# PHYSICO-CHEMICAL PARAMETERS AND MICROORGANISMS AS WATER QUALITY INDICATORS OF TELUK BAHANG RESERVOIR AND BATU FERRINGHI TREATMENT PLANT


**YASSER ABDUL KADER AL-GAHWARI**

**UNIVERSITI SAINS MALAYSIA**


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**By**

**YASSER ABDUL KADER AL-GAHWARI**

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## DEDICATION

*To*

*My Father's soul,*

*My loving mother,*

*My wife*

*My brothers and sisters*

*&*

*My relatives*

*For their prayers, patience, devotion and encouragement*

*throughout the entire time spent in completing this thesis.*

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☞ ✐ *YASSER A. M. ALGAHWARI* ✐ ☜

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**ABSTRAK**

Kajian ini telah dijalankan bermula dari bulan Mei 2005 hingga Disember 2006 untuk memantau dan menilai tahap kualiti air Empangan Teluk Bahang dan Loji Rawatan Batu Ferringhi. Sepuluh stesyen telah ditetapkan untuk pengumpulan sampel. Stesyen pertama hingga kelapan adalah disekitar empangan manakala stesyen kesembilan adalah distesyen rumah pam dan stesyen kesepuluh pula di Loji Rawatan Batu Ferringhi (air yang telah dirawat). Pengumpulan sampel dijalankan bagi mengukur parameter fiziko-kimia dan kelompok fitoplankton dan bilangannya, mengenalpasti *oocysts Cryptosporidium parvum, Giardia lamblia cysts*, koliform *faecal* dan bilangan *E.coli.*

Sejumlah 176 spesies fitoplankton telah direkodkan termasuk 65 yang tidak dapat dikenalpasti. Kepadatan fitoplankton ketika kajian ini dijalankan berubah dari $0.68 \times 10^4$ kepada $6.10 \times 10^4$ sel/$m^3$. Kesemua stesyen didapati mempunyai indeks kepelbagaian spesies yang kurang daripada 1. Ini menunjukkan bahawa Teluk Bahang adalah sebuah tasik oligotrofik. Walaupun terdapat petunjuk pencemaran *faecal* dalam stesyen empangan dan air mentah, *Cryptosporidium parvum oocysts* tidak dapat dikesan langsung dalam air yang dikumpul daripada kesemua stesyen. Darjah penghitungan *Giardia lamblia cysts* dalam stesyen empangan adalah dari 0 hingga 38 *cysts*/100L. Berdasarkan pemerhatian, bakteria *E. coli* mempunyai kaitan konsisten dengan kolifom *faecal* dan merupakan penunjuk alternatif kontaminasi *faecal* air yang lebih sesuai.

Hasil parameter fiziko-kimia setiap sampel yang dikumpul diempangan berubah semasa musim hujan dan kemarau. Distesyen pertama, kedua dan ketiga dimana kawasannya mengalami aliran air masuk, air larian hutan, serta pereputan pokok yang tenggelam mempunyai tahap oksigen terlarut yang rendah, nilai turbiditi, pH, konduktiviti, nutrient dan kandungan logam yang tinggi. Kesemua nilai parameter fiziko-kimia yang disebut didapati tidal melebihi syarat Kriteria Kualiti Air JAbatan Alam Sekitar Malaysia dan nilai yang telah ditetapkan oleh World Health Organization (WHO) serta Kementerian Kesihatan Malaysia (MOH) untuk air minuman. Keputusan ini menunjukkan bahawa air empangan yang telah dikaji masih dalam keadaan baik dan berkualiti, sesuai untuk pertumbuhan organisma akuatik dan tidak berbahaya kepada benda hidup.

**PHYSICO-CHEMICAL PARAMETERS AND MICROORGANISMS AS WATER QUALITY INDICATORS OF TELUK BAHANG RESERVOIR AND BATU FERRINGHI TREATMENT PLANT**

## ABSTRACT

The present study was conducted from May 2005 to December 2006 to monitor and evaluate the water quality status of Teluk Bahang Reservoir and Batu Ferringhi Treatment Plant. Ten stations were selected for this purpose. The1$^{st}$-8$^{th}$ stations were in the reservoir, the 9$^{th}$ was station in pump house station (raw water) and the 10$^{th}$ station was in Batu Ferringhi Treatment Plant (treated water). The water sampling were carried out for several physico-chemical parameters and measurements of phytoplankton assemblages and counts, detection of *Cryptosporidium parvum* oocysts, *Giardia lamblia* cysts, faecal coliforms and *E. coli* numbers.

