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Toxic Cyanobacterial Blooms: A Potential Challenge for Malaysian Water Safety

Bloom Cyanobacteria: Satu Ancaman terhadap Keselamatan Sumber Air Di Malaysia

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Abstract

Eutrophication increases primary productivity in water bodies and results in an increased incidence of excessive proliferation of algal biomass, particularly cyanobacteria. To date, the occurrence of high cyanobacterial biomass, known as bloom, is considered as a major threat to the safety of world's water resources. This is due to the fact that cyanobacterial bloom could lead to serious negative impacts on public health and affect the stability of aquatic ecosystems with significant economic loss. Many cyanobacterial genera including *Microcystis*, *Planktothrix*, and *Anabaena,* produce hepatotoxic microcystins, which, if ingested, cause acute and chronicle poisoning in animals and humans. Due to their toxic characteristic, cyanobacterial bloom and the potential microcystin contamination have been seriously addressed in many countries throughout the world. To protect public health, World Health Organization (WHO) had set up provisional guideline values of 1 and 20 µg L^{-1} hepatotoxic microcystin for drinking and recreational water, respectively. In addition, some countries (e.g. Australia and Canada) have established slight variants of the guideline based upon their local requirements. However, the occurrence of toxic cyanobacteria and its risks on public health remains unclear and largely neglected in Malaysia. This is due to the fact that inadequate attention is drawn towards realizing the importance of assessing the risks of toxic cyanobacterial bloom in Malaysian water bodies. Due to the regional hot tropical climate and increasing nutrients input, it is becoming critical to address toxic cyanobacterial bloom issues in Malaysian water bodies. This paper aims to create awareness towards the potential occurrence and harms of cyanobacteria by providing an overview of toxic cyanobacterial bloom on a global scale, health risks associated with microcystin, and the importance of addressing this issue in Malaysian water bodies.

Keywords eutrophication, cyanobacterial bloom, hepatotoxic microcystin, public health, Malaysian water bodies, drinking and recreational water

Abstrak

Eutrofikasi meningkatkan produktiviti primer dalam sumber air dan menyebabkan peningkatan insiden proliferasi biojisim alga yang berlebihan, terutamanya cyanobacteria. Sehingga kini, kehadiran biojisim cyanobacteria yang tinggi, dikenali sebagai *bloom*, dianggap sebagai satu ancaman terhadap keselamatan sumber air dunia. Ini adalah disebabkan *bloom* cyanobacteria boleh membawa kepada impak negatif yang serius terhadap kesihatan awam dan memberi kesan terhadap kestabilan ekosistem akuatik dengan kerugian ekonomi yang signifikan. Pelbagai genera cyanobacteria termasuk *Microcystis*, *Planktothrix*, dan *Anabaena* yang menghasilkan microcystin hepatotoksin yang mana jika diingesi boleh menyebabkan keracunan akut dan kronik dalam haiwan dan manusia. Disebabkan ciri-ciri toksiknya, *bloom* cyanobacteria dan potensi kontaminasi microcystin telah ditangani secara serius oleh banyak negara di seluruh dunia. Untuk melindungi kesihatan awam, Pertubuhan Kesihatan Sedunia (WHO) telah menyediakan garis panduan pada nilai 1dan 20 µg L^{-1} microcystin hepatotoksin untuk air minuman dan air bagi tujuan rekreasi. Disamping itu, beberapa negara (contoh: Australia dan Kanada) telah menetapkan garis panduan dengan sedikit variasi berdasarkan keperluan tempatan. Walau bagaimanapun, kehadiran cyanobacteria toksik dan risiko ke atas kesihatan awam masih tidak jelas dan sangat diabaikan di Malaysia. Ini disebabkan oleh kekurangan perhatian terhadap kepentingan penilaian risiko *bloom* cyanobacteria toksik dalam sumber air di Malaysia. Ekoran daripada iklim tropika yang panas dan peningkatan kandungan nutrien, *bloom* cyanobacteria dalam sumber air di Malaysia menjadi satu isu yang kritikal untuk ditangani. Artikel ini bertujuan untuk mewujudkan kesedaran terhadap potensi kehadiran dan ancaman cyanobacteria dengan memberikan gambaran *bloom* cyanobacteria toksik pada skala global, risiko kesihatan yang dikaitkan dengan microcystin dan kepentingan menangani isu ini dalam sumber air di Malaysia.

