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ORIGINAL PAPER

Water quality of tropical reservoir based on spatio-temporal variation in phytoplankton composition and physico-chemical analysis

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Abstract This study assessed the water quality of Mengkuang Reservoir, Penang, Malaysia, by its trophic status according to a Carlson Modified Trophic Index (CMTSI) and by its biological parameters using Shannon–Wiener diversity index (H') and saprobic index. The study conducted from August 2005 to July 2006 showed that mean values of CMTSI (nutrients), CMTSI (chlorophyll *a*) and CMTSI (Secchi depth) were 27.18 ± 8.73, 40.63 ± 7.12 and 41.74 ± 6.38, respectively. The mean values of CMTSI indicated that the reservoir was oligotrophic. Mean value of H' was 2.15 bits/individual, showing that the water quality based on H' value was in class III (slightly polluted). Saprobic index value (2.24) also revealed that the reservoir was moderately polluted (class II). The occurrence of *Anabaena*, *Microcystis*, *Oscillatoria*, *Nostoc*, *Dinobryon*, *Chroococcus*, *Staurastrum paradoxum* and *Mallomonas* which are indicators of toxic and polluted waters was also recorded. This study therefore showed the importance of phytoplankton composition and community structure as a reliable and important tool to assess the degree of pollution in Mengkuang Reservoir. Long-term assessments of biological and chemical parameters in the reservoir are necessary, and phytoplankton community structure as bioindicator provides unique information about the ecosystem. This information is potentially useful as an early warning sign of deteriorating condition and thus gives insight into the overall ecology of lakes and will assist in the future conservation and management of this lentic ecosystem.

Keywords Trophic status · Shannon–Wiener diversity index · Saprobic index · Mengkuang Reservoir · Malaysia

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Introduction

Economic development in Malaysia has increased in the recent 20 years. This development has been accompanied with more land use, increase in population urbanization, industrialization and the expansion of irrigated agriculture. The quantity and quality of water supply are affected by these factors and polluted by them (Ho 1994). Knowledge of the current status of water conditions and determination of its mechanism are prerequisites to devising a sound solution to the problem (Le et al. 2010). The increasing of population increases the demand for water, while freshwater resources are limited. Multiple reservoir uses and human activities at the watershed change the nutrient inputs that induce modifications of the reservoir's trophic status, biotic assemblages and chemical–physical conditions (Molisani et al. 2010). Therefore, it is important to protect the existing freshwater resources.

There are only two natural lakes in Malaysia, namely Tasik Chini and Tasik Bera (Ali and Lee 1995). Man-made lakes or reservoir dominates the Malaysian lentic environment. In Malaysia, there are 63 large impoundments with a total storage of 25 billion m^3, ranging in size from 10 ha (Mahang dam) to 37,000 ha (Kenyir dam). The roles of these dams are hydro-electric power generation, irrigation, drinking water supply, fisheries and recreational and tourist promotion (Ho 1994). Appropriate management and monitoring of drinking water supply is crucial. Monitoring of physico-chemical parameters is a routine water quality assessment in drinking water supply in Malaysia (Azrina et al. 2006). Chemical analysis has some inadequacy such as time, cost and technical limitations (Wu et al. 2005). Meanwhile, biological studies are able to provide continuous temporal and spatial information in water ecosystem without aforementioned limitations (Swaminathan 2003). In Malaysia, biological monitoring in water supplies normally involved total coliform count for detection of fecal pollution, while bloom of phytoplankton (eutrophication) is important as well as fecal pollution in the reservoirs. High phytoplankton density poses problems in drinking water treatment processes and recreational activities. Therefore, biomonitoring based on algal studies is necessary to provide sufficient information in water quality deterioration in reservoirs (Yap 1997; Swaminathan 2003). The advantages of employing algae in biomonitoring of aquatic environment are based on the fact that these organisms reflect the concentration of physico-chemical parameters in the water ecosystems (Zbikowski et al. 2007). Algal communities quickly reflected environmental stressors because of their short life cycles (McCormic and Cairns 1994). Therefore, changes in the algal community can reflect the occurrence of pollutants or other environmental stressors (Johnstone et al. 2006), especially nutrients, which cause dramatic increase in algae. This event led to low oxygen concentration that affects other organisms in aquatic food chain (Camargo and Alonso 2006).

Studies on water ecosystems in Malaysia have progressed in the last 30 years (Yeng 2006) through many organizations which include local universities, government departments, research centers and non-governmental organizations (Ho 1994). Stobutzki et al. (2006) reported that water quality deterioration and habitat modification in Malaysia reduced the fish production to 4–20 % of the original yields. Meor Hussain et al. (2002) studied water quality parameters and distribution of zooplankton in Chenderoh Reservoir which was built for power generation. They found that the reservoir, especially in embayment area, was at risk of eutrophication event, because some of the chemical and biological factors (chlorophyll, primary productivity and nutrients) were increased compared to earlier studies in the area.

However, a few studies have been conducted on water quality in relation to distribution and species composition of algae (Yap 1997; Wan Maznah and Mansor 2002). In many European developed countries, the algological studies and the use of this branch of science in water supply have increased (Stevenson and Smol 2003). In fact, the growth of this science in waterworks practice shows the importance of algal metabolism and algal events in relation to physico-chemical parameters and water quality (Camargo and Alonso 2006). Hence, Malaysia as a developing country needs a comprehensive and continuous biological monitoring of water supplies to predict and prevent the occurrences of water pollution and eutrophication event (Ho 1994), especially in drinking water supply. Therefore, due to the importance of Mengkuang Reservoir as a supply of drinking water in Penang State and lack of biological study in this area, this reservoir was chosen to be studied.

This paper provides the first comprehensive evaluation and scaling of the levels of the phytoplankton and physical and chemical parameters in this reservoir using various classification criteria. The research was undertaken from August 2005 to July 2006, to provide detailed information on the water quality of Mengkuang Reservoir, which was located in the northeast of Penang Island, Peninsular Malaysia, with emphasis on temporal trophic conditions in surface layer. The Shannon–Wiener diversity index (H') and saprobic index of phytoplankton were determined to test its suitability as bioindicator of reservoir ecosystem health.

Materials and methods

Study site and sample collection

This study was carried out at Mengkuang Reservoir, Penang, at the northwest of Malaysia (Fig. 1). The reservoir supplies more than 80 % of drinking water to Penang State. The catchments and surface area are 3.90 and 1.74 km^2, respectively. The maximum width from west to east is 1.21 km, and the maximum length from north to south is 2.40 km. The maximum level of water was 43.3 m above sea level. The mean depth during the study period was 17.9 m, and the maximum depth was 21.2 m near the tower. According to Buraschi et al. (2005), the study area was relatively deep. Mengkuang Reservoir receives up to 90 % of water input from Kulim River (Fig. 1). There is also one canal from Muda River which supplies only 10 percent of water to the reservoir. There is also temporal source of water from Mengkuang River into the reservoir. Input of water from this river is minor, and it is limited only during rainy seasons. This area, like other tropical regions, is characterized by high humidity and temperature, and abundant rainfall, with two dominant seasons, dry and rainy seasons. The dry season is from February to August, while the rainy season occurs from September/October to January.

In this study, the reservoir was divided into three transects from north to south with 9 sampling stations (Fig. 1).

