WATER QUALITY CHARACTERISTICS OF MENGKUANG RESERVOIR BASED ON PHYTOPLANKTON COMMUNITY STRUCTURE AND PHYSICO- CHEMICAL ANALYSIS

by

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**Thesis submitted in fulfillment of the requirements
for the degree of Master of Science**

June, 2008

ACKNOWLEDGMENT

I wish to express my great thanks to my supervisor Dr. Wan Maznah Wan Omar for providing a friendly area for working at the lab, supporting, guiding, reading and correcting of the thesis. I truly appreciate her continuous help during the lab work and writing.

Thank you also to Professor Mashhor Mansor for supporting the project and Dr. Khoo for the valuable discussions concerning the thesis. I also would like to express gratitude to En. Yaakob, En. Hamzah, En. Teo, En. Nordin, En. Mothu, all the staff of the microscope lab (En. Muthu, En. Johary and Kak Milah), Abang Amir, Zarulall, Johan, Nik, Teo, Faradina, Hazeman, Mas, Intan, Maria, Nor Zailani binti Mohamad, Nurul Hidayah Yahya and the members of the office of the School of Biology, especially Jesica who helped me in sampling and laboratory works. This study would not be possible without their friendly help. Also, the warmest thanks to Universiti Sains Malaysia, because this project could not be conducted without the financial supports of USM.

I also want to thank Mr. Lo, the kind personnel of PBA in the office of Mengkuang Dam. He had superior cooperation with the sampling team and also provided historical information of Mengkuang Dam and rainfall data during this period of study.

I also appreciate to my Iranian Company (Ecological Academy of Caspian Sea) that gave me this opportunity to study at USM.

I am especially grateful to my dear husband (Hassan), my children (Yasaman and Manouchehr), our parents and our siblings in Iran, for their love, patience, guidance and support during my study.

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LIST OF ABBREVIATIONS

Abbreviation	Description
AN	Ammonium
APHA	American Public Health Association
BOD	Biochemical oxygen demand
Chl-*a*	Chlorophyll-*a*
COD	Chemical oxygen demand
CMTSI (Nut.)	Carlson modified trophic state index based on nutrient
CMTSI (Chl.)	Carlson modified trophic state index based on chlorophyll-*a*
CMTSI (SD)	Carlson modified trophic state index based on Secchi disc depth
DIN	Dissolved inorganic nitrogen
DO	Dissolved oxygen
DOE –UM	Department of Environment, University of Malaya
DON	Dissolved organic nitrogen
E	Geographical East
EC	Electrical conductivity
GPP	Gross primary production
H′	Shannon-Wiener diversity index
HCl	Hydro choleric acid
ISI	Importance Species Index
M.R	Mengkuang Reservoir
$MgCO_3$	Magnesium carbonate
N	Geographical North
OD	Optical density
PBA	Perbadanan Bekalan Air
pH	Power of hydrogen(Acid balance)
SI	saprobic index
SD	Secchi disc depth (Water transparency)
S.R	Species richness
SRP	Soluble reactive phosphate
TDS	Total dissolved solids
TN	Total nitrogen
TP	Total phosphorus
TSS	Total suspended solids
WQI	Water quality index

LIST OF SYMBOLS

Symbol	Description
^oC	Degree Celsius
Cells/l	Cells per liter
m	Meter
mgC/ m^3/ hour	Milligram Carbon per meter cube per hour
mg/l	Milligram per liter
mg/m^3	Milligram per meter cube
mm/month	Millimeter per month
mm/year	Millimeter per year
µm	Micrometer
µS/cm	Micro Zimens per centimeter