Kata kunci eutrofikasi, *bloom* cyanobacteria, microcystin hepatotoksin, kesihatan awam, sumber air di Malaysia, air minuman dan air rekreasi

Background

The world population had increased significantly in the last five decades from 3 billion in 1960 to 7 billion in 2011 (World Bank, 2012). Based on the current population growth rate, the world's population is projected to increase to 8.1 billion by 2025 (Population Reference Bureau, 2012). At a national level in Malaysia, the total population in 2025 is estimated at 35 million based on the average annual population growth rate of 2% (Population Reference Bureau, 2012). The increasing human population is causing agricultural, domestic and industrial water uses to grow rapidly, both at a global and national levels (Rosegrant and Cai, 2002). At a global level, the total water withdrawals are projected to increase from 3,906 km^3 in 1995 to 4,794 km^3 in 2025. The total global water withdrawals in 2025 will represent 10% of the total renewable water resources. High amount of rainfall in Malaysia, averaging 2500 mm annually, has contributed to high total renewable water resources that is estimated at 580 km^3 (World Resources Institute, 2009). The total national water withdrawal is estimated to represents only 1.56 % of the total renewable water resources (World Resources Institute, 2009). This low percentage indicates that Malaysia is blessed with an abundant of renewable water supply.

Despite being rich in renewable water supply, Malaysia is facing a great challenge to sustain the quality of its available water resources. Rising global temperatures and changes in the hydrological cycle, along with increase in human activities (Paerl *et al*., 2011), has increased nutrient loading into water bodies and leading to deterioration in the quality of the available water resources (IPCC, 2008; Paerl *et al*., 2011). As published in Malaysia Environmental Quality Report 2010, the number of water bodies that are seriously polluted by ammoniacal nitrogen had increased significantly from 160 in 2008 to 218 in 2010 (Department of Environment, 2010) (Figure 1). The accumulation of high ammonia promotes eutrophication in water bodies. Eutrophication increases primary productivity and result in an increased incidence of excessive proliferation of algal biomass (Chorus and Bartram, 1999).

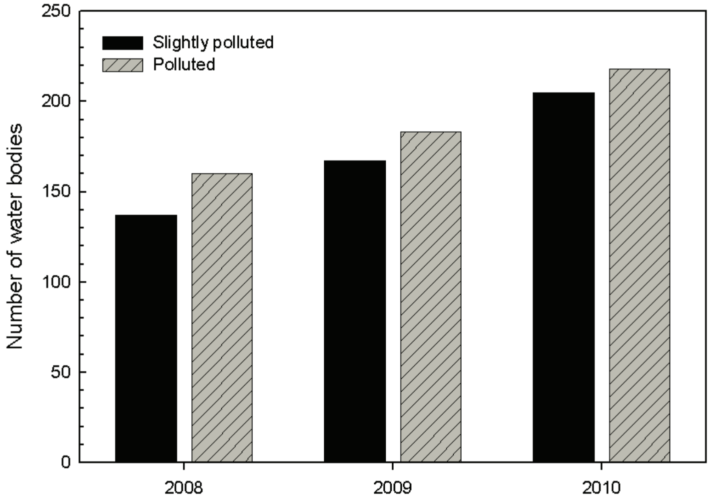

Figure 1 Malaysia river water quality trend based on ammoniacal nitrogen index (Department of Environment, 2010)

Algae bloom

The term algae refer to microscopically small, photosynthetic and unicellular organisms, which finely disperse in the water column. These organisms are commonly found in freshwater, wastewater, estuaries and oceanic environment (Chorus and Bartram, 1999). Under high nutrients loading, particularly nitrogen and phosphorus, algae can rapidly proliferate and dominate the planktonic community (Chorus and Bartram, 1999). This phenomenon is termed as bloom, where algae concentrations may reach millions of cells per milliliter. In freshwater systems, chlorophyll-a concentration above 50 $\mu g\ L^{-1}$ represents a significant algae bloom (Chorus and Bartram, 1999). Excessive algae growth in freshwater systems including lakes, drinking water reservoirs and other waterways is often associated with the dominance of cyanobacterial species (Codd, 2000).

