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Gurminder Kaur Sardool Singh
Malaysia-Japan International Institute of Techoology, Universiti Teknologi Malaysia

Perumal Kuppan
Marine Biotechnology Laboratory, Institute of Bioscience, Universiti Putra Malaysia

Goto, Masafumi
Kajima Technical Research Institute

Sugiura, Norio
Graduate School of Life and Environmental Sciences, University of Tsukuba

他

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Gurminder Kaur Sardool Singh[*1], Perumal Kuppan[*2], Masafumi Goto[*3], Norio Sugiura[*4], Megat Johari Megat Mohd Noor[*1], Zaini Ujang[*5]

[*1]Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia
[*2]Marine Biotechnolgy Laboratory, Institute of Bioscience, Universiti Putra Malaysia
[*3]Kajima Technical Research Institute, Japan
[*4]Graduate School of Life and Environmental Sciences, University of Tsukuba, Japan
[*5]Vice-Chancellor, Universiti Teknologi Malaysia

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This study is on physical water quality data with regards to algal bloom occurrence in a shallow eutrophic reservoir in Malaysia. Some of the important physical parameters emphasized for future remedial studies for the Semberong Dam, a tropical reservoir, are dissolved oxygen, temperature and light intensity. The use of *Planktothrix* culture as a dominant algae or a mixed culture with a spike of this dominant algae is suggested for remedial study. Other influencing factors for consideration are food-web interaction such as influence of macrophytes; metereological mainly climatic features, wind-flows and rainfall; as well as hydrological factors such as water inflows, lake size and depth, catchment area apart from human and agricultural activities effecting algal bloom formation.

1. Introduction

Reservoirs and lakes worldwide suffer from eutrophication and algal blooms such as *Microcystis*, *Planktothrix*[1)], known to pose lethal effects in humans and animals[2)] apart from water quality, ecosystem and infrastructural damage.

The very rapidly progressing eutrophication in the last twenty-five years needs to be addressed moreover in the tropical regions where eutrophication is bound to take place all year around[3)]. The causes and consequences of eutrophication and algal bloom, though approximately same in temperate and tropical lakes and reservoirs, vary in terms of temperature changes, diversity, seasonality and succession of species[3)]. For this reason, remediation technologies introduced in temperate regions may not be easily applicable to tropical regions, thus creating the need to develop appropriate technology for tropical countries.

However, in order to study and develop remedial strategies, it is crucial to understand and identify the influencing or driving factors of algal communities. It is noticed that these are recurrently being researched[4)] furthermore in tropical regions where such information is still scarce[5)].

A local paper highlighted that the research gaps in lake and reservoir management research in Malaysia include physical characteristics, patterns of stratification, lake water balance and residence time, nutrient retention and development of effective control measures some of which may be revealed through this research[6)].

Research on algal blooms in tropical reservoirs are very limited and existing remediation techniques such as aeration have only been successful in destratifying and reducing the level of manganese and iron as well improving level of dissolved oxygen in the hypolimnion zone[7,8,9)]. An aeration research in Sg Terip reservoir, located in Negeri Sembilan, Malaysia could not reduce the level of chlorophyll-a, an indicator of algal density, and its concentration was still high at the depth of 3 m depth.

The authors are for this reason motivated to study a shallow eutrophic reservoir to identify the physical characteristics with algal type and density to develop appropriate remedial strategies.

2. Influencing factors for remediation

2.1 Thermal stratification and climatic zone

Research has proven that in the tropical reservoirs, stratification occur throughout the year unlike in the temperate region where stratification occurs mainly in summer[10)]. Countries in the tropical regions do not have four seasons, they are warm throughout the year and overturn does not occur in these lakes. However the level of stratification in tropical region is low as constant heat warms up the surface of the reservoirs[11)].

Tropical zones closer to equatorial have low wind effects leading to year round stratification. Since stratification influences the mixing depth (the epilimnion); the epilimnion depth would not change much unless during rain and strong winds which will temporarily destratify and increase the epilimnion depth[11)].

2.2 Dissolved Oxygen (DO)

Dissolved oxygen is influenced by various factors such as supply of oxygen through algal photosynthesis; sources obtained from inflow; re-aeration at water surface; uptake of oxygen through respiration of algae,

bacteria, macrophytes and fish; nitrification to nitrate and nitrite; and decomposition by detritus and dissolved organic matter[11,12].

Oxygen is also taken up or consumed by sediments at the bottom of the lake or reservoir. Sediment Oxygen Demand (SOD) by organic sediments influence nutrient releases. When SOD is zero or when DO value in above a minimal value, release of nutrient mainly inorganic carbon, phosphate, ammonium and silica do not occur. Oxygen levels are thus of high importance to reservoir as well as its processes with regards to living species, decay, SOD, nitrification and release of nutrients from sediments to water[13].