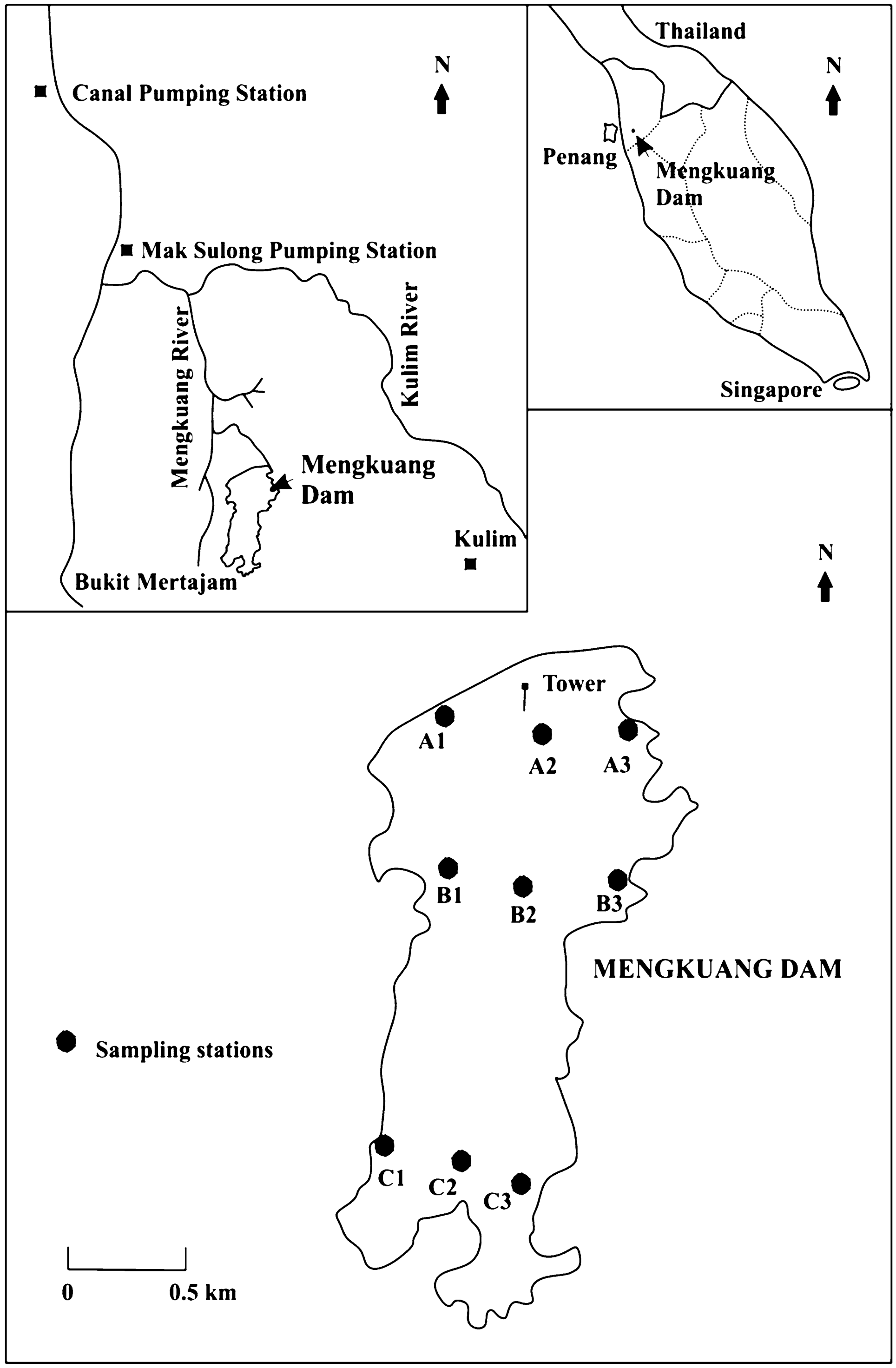


Fig. 1 Geographical position of Mengkuang Reservoir

The middle transect was located in the limnetic zone, from the tower (the place where water withdrawal occurs) to the end of the reservoir. Two other transects (littoral stations) were at the west and east of the middle transect. Three sampling stations established on the middle transect were A2, B2 and C2 (Fig. 1). Station A2 with maximum depth 21.2 m and mean depth 17.9 m was near to the tower. Station B2 located at the middle of the reservoir has maximum and mean depths of 19.0 and 17.9 m, respectively, and it is also far from fishing and other human activities and thus was served as a reference station for this study. In the south part, station C2 with the maximum and mean depths of 16.0 and 12.6 m, respectively, was the last station of limnetic zone. Stations A1, B1 and C1 were located in the west zone. Station C1 was situated near a fishing site, thus representing a station with human activity. Stations A3, B3 and C3 were located in the east zone and surrounded by corridor vegetation. The maximum depth at littoral stations was from 2 to 3.5 m.

Field samplings were carried out monthly from August 2005 to July 2006 for water quality variables and phytoplankton collection. The mean values of the variables and parameters, namely chlorophyll *a*, total phosphorus, total nitrogen and Secchi disk depth (SD), were used for the computation of the Carlson Modified Trophic State Index (CMTSI) (Sigua et al. 2006; Begliutti et al. 2007; Robertson et al. 2008: Offem et al. 2011). Chlorophyll *a* was measured according to Boyd and Tucker (1992), while in situ measurement of Secchi disk depth was taken using a standard Secchi disk (22 cm diameter) (Wetzel 1995). Unfiltered water samples were used to measure total phosphorus by the ascorbic acid method (Boyd and Tucker 1992). Total nitrogen (TN) was determined from unfiltered water samples using the reduction column and diazotization method (Boyd and Tucker 1992). Water quality classification based on CMTSI was adapted from Begliutti et al. (2007) and Molisani et al. (2010).

Phytoplankton samples were obtained by filtering four liters of water through phytoplankton net with mesh size of 35 μm. The water was prefixed in 4 % formalin and Lugol's solution for further examination in the laboratory. Microalgal enumeration was carried out by sedimentation method in a counting chamber using inverted microscope (Edler 1979; Lobban et al. 1998). Phytoplankton was identified with the help of taxonomic keys, drawings and descriptions given in Habit and Pankow (1976), Pentecost (1984), Round et al. (1990), Nygaard (1991), Salleh (1996) and Wehr and Sheath (2003). The relative numbers and percentage of each phytoplankton species per unit volume of water were calculated according to APHA (1998).

Statistical analysis

Importance species indices (ISIs) were calculated for each taxon by multiplying the percent frequency of the taxon by its average relative density. This index is preferable comparing average density since it reflects both the distribution and abundance of a taxon in the ecosystem (Rushforth and Brock 1991).

The concept of bioindicators and the specific saprobic zone of algal species were used to assess the extent of organic pollution in the reservoir and expressed in the form of biotic index. The index of saprobic condition (*S*) was calculated according to the index of saprobity suggested by Pantle and Buck (1955). The Saprobian system employs the concept of indicator species with the assumption that the presence of certain species indicates a particular set of environmental conditions. The concept defines the niche space of an organism, that is, each organism has a particular set of environmental prerequisites essential to its survival. Classification of surface water based on saprobic index (SI) values was according to Ansbaek and Valatka (2001).