Cyanobacterial bloom

Cyanobacteria are photosynthetic prokaryotic organisms that are also known as blue-green algae (Chorus and Bartram, 1999). This group of microorganisms contains chlorophyll-*a* and assimilates CO_2 for photosynthesis with two photosystems (Chorus and Bartam, 1999). Cyanobacteria are one of the first organisms to appear on Earth, and this was shown by evidence of numerous stromatolites that occurred from the Archean to the late Mesozoic (Altermann and Kazmierczak, 2003). The most common cyanobacteria in fresh water include *Microcystis* spp., *Cylindrospermopsis* spp., *Planktothrix* spp., *Synechococcus* spp., *Oscillatoria* spp., *Anabaena* spp., *Anabaenopsis* spp., *Lyngbya* spp., *Aphanizomenon* spp., *Nostoc* spp., and *Synechocystis* spp (Chorus and Bartram, 1999). Some of the commonly occurring cyanobacteria are shown in Figure 2.

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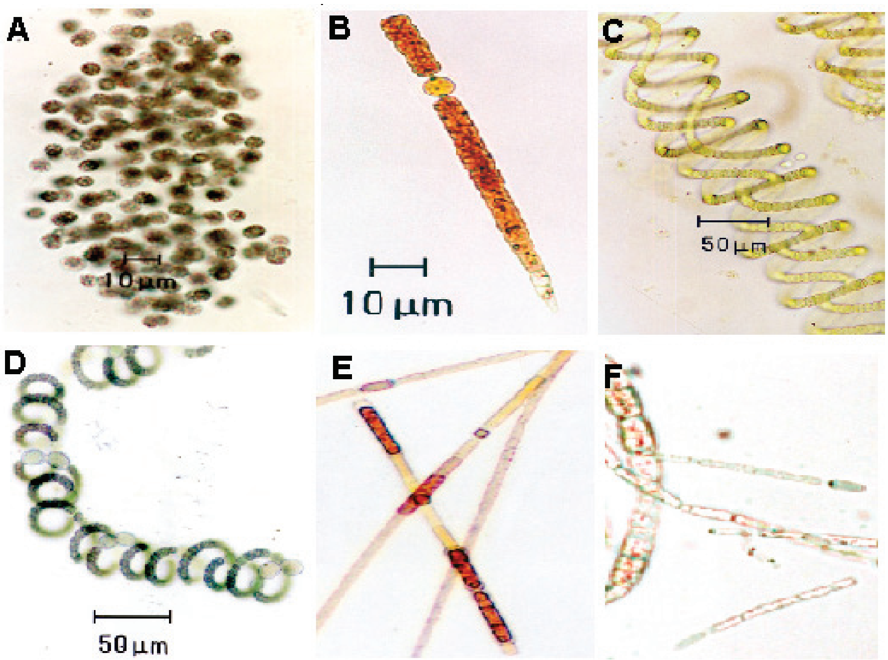

Figure 2 The most common cyanobacteria in fresh water (**A**: *Microcystis* spp.; **B** and **C**: *Anabaena* spp.; **D**: *Anabaenopsis* spp.; **E**: *Aphanizomenon* spp.; **F**: *Cylindrospermopsis* spp.)

To date, cyanobacterial blooms have become prevalent worldwide and considered as a major challenge in the management of water resources. Field surveys in Europe, North America, South America, Australia, Asia and Africa, have shown that cyanobacterial blooms can occur under a range of environmental conditions (Zurawell *et al*., 2005) (Figure 3).