2.3 Light transmission and intensities

Light is important limiting factor as long as nutrients are available[14]. Local study by Arumugam and Furtado[15] on Subang Lake showed the effects of light attenuation, photosynthetic activity is limited to upper layers whereas deeper layers decomposition activity is dominant. In this study algae mostly found up to 3 m depth with some species abundant 6 m depth.

As cyanobacteria blooms often develop in eutrophic lakes, it was originally assumed that they required high phosphorus and nitrogen concentration. However their ability to grow at higher rates in low light intensities enabled them to often develop blooms in nutrient-rich eutrophic waters. At 1 m depth diatoms grew faster than cyanobacteria, whereas at 2 m growth rate was found to be the same for all types of algal genera; however at 3 m only cyanobacteria grew at very low intensities[14]. This means that cyanobacteria does not require very high intensities of light to grow, dim light is sufficient.

3. Study site and methodology

3.1 Description of the reservoir

The research area (Fig 1) in this research is Semberong reservoir, located at latitudes 1°59'53.504N - 2°03'59.184N and longitudes 103°11'28.409E – 103°16'40.651E in Kluang, Johor, Malaysia[16]. The reservoir surface area is 8.5 km^2, it has a capacity of 18 million m^3 with a catchment area of 130 km^2 and dam height of 11m[17]. It serves as a water supply reservoir providing water to the Semberong Barat population. This reservoir is surrounded by agricultural lands and animal husbandry as pollutant sources and there is no buffer zone between these and the water body[16,17].

3.2 Climate information

Malaysia is a tropical country, windflow is generally light but with some uniform periodic patterns. The southwest monsoon season occurs later half of May or early June till September and the windflow is below 15 knots, meanwhile northeast monsoon from November to March brings a flow of 10 to 20 knots. However during the intermonsoon seasons, the winds are generally light and variable with the equatorial trough lying over Malaysia at this time.

The monthly rainfall patterns of the Peninsula Malaysia with the exception of the southwest coastal area has two periods of maximum rainfall that is in October to November and April to May. In between this, the rainfall is minimum. Sunshine and solar radiation are abundant as Malaysia is close to equator, averagely there is six hours of sunshine per day. Rate of evaporation is affected by cloudiness and temperature and when its cloudy there is less sunshine resulting in lesser solar radiation and lower temperature. The rainy months have lower evaporation while the drier months higher [18]. This part of Johor where the Semberong reservoir is located is from one the driest zones in the country (Fig 2). A study on rainfall statistics between 1975 – 2004 shows Semberong area has among the lowest annual rainfall that is 2131.92 mm[19].

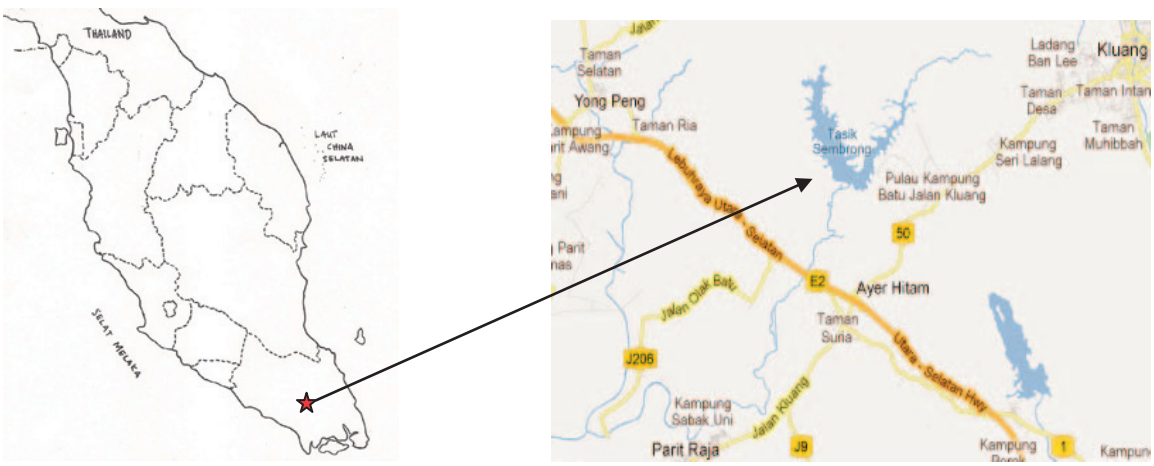


Fig. 1 Semberong Dam location in Johor, Malaysia.