A total of 176 phytoplankton species were recorded including 65 unidentified ones. The abundance of phytoplankton during this study varied from 0.68 x $10^4$ to 6.10 x$10^4$ cells/$m^3$. All stations recorded species diversity index of lower than 1. This reflects that the Teluk Bahang Reservoir is an oligotrophic lake. From this study although there is an indication of faecal contamination in the reservoir stations and raw water, however there was no *Cryptosporidium parvum* oocysts in the water taken from all the sampling stations were detected. The enumeration range of *Giardia lamblia* cysts in the reservoir stations was from 0 to 58 cysts/100 L and the positive samples results of raw water ranged from 0 to 38 cysts/100 L. The results of *E. coli* bacteria have been observed to be in consistent association with faecal coliforms and the first has been found to be an alternative and a more suitable indicator of faecal contamination in water.

The results of physico-chemical parameters varied during the dry and wet seasons at all the sampling stations in the reservoir. Lower dissolved oxygen and higher results of turbidity, pH, conductivity, nutrients and heavy metals were recorded at the 1$^{st}$, 2$^{nd}$ and

3rd stations which faced the stream inflow, forest runoff combined with decomposition of submerged trees in those areas. The levels of all these physico-chemical parameters were found to be under the DOE Water Quality Criteria for Malaysia as well as the acceptable standard values set by the World Health Organization (WHO) and Ministry Of Health, Malaysia (MOH) for drinking water. These results indicate that the reservoir water of the proposed study is still in good conditions and quality, suitable for healthy growth of aquatic organisms and not hazardous to life forms.

# CHAPTER 1

## 1.0 Introduction

### 1.1 Background

Water is an essential natural resource for sustaining life and our environment on this earth. Water is always available in abundance on this planet as a free gift of Allah. Water is not only vital to life but it is also a vital component of healthy functioning of any ecosystem **(Simmons, 1999)** as it is in continuous interaction with the surrounding air and land and living things. Water is also geologically important because of its role in weathering, erosion, transportation and deposition of sediment **(The Atlas of Canada, 2004)**. Unfortunately, unless we use our water wisely, the water bodies such as rivers, lakes, and groundwater etc. can become depleted or polluted, and unavailable or unsuitable for life. Water is not only the survival resource of all living beings but also the main vector for all development activities and is integratedly related with all ecological and societal processes **(Viessman and Hammer, 1998)**.

The aquatic ecosystem is a major subdivision of the biosphere. Almost 71% of the earth's surface area is covered by water. In terms of total volume of water, around 97% of the world's water is saline. This means that less than 3% of the water volume in the world is actually freshwater **(Gleick, 1996)** (Figure 1.1). However, not all of this freshwater is readily available for use by humans and less than 1% of it is used for drinking **(Gray, 1994)**.

One of the main concerns of the 21$^{st}$ century is drinking water. The drinking water has become a subject of constant attention, and it has a focal point of our life and welfare. Malaysia has an annual rainfall of 3000 mm or 990 billion $m^3$ of which 566 billion $m^3$