Figure 3 Global occurrence of cyanobacterial blooms (modified after Zurawell *et al*., 2005)

Unlike in many developed countries, the occurrence of toxic cyanobacterial remains largely neglected in Malaysia. Based on ISI web of knowledge, CyanoNet database and Malaysian peer-reviewed journal, to date, the studies on phytoplankton in Malaysia are not specifically focusing on toxic cyanobacterial bloom and cyanobacterial toxin (Marshall *et al*., 1995; Yusoff *et al*., 1997; Lassen *et al*., 2004; Anton *et al*., 2008; Lee and Bong, 2008; Sidik *et al*., 2008). Furthermore, these studies are mostly discussing on the occurrence of harmful algal bloom in coastal areas, rather than in freshwater and drinking water reservoirs. Sudden and large amount of fish kill cases have been constantly reported in many water bodies in Malaysia. However, no cases were investigated in relation to toxic cyanobacterial bloom. This is due to the fact that inadequate attention is drawn towards realizing the importance of assessing the risks of toxic cyanobacterial bloom in Malaysian water bodies, particularly in drinking water reservoirs. Therefore, it is important to firstly understand the potential implications of toxic cyanobacterial bloom, particularly when human are at risks when exposed to this emerging problem.

Consequences of toxic cyanobacterial bloom

The excessive growth of cyanobacterial biomass may impart color, odor and tastes of water (Havens, 2007). Additionally, high cyanobacterial biomass in freshwater systems is likely to affect the structure of zooplankton community and change the stability of aquatic ecosystems (Ghadouani *et al*., 2006). Moreover, high cyanobacterial biomass, particularly when dominated by buoyant *Microcystis* spp., lead to the formation of green scum on surface of the water bodies (Figure 4). The issue of high cyanobacterial biomass is also affecting the treatment efficacy in wastewater treatment plant due to biomass accumulation in pipe and pumping delivery infrastructure (Barrington *et al*., 2011). The most important additional concern is the excessive growth of cyanobacterial biomass with its toxin contamination, which can seriously deteriorate the quality of the water resources and present health hazards to human and animal (Havens, 2007; Djediat *et al*., 2011).

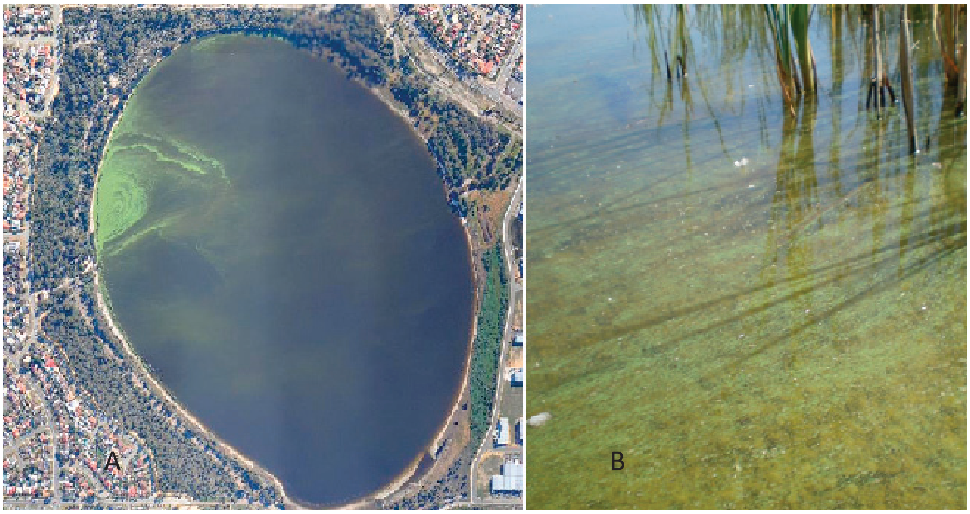

Figure 4 Satellite image (A) and photograph (B) of the excessive cyanobacterial growth in Yangebup Lake, South West Australia *(source of satellite image: www.nearmap.com; source of photograph: Sinang, S.C., 2011)*

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Health risks of toxic cyanobacterial bloom

The presence of high cyanobacterial biomass in water bodies, either used for drinking or recreational purposes, may pose serious health risks for human and animal populations. This is due to the fact that various cyanobacterial genera including *Microcystis*, *Anabaena*, *Anabaenopsis*, and *Planktothrix* are capable of producing a range of toxins including hepatotoxic microcystin, which can have lethal and sub-lethal effects in both humans and animals (Falconer, 2005). Microcystin has been previously described as "fast-death factor" (Bishop *et al*., 1959). Microcystin is potent and it is the most commonly encountered cyanobacterial toxin that is likely to pose a risk to the consumers of drinking and recreational water (Falconer and Humpage, 2005).