Species diversity for each site was determined using Shannon–Wiener Index (H') (Shannon and Weaver 1963; Brower et al. 1998). A water quality classification based on the diversity index of phytoplankton was applied according to Wilhm and Dorris (1968), Wilhm (1970) and Kitsiou and Karydis (2000). Based on the range of H' values obtained in this study, a five-class classification system was computed to assess the water quality of the sampling stations during the study period. Pearson's correlation was performed to indicate relationships between physical and biological parameters.

Prior to analysis, environmental variables were log-transformed ($\log_{10} x$) and algal density was $\log_{10} (x + 1)$-transformed (Zar 1974; Delong and Brusven 1993; Dixon and Chiswell 1996). One-way ANOVA was used to detect statistically significant differences in environmental parameters and abundance of phytoplankton between months and sampling stations. The *t* test (independent-samples test) was used to test the difference in diatom community structure between dry and wet seasons. The principal component analysis (PCA) was used to understand the correlation structure of the collected data and identify the most important factors such as saprobic index, phytoplankton community and the environmental parameters contributing to the data structure (Padro et al. 1993). PCA is also applied to find associations between parameters so that the number of measured parameters can be reduced. The calculation of PCA in R-mode was carried out using Multivariate Statistical Package (MVSP), version 3.13d. PCA in Q-mode was carried out using SPSS.

Results and discussion

CMTSI parameters varied during the study period (Fig. 2) and were significantly different between sampling months ($P < 0.01$). There was no significant difference in the environmental parameters as well as abundance of phytoplankton among the sampling sites (ANOVA, $P > 0.05$). Table 1 shows monthly values of CMTSI at Mengkuang Reservoir during 2005–2006. Results indicated that the trophic state of the reservoir was oligotrophic during dry and wet seasons with lower CMTSI values in rainy season (Fig. 3). Indices of trophic state showed that all stations were mesotrophic based on chlorophyll *a* and Secchi disk

Fig. 2 Monthly variations in CMTSI parameters in Mengkuang Reservoir from August 2005 to July 2006

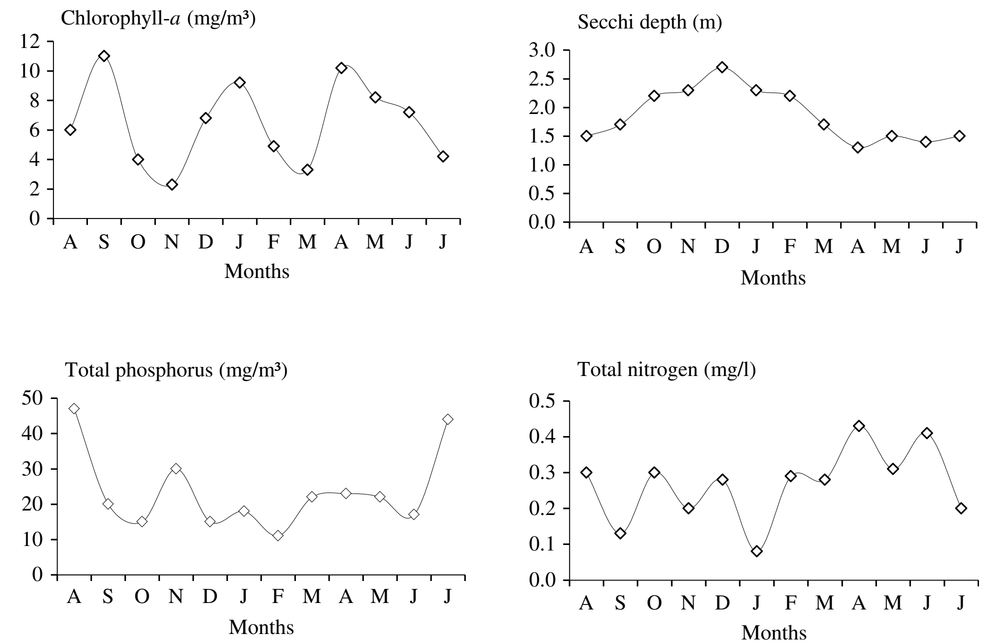


Table 1 Trophic state indices (CMTSI) in Mengkuang Reservoir

Months	CMTSI (Chl-*a*)	CMTSI (SD)	CMTSI (nutrient)	CMTSI[a]	Trophic state
August 05	35.62	47.25	33.84	38.90	Oligotrophic
September 05	49.67	44.92	15.47	36.69	Oligotrophic
October 05	31.11	37.40	26.38	31.63	Oligotrophic
November 05	29.50	36.06	23.23	29.60	Oligotrophic
December 05	42.15	29.74	28.90	33.59	Oligotrophic
January 06	48.30	34.01	6.94	29.75	Oligotrophic
February 06	39.25	35.87	27.17	34.09	Oligotrophic
March 06	33.81	41.10	34.25	36.39	Oligotrophic
April 06	50.16	49.08	39.79	46.35	Oligotrophic
May 06	47.47	45.71	31.13	41.44	Oligotrophic
June 06	44.43	47.43	30.26	40.70	Oligotrophic
July 06	41.05	46.78	22.18	36.67	Oligotrophic
Mean (±SD)	41.04 ± 7.27	41.28 ± 6.43	26.62 ± 8.87	36.51 ± 5.01	Oligotrophic

CMTSI[a] = average of CMTSI (SD), CMTSI (Chl-*a*), CMTSI (nutrient)

depth, but were in oligotrophic state based on nutrients (Table 1). There was no significant difference in trophic indices between stations (ANOVA, $P > 0.05$) and seasons (*t* test, $P > 0.05$). Trophic state is a function of nutrient and other parameters levels and assesses lake changes by simplifying complex environmental variables (Wetzel 1983; Robertson et al. 2008; Sheela et al. 2011; Offem et al. 2011). Mengkuang Reservoir can be classified as eutrophic, taking into consideration TN and Secchi disk transparency (mean TN >60 µg/l and Secchi disk <2.45 m), and mesotrophic, based on Chl-*a* and TP (average Chl-*a* >4.7 µg/l and TP <84.4 µg/l) (Nürnberg 1996; Phillips et al. 2008; Tian et al. 2011). The mean value of CMTSI (Chl-*a*) and SD were close to mesotrophic condition (CMTSI > 40), but CMTSI (nutrient) was lower (CMTSI < 30), showing the oligotrophic state (Robertson et al. 2008). However, the overall value of CMTSI represented oligotrophic state (CMTSI < 50) of the reservoir, either in rainy or in dry season. The dry season trophic state of the tropical lakes is more advanced because of the dilution factor by rain water (Offem et al. 2011). A representative and reliable estimation of the quality of surface water is crucial due to the spatial and temporal variations in water chemistry (Bollinger et al. 1999). Several authors have introduced different criteria for the classification of freshwater trophic level; most of them are based on phosphorus, nitrogen compounds and chlorophyll *a* concentrations (e.g., Vollenwieder 1998; Wetzel 1983; Molisani et al. 2010; Sheela et al. 2011). In January, CMTSI (Chl-*a*) was relatively high, while CMTSI (nutrient) recorded the lowest value. This may be due to consumption of nutrients resulting from high abundance of phytoplankton, and chlorophyll *a* is a reliable measure of phytoplankton biomass (Behrenfeld and Boss 2006). Trophic state index based on chlorophyll *a* has been found to be a reliable means for quantifying trophic state in tropical lakes (Offem et al. 2011).