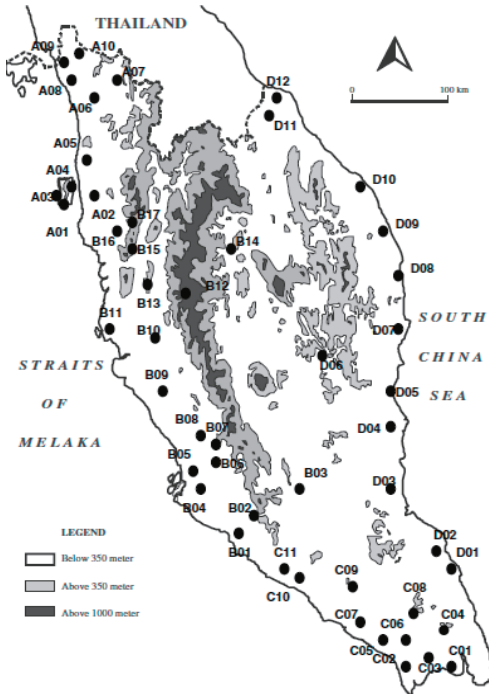


Fig. 2 Daily rainfall data for 50 stations over a duration of 30 years (1975-2004)[19].

3.3 Water sampling and methods

Investigation of algal genera with measurements of physicochemical parameters at various depth and zones was conducted. Six sampling points (Fig 3) were selected including one point at an upstream river and five points at the reservoir. *In-situ* parameters measured were pH, temperature, dissolved oxygen, conductivity, Total Dissolved Solids (TDS) and Oxidation-Reduction Potential (ORP) using Horiba multiparameter checker. Secchi depth measurments was taken using Secchi disc, however in the upcoming measurements, photosynthetically active radiation (PAR) will be identified to obtain actual light transmission and attenuation along the depth. One liter water was sampled and preserved with Lugol's solution followed by sedimentation to concentrate the algae for identification and enumeration. Water was also sampled for chemical parameters mainly nitrate (NO_3), total nitrogen (TN), ammonia (NH_3), phosphorus (PO_4), silica, chemical oxygen demand (COD) and total organic carbon (TOC), iron (Fe) and zinc (Zn), however this data is not used in this study. This paper will only describe the physical water profile along with spatial algal bloom distribution for research on development of algal bloom remediation technology.

4. Results and discussion

Water quality results of July 2012 show the changes in the curve for almost all physical parameters temperature, pH, DO, conductivity, TDS, turbidity and ORP occur at a depth of 0.1 - 0.3 m (Fig 4 and 5). These changes are suspected to be caused by the abundance of algal bloom at this depth.

4.1 Thermal stratification

Physical measurements from this study demonstrated that the vertical profile of temperature of the reservoir from surface (0.3-0.5 m) to 1.5 m depth is 28.1 - 31.7 °C which means there is a weak stratification in this reservoir. These findings are similar to previous studies (Table 1) despite some limitations disabling the capture of measurements up to the bottom hypolimnion layer. Sahoo and Luketina reported that thermal stratification of tropical reservoir ranged 0.5 - 5 °C and does not exceed 15 and 25 °C for any semi-tropical and temperate reservoirs respectively[20]. At the time the water was sampled, winds are expected to be low < 15 knots (7.7 m/s)[18] and rainfall also low around 2 mm with a water level of 8.77 m based on readings from the Drainage and Irrigation Department's monitoring station close to the reservoir intake[17]. As wind-flow is low and rainfall is minimal, mixing will be less and stratification will most likely persist in this situation.

4.2 DO, pH and ORP variations

A minimum of 4.01 and maximum of 9.98 mg/l DO was obtained in this profile. DO at surface seems higher than layers below, could be the result of photosynthesis of algae versus its respiration similar to the finding in another local paper[15]. Meanwhile the surface water temperature is low when the DO is higher. On the other hand at the deeper layers of the reservoir, temperatures increase as DO reduces. DO is lowest for point 2 where the colour of the water was greenest and with ruminant farming possibly the cause of this reduced oxygen. Quality of water in general can be categorized based on its DO levels. At the surface, water at point 3, 4, 5 and 6 is of good water quality (above 8.0 mg/l) except point 2 which is slightly to moderately polluted (4.5 – 8.0 mg/l). However for deeper layers, point 4 is of good quality, point 5 slightly polluted, point 3 and 6 moderately polluted whereas point 2 moderate to heavily polluted. Point 2 and 3 is where animal husbandry is the main pollutant source. Water quality at point 6 is crucial as this water is taken up the water treatment plant for drinking water.

At points 4, 5 and 6 the DO and algae are both of the highest values which is possibly due to the photosynthesis of algae. Meanwhile other studies describe the reduction in oxygen levels mainly at the bottom during blooms occur as a result of algae having short life and the fact that decomposition consumes oxygen levels[11]. We will need more data up to the bottom of the reservoir to identify the lowest level of DO in the deeper layers of the reservoir.