Humans may be exposed to cyanobacterial toxins through direct contact and ingestion of toxic cyanobacteria from drinking or recreational water (Chorus *et al*., 2000). Humans may also be exposed to cyanobacterial toxins through the consumption of contaminated shellfish (Chorus *et al*., 2000) and intravenous exposures related to medical procedures (Azevedo *et al*., 2002). In the past, scientific studies on human illness due to cyanobacterial toxins were reported in the USA, Australia, Brazil, China, and England as early as 1931 (Chorus and Bartram, 1999) (Table 1).

Table 1 Examples of early reports of human illness associated with the exposures to cyanobacterial blooms

Year	Location	Routes of exposure	Signs and symptoms	Number affected	References
1931	Ohio and Potomac rivers, USA	Drinking water	Gastrointestinal illness	5000-8000	Tisdale, 1931 as cited in Chorus *et al*., 2000
1979	Palm Island, Australia	Drinking water	Gastrointestinal illness	>100	Griffiths and Saker, 2003
1989	England	Recreational water	Pneumonia	10	Van Apeldoorn, 2007
1993	China	Drinking water	Liver cancer	202	Yu, 1995
1996	Caruaru, Brazil	Intravenous exposure (dialysis)	Acute liver failure	100 (52 deaths)	Azevedo *et al*., 2002

In the USA, a massive *Microcystis* spp. bloom in the Ohio and Potomac Rivers caused gastrointestinal illness to between 5000 and 8000 people whose drinking water was sourced from these affected rivers (Tisdale, 1931 as cited in Chorus *et al*., 2000). In 1979, a bloom of *Cylindrospermopsis raciborskii*, contaminated a drinking water reservoir in Palm Island, Australia, resulted in the serious illness of over 100 people from an Aboriginal community (Griffiths and Saker, 2003). In 1989, cases of severe pneumonia were reported in England, when army recruits were exposed to *Microcystis aeruginosa* blooms while swimming and canoeing (Van Apeldoorn *et al*., 2007). In 1993, incidences of liver cancer in China were correlated to people drinking from cyanobacterial infested surface water (Yu, 1995). In 1996, the worst recorded incidence of human fatalities from cyanobacterial toxins was reported in Caruaru, Brazil, when 100 patients developed acute liver failure, which resulted in 52 deaths after being exposed to cyanobacterial toxins during renal dialysis (Azevedo *et al*., 2002). These human exposures to cyanobacterial blooms and toxins with associated health outcomes were reported to be related to microcystin poisoning (Codd *et al*., 2005).

The importance of addressing the issue of toxic cyanobacterial bloom in Malaysian water bodies

Regional hot tropical climate promotes the occurrence of toxic cyanobacterial bloom

Current studies have proposed a range of physicochemical factors which trigger the occurrence of cyanobacterial bloom in freshwater ecosystems. Among other factors, high water temperatures are known as the basis for the presence of massive cyanobacterial biomass (Paerl and Huisman, 2008). Cyanobacterial blooms are often observed in warmer seasons (Falconer and Humpage, 2005). Temperatures exceeding 25ºC are known to provide optimum conditions for cyanobacteria to grow rapidly and dominate in water bodies through regulation of cyanobacterial photosynthetic capacity, respiration and growth rate (Robarts and Zohary, 1987). High temperatures favors the formation of high cyanobacterial biomass through the migration of biomass from sediment into the water column (Schöne *et al*., 2010), increasing stratification and reducing vertical mixing (Paerl and Huisman, 2008), and enhanced hypolimnetic phosphorus accumulation from sediment (Sondergaard *et al*., 2003). In Malaysia, annual mean temperatures range between 25 to 28ºC (Malaysian Meteorological Department, 2010). Therefore, hot tropical climate in Malaysia may trigger massive presence of cyanobacterial biomass in the majority of water bodies, and further suggesting the potential risks associated with toxic cyanobacterial bloom.

