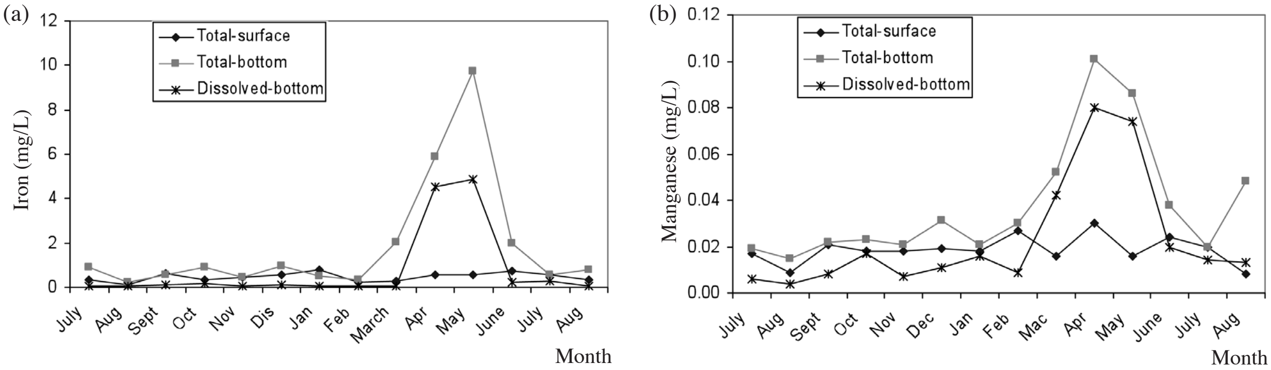

FIGURE 6. (a) Iron and (b) manganese concentrations at Site 3 (surface-0.5 m from surface, bottom-0.5 m from bottom)

CONCLUSION

The reservoir did experience thermal stratification and the level of stratification varied at different time of the year. During the strongest stratification period between March and July, the dissolved oxygen concentration was found to diminish significantly with depth, thus creating the anaerobic condition in the hypolimnion layer. An elevated concentrations of total iron and manganese were found in the bottom water with most of the total concentrations were dominated by the dissolved forms. The monsoon season and intense rainfall events play a significant role in the natural destratification of the reservoir. The dissolved oxygen concentration in the bottom water was increased resulting in the decreasing of iron and manganese to the lower concentrations. However, this condition only remained for a shorter period of time and the concentration continued to increase with the onset of the thermal stratification.

Since the problem of high iron and manganese concentrations is related to oxygen depletion in the water column, one of the option that could be taken is by implementing artificial destratification using diffused air aeration system in the reservoir. By mixing the entire water column, the occurrence of thermal stratification can be prevented. Once the dissolved oxygen remains at high concentrations, the precipitation rate of dissolved iron and manganese in the reservoir will increase thus improved the raw water supply quality substantially.

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REFERENCES

American Public Health Association 1998. *Standard Methods for the Examination of Water and Waste Water*. 15th Edition. Washington D.C.: APHA-AWWA-WPCF.

Davidson, W. 1993. Iron and manganese in lakes. *Earth Science Reviews* 34(2): 119-163.

Lawson, R. & Anderson, M.A. 2007. Stratification and mixing in Lake Elsinore, California: An assessment of axial flow pumps for improving water quality in a shallow eutrophic lake. *Water Research* 41(19): 4457-4467.

Lukatelich, R., Robertson, D., Boland, K., Imberger, J. & Patterson, J. 1999. Stratification, mixing and water quality in Darwin water supply reservoir, *Urban Water Research Association of Australia* 34: 1-60.

Palancar, M.C., Aragon, J.M., Sanchez, F. & Gil, R. 2006. Effects on warm water inflows on the dispersion of pollutant in small reservoir. *Journal of Environmental Management* 81(3): 210-222.

Wetzel, R. 1983. *Limnology*. Philadelphia: Saunders College Publishing.

Zaw, M. & Chiswell, B. 1999. Iron and manganese dynamics in lake water. *Water Research* 33(8): 1900-1910.

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