The ORP is positive, this means that this part of the reservoir sampled is aerobic and this is usually the case in daylight, however in the night, we would expect ORP values to change from positive to negative readings[21].

pH value is ranged between a minimum of 5.17 and maximum of 8.28, it seems to have an acceptable value for natural waters, however it is slightly acidic for point

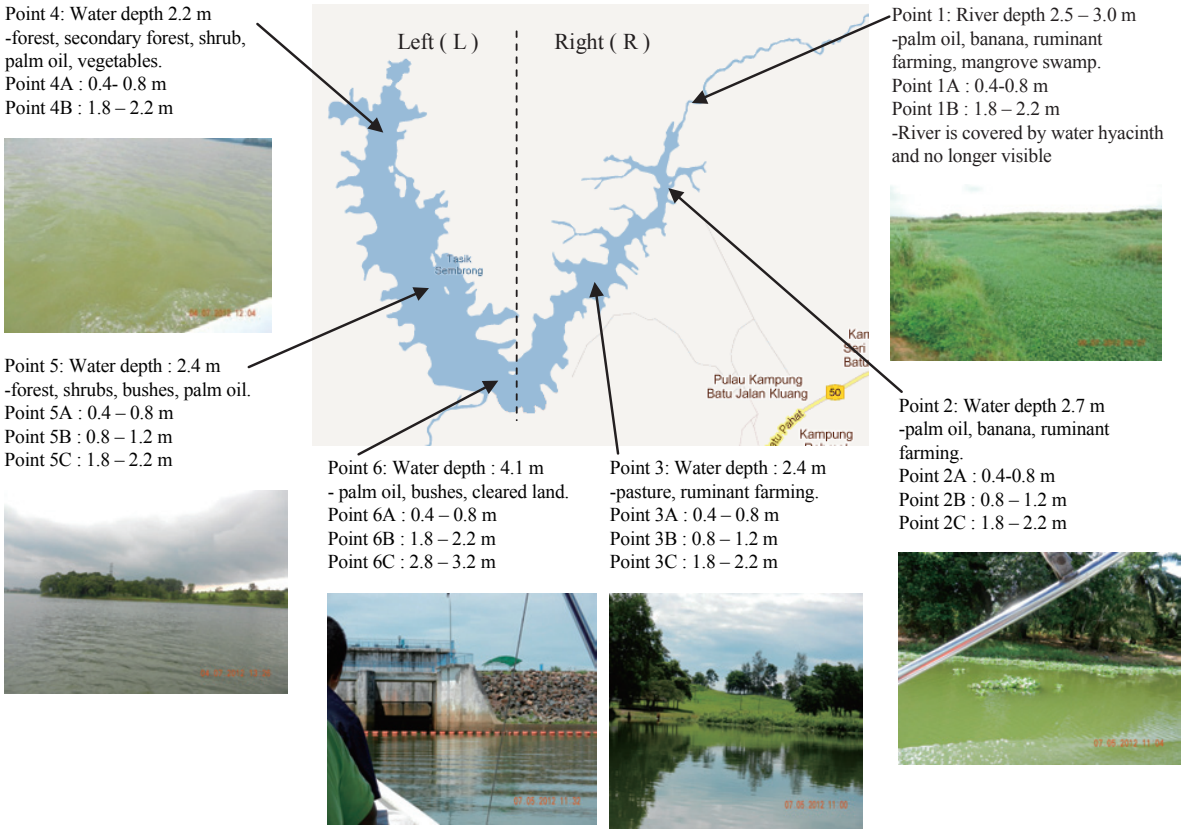


Fig. 3 Sampling stations at Semberong Dam.

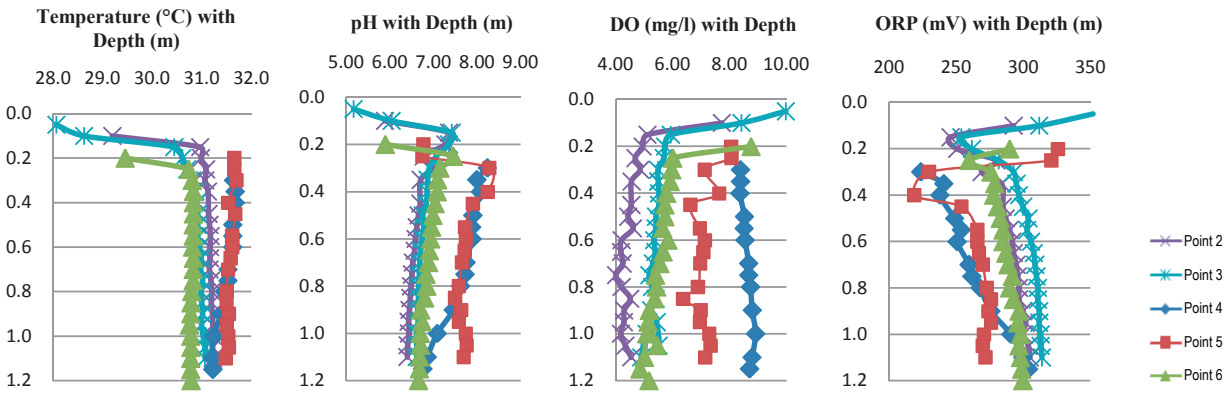


Fig. 4 Physical data for Semberong Dam.