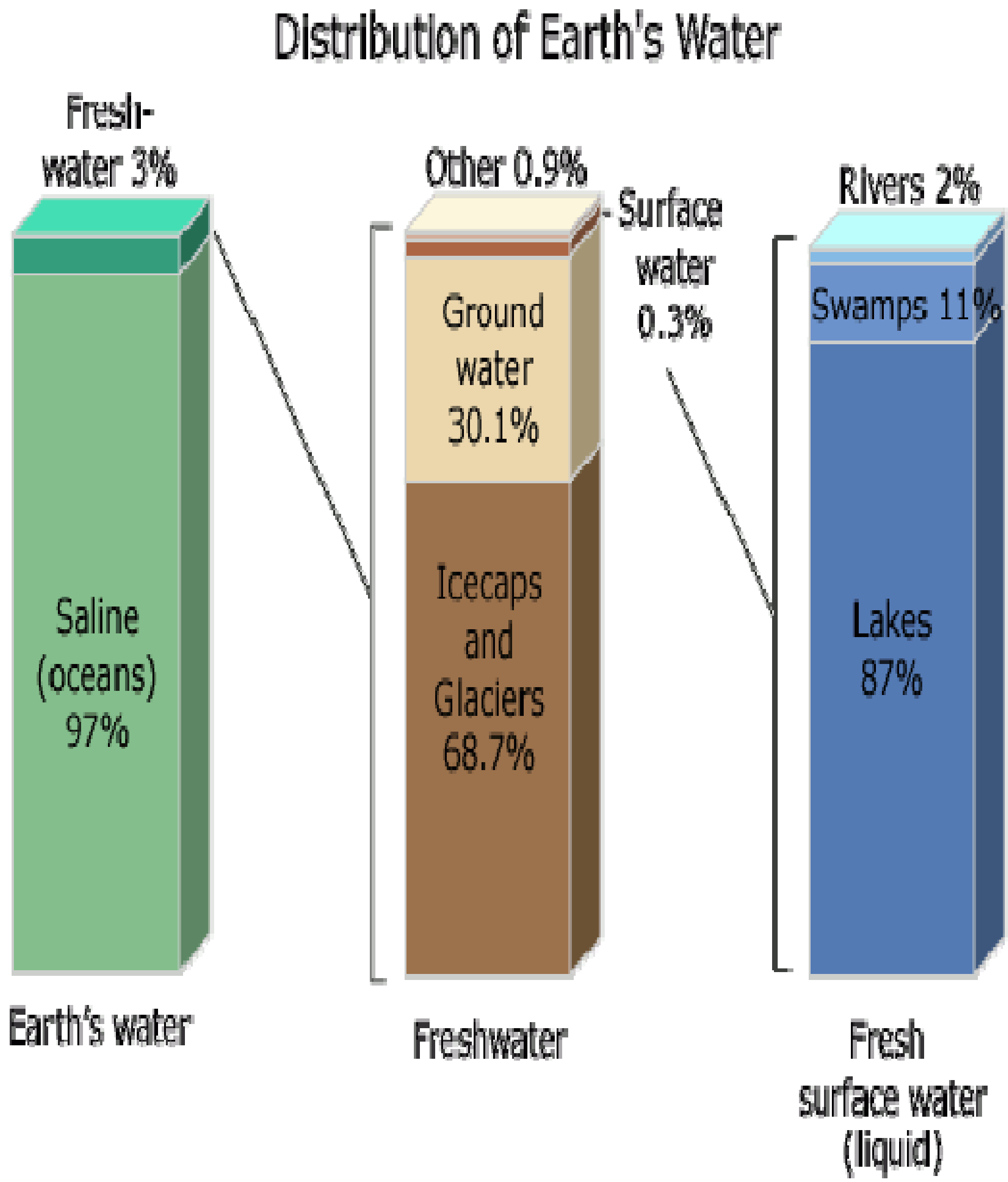


**Figure 1.1** Distribution of Earth's Water according to **Gleick (1996)**.

appears as surface run-off, 64 billion $m^3$ becomes groundwater recharge and 360 billion $m^3$ return to the atmosphere through evapo-transpiration. Being the nation with the highest water consumption, freshwater resources such as streams and rivers are of paramount importance to the development of the country since they contributed up to 98% of the total water used in Malaysia and the rest are from the groundwater **(WWF, 2007)**.

Sources of drinking water such as streams, rivers, lakes, dams, reservoirs and groundwater may be affected or contaminated either directly or indirectly. The direct affection or contamination is caused by chemicals or disease-causing organisms. The sources of contamination may be either human or animal wastes, discharging mostly from the sources within the catchments **(Stein, 2000)**, entering as a result of surface run off, or indirectly by air pollution. Despite the importance of water, people in general, lack access to safe drinking water. Without access to safe drinking water, people cannot lead healthy and productive lives. The World Health Organization (WHO) has repeatedly insisted that the single major factor that is adversely influencing the general health and life expectancy of a population in many countries is ready access to clean drinking water **(Nash and McCall, 1995)**. In developing countries, freshwater is often contaminated and unfit for drinking. One reason for this problem is that in these countries, 90% of urban sewage is discharged untreated into rivers, lakes and coastal waterways. Approximately 900 million people suffer from water-related diarrheal illnesses each year. Millions more suffer from water-related diseases such as cholera, elephantiasis and hookworm **(Gore, 2005)**.