CIRI-CIRI KUALITI AIR DI EMPANGAN MENGKUANG BERDASARKAN STRUKTUR KOMUNITI FITOPLANKTON DAN ANALISIS FISIKO- KIMIA

ABSTRAK

Kajian kualiti air ini telah dijalankan di Empangan Mengkuang, Pulau Pinang yang terletak di bahagian barat laut, Malaysia. Kajian ini menumpukan terhadap komposisi dan variasi ruang-masa fitoplankton serta parameter fiziko-kimia, dan kajian dijalankan kerana kepentingan takungan ini sebagai bekalan air minuman dan kekurangan data algologi di kawasan kajian. Sembilan stesen persampelan telah dipilih di mana 6 stesen terletak di zon litoral dan 3 stesen di zon limnetik. Persampelan dilakukan pada setiap bulan dari permukaan air hingga ke dasar dengan jarak perantaraan 5 meter di sepanjang tempoh setahun bermula dari bulan Ogos 2005 hingga bulan Julai 2006 yang meliputi dua musim tropika yang berbeza (musim kering dan musim hujan). Julat tahunan suhu (29.28 – 33.50 ºC), DO (3.25 – 9.20 mg/l), COD (2 – 54 mg/l), pH (4.5 – 9.44), EC (40 - 70 µS/cm), TSS (0.22 – 30.00 mg/l), tahap kedalaman penembusan cahaya (1.15 – 3.10 m), klorofil *a* (0.03 – 19.36 mg/m^3), pengeluaran primer kasar (14.27 – 100.25 mgC/m^3/hour), PO_4-P (0.00 – 0.07 mg/l), NH_4^+-N (0.00 - 0.32 mg/l) and NO_3^- -N (0.00 – 0.13 mg/l) di permukaan air telah direkodkan. Variasi bermusim EC, TSS, TDS, tahap kedalaman penembusan cahaya, nitrat, pengeluaran primer kasar dan kelimpahan fitoplankton telah dicatatkan yang secara signifikan lebih tinggi semasa musim hujan. Walau bagaimanapun, tiada perbezaan signifikan komponen kimia dan komposisi fitoplankton di antara stesen ($p>0.05$). Suhu, DO, pH, klorofil *a* dan kelimpahan fitoplankton berkurangan dari permukaan ke dasar, sementara EC, TSS, TDS, jumlah kepekatan fosforus dan nitrogen meningkat secara vertikal. Menuju ke dasar menunjukkan bahawa kelimpahan fitoplankton dipengaruhi oleh nitrogen dan fosfate serta penembusan cahaya. Sebaliknya, faktor fizikal dan kimia ini dipengaruhi oleh taburan hujan, pengepaman air dan larian air, proses kitaran dalaman (penguraian dan pemineralan) serta komuniti biologi. Sejumlah 128 spesies fitoplankton telah dikenalpasti dari permukaan ke bahagian dasar. Divisi Chlorophyta yang terdiri daripada *Staurastrum apiculatum*, *Staurastrum paradoxum* adalah paling dominan di permukaan air. *Glenodinium lenticula* dan *Lygnbya* sp adalah species yang ketiga dan keempat paling dominan. Julat indeks kesamarataan dan Indeks Shannon-Weiner masing-masing adalah 0.21-0.62 dan 1.28-2.80 (bit/individu). Pengiraan indeks keadaan trofik modifikasi Carlson berdasarkan klorofil *a* dan tahap kedalaman penembusan cahaya menunjukkan bahawa takungan air ini menghampiri keadaan mesotrofik, takungan ini juga disahkan oleh nilai nisbah N/P. Merujuk kepada Indeks Shannon-Weinner dan Indeks Saprobik, takungan air ini masing-masing diklasifikasikan dalam kelas III (sedikit tercemar) dan kelas II (sederhana tercemar). Kajian ini turut merekodkan kehadiran *Anabaena, Microcystis, Oscillatoria, Nostoc, Dinobryon, Chroococcus, Dictyosphaerium ehrenbergianum, Staurastrum paradoxum* dan *Mallomonas* yang menjadi penunjuk kepada ketoksikan, bau dan rasa yang kurang menyenangkan serta pencemaran di dalam ekosistem akuatik. Secara kesimpulannya, kajian ini dapat menunjukkan kelebihan dan kepentingan kajian algologi untuk mengesan pengurangan tahap kualiti air dalam ekosistem akuatik.

WATER QUALITY CHARACTERISTICS OF MENGKUANG RESERVOIR BASED ON PHYTOPLANKTON COMMUNITY STRUCTURE AND PHYSICO-CHEMICAL ANALYSIS

ABSTRACT

This study was carried out at Mengkuang Reservoir (M.R), Penang, in the northwest of Malaysia. This study focused on the spatio-temporal variation of phytoplankton composition and physico-chemical parameters, and was conducted due to the importance of the reservoir as a drinking water supply and also the lack of algological data of the studied area.

Nine sampling stations were selected with six stations in littoral zone and three stations in the limnetic zone. Monthly samples were collected from the water surface to the bottom, with 5 meter intervals over a one-year period from August 2005 to July 2006, which were comprised of two different tropical seasons (the dry and rainy seasons). Physico-chemical parameters showed the following ranges on the surface water of Mengkuang Reservoir: temperature (29.28 – 33.50 ºC), DO (3.25 – 9.20 mg/l), COD (2 – 54 mg/l), pH (4.5 – 9.44), EC (40 - 70 µS/cm), TSS (0.22 – 30.00 mg/l), transparency depth (1.15 – 3.10 m), Chl-*a* (0.03 – 19.36 mg/m^3), gross primary production (14.27 – 100.25 mgC/m^3/hour), PO_4-P (0.00 – 0.07 mg/l), NH_4^+-N (0.00 - 0.32 mg/l) and NO_3^- -N (0.00 – 0.13 mg/l). The seasonal variation was observed in nitrate, EC, TDS, transparency depth, and abundance of phytoplankton which were significantly higher during rainy season ($p<0.05$). However, there was no significant difference in chemical components as well as abundance of phytoplankton between stations ($p>0.05$). Temperature, DO, pH, Chl-*a* and abundance of phytoplankton decreased from the surface to the bottom, while EC, TSS, TDS, total phosphorus and total nitrogen increased vertically towards the bottom. The results indicated that abundance of phytoplankton was affected by nitrogen and phosphate, ions availability and light penetration. On the other hand, these physical and chemical factors were affected by the amount of rainfall, water pumping and water draw off, inter cycling process (decomposition and mineralization) as well as biological community. A total of 128 phytoplankton species were identified. The dominant division was Chlorophyta, which were mainly composed of *Staurastrum apiculatum* and *Staurastrum paradoxum.* The third and fourth dominant species were *Glenodinium lenticula* (Pyrrophyta) and *Lyngbya* sp. (Cyanophyta), respectively. The range of evenness and Shannon-Weiner's index was 0.43-0.56 and 1.91-2.45 (bits/individual) in M.R, respectively. Calculation of the Carlson modified trophic state index showed that the reservoir was near to a mesotrophic state based on Chl-a and transparency depth. The mesotrophic state of the reservoir was also confirmed by the N/P ratio value. Based on the Shannon-Weiner's and saprobic indices, the reservoir was in class III (slightly polluted) and class II (moderately polluted), respectively. The study also recorded the presence of *Anabaena, Microcystis, Oscillatoria*, *Nostoc, Dinobryon, Chroococcus, Staurastrum paradoxum* and *Mallomonas* which are indicators of toxic, unfavorable odors and flavors, and pollution in aquatic ecosystems. As a conclusion, this study showed the ability of algological studies to provide early warning of water degradation and its importance in water quality assessment.