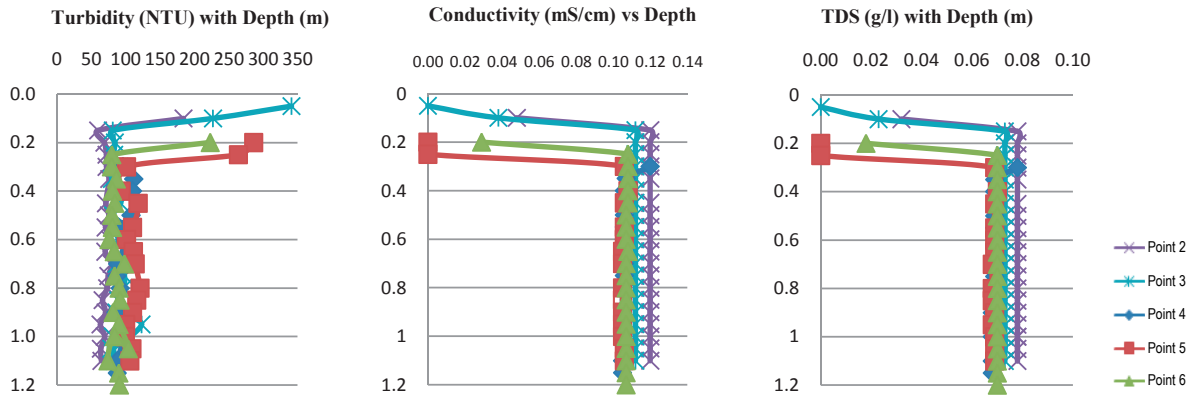


Fig. 5 Turbidity, conductivity and TDS data for Semberong Dam.

Table 1 Stratification profile for Malaysian and Singaporean lakes/reservoirs

Reservoir (depth)	Maximum depth	Temperature (bottom)	Temperature (surface)	Temperature gradient	Reference
Semberong, Kluang, Johor, Malaysia	11 m	32 °C (0.3 – 1.2 m depth)	28 °C (0.1 – 0.3 m depth)	3 – 4 °C	This study 2012
Kenyir Lake, Terengganu, Malaysia	145 m	30 °C (10 m depth)	31 °C (0.5 m depth)	1 – 2 °C	A.Rouf, S.M.Phang and M.Ambak (2010)[22]
Tasik Biru, Sarawak, Malaysia	70 m	27 °C (70 m depth)	33 °C (0 m depth)	5 – 6 °C	S.A.Sari, Z.Ujang and U.K.Ahmad (2006)[23]
Sg Terip Reservoir, Malaysia	40 m	-	-	2 – 4 °C	M.A.Kassim, M.I.Mohd Said and N.Carlo (1998)[24]
Upper Pierce Reservoir, Singapore	22 m	27 °C (18 m depth)	31 °C (0 m depth)	3 – 4 °C	G.B.Sahoo and D.Luketina (2006)[11]
Upper Pierce Reservoir, Singapore	22 m	26 °C	32 °C	6 °C	S.L.Yang, K.N. Tiew and C.T.Chan (1993)[25]
Bedok Reservoir, Singapore	18 m	-	-	0 – 4 °C	S.L.Yang (1992)[10]

3 could be resulting from more pollutants as this is the point where animal husbandry exist. Surface waters are slightly more acidic than the deeper layers, probably as a result of the incoming pollutants close to the surface. Unlike in the day, where oxygen is produced through photosynthesis to raise pH values, pH would expect to be lower at night as a result of no photosynthesis and production of carbon dioxide (CO_2).

In water quality modelling, dissolved oxygen is regarded as the single parameter to provide a state of a water system, in conjunction with phytoplankton; and is prefered to temperature or salinity for hydrodynamic calibration of model such as CE-QUAL-W2. Reasons for this are DO has gradients at different locations in the water bodies then either temperature or salinity, also it is more dynamic as it easily changes with windflows[13].

4.3 Light and transparency

Secchi depth reduced from 0.8 m in May to 0.2 m in July indicating the shift to drier season where the depth at which light was transmitted water reduced. This means euphotic depth is 1.6 m in May but increasing to 0.4 m in July. This euphotic depth is derived from the equation where euphotic depth is two times the Secchi depth[26].

This reservoir had a turbidity of 50 – 350 with higher turbidity at the surface layer than bottom layers. This coincides with low levels of TDS and conductivity (Fig 5) which means there are less anions and cations present at the surface and very low or no salinity.