The occurrence and relative abundance of certain phytoplankton species can be related to water quality and can be indicators of water pollution (Wan Maznah and Mansor 2002; Unuoha et al. 2011), for example, *Anabaena*, *Microcystis*, *Oscillatoria* and *Nostoc* were rare in Mengkuang Reservoir, but could be considered as potential toxic and polluted water indicators (Kumari et al. 2008). *Dinobryon*, *Mallomonas*, *Anabaena*, *Chroococcus*, *Dictyosphaerium ehrenbergianum* and *Staurastrum paradoxum* (among the twenty major species in Mengkuang Reservoir, Fig. 4) can be considered as having the potential of producing unfavorable odors and flavors (Palmer 1980). Díaz-Pardo et al. (1998) reported that a phytoplankton community dominated by chlorophyceans replaced by cyanophyceans, especially *Microcystis aeruginosa*, showed severe sign of eutrophication in a subtropical lake in Mexico. Aquatic pollution can be observed with fairly rapid and fairly marked reduction in certain species and possibly a proliferation of another species (Wu 1984; El-Sheekh et al. 2010).

Most of the Chlorophyta species that were frequently observed in Mengkuang Reservoir are commonly classified as an indicator of oligotrophic environments in literature (Kalff 2002; Offem et al. 2011); however, high abundance of *Staurastrum apiculatum* was recorded in January and July which coincided with eutrophic state (based on N/P ratio) in Mengkuang Reservoir. *Glenodinium lenticula* could be considered as an indicator of high eutrophic state, because it was recorded in high abundance in the months with low values of N/P ratio (eutrophic). Therefore, the trophic state of Mengkuang Reservoir based on phytoplankton community structure differed temporally. The classification of trophic state based on phytoplankton species should be confirmed by other evidences or indices such as N/P ratio or other index of trophic state (Gasiunaite et al. 2005).

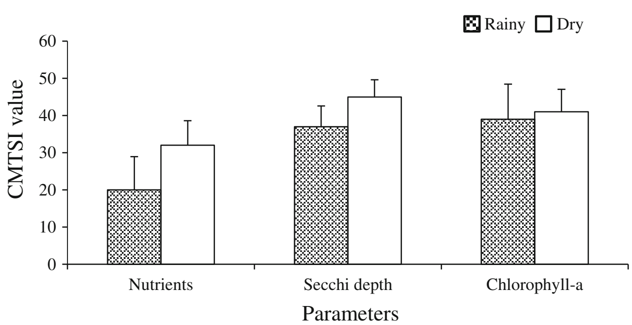
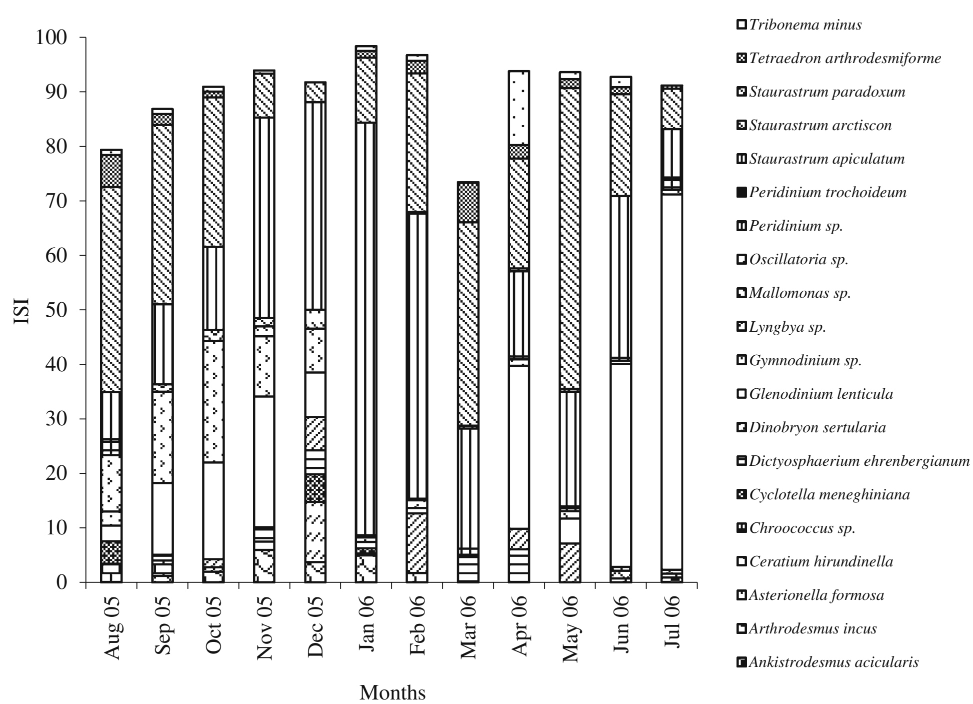


Fig. 3 Values of CMTSI in rainy and dry seasons at Mengkuang Reservoir (August 2005–July 2006)

Fig. 4 ISI of 20 major species of phytoplankton at Mengkuang Reservoir in 2005–2006



According to ISI, there were 20 major species of phytoplankton in Mengkuang Reservoir for the period 2005–2006 (Fig. 4). *Staurastrum paradoxum*, *Staurastrum apiculatum*, *Glenodinium lenticula* and *Lyngbya* sp. showed the highest values of ISI and were the dominant species during the study period. Diversity (H') and evenness were slightly higher during the rainy season (September to December 2005, Table 2). Statistical analysis indicated that H' and evenness values were significantly different between months ($P > 0.01$), but were not spatially significantly different (ANOVA, $P > 0.05$). Based on H' values, most of the sampling stations were in class III (slightly polluted) during rainy season and in class IV (moderately polluted) and class V (polluted) during dry season (Table 3). Overall water quality of Mengkuang Reservoir based on H' was in class III (slightly polluted) (Table 3). *Staurastrum paradoxum*, *Staurastrum apiculatum* and *Glenodinium lenticula* that occurred in high abundance during dry period could be indicators of polluted waters.

Evenness and H' decreased in July, due to high abundance of one particular species (*Glenodinium lenticula*). Tracanna et al. (2006) reported that population maximum values are parallel with diversity minimum values, where population growth is generally due to the excessive proliferation of very few species. Offem et al. (2011) concluded that the presence of species (quality enumeration) is insufficient for the assessment of water quality, and the whole community structure is important to characterize the water condition. The percentage contribution of the dominant species in structuring the community is also important to supplement the importance of species composition in defining the water conditions. Predominance of one group or one particular species indicates a sign of possible problem. In January and July 2006, a very high abundance of certain species (*Staurastrum apiculatum* and *Glenodinium lenticula)* indicated that the phytoplankton community structure was not balanced biologically. In Mengkuang Reservoir, high abundance of Pyrrophyta increased the trophic state and the class of pollution in some stations based on Shannon–Wiener diversity index (from class III to IV and V, Table 3). Early detection of such condition can therefore help in controlling these algae before any serious problem emerges, and identification of species that have the tendency to form bloom is useful to predict eutrophication. Bloom of Pyrrophyta in Malaysian reservoir has been reported by Tan and Anton (1992) in Pansoon Reservoir.