CHAPTER 1

INTRODUCTION

Reservoirs are formed or modified by human activity for specific purposes, in order to provide a reliable and controllable resource. Reservoirs are usually found in areas of water scarcity or excess, or where there are agricultural or technological reasons to have controlled water resources (Wetzel, 1995).

In Malaysia, there are 63 large reservoirs with a total storage of 25 billion m^3 ranging in size from 10 ha (Mahang Reservoir) to 37000 ha (Kenyir Reservoir). The roles of these reservoirs are hydro-electric power generation, irrigation, drinking water supply, fisheries, recreational and tourist activities (Ho, 1994).

Penang is one of the Malaysian States which is located in the northwest of Malaysia. This state has six reservoirs (dam structure) managed by PBA (Perbadanan Bekalan Air). Among these reservoirs, Mengkuang Reservoir (M.R) has the highest capacity. Capacity of Mengkuang Reservoir is almost 9 times more than Air Itam Reservoir (Table 1.1). The present water supplies are enough for Penang State, but with increasing population, the government should manage and conserve the existing water supply.

M.R was constructed in 1981. Impoundment of the reservoir started in 1984 but operation of the reservoir started in 1985. M.R is a modified homogeneous earthfill embankment. The spillway and drawoff work are combined in a single intake tower, directly upstream of the reservoir. The draw off work is comprised of four intakes at different levels in the intake tower.

The catchment area of M.R is surrounded by natural tropical forest and some recreational spot featuring landscaped gardens, and sitting benches. M.R supplies drinking water for Penang Island, Butterworth and other parts of this state. M.R is a part of the Mengkuang pumped storage scheme. It supplies more than 81 million gallons of untreated water per day to the Sungai Dua treatment plant.

Table 1.1: Reservoirs (dam structure) in Penang State (PBA, 2004).

Name	Year Built	Type of Reservoir	Capacity (Million liters)
Teluk Bahang	1999	Earth Filled	19,240
Air Itam	1963	Earth Filled	2,609
Mengkuang	1985	Earth Filled	23,636
Bukit Panchor	1975	Reinforced Concrete	273
Cherok To'kun	Not available	Reinforced Concrete	85
Berapit	Not available	Reinforced Concrete	170

Economic development in Malaysia has increased in the recent 20 years. This development is associated 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 (Ho, 1994). The increasing of population increases the demand for water while freshwater resources are limited. Therefore, it is important to protect the existing freshwater resources.

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 inadequacies 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 involves 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. Consumers may have difficulties in using the water because of its taste and odor, and they may also experience a toxic effect (Welch, 1992). Therefore algal studies (biomonitoring) are necessary to provide sufficient information in water quality and water degradation in reservoir (Yap, 1997; Swaminathan, 2003). The advantages of employing the algae in biomonitoring of aquatic environment are based on the fact that these organisms reflect the concentration of physico-chemical parameters in the water ecosystem (Zbikowski *et al*., 2007). Algal communities quickly reflected environmental stressors because of their short lifecycles (McCormick 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 causes dramatic increase of algae. This event led to low oxygen condition that can affect other organisms in the aquatic food chain (Camargo and Alonso, 2006).

Studies on water ecosystems in Malaysia has progressed in the last 30 years through many organizations which include local universities, government departments, research centers and non-governmental organizations (Ho, 1994). However, a few studies have been done on water quality in relation to distribution and species composition of algae (Yap, 1997; Wan Maznah and Mansor, 2000). In many developed European countries the algological study, and the use of this branch of science in water supply, has 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 the M.R 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 study investigates the relation between physico-chemical parameters and distribution of phytoplankton. Due to the role of stratification in reservoir function and decomposition to provide internal nutrient, vertical survey is also important in tropical reservoir. Therefore the objectives of this study are:

1- To determine physico-chemical parameters and their temporal and spatial fluctuation.

2- To study temporal and spatial distribution of phytoplankton community.

3- To study relationships between phytoplankton and physico-chemical parameters.

4- To determine the status of water quality of the reservoir based on chemical and biological indices.

1.1 Literature Review

There are two types of inland water bodies, running or lotic waters and standing or lentic waters. Lotic waters include all forms of waters that whole body of water moves continuously in a specific direction, such as rivers and streams. Running waters dominate the Malaysian aquatic environment and support a rich diversity of inland habitats (Khoo *et al*., 2003). Standing or lentic waters include all forms of waters with no unidirectional water flow. Movement may occur in the form of wave action and internal currents. Lakes, reservoirs, ponds and lagoons are in this group (Kalff, 2002). There are only two natural lakes in Malaysia namely Tasik Chini and Tasik Bera (Ali and Lee, 1995). Man-made lakes or reservoirs dominate the Malaysian lentic ecosystems.

Standing water, compared to running water, is relatively stable. The main factor for the changes in lentic ecosystem is the rate of exchange of water through the system (retention time). In lakes or reservoirs, chemical, physical and biological characteristics are related to inflow and outflow of water. Therefore, changes of water characteristics may occur annually, seasonally, or diurnally. In lentic ecosystems, the remaining substances may persist for a long time after pollution ceased. Therefore, sometimes algal bloom is not contributed by the increasing nutrient inflow, but due to input of nutrients from benthic sediments (Hellawell, 1986).

Lakes are natural features of accumulation of fresh water in depressions. Sources of water in lakes include rainfall, melting snow, runoff, stream flow, and groundwater flows (Wetzel, 1995). Unproductive lakes become eutrophic gradually with the passage of time. Normally, the process of lake succession takes hundreds to thousands of years, but under anthropogenic pressure this process is much faster.