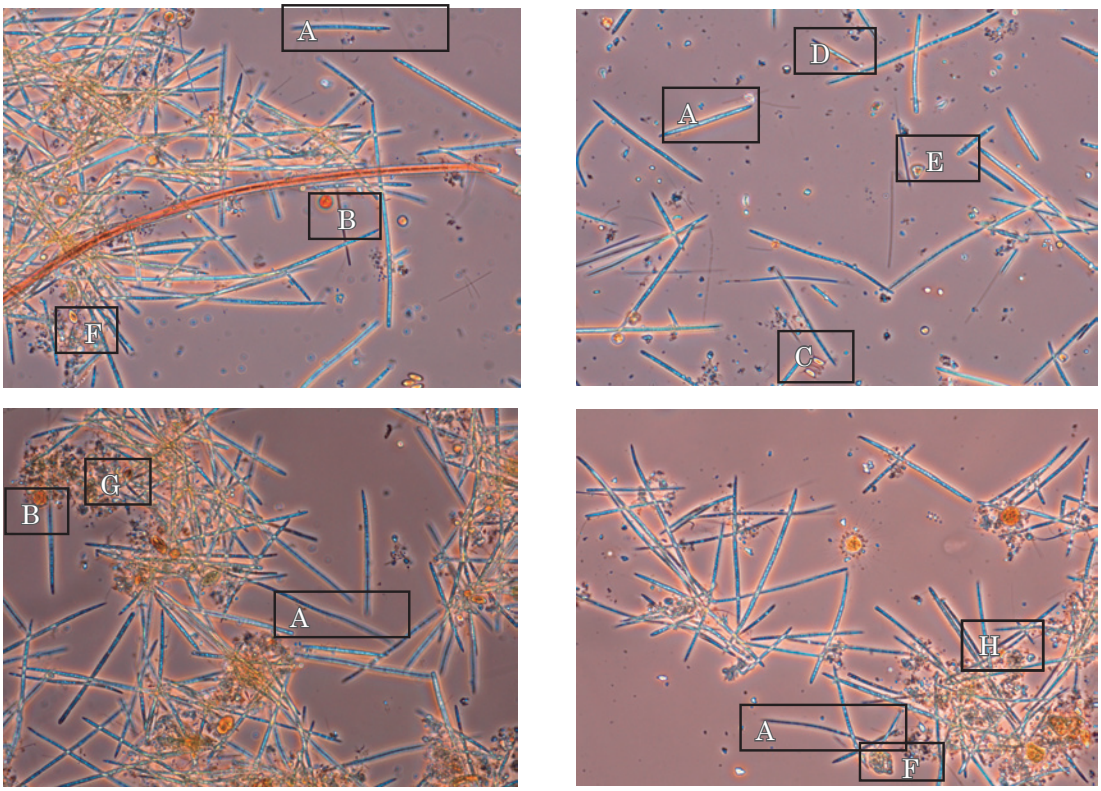
Tendency of cyanobacteria blooms are still high or in fact higher in turbid waters as they survive in dim light unlike other forms of algae such as green algae and euglenophyta[14]. Thus the reduced light transmission during drier season, in fact raises our concern. Remediation strategies designed in the laboratory will have to consider not only the concentrations of cyanobacteria during dim light conditions but the layer at which they reside as a result from their motility or buoyancy. The use of a PAR sensor to accurately provide the attenuation of light transmission throughout the water body is proposed. This could enable the discovery of a specific relationship or equation between Secchi depth and euphotic depth perhaps including other factors for reservoirs and lakes in the tropical regions.

4.4 Algal identification and density

According to identification performed using phase-constrast microscope, five types of algae were found, cyanophyta, clorophyta, euglenophyta, chrysophyta and pyrrophyta. The dominant species observed in all reservoir samples was *Planktothrix*, pictures of some algal genera are shown in Fig 6. The term cyanophyta is used interchangeably with cyanobacteria.

Algal density in the reservoir was found to be very high at a maximum of 66000 cells/ml compared to the river which had a maximum of 140 cells/ml. The density obtained in this study for cyanobacteria is within a minimum and a maximum of 20000 and 65000 cells/ml respectively (Fig 7). It was noted that there is a higher density of cyanophyta in the left wing of the reservoir than the right wing. This fluctuation is believed to be concurrent with influence of nutrients such as nitrogen and phosphorus as other research has shown[14,27]. It was found that total algae concentrations were most sensitive to changes in phosphates in temperate reservoir and nitrates for the tropical reservoir[27]. However more information on these nutrient levels is required to conclude the relationship between algal density and nutrient factors for remediation purpose.

There is a decrease of algal density for point 6A where waters from left wing of reservoir (L) point 5A and right wing of reservoir (R) point 3A possibly meet. It is possible that the addition of carp fish may have led to the decrease of algal density at point 6A of the reservoir.