Diversity indices of microalgae have been used as an indicator of the water quality and trophic status of aquatic environments (Shanthala et al. 2009). In this study, diversity index values showed moderate contamination of the

Table 2 Phytoplankton species diversity (H'), evenness and richness in Mengkuang Reservoir in 2005–2006

Months	Richness	Evenness	H' (bits/individual)
August 05	47	0.573	2.40
September 05	59	0.580	2.71
October 05	55	0.624	2.80
November 05	52	0.581	2.59
December 05	49	0.604	2.76
January 06	58	0.254	1.28
February 06	52	0.327	1.75
March 06	48	0.390	1.85
April 06	51	0.597	2.54
May 06	44	0.387	1.77
June 06	36	0.400	1.70
July 06	48	0.213	1.60
Rainy	54.6 ± 3.7	0.529 ± 0.138	2.43 ± 0.58
Dry	46.6 ± 5.4	0.412 ± 0.134	1.94 ± 0.37

Table 3 Water quality classification based on phytoplankton Shannon–Wiener diversity index (H') values in Mengkuang Reservoir from August 2005 to July 2006

Stations	Aug 05	Sept 05	Oct 05	Nov 05	Dec 05	Jan 06	Feb 06	Mar 06	Apr 06	May 06	Jun 06	Jul 06
A1	IV	III	III	III	III	II	V	III	IV	III	IV	III
A2	III	IV	III	III	III	IV	II	III	II	IV	III	V
A3	III	IV	III	III	III	IV	III	III	II	III	III	V
B1	IV	III	II	III	III	III	III	III	II	III	IV	V
B2	II	III	III	III	III	IV	IV	V	III	IV	II	IV
B3	II	IV	III	III	III	III	II	III	III	IV	III	II
C1	III	III	II	III	III	II	I	I	III	III	III	III
C2	IV	III	IV	III	III	III	IV	IV	III	II	II	I
C3	II	II	III	III	III	II	IV	II	II	IV	IV	III
Reservoir	III	III	III	III	III	III	III	III	III	III	III	III

I = excellent; II = good quality; III = slightly polluted; IV = moderately polluted; V = polluted reservoir (Salusso and Morana 2002) during the sampling months ($1 < H' < 3$, Table 3). This classification was made based on the assumptions that the number of species and diversity decreased in response to anthropogenic stress (Stewart 1995; Offem et al. 2011), and a pollution stress would simplify the structure of the community (Rogozin 2000). However, some researchers reported that species richness and diversity increased under moderate stress (Wan Maznah and Mansor 2002; Nather Khan ISA 1991; Hill et al. 2000). Ho and Peng (1997)classified three rivers in northern Peninsular Malaysia as slightly polluted (class III) based on H'. They believed that communities with low species diversity do not necessarily indicative of polluted waters. Many studies concluded that the relationship between diversity and environmental quality is complex (Podani 1992), and the diversity changes can be related to changes in water quality when the diversities of communities with similar species pool are compared (Stevenson 1984).

The monthly and spatial values of SI are shown in Table 4. The mean value of SI was from 2.14 to 2.21 which represents class II (moderately polluted) (Fig. 5). There was no significant difference in SI between stations (ANOVA, $P > 0.05$) and seasons (*t* test, $P > 0.05$). However, monthly values of SI were significantly different (ANOVA, $P > 0.01$). To determine the relationship between saprobic values, environmental parameters and phytoplankton species, PCA test was used. PCA based on saprobic values and some of the physical and chemical parameters (dissolved oxygen, COD, BOD, pH, nitrate, ammonium, DIN, TN, phosphorus and TP) are presented in Table 5. Based on the results, the first four components with initial eigenvalues larger than 1 represented the main influences (68 % of the total variance) on this test. The first component was composed of nitrogen components (ammonium, nitrate, DIN and TN). It explained 19.4 % of the total variance. The second component accounted for 16.5 % of the variance. This component showed that COD, DO, pH, TP and TN were related to saprobic index. The third and forth components had 16.4 and 16.1 % of total variance, respectively. Figure 6 was drawn using the abundance of 20 major species of phytoplankton and saprobic index during the sampling period. It showed that saprobic index in Mengkuang Reservoir was characterized by *Ankistrodesmus acicularis*, *Ceratium hirundinella*, *Chroococcus* sp., *Gymnodinium* sp., *Lyngbya* sp., *Oscillatoria* sp., *Peridinium trochoideum*, *Staurastrum arctiscon* and *Staurastrum paradoxum.*

On the contrary, saprobic condition can be related to water quality. Saprobic index values provide a refinement of the general picture obtained by chemical analysis (Wan Maznah and Mansor 2002; Tracanna et al. 2006), and saprobic index correlated with parameters related to

Table 4 Monthly values of saprobic index at different stations in Mengkuang Reservoir from August 2005 to July 2006

Stations	Aug 05	Sept 05	Oct 05	Nov 05	Dec 05	Jan 06	Feb 06	Mar 06	Apr 06	May 06	Jun 06	Jul 06
A1	2.46	2.32	2.25	2.03	1.98	1.95	1.93	2.10	2.19	2.16	2.19	2.14
A2	2.43	2.32	2.29	2.22	2.10	1.87	2.03	2.09	2.09	2.27	2.00	2.10
A3	2.21	2.40	2.23	2.24	2.09	2.06	2.14	2.09	2.17	2.37	2.05	2.15
B1	2.53	2.25	2.17	2.20	2.23	2.14	2.07	2.22	2.16	2.30	2.15	2.15
B2	2.42	2.31	2.33	2.11	2.16	2.01	2.21	2.27	2.19	2.34	2.08	2.17
B3	1.88	2.27	2.22	2.14	2.20	2.15	1.99	2.22	2.23	2.17	2.17	2.10
C1	2.32	2.29	2.30	2.18	2.04	2.18	2.06	2.30	2.22	2.26	2.15	2.19
C2	2.21	2.08	2.28	2.18	2.07	2.06	2.15	2.18	2.12	2.33	2.05	2.28
C3	2.25	2.25	2.38	2.23	2.11	2.10	2.28	2.10	2.22	2.46	1.97	2.14
Reservoir	2.30 ± 0.20	2.28 ± 0.09	2.27 ± 0.06	2.17 ± 0.07	2.11 ± 0.08	2.06 ± 0.10	2.10 ± 0.11	2.18 ± 0.08	2.18 ± 0.05	2.30 ± 0.09	2.09 ± 0.08	2.16 ± 0.05

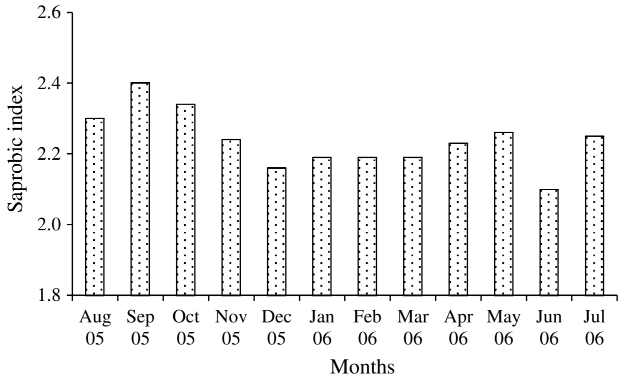


Fig. 5 Saprobic index values in Mengkuang Reservoir from August 2005 to July 2006