Reservoirs are man-made water bodies constructed for irrigation, drinking water supply, industries, navigation and power production, with variable size and depth (Maitland, 1978). Water levels in reservoirs are related to river discharge that fluctuates seasonally. In storage reservoirs, water level is controlled by pumped in-flows and out-flows. High algal production is more pronounced in shallow water bodies, but in deep reservoir there is more occurrence of stratification. In stratified reservoir there is more nutrient supply for algal growth (Maitland, 1978).

Runoff waters to reservoirs are larger and more related to rainfall than natural lakes. In reservoirs inflows of water are primarily canalized and often not intercepted, so they have high energy for erosion and large sediment-loading. There are also extensive loads of dissolved and particulate matters into the water body. Surface areas of drainage basins of reservoirs are larger than natural lake. In other words a reservoir is a very dynamic lake (Wetzel, 1995).

1.1.1 Characteristics of reservoirs

Morphometry is an important tool to identify water body, because it can be indirectly related to water quality. Morphometry factors that are usually used are lake area, zone, altitude, maximum depth and mean depth (to classify water in deep and shallow waters) (Buraschi *et al*., 2005).

There is no certain boundary for classification of lake based on depth and size. According to Goldman and Horn (1983), lakes with a depth of more than 100 m are relatively deep and reasonably large with an area of more than 40-80 ha. Buraschi *et al*. (2005) characterized the lake levels as very shallow (mean depth < 3 m); shallow (mean depth 3-15 m) and deep (mean depth >15 m). Lakes with surface area of 0.5 -1 km^2, 1-10 km^2, 10-100 km^2 and >100 km^2 are called very small, small, large and very large lake respectively.

The most important physical factor of a reservoir is light. It affects the temperature, potential photosynthesis, and dissolved oxygen. Latitudinal, seasonal and diurnal gradients affect the amount of light that surface water absorbs. Aphotic and euphotic zone are related to light penetration. Euphotic zone refers to the maximum depth of water column that plants can grow (Wetzel, 1995). The littoral and limnetic zones are contained within the euphotic zone. The littoral zone is situated near the shore where rooted plants grow. It is the most productive zone, because primary productivity in this zone is contributed by floating, submerged and rooted aquatic plants and phytoplankton. Light intensity and nutrients is high in this zone. Waters are well mix by wind. Limnetic zone is an open area of lake from surface to the depth where sunlight can penetrate. At the end of this zone is referred as the compensation level and described as the point that photosynthesis and respiration are equally balanced. In this depth light decreased to about 1 percent of that at the surface (Goldman and Horne, 1983). The producer in limnetic zone is only phytoplankton. The profundal zone is the deep, dark water that sunlight cannot penetrate. In the bottom zone (below profundal zone) of freshwater there is benthic life comprised of decomposers and insects larvae. Decomposition increases nutrient content and other harmful substances such as hydrogen sulphide or ionized ammonia (Chareonpanich *et al*., 1994). Hydrogen sulphide is very toxic, but ionized ammonia is a nutrient which is more easily taken up than nitrate. However, if the pH value exceeds 8.5, a rapid increase in unionized ammonia occurs, which is very toxic for fish (Kim *et al*., 2006).

The greatest source of heat in water is solar radiation by direct absorption. Transfer of heat from the air and from the sediments occurs in relatively small amounts (Wetzel, 1995). Temperature of surface water is affected by latitude, altitude, and season, time of the day, air circulation, flow and depth of the water body. In turn, physical, chemical and biological characteristic are affected by temperature.

In tropical area, except for the deserts, the temperature is high throughout the year. There are no extreme seasonal changes and most of the flora and fauna generally remain abundant all over the year. Rainfall is the major climatic factor in the tropics, while in temperate regions temperature is the main climatic factor (Ewusie, 1980).

Temperature directly and indirectly affects the vertical distribution of plankton. The direct effect is on plankton mobility which selects certain favorable temperature. The indirect effect is by changing the density and viscosity of water. Indirect effect is on planktons, which are carefully adjusted to flotation (Sze, 1998). There is sufficient solar radiation for photosynthetic processes at the surface water of tropical region. However, intensity of heat damages the phytoplankton cells. Therefore, phytoplankton move vertically to protect themselves from intensity of heat and light at the surface layer.

In tropical lakes, the difference of temperature between the surface and bottom is only about 4.5ºC, sometimes less, even in lakes of great depths. Thermal stratification occurs over a smaller difference of temperature compared to temperate region. Usually 0.3ºC decreases of water temperature per meter is able to onset stratification in tropical lake (Guzman, 2005). Stratification prevents exchange of dissolved oxygen and nutrient elements between upper and lower layers in the water column. Therefore, it can restrict photosynthesis and production (Szyper and Lin, 1990). However, in tropical lakes thermal stratification usually occurs in short duration and is unstable and easily eliminated by wind and water mixing (Guzman, 2005). In reservoirs the use of multi-level off-takes, artificial mixing (Cox *et al*., 1998) or aeration device (Vandermeulen, 1992) is able to destratify and modify the thermal structure.

Electrical conductivity (EC) is a measure of the ability of a solution to conduct an electric current. EC relates to total amount of dissolved ions in the water and has positive correlation with trophic gradient and phytoplankton abundance (Diaz *et al*., 2007). Sources of pollutants such as wastewater from sewage treatment plants, agricultural runoff, and urban runoff increases ions in water, which leads to an increase of EC (Nather Khan, 1990a). EC increases also during thermal stratification in hypolimnion due to an increase of decomposition.

Conductivity of the lakes generally is lower during the rainy seasons than dry season. It is due to a dilution by rain and less evaporation during the rainy season, especially in lakes with short retention time (Zinabu, 2002).