High nutrients loading into water bodies

In addition to warm water temperatures, high phosphorus and nitrogen concentrations are also assumed to be the primary triggers for massive cyanobacterial growth (Chorus and Bartram, 1999; Paerl *et al*., 2011). In Malaysia, discharges from manufacturing industries, agriculture and sewage treatment plants are known as the major water pollution sources. As published in Malaysia Environmental Quality Report 2010 (Department of Environment, 2010), 20,348 water pollution point sources were recorded, and these comprise of manufacturing industries (9,069: 44.57%), sewage treatment plants (10,025: 49.27%), animal farms (754: 3.70%) and agro-based industries (500: 2.46%).

On top of the identified pollution sources (point sources), non-point sources pollution also contribute to high nitrogen and phopshorus loading into water bodies. Non-point sources pollutions are derived from surface runoff, which the carrying capacity of pollutants depends on catchment's land use (Eisakhani *et al*., 2009). In Malaysia, excessive use of fertilizers on agricultural land has been described as the major contributor of phosphorus and nitrogen into waterways (Eisakhani *et al*., 2009). Annual total nitrogen and phosphorus loads per km^2 agricultural area is estimated as 4102 kg per year and 1211 kg per year, respectively. Furthermore, based on Malaysia land use statistic 2008 (World Bank, 2012), more than 79000 km^2 (24% of total area) was allocated for agricultural activities. Therefore, surface runoff from the total agricultural area may introduce up to 324058 tonnes nitrogen

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and 95669 tonnes phosphorus into Malaysia waterways per year (Eisakhani *et al*., 2009). Due to the vast amount of potential nutrients loading from both point and non-point sources, it is now important to realize that this condition may amplify the occurrences and severity of toxic cyanobacterial bloom in our water bodies. Further eutrophication is expected in the local bodies as changes in land use pattern are expected to sustain the future human population and food production.

The quality of water bodies used for recreational and water supply

National Hydraulics Research Institute of Malaysia has listed 90 natural and artificial lakes that are accessible for public uses (NAHRIM, 2009). Out of 90, 49 lakes were classified as eutrophic based on Carlson tropic state index. Additionally, 53 and 11 of the identified lakes are mainly utilized for water supply and recreational activities, respectively. Raw water intakes and recreational activities taking place these eutrophic water bodies may pose significant health risks if the occurrences of toxic cyanobacteria and its associated toxins are continuously being neglected.

Inadequate guideline and enforcement for cyanobacterial monitoring in Malaysian water bodies

In relation to public health protection, World Health Organization (WHO) had set up provisional guideline values of 1 and 20 $\mu g\ L^{-1}$ microcystin for drinking and recreational water, respectively (WHO 1998,2003). In Malaysia, the available guideline regarding the safe and potable water supply throughout Malaysia is based on criteria listed in national standard for drinking water quality established in year 2000. Cyanobacterial biomass is not included as a parameter that needs to be monitored in both raw and treated water. On the other hand, microcystin is listed as one of the organic substances which the maximum concentration should not exceed 1 $\mu g\ L^{-1}$ in treated water. Even so, microcystin is set to be monitored only when necessary. Therefore, there are possibilities that the occurrences of cyanobacterial biomass and microcystin have been largely unidentified as these parameters are not being monitored regularly.

Potential contamination of cyanobacterial toxin in food sources

Malaysia is producing a vast amount of fishes through aquaculture systems (Ministry of Agriculture, 2011). Previous study has reported that microcystin contamination is common in aquaculture production systems (Barros *et al*., 2010). This is due to the fact that large portion of nutrients from fish feed will be released into water column and may promote the excessive growth of algal biomass including cyanobacteria. On the other issue, irrigation of paddy field with microcystin-contaminated water could also introduce microcystin into food chain through rice consumption (Chen *et al*., 2012). Therefore, it is worth to consider the issue of toxic cyanobacterial bloom as it could pose significant health risks due to contamination of food sources by microcystin.

Steps forward

Against this background, it is important to address the issue of toxic cyanobacterial bloom in Malaysian water bodies as it poses significant health risks to human and also degrading the quality of the available water resources. The awareness on this issue is crucial to avoid significant economic loss and negative impact on public health. Therefore, more research is needed to enhance our understanding on the occurrence and dynamics of cyanobacterial bloom and its associated toxin in Malaysian water bodies.

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