Table 5 PCA of environmental parameter and saprobic index in Mengkuang Reservoir in 2005–2006

Parameters	Component 1	Component 2	Component 3	Component 4
COD		0.343		0.745
NH_4^+	0.881			
BOD				0.774
DO		−0.429	0.368	0.610
pH		−0.869		
TP		0.329	0.815	
PO_4^{-3}			0.868	
NO_3^-	−0.301		−0.419	−0.314
DIN	0.955			
TN	0.493	0.337		0.306
Saprobic index		0.702		
Eigenvalues	2.138	1.815	1.805	1.766
Percentage of variance	19.4	16.5	16.4	16.1
Cumulative percentage	19.4	35.9	52.4	68.4

COD = chemical oxygen demand; NH_4^+=ammonium; BOD = biochemical oxygen demand; DO = dissolved oxygen; TP = total phosphorus concentration; PO_4^{-3} = phosphate concentration; NO_3 = nitrate concentration; DIN = dissolved inorganic nitrogen; TN = total nitrogen concentration

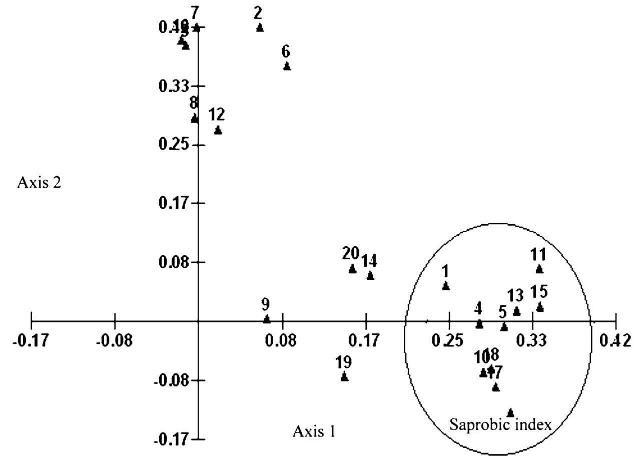


Fig. 6 PCA plot based on the abundance of major phytoplankton species and saprobic index in Mengkuang Reservoir in 2005–2006. 1 = *Ankistrodesmus acicularis*; 2 = *Arthrodesmus incus*; 3 = *Asterionella formosa*; 4 = *Ceratium hirundinella*; 5 = *Chroococcus* sp.; 6 = *Cyclotella meneghiniana*; 7 = *Dictyosphaerium ehrenbergianum*; 8 = *Dinobryon sertularia*; 9 = *Glenodinium lenticula*; 10 = *Gymnodinium* sp.; 11 = *Lyngbya* sp.; 12 = *Mallomonas* sp.; 13 = *Oscillatoria* sp.; 14 = *Peridinium* sp.; 15 = *Peridinium trochoideum*; 16 = *Staurastrum apiculatum*; 17 = *Staurastrum arctiscon*; 18 = *Staurastrum paradoxum*; 19 = *Tetraedron arthrodesmiforme*; and 20 = *Tribonema minus*

organic pollution (Kalyoncu et al. 2009). For instance, in Skadar Lake, the stations that were contaminated with sewage water showed higher value of saprobic index (Rakocevis-Nedovic and Hollert 2005). Wan Maznah and Mansor (2002) and Kalyoncu et al. (2009) reported that the sampling stations with higher value of saprobic index were characterized by highly tolerant diatom species which survive in highly polluted environment. However, Mengkuang Reservoir was classified in class IIIß (moderately polluted) for the whole period of study, but the sampling months with the minimum and maximum values of saprobic index (June and September, respectively) showed different dominant species with different ISI values. Saprobic index depends on the abundance of indicator species and is consequently insensitive to rare species (Danilov and Ekelund 2001). Saprobic condition was supported by more abundance of Cyanophyta and Pyrrophyta and some species of Chlorophyta (with high saprobic index). Cyanophyta and Pyrrophyta are good indicators of organic pollution as well as saprobic conditions (Hynes 1966; Palmer 1980; Sorokin 1999).

CMTSI of the reservoir showed stability during the study period (oligotrophic status). Water quality index (WQI) based on chemical and physical parameters indicated that the reservoir had a good-to-excellent water quality throughout the study period (Makhlough et al. 2006). In this study, biological monitoring using phytoplankton community attributes showed that the water condition is mildly polluted. The reservoir is slightly disturbed by human activities, for example, fish-feeding by visitors contributed more nutrients and disturbed the balance of phytoplankton community. This is one of the advantages of using microalgae as biological indicators, as we can detect trace of pollution not recorded by chemical analysis. Algae can serve as an indicator of the degree of deterioration of water quality and are valuable indicators of short-term impacts (Hill et al. 2000; Li et al. 2011; Schletterer et al. 2011). Combination of several physical and chemical parameters with biological monitoring is essential to assess the degree of pollution and to reflect the lake condition (Noges and Noges 2006). Since different indices reveal different aspects of a water body, managers of such a resource would be able to identify the source of disturbance on a water body. Mengkuang Reservoir is at the risk of anthropogenic source of pollution. The water authorities should monitor any possible bloom of pollutant or toxic species of phytoplankton (*Oscillatoria* sp. and *Lyngbya* sp.), which are already occurred in the lake in moderate abundance in certain months during the study period. It is important to shift the environmental monitoring from solely reliance on chemical indicators toward the increasing use of biological condition (McCormic and Cairns 1994; Yap 1997; O'Farrell et al. 2002; Kalyoncu et al. 2009; Offem et al. 2011). Biomonitoring can be a tool for quick and reliable identification of local impacts on biota, which stay undetected using routine chemical and physical monitoring (Danilov and Ekelund 2001). Understanding phytoplankton community structure provides insight into the overall ecology of lakes and will assist in the future conservation and management of this lentic ecosystem (Salm et al. 2009).

The reservoir, being a source of drinking water, should meet the criteria of good water quality and should be in low level of pollution. A continuous biological monitoring program will help the manager and local authority to identify potential pollutants and toxic species in the area.

Conclusion

Mengkuang Reservoir was oligotrophic based on CMTSI. However, the classification of water quality based on diversity index (H') of phytoplankton showed that the reservoir was slightly polluted. Diversity index is a community structural analysis, so its application in environmental monitoring should be supplemented by other indices and parameters. Saprobic index also showed that the reservoir was moderately polluted. Microalgal species composition and abundance was a reliable and important tool to assess the degree of pollution in Mengkuang Reservoir. Long-term assessments of biological and chemical parameters in the reservoir are necessary for an effective prediction and management of excessive algal growth (eutrophication).