Total suspended solids (TSS) and total dissolved solids (TDS) correspond to non-filterable and filterable residue, respectively. Suspended matter consists of silt, clay, fine particles of organic and inorganic matter, soluble organic compounds, plankton and other microscopic organisms. Therefore, turbidity and transparency change seasonally according to biological activity in the water and heavy rainfall (Maitland, 1978). TSS prevents the penetration of sunlight into the water column and has a negative effect on the primary production of phytoplankton (Liu, 2005).

Alkalinity is the acid-neutralizing capacities of water. Most natural waters contain low acidity. Alkalinity is the indicator of the concentration of carbonate, bicarbonate and hydroxide, but it may include contributions from borate, phosphates, silicates and other basic compounds. Therefore, lakes that are located near agricultural or urban landscapes have higher levels of alkalinity. Waters of low alkalinity (< 24 mg /l as $CaCO_3$) have a low buffering capacity.

pH is an important variable in water quality assessment. It is affected by many biological (photosynthesis and respiration) and chemical processes (decomposition) in water body and all processes which are related to water supply and treatment. In unpolluted waters, pH is controlled by the balance between the carbon dioxide, carbonate and bicarbonate ions. Daily variations in pH can also be caused by the photosynthesis and respiration cycles of algae in eutrophic waters. High value of pH (more than 8.5) is recorded in waters with high organic content and eutrophic condition (Kalff, 2002).

Dissolved oxygen (DO) is essential to all forms of aquatic life. The DO content of natural waters is affected by photosynthetic activity, temperature, pressure, salinity, and turbulence. Extreme input of organic matters from sewage decrease DO concentration in the reservoir.

In tropical area, rate of decomposition is high at the bottom. Therefore, oxygen production (through photosynthesis) is less than oxygen consumption. Furthermore, the DO levels generally decline with depth and such lakes have clinograde oxygen profiles. By decreasing oxygen levels some sensitive animals may migrate, weaken, or die (Mackinnon *et al*., 1996). The same condition happens in stratified water columns. Khoo *et al*. (2003) reported that sharp stratification of dissolved oxygen between 7 m and 8 m of depths in a deep reservoir Tasek Kenyir. The zone below this depth was anaerobic because of decomposition. Within the anaerobic zone, high levels of sulphide were also detected. Natural eutrophication of the lake is strongly influenced by anaerobic conditions at the bottom (Ciglenecki *et al*., 2005).

Biochemical oxygen demand (BOD) is a measure of the amount of oxygen consumed by microorganisms during the decomposition of organic matter in aquatic water bodies. During the first 5 days microorganisms consume (decompose) more than 80% of carbon components. Therefore, BOD_5 test measures the oxygen demand for carbon components in 5 days. However, this process in tropical areas is complete in 3 days (Hii *et al*., 2006). The rate of oxygen consumption is affected by temperature, pH, the presence of certain kind of microorganisms, and the type of organic and inorganic materials in the water (Sapari, 1996). BOD is high at the bottom of tropical region, due to thermal stratification and high microbial activity. Concentrations of BOD in unpolluted waters are 3 mg/l as O_2 or less (DOE, 2001).

Chemical oxygen demand (COD) is a measure of oxygen that is required for oxidation of organic and inorganic matters in water. COD is affected by sewage and industrial plants. The COD concentration in unpolluted surface waters is less than 25 mg/ l as O_2 (APHA, 1992; DOE, 2001).

1.1.2 Nutrients

Nutrients are essential for survival, reproduction and growth of phytoplankton. Extreme input of nutrients into water ecosystems leads to an excessive algal growth which is referred to as eutrophication. In fresh water, reducing the input nutrients, especially phosphorus and nitrogen are able to control eutrophication (Kalff, 2002).

The forms of nitrogen in water are dissolved inorganic nitrogen (DIN) and dissolved organic nitrogen (DON). DIN is comprised of N_2, ammonium, nitrite and nitrate (Welch, 1992). Nitrogen enters the ecosystem from the atmosphere through biological process (nitrogen fixation). Ammonia constitutes the first stage in mineralization of organic nitrogen. Phytoplankton may prefer to use ammonium than other forms of nitrogen. Ammonia may also be exchanged between sediments and the overlying water. Ammonia occurs in small amounts in natural waters (less than 0.1 ppm). The amounts exceeding 2.5 ppm are generally lethal and the quantities of more than 1 ppm usually indicate organic pollution. Usually the sources of ammonia pollution are from domestic sewage, industrial waste and fertilizer run off. High ammonia concentrations may also be found at the bottom of tropical lakes which are anoxic.

Other forms of DIN are nitrite and nitrate. Most of nitrite rapidly oxidizes to nitrate. Nitrate ion is the common form of combined nitrogen in natural waters and is an essential nutrient for aquatic plants. Generally, nitrate is not in great amount in natural water. Water may become enriched in nitrate by changes in the drainage area (Welch, 1992). These changes can be seen in rural and suburban areas, where inorganic nitrate fertilizers (usually ammonium nitrate or ammonium phosphate) are used in agricultural land (Moss, 1998).

Phosphorus exists as dissolved and particulate forms in water. The forms of dissolved phosphorus (orthophosphate or soluble reactive phosphate) are inorganic and organic phosphorus. Total phosphate represented by organic and inorganic dissolved phosphorus and phosphate which is attached to particulate matter. Natural sources of phosphorus are mainly from rocks. Decomposition of organic matters at the bottom of stratified water provide inorganic nutrient (nitrogen and phosphors component) for algal growth in tropical reservoirs and lakes (Kalff, 2002).