Planktothrix **(A)**, *Trachelomonas* **(B)**, *Scenedesmus* **(C)**, *diatom* **(D)**, *Tetraedron* **(E)**, *euglenoids* **(F)**, *Selenastrum* **(G)**, *Staurastrum* **(H)**

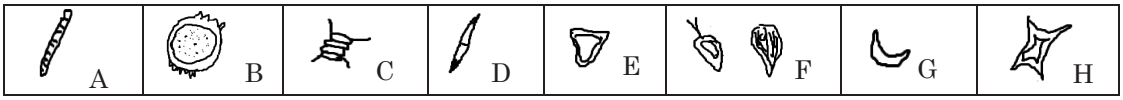
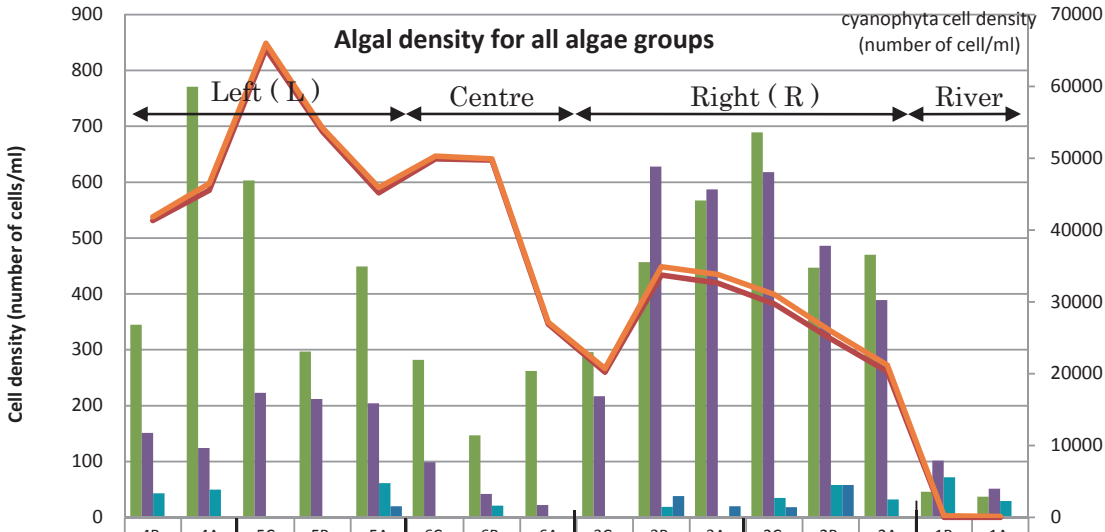


Fig. 6 Algae genera for sample point 2 under 40 x magnification showing *Planktothrix* as dominant genera.



	4B	4A	5C	5B	5A	6C	6B	6A	3C	3B	3A	2C	2B	2A	1B	1A
Chlorophyta	345	771	603	297	449	282	147	262	296	457	567	689	447	470	46	37
Euglenophyta	151	124	223	212	204	99	42	22	217	628	587	618	486	389	102	51
Chrysophyta	43	50	0	0	61	0	21	0	0	19	0	35	58	32	72	29
Pyrrophyta	0	0	0	0	20	0	0	0	0	38	20	18	58	0	1	1
Cyanophyta	41320	45513	65168	53721	45177	49890	49706	26891	20203	33733	32632	29680	24856	20308	14	17
Total algae	41859	46458	65994	54230	45911	50271	49917	27175	20716	34875	33806	31040	25905	21199	234	135

Fig. 7 Algal density for all algae groups (refer to Fig 3 for sampling points).

According to the World Health Organization Guidelines for Safe Practice in Managing Recreational Waters, the guidance level for relatively low probability of adverse health effects is 20,000 cyanobacterial cells/ml whereas moderate probability of adverse health effects is 100,000 cyanobacterial cells/ml[28]. The cyanobacteria density thus falls between the two categories of adverse health effects (Table 2). These results are of concern and to confirm if these cyanobacterial genera are toxigenic, some form of bioassay screening should be performed.

Operational alert level guide for utilities in Australia known as Management Strategies for Cyanobacteria: A Guide for Water Utilities[29] defines levels for four toxic cyanobacteria that is *Microcystis aeruginosa*, *Anabaena circinalis*, *Cylindrospermopsis raciborskii* and *Nordularia spumigena* at levels 2,000 to 12,000 depending on species.

In the United States, numerous states have formulated different public health criteria for cyanobacteria. Vermont and Oregon produced their own guide to reduce risk to recreational users when toxigenic cyanobacteria are present. If *Microcystis* or *Planktothrix* is present at ≥ 40,000 cells/mL, the guide suggests health advisories to be posted at the reservoir to alert the public, otherwise if these two species are absent then health advisories are only posted if sum of total toxigenic taxa is at ≥ 100,000 cells/mL[30].

In a research in a tropical shallow reservoir, it is seen that presence of floating macrophytes, does not allow much light transmission thus small flagellate and cyanobacteria are favoured[31]. Such studies reveal the importance of submerged or floating macrophytes on the phytoplankton community apart from the physical and nutrient parameters[29]. This has to be considered as part of the conditions in the reservoir during remedial studies.