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References

Ali AB, Lee KY (1995) Chenderoh Reservoir, Malaysia: a characterization of a small-scale, multigear and multispecies artisanal fishery in the tropics. Fish Res 23:267–281

Ansbaek J, Valatka S (2001) Surface water classification and implementation strategy. Danish Environmental Protection Agency, DANCEE and the Ministry of Environment of Lithuania, Technical Report No. 1.1, pp 54

APHA (American Public Health Association) (1998) Standard methods for the examination of water and wastewater, 20th edn, American Public Health Association

Azrina MZ, Yap CK, Ismail AR, Ismail A, Tan SG (2006) Anthropogenic impacts on the distribution and biodiversity of benthic macroinvertebrates and water quality of the Langat River, Peninsular Malaysia. Ecotox Environ Safe 64:337–347

Begliutti B, Buscarinu P, Marras G, Sechi GM, Sulis A (2007) Reservoirs water-quality characterization for optimization modelling under drought conditions. Part 1—reservoirs trophic state characterization. In: Rossi G, Vega T, Bonaccorso B (eds) Methods and Tools for Drought Analysis and Management. Springer, The Netherlands, pp 239–261

Behrenfeld MJ, Boss E (2006) Beam attenuation and chlorophyll concentration as alternative optical indices of phytoplankton biomass. J Mar Res 64:431–451

Bollinger JE, Steinberg LJ, Harrison MJ, Crews JP, Englande AJ, Velasco-González C, White LE, George WJ (1999) Comparative analysis of nutrient data in the lower Mississippi River. Wat Res 33:2627–2632

Boyd CE, Tucker CS (1992) Water quality and pond soil analyses for aquaculture. Auburn University, Birmingham, Alabama, Alabama agricultural experiment station

Brower JE, Zar JH, von Ende CN (1998) Field and laboratory methods for general ecology, 4th edn. WCB McGraw-Hill, New York, p 273

Buraschi E, Salerno F, Monguzzi C, Barbiero B, Tartari G (2005) Characterization of the Italian lake-types and identification of their reference sites using anthropogenic pressure factors. J Limnol 64(1):75–84

Camargo JA, Alonso A (2006) Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: a global assessment. Environ Int 32(6):831–849

Danilov RA, Ekelund NGA (2001) Comparative studies on the usefulness of seven ecological indices for the marine coastal monitoring close to the shore on the Swedish East Coast. Environ Monit Assess 66:265–279

Delong MD, Brusven MA (1993) Storage and decomposition of particulate organic matter along the longitudinal gradient of an agriculturally-impacted stream. Hydrobiologia 258:77–88

Díaz-Pardo E, Vazquez G, López- López E (1998) The phytoplankton community as a bioindicator of health conditions of Atezca Lake, Mexico. Aquat Ecosyst Health Manag 1:257–266

Dixon W, Chiswell B (1996) Review of aquatic monitoring program design. Wat Res 30(9):1935–1948

Edler L (1979) Recommendations for marine biological studies in the Baltic Sea. Phytoplankton and Chlorophyll. National Swedish Environment Protection Board, pp 1–38

El-Sheekh MM, Deyab MAI, Desouki SS, Eladl M (2010) Phytoplankton compositions as a response of water quality in El Salam canal, Hadous drain and Damietta branch of River Nile, Egypt. Pak J Bot 42(4):2621–2633

Gasiunaite ZR, Cardoso AC, Heiskanen AS, Henriksen P, Kauppila P, Olenina I, Pilkaityte R, Purina R, Razinkovas I, Sagert A, Schubert S, Wasmund N (2005) Seasonality of coastal phytoplankton in the Baltic Sea: influence of salinity and eutrophication. Est Coast Shelf Sci 65(1–2):239–252

Habit RN, Pankow H (1976) Algenoflora der Ostsee II. Gustav Fischer Verlag, Jena University Rostock Publication, Germany, Plankton

Hill BH, Herlihy AT, Kaufmann PR, Stevenson RJ, McCormick FH, Johnson CB (2000) Use of periphyton assemblage data as an index of biotic integrity. J N Am Benthol Soc 19(1):50–67

Ho SC (1994) Status of limnological research training in Malaysia. In: D Dudgeon, PKS Lam (eds), Inland waters of tropical Asia and Australia: conservation and management, Mitt Int Ver Limnol, vol 24, pp 129–145

Ho SC, Peng T (1997) The use of river plankton and fish in the water quality classification of Sungai Perai, Sungai Juru and Sungai Perlis. J Ensearch 10:115–124

Hynes HBN (1966) The biology of polluted waters. Liverpool University Press, UK

Johnstone C, Day JG, Staines H, Benson EE (2006) The development of a 2,2′-azinobis-(3-ethyl-benzothiazoline-6-sulfonic acid) radical cation decolourisation essay for evaluating total antioxidant status in an alga used to monitor environmental impacts in urban aquatic habitats. Ecol Indic 6(2):280–289

Kalff J (2002) Limnology of inland water ecosystems. Printed Hall, New Jersey, USA, Upper Saddle River

Kalyoncu H, Çiçek NL, Akköz C, Yorulmaz B (2009) Comparative performance of diatom indices in aquatic pollution assessment. Afr J Agric Res 4(10):1032–1040

Kitsiou D, Karydis M (2000) Categorical mapping of marine eutrophication based on ecological indices. Sci Total Environ 255:113–127

Kumari P, Dhadse S, Chaudhari PR, Wate SR (2008) A biomonitoring of plankton to assess quality of water in the lakes of Nagpur City. In: Sengupta M, Dalwani R (eds) Proceedings of Taal 2007: the 12th Lake conference, pp 160–164

Le C, Zha Y, Li Y, Sun D, Lu H, Yin B (2010) Eutrophication of lake waters in China: cost, causes, and control. Environ Manag 45:662–668

Li Y, Li J, Liang Z, Yin W, Hu L, Shi J, Wang Y (2011) Planktonic algae and epilithic algae in typical rivers of Danjingkou Reservoir. Adv Mat Res 356–360:59–62

Lobban CS, Chapman DJ, Kremer BP (1998) An experimental phycology laboratory manual. Cambridge University Press, UK

Makhlough A, Wan Maznah WO, Mansor M (2006) Water quality of Mengkuang Dam based on WQI (Water Quality Index) model. In: Proceedings of ICENV (International Conference of Environment), pp 60

McCormic PVJ, Cairns JR (1994) Algae as indicators of environmental change. J Appl Phycol 6:50–526

Meor Hussain MAF, Ahyaudin A, Amir Shah R, Shah M (2002) The structure and dynamics of net-zooplankton communities of the littoral versus limnetic zone of a typical embayment in a small flow through tropical reservoir. J Biosains 13(2):23–34

Molisani MM, de Sousa Barroso H, Becker H, Moreira MOP, Hijo CAG, do Monte TM, Vasconcellos GH (2010) Trophic state, phytoplankton assemblages and limnological diagnosis of the Castanháo Reservoir, CE Brazil. Acta Limnol Bras 22(1):1–12

Nather Khan ISA (1991) Effect of urban and industrial wastes on species diversity of the diatom community in a tropical river, Malaysia. Hydrobiologia 224:175–184

Noges and Noges (2006) Indicators and criteria to assess ecological status of the large shallow temperate lakes Peipsi (Estonia/Russia) and Vortsjarv (Estonia). Boreal Environ Res 11:67–80

Nürnberg GK (1996) Trophic state of clear and colored, soft- and hardwater lakes with special consideration of nutrients, anoxia, phytoplankton and fish, Lake. Reserv Manag 12:432–447

Nygaard G (1991) Seasonal periodicity of planktonic desmids in oligotrophic lake Grane Langsø, Denmark. Hydrobiologia 211:195–226

O'Farrell I, Lombardo R, Tezanos PP, Loez C (2002) The assessment of water quality in the lower Lujan river (Buenos Aires, Argentina): phytoplankton and algal bioassays. Environ Pollut 120:207–218