Organisms need phosphorus compounds for their maintenance. It is generally the limiting nutrient for algal growth. There is general agreement that an increase in nutrients, particularly phosphorus, is necessary to develop eutrophication. Phytoplankton carries away phosphorus after dying and sinks to the lake bed. Restoration of phosphorus to the upper waters is carried out by inflow of water rich in phosphorus, and by the return of phosphorus contained in the dead phytoplankton or other materials through phosphorus cycle (Cole, 1979; Goldman and Horn, 1983).

Relative amounts of major nutrients (C, H, O, N and P) are important for the growth, biomass, physiological state, and community structure of phytoplankton (Aralar *et al*., 2004).

The major limiting factors in aquatic ecosystems are nitrogen and phosphorus. A water body is nitrogen limited when N/P mass ratio is less than 9:1 based on Salas and Martino (1991) and 10:1 based on Welch (1992). In this condition, phytoplankton species that can fix atmospheric nitrogen (e.g. Cyanophyta) can grow well. Water bodies with N/P ratios greater than 20:1 are considered phosphorus limited. Anton and Abdullah (1982) studied the effects of nutrient enrichments on phytoplankton composition in Ulu Langat Reservoir, Selangor, Malaysia. Their results showed obvious changes in phytoplankton composition in response to the addition of both NO_3-N and PO_4-P. When nitrogen was the limiting factor, the dominant group was Cyanophyta, followed by Bacillariophyta.

The N/P ratio provides valuable information on the trophic state of water bodies (Grayson *et al*., 1997). Oligotrophic lakes have higher N/P ratio than eutrophic lakes. Welch (1992) reported the N/P ratio of 70/1 in oligotrophic lakes while the ratio in hypertrophic lakes was 4/1.

1.1.3 Physico-chemical assessment

Anthropogenic factors as well as natural processes degrade surface waters and impair their use for drinking, industry, agriculture, recreation and other purposes. Due to the spatial and temporal variations in water chemistry, a monitoring program and reliable estimation of the quality of surface waters are necessary. Water quality index (WQI) is very useful for the classification of the monitored waters. The WQI can give an indication of the health of a reservoir. This index is a mathematical instrument used to transform large quantities of water characterization data into a single number, which represents the water quality level (Sanchez *et al*., 2007).

Department of Environment Malaysia (DOE-UM, 1994) has proposed a regional classification of WQI (Table 1.2). WQI is widely used in water quality assessment of rivers. However, it is also applied in lentic water by some researchers (Hernandez-Romero *et al*., 2004; Sanchez *et al*., 2007; Othman *et al*., 2007).

Table 1.2: Water Quality Standards for Malaysia (DOE, 2001).

Parameters	**unit**	**Class I**	**Class II**	**Class III**	**Class IV**	**Class v**
pH		6.5 - 8.5	6 - 9	5 - 9	5 - 9	
EC	µS/cm	1000	1000		6000	
DO	mg/l	7	5 - 7	3 - 5	< 3	< 1
BOD	mg/l	1	3	6	12	>12
COD	mg/l	10	25	50	100	> 100
Dissolved solid	mg/l	500	1000		4000	
Suspended solid	mg/l	25	50	150	300	> 300
NH_4^+	mg/l	0.1	0.3	0.9	2.7	> 2.7
NO_3^-	mg/l	natural	7		5	> 5
WQI		91-100	71-90	51-70	26-50	0-25
Water quality		Excellent	Good	Medium	Bad	Very bad

1.1.4 Algae as bioindicator

Aquatic systems contain a wide variety of microorganisms, which interact with each other in various food webs. One of the main types of microorganisms in aquatic ecosystems is plankton.

Phytoplankton are microscopic photosynthetic organisms having little or no resistance to the currents and living free-floating in open or pelagic waters. They are found in unicellular, colonial or filamentous forms (APHA, 1992). Phytoplankton is a photosynthetic plant and is grazed by zooplankton and small fish (Buraschi *et al*., 2005). There are various phytoplankton classifications. Kalff (2002) classified phytoplankton based on respective pigmentations into eight divisions: 1) Cyanophyta (Blue-green algae) 2) Chlorophyta (Green algae), 3) Chrysophyta (Golden-brown algae), 4) Bacillariophyta, 5) Cryptophyta, 6) Pyrrophyta (Dinoflagellate), 7) Euglenophyta, and 8) Rhodophyta (Red algae).

Growth and reproduction of organisms are related to their particular requirements. Therefore, the presence or absence of particular species indicates the conditions of an environment. The use of bioindicator in environmental monitoring has some general advantages over chemical assessment, such as (1) reducing the cost for frequent sampling and analysis (Wu *et al*., 2005), (2) the equipment is relatively cheap (Kienzl *et al*., 2003), (3) relatively simple analysis (Zbikowski, *et al*., 2007), (4) the possibility to detect short term changes in water quality as well as long term changes in environment, and (5) sensitivity to various factors that affect the environment (Stein *et al*., 2007). This led to a global trend of using biological criteria in environmental assessment and pollution monitoring (Wu *et al*., 2005).

Ideally all types of organisms (bacteria, algae, rooted plants and invertebrates) are suitable as indicators of pollution and should be studied, but their suitability depends upon laboratory facilities, technical skills and the objectives of the study. Each organism has advantages as indicator of ecosystems, and it is important that the organism reflect the situation of the study area (Anton, 2000). The advantages of using algae as a bioindicator are: algae responds rapidly to environmental changes and their reproduction is in short period. Algal sampling is easy, cheap and provides unique information compared to big sized organisms. Furthermore, algae are important in aquatic ecosystem as primary producers and to form bloom. Finally, phytoplankton have worldwide distribution and they are available everywhere (McCormick and Cairns, 1994).