Table 2 World Health Organization Guidelines for Safe Practice in Managing Recreational Waters[29]

Guidance Level	Health risks	Typical actions
Relatively low probability of adverse health effects - 20,000 cyanobacterial cells/ml or 10 µg chlorophyll-a/litre with dominance of cyanobacteria	• Short-term adverse health outcomes, e.g., skin irritations, gastrointestinal illness	• Post on-site risk advisory signs • Inform relevant authorities
Moderate probability of adverse health effects - 100,000 cyanobacterial cells/ml or 50 µg chlorophyll-a/litre with dominance of cyanobacteria	• Potential for long-term illness with some cyanobacterial species • Short-term adverse health outcomes, e.g., skin irritations, gastrointestinal illness	• Watch for scums or conditions conducive to scums • Discourage swimming and further investigate hazard • Post on-site risk advisory signs • Inform relevant authorities
High probability of adverse health effects - Cyanobacterial scum formation in areas where whole-body contact and/or risk of ingestion/aspiration occur	• Potential for acute poisoning • Potential for long-term illness with some cyanobacterial species • Short-term adverse health outcomes, e.g., skin irritations, gastrointestinal illness	• Immediate action to control contact with scums : possible prohibition of swimming and other water contact activities • Public health follow-up investigation • Inform public and relevant authorities

Table 3 Threshold definitions with lower threshold for 'Notification' and trigger level for 'Alert 2'; adopted from Management Strategies for Cyanobacteria : A Guide for Water Utilities (Australia)[30]

Species	Notification (Alert Level 1)	Alert (Alert Level 2)
	Cell Numbers (cells mL^{-1})	Cell Numbers (cells mL^{-1})
Microcystis aeruginosa	2,000	6,500
Anabaena circinalis	6,000	20,000
Cylindrospermopsis raciborskii	4,500	15,000
Nodularia spumigena	12,000	40,000

5. Conclusion and Recommendation

5.1 Simulation of conditions in remediation study

Based on finding of this research, and other research including a study in a tropical shallow reservoir in Brazil it was demonstrated that periodic stratification do influence the phytoplankton community[4]. Thus it is suggested to produce or simulate stratified temperature profiles in laboratory scale remedial study by use of thermocouples or heating and cooling immersion coils in the tank. The minimum temperature applied is suggested to be 18 – 25 °C to represent a cooler/rainy day with 35 – 40 °C on a warmer day based on the various stratification findings of reservoirs in Malaysia and Singapore (Table 1).

DO sink and input effects from components of the food web such as macrophytes, zooplankton and fishes may also contribute as influencing factors and could be considered during study[4]. It is recommended to simulate DO level in a range of 4.0 – 10.0 mg/L using wind effects to re-aerate waters in the laboratory scale experimental tank for better results. The consideration of floating and submerged macrophytes with regards to influence on water quality should be done as well[4,32]. Perhaps it may be beneficial to add some floating macrophytes into the experimental tank to obtain better representation on the influence on DO and nutrients. However since at the Semberong reservoir these macrophytes are removed or cleared, these could be removed from the tank to make comparison between result before and after removal.

Mixed algae culture with *Planktothrix*, a filamentous cyanobacteria, as dominant genera is suggested for this experiment. Mixture with different types of cyanobacteria is also possible as our main concern is to eliminate the dominant cyanobacteria species during remediation. Species dominance has been proven in some studies, mainly for cyanobacteria[31]. In shallow lakes and reservoirs, *Planktothrix* has been found to be dominant all year around[32].

Light source could be used to simulate sunshine along with use of filters to produce higher light and dimmer light intensities. The simulation of light will influence the layers at which the cyanobacteria move up or down during the experiment.

5.2 Other influencing factors

Lake size, volume, catchment area and residence time are known to influence algal cell concentrations. The increasing catchment area and residence time caused a significant increase in algal cell concentration in a research on subtropical reservoirs in Australia[33]. This was explained by the researchers as a result from higher nutrient loading from larger catchment area leading to higher algal densities. They concluded that thre are four basic factors expected to influence algal growth which are residence time, light availability, mixing and water depth. Thus the best remediation measure will be a mechanism to induce mixing to lower the residence time and influence turbidity and and dissolved or suspended solids that effects light availability and intensity[33]. This however varies according to water depth as well as floating macrophytes as implied by various studies, and are noteworthy factors in development of remedial measures. Climatic zone, rainfall events, wind flow, sunshine and evaporation apart from lake size and depth are important factors as well in influencing residence time and algal bloom occurrence[19,34].

As algal concentrations seem to be most sensitive to changes in phosphates for temperate lake and nitrates for tropical lake[27], the influence by nutrients will be studied in another paper. Literatures also showed that different species are influenced differently by changes in nitrogen and phosphorus concentrations[5,33]. In temperate regions, high temperatures and increases in nutrient concentration during end-summer and mid-autumn have led to decrease in green algae but increase of *Aphanocapsa* and dinoflagellates[34]. This is known as seasonal succession of phytoplankton.

The discussions in this paper open paths for future needs such as consideration of influence of nutrients, macrophytes, air temperature, water inflow and residence time for the remedial work.

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