Offem BO, Ayotunde EO, Ikpi GU, Ada FB, Ochang SN (2011) Plankton-based assessment of the trophic state of three tropical lakes. J Environ Protect 2:304–315

Padro R, Barrado E, Castrillejo Y, Valasco MA, Vaga M (1993) Study of the contents and speciation of heavy metals in river sediments by factor analysis. Anal Lett 26:1719–1739

Palmer CM (1980) Algae and water pollution. The identification, significance, and control of Algae in water supplies and in polluted water. Castle House Publication, London

Pantle R, Buck H (1955) Die biologische Uberwachung der Gewasser und die Darstellung der Ergebnisse. Gas Wasserfach 96:604

Pentecost A (1984) Introduction to Freshwater Algae. Richmond Publishing Co., Ltd., England

Phillips G, Pietiläinen OP, Carvalho L, Solimini A, Solheim AL, Cardoso AC (2008) Chlorophyll—nutrient relationships of different lake types using a large European dataset. Aquat Ecol 42:213–226

Podani J (1992) Monitoring system. In: Kovacs M (ed) Biological indicators in environmental protection. Ellis Horwood Series in Environmental Management, Science and Technology, UK, pp 12–18

Rakocevis-Nedovic J, Hollert H (2005) Phytoplankton community and chlorophyll a as trophic state indices of Lake Skadar (Montenegro, Balkan). Environ Sci Pollut R 12:146–152

Robertson DM, Schladow SG, Holdren GC (2008) Long-term changes in the phosphorus loading to and trophic state of the Salton, Sea, California. Hydrobiologia 604:21–36

Round FE, Crawford RM, Mann DG (1990) The Diatoms Biology and Morphology of the Genera. Cambridge University Press, Cambridge, p 747

Rushforth SR, Brock JT (1991) Attached diatom communities from the lower Truckee River, summer and fall, 1986. Hydrobiologia 224:49–64

Salleh A (1996) Alga Air Tawar. Dewan Bahasa dan Pustaka Kuala Lumpur, Ampang/Hulu Kelang, Selangor Darul Ehsan

Salm CR, Saros JE, Martin CS, Erickson JM (2009) Patterns of seasonal phytoplankton distribution in prairie saline lakes on the northern great plains (USA). Saline Syst 5:1–13

Salusso MM, Morana LB (2002) Comparison of indices in the monitoring of two lotic systems in the northwest Argentina. Rev Biol Trop 50:327–336

Schletterer M, Schönhuber M, Fureder L (2011) Biodiversity of diatoms and macroinvertebrates in an east European lowland river, the Tudovka River (Tver Region, Russia). Boreal Environ Res 16:79–90

Shannon CE, Weaver W (1963) The Mathematical Theory of Communication. University of Illinois Press, Urbana, p 117

Shanthala M, Hosmani S, Hosetti B (2009) Diversity of phytoplankton in a waste stabilization pond at Shimoga Town, Karnataka State, India. Environ Monit Assess 151:437–443

Sheela AM, Letha J, Joseph S, Ramachandran KK, Sanalkumar SP (2011) Trophic state index of a lake system using IRS (P6-LISS III) satellite imagery. Environ Monit Assess 177(1–4):575–592

Sigua GC, Williams MJ, Coleman SW, Starks R (2006) Nitrogen and Phosphorus Status of Soils and Trophic State of Lakes Associated with Forage-Based Beef Cattle Operations in Florida. J Environ Qual 35:240–252

Sorokin Y (1999) Aquatic microbial ecology, a textbook for students in the environmental sciences. Backhuys Publishers, Leiden

Stevenson RJ (1984) Epilithic and epipelic diatoms in the Sandusky River with emphasis on species diversity and water pollution. Hydrobiologia 114:161–175

Stevenson RJ, Smol JP (2003) Use of algae in environmental assessments. In: Wehr JD, Sheath RG (eds) Freshwater algae of North America, ecology and classification. Academic Press, USA, pp 775–804

Stewart PM (1995) Use of algae in aquatic pollution assessment. Nat Area J 15(3):234–239

Stobutzki IC, Silvestre GT, Abu Talib A, Krongprom A, Supongpan M, Khemakorn P, Armada N, Garces L (2006) Decline of demersal coastal fisheries resources in three developing Asian countries. Fish Res 78(2–3):130–142

Swaminathan MS (2003) Biodiversity: an effective safety net against environmental pollution. Environ Pollut 126:287–291

Tan S, Anton A (1992) The ecology of dinoflagellate blooms in a tropical reservoir. In: Hussein MY, Sajap AS, Japar SB (eds) Status ecologi semasa menjelang 2020. Universiti Kebangsaan Malaysia, Persidangan Ecology Malaysia, pp 169–172

Tian C, Pei H, Hu W, Xie J (2011) Assessment of trophic status for Dongping Lake using comprehensive trophic state index and diversity indices. Bioinformatics and biomedical engineering, (iCBBE) 2011 5th international conference on, pp 1–4

Tracanna BC, Martínez de Marco SN, Amoroso MJ, Romero N, Chaile P, Mangeaud A (2006) Physical, chemical and biological variability in the Dr. C. Gelsi reservoir (NW Argentine): a temporal and spatial approach. Limnetica 25(3):787–808

Unuoha PC, Nwankwo DI, Chukwu LO, Wim V (2011) Spatio-temporal variations in phytoplankton biomass and diversity in a tropical eutrophic lagoon, Nigeria. J Am Sci 7(8):33–46

Vollenwieder RA (1998) The scientific basis of lake and stream eutrophication with particular reference to phosphorus and nitrogen as eutrophication factors. OECD Tech Rep 27:1–182

Wan Maznah WO, Mansor M (2002) Aquatic pollution assessment based on attached diatom communities in the Pinang River Basin Malaysia. Hydrobiologia 487:229–241

Wehr JD, Sheath RG (2003) Freshwater algae of North America: ecology and classification. Academic Press, New York, p 918

Wetzel RG (1983) Limnology. WB Saunders Co, Philadelphia

Wetzel RG (1995) Limnological Analyses, 2nd edn. Spring, New York

Wilhm JL (1970) Range of diversity index in benthic macroinvertebrate populations. Water Poll Control Fed 42:221–224

Wilhm JL, Dorris TC (1968) Biological parameters for water quality criteria. Bioscience 18:477–481

Wu JT (1984) Phytoplankton as bioindicator for water quality in Taipei. Bot Bull Acad Sinica 25:205–214

Wu RSS, Siu WHL, Shin PKS (2005) Induction, adaptation and recovery of biological responses: implications for environmental monitoring. Mar Pollut Bull 51:623–634

Yap SY (1997) Classification of a Malaysian river using biological indices: a preliminary attempt. Environmentalist 17(2):79–86

Yeng CK (2006) A study on limnology and phytoplankton biodiversity of Ahning Reservoir. Dissertation, University Sains Malaysia, Kedah

Zar JH (1974) Biostatistical analysis, 1st edn. Prentice-Hall Inc, New York, p 620

Zbikowski R, Szefer P, Latala A (2007) Comparison of green algae *Cladophora* sp. and *Enteromorpha* sp. as potential biomonitors of chemical elements in the Southern Baltic. Sci Total Environ 387:320–332