Different biological assessments show various characteristics of phytoplankton, such as chlorophyll *a*, species diversity, evenness, species richness, and similarity indices. Multivariate analyses show the community structure and primary productivity is a community metabolism characteristic. Saprobic and trophic indices, and Palmer scale are characteristics that reflect the ecosystem conditions such as water quality, pollution and trophic levels (McCormick and Cairns, 1994).

The green pigment (chlorophyll) is present in most photosynthetic organisms and provides an indirect measure of algal biomass and an indication of the trophic status of a water body. It is usually included in assessment programme for lakes and reservoirs, since excessive algal growth makes water unsuitable or more difficult to treat (Kuo *et al*., 2007).

The growth and density of planktonic algae in a water body is related to many biotic factors such as grazing by zooplankton or other organisms and abiotic factors such as nutrients (principally nitrates and phosphates), temperature and light (Goldman and Horn, 1983).

The photosynthetic production of organic matter from inorganic substances under light in aquatic system is called primary production. Phytoplankton communities are the main producers in the water column. Measurement of primary productivity can show population of phytoplankton, trophic state, and penetration rate of light and energy available for secondary producers (Sorokin, 1999).

1.1.5 Saprobic System

The evaluation of water quality based on self-purification zone of phytoplankton (saprobic indicators) is widely used in European and Asian countries (Walley *et al*., 2001; Barinova *et al*., 2004). Kolkwitz & Marsson (1902) developed the saprobic system for assessment of organic pollution using animals and plants assemblages. The lists of indicator species of alga, zooplankton, and benthic, were added by other researchers (Ismaely Sari, 2000).

In saprobic system, the classification of water body is made according to the amount of saprobic activity. The purpose of this index is for the arrangement of water bodies on a numerical scale according to their saprobity (Heckman *et al*., 1990; Ismaely Sari, 2000).

The saprobic system is applicable only to organic pollution undergoing bacterial decomposition and is unsuitable for the assessment of toxin or other pollution. This index is applicable for natural small water bodies and artificial reservoirs. It is also applicable to all fresh water and marine environment which contain organic matter pollutants. In other words, this system can be used in a wide range of aquatic environment, such as assessment of water quality for drinking water, industrial and surface water pollution (Dokulil, 2003).

1.1.6 Trophic State

High trophic state may lead to eutrophication (Smith *et al*., 1999). Therefore, trophic state is an indicator of pollution and water quality level.

Trophic state is assessed with different methods, such as direct measurement of nitrogen and phosphorus compound concentrations (predictors) (Vollenweider, 1975). Other researchers utilized the effects of nutrient enrichment (response variables) through indirect measurement such as an increase in algal biomass and turbidity, or oxygen depletion (Cruzado, 1987) (Tables 1.3 and 1.4). Many researchers used both types of measurements in trophic state assessments. For example, Carlson (1977) established a classification of trophic state based on combined biological parameter (chlorophyll-*a*), physical parameter (Secchi disk transparency) and chemical parameter (phosphate). Phosphate concentration was used as one of the variables because it limits algal growth in most lakes. Chlorophyll-*a* is one component of this classification, because of the link between chlorophyll-*a* and phosphate, and its contribution to algal biomass. Transparency is influenced by the absorption characteristics of the water and its dissolved and particulate matter. In a water body with low TSS, the Secchi disk transparency is influenced by biological components, especially algal density (Welch, 1992).

Carlson’s formula was conducted mainly in temperate lakes with phosphate limitation. This method was modified by Kratzer & Brezonik (1981) for lakes in other region with nitrogen limitation.

Table1.3: Lake trophic status (City of Lakeland, 2001).

Trophic class	**Typical Characteristics**	**Transparency depth (cm)**	**Chlorophyll (algae) (µg/l)**	**Total Phosphorus (µg/l)**	**Total Nitrogen (mg/l)**
Oligotrophic	Low nutrients, clear water, few plants	>39.6	<3	<15	<0.04
Mesotrophic	Moderate nutrients, dominated by plants or algae, good water transparency	24.4- 39.6	3 - 7	15 - 25	0.04 - 0.06
Eutrophic	High nutrients, frequent algae blooms and/or dense grass beds, moderate to poor water transparency	9.1- 24.4	7 - 40	10 - 25	0.06 - 1.50
Hypereutrophic	High nutrients, persistent algae blooms, poor water Transparency	<9.1	> 40	>25	>1.50

Table 1.4: Lake trophic classifications based on Wetzel (1983).

Parameter		**Oligotrophic**	**Mesotrophic**	**Eutrophic**
Total Phosphorus	Average	8	26.7	84.4
(µg/L)	Range	3.0-17.7	10.9 - 95.6	16.0 – 386.0
Chlorophyll-*a*	Average	1.7	4.7	14.3
(mg/m^3)	Range	0.3 - 4.5	3.0 – 11.0	3.0 – 78.0
Transparency	Average	9.9	4.2	2.6
depth (m)	Range	5.4 - 28.3	1.5 – 8.1	0.8 – 7.0

1.1.6.1 Trophic state and phytoplankton community

Some of the trophic classifications are based on phytoplankton community (Mason, 1991). Palmer (1980) introduced the list of algae that are important in eutrophic lake. These species are *Merismopedia, Anabaena, Microcystis, Lyngbya, Oscillatoria, Rivularia, Chroococcus*, *Ceratium hirundinella*, *Closterium, Cosmarium, Ankistrodesmus falcatus*, *Scenedesmus, Oocystis, Asterionella formosa, Gyrosigma attenuatum, Melosira granulata, Navicula, Nitzschia, Tribonema,* and *Euglena.* There is also a list of phytoplankton species from Hutchinson (1957) in different trophic state. According to his studies oligotrophic lake has species of *Staurastrum*, *Cyclotella* and *Dinobryon*. *Pediastrum* and *Peridinium* are indicators of mesotrophic and eutrophic water while *Crucigenia, Dictyosphaerium* and *Tetraedron* are indicators of eutrophic state in his classification. *Asterionella* and *Melosira granulata* may be observed in oligotrophic lake as well as eutrophic lake (Hutchinson, 1957). In other study *Snowella* (Lepisto and Rosenstrom, 1998) was identified as indicators of eutrophic condition. *Arthrodesmus incus* and *Diatoma vulgaris recorded* as oligotrophic species in Heinonen (1980) trophic classification.

Classification of trophic state is feasible by the results obtained in saprobic system (Dokulil, 2003).Therefore, identification of phytoplankton species provides useful information on trophic state in water ecosystems.

1.1.7 Community structure analysis as indicator of water conditions

Diversity is a parameter of community structure which is related to the number of species (species richness) and abundance. This parameter is presented in several ways by different researchers. One of the common diversity indices is Shannon-Wiener index (H′) (Krebs, 1999). H′ has been used widely in environmental monitoring (Washington, 1984).

Rakocevis-Nedovic and Hollert (2005) found that with decreasing H′ value, the trophic status shifted from oligotrophic to eutrophic condition. According to the study of Salusso and Morana (2002), there are 3 classes of pollution status based on H′. In their scale, water bodies with H′ more than 3 has no contaminant, H′ values ranged 1-3 contain moderate contaminants and H′ <1 indicates high pollution level.

In some studies, species richness and evenness were used to compare of different trophic status (Kitsiou & Karydis, 2000). Wilham and Dorris (1968) and Wilham (1970) also proposed a water quality classification based on H′.

1.1.8 Biomonitoring in Malaysia

In Malaysia, most of the information in water quality studies were not published or they are available through regional seminars, or internal university presses. Water quality assessment was carried out based on different aspects such as physical and chemical pollution. It was found that the main physical pollution of reservoirs in Malaysia is from sediment. Ringlet Reservoir was clogged due to high levels of sediment. This environmental problem has sharply reduced fish production in Ringlet Reservoir (Ho, 1994).

Malaysian rivers and reservoirs are suffering from an increase of population and urbanization, industrialization and agricultural activities (Sumiani *et al*., 2007). These pollution sources negatively affected the ecosystem as reflected by chemical elements in aquatic water bodies.

Fulbright (1982) observed that surface water on the west coast in Peninsular Malaysia had high suspended dissolved solids and alkalinity. He concluded that surface water was deteriorated due to urban development. Ulu Lepar wetland (Nather Khan, 1990a) and Sungai Kecil (Nather Khan, 1990b) showed low water quality, affected by palm oil factories around the water bodies and discharge of domestic wastes from the nearby household areas. Mohamed *et al*. (2002) found that because of pollution, most rivers in Sabah have wide variations of suspended solids (SS) and COD concentrations. Othman *et al*. (2007) investigated water quality of Chini Lake in Peninsular Malaysia. Based on their study, water quality in Chini Lake was in Class II (good quality). However, some stations showed lower class of water quality (class III) because of the expansion of agricultural land (palm oil tree).

Some of the researchers focused on the relation between water quality degradation and biological indices and community. Yeng (2006) showed that the increase of water pollution was associated with the appearance of certain phytoplankton (dinoflagellate) in the Ahning Reservoir. Nather Khan (1991) reported higher diversity values of phytoplankton in the moderately polluted stations compared to polluted stations in the Linggi River Basin Malaysia. Yap (1997) used H′ and saprobic index of phytoplankton for water quality assessment of river ecosystem. He concluded that ecological knowledge can be used in the management of water body. Ho & Peng (1997) also worked on H′ values of phytoplankton community in three rivers (Sungai Perlis, Sungai Perai and Sungai Juru) in northern Peninsular. They classified the three rivers in class III (slightly polluted) based on H′ values. Periphytic algae in the Pinang River were studied by Wan Maznah and Mansor (2002). They reported that the sampling stations with higher value of saprobic index (higher level of water pollution) had the most tolerant species of diatom which are best adapted to the stressful environment.

Distribution and biodiversity of benthic macroinvertebrates in Langat River with different level of water quality were studied by Arzina *et al*. (2006). They defined some sensitive and tolerant species of benthic macroinvertebrates according to their resistance to water pollution. These species can be used as bioindicator of clean and polluted water.

Stobutzki *et al*. (2006) reported the reduction of fish production to 4–20% of the original yields were the result of water quality degradation and habitat alteration in Malaysia.

In Malaysia the determination of trophic state mainly conducted by measurement of physico-chemical parameters, primary productivity and chlorophyll-*a*. In a study conducted in Muda and Pedu Reservoir by Zulkifli (1980), it was found that both reservoirs were slightly eutrophic by moderate levels of nitrogen, alkalinity and pH. There were no villages and settlements in the catchment areas. Thus, the source of nutrient was probably from natural enrichment.

Ali (1996) studied Temenggor and Bersia Reservoirs (hydroelectric power generation dam). His study showed that the reservoir was oligotrophic with low concentration of nutrients such as orthophosphate and nitrate, low primary productivity and chlorophyll-*a*, and high transparency (2-5 m). He concluded that these two reservoirs were unaffected by human activities. Meor *et al*. (2002) showed that the Chenderoh Reservoir, especially in embayment area was at risk of eutrophication, because some of the chemical and biological factors (chlorophyll-*a*, primary productivity and nutrients) were increased compared to earlier studies in this area.

All the studies provided useful information for conservation and maintenance of high quality water resources for various purposes, including human consumption, irrigation, protection of wildlife and native fish populations and recreation.