Fresh surface water, as the main source of drinking water, is important for human water supply especially in Asia whereby the people are directly dependent upon this source (**Foster, 1995)**. Scientists are becoming increasingly concerned about the potential public health impact of environmental changes originating from human activities and natural resources **(Carpenter, 2002)**. In Malaysia, river water is the main source of constructed dam's water which is supposed to be the main source of safe and reliable drinking water especially after treatment process. Many countries, including Malaysia, are subjected to periods of drought especially during the dry season and, therefore, man made multi purpose reservoirs, including drinking water sources, are very common in these regions. Man made dams and reservoirs have increased in Malaysia but published works on the limnology of these sources remains limited **(Ho, 1995)**. There are over 50 reservoirs that have been built all over Malaysia and many are still in construction to fulfill the high demand of clean water supply as well as for irrigation and domestic demand **(Ali, 1997)**. One of the early attempts of limnological study was done by **Lai and Chua (1980)** on Muda and Pedu Reservoirs. Their work provided useful information on water quality status and fish diversity of the reservoirs. Other researchers **(**e.g. **Jalal et. al., 1999; Yusoff and Ambak, 1999)** studied the physical and chemical characteristics of Kenyir Reservoir.

Freshwater acts as chemical medium for the transport of various substances. These substances are sometimes referred to as constituents, contaminants or pollutants. Generally, the waterbodies in the world receive loads of nutrients derived from natural (forests) or human activities - mainly industry and urban effluents - creating favorable conditions for microorganisms blooming especially phytoplankton **(Bouvy et. al., 2000)**.

Surface water may become contaminated by chemicals or disease-causing organisms from animal and human waste as a result of surface runoff and waste disposal directly into streams. Many areas in Malaysia are now confronted with decline in quantity and quality of existing water resources. On the other hand, economic development has put pressure on the natural environment leading to a negative impact on the life supporting ecosystem (**DOE, 2003)**. With increasing demands on water resources and contamination from human activities the potential outbreaks of water-borne disease in Malaysia continue to grow. The quality of treated and untreated water is typically determined by monitoring microbial presence, especially faecal coliforms bacteria, phytoplankton, parasites, and physico-chemical properties **(DWAF, 1996; USA-EPA, 1999)**. Although nature has some ability to recover from many kinds of environmental damage, water resources must be protected and properly monitored and managed at all time. Conservation of freshwater ecosystems is of the priorities to the World Life Fund. These freshwater resources and ecosystem will only be conserved through management based on the ecological conditions of these sources **(Schot et. al., 2001)**.

Certain knowledge of the responses of biota to changes in water quality of reservoirs could constitute an important tool to be used by water managers to continually and rapidly assess the quality of waters that they are managing. Management of river and dam water quality has become increasingly important due to decline in water quality caused by human activities or run off. Successful implementation of efficient management strategies requires the monitoring of water quality changes. A monitoring program and a preventative and reliable estimation of the quality of the surface waters are necessary **(Sa´nchez, et. al., 2007)**. This monitoring simulates and assesses cause and effect relationship of river and dam water quality. However, chemical, physical and biological compositions of surface water are the prime factors on which the suitability of the water for drinking, domestic, industrial or agricultural purpose depends **(Sharma, 2002)**. Data from biomonitoring studies are becoming available and are increasingly used to understand the presence of chemicals in the water body and their effects on human health. This data can also be used to assess environmental risks in specific sites. Water quality data can be indicating that microorganisms are capable of causing effects of public-health significance, and environmental changes. Biological communities reflect the overall ecological integrity and thus provide a board measure of the stressors aggregate impact and an ecological measure of fluctuating environmental conditions.

Currently, the quality of water is estimated through the measurement of microorganisms such as faecal coliforms, *Escherichia coli*, parasites and phytoplankton. The main sources of water contamination are bacteria, phytoplankton (blue green algae), parasites and viruses **(Stein, 2000)**. The bacteria principally come from water contaminated by human or animal faeces. Waterborne disease outbreaks can be traced primarily to the contamination of water with faecal matter. Because of the difficulties of monitoring water for all of the known pathogens that can be transmitted by a waterborne route, indicator organisms (e.g., coliforms, faecal coliforms and *E. coli*) are used widely as surrogates for the detection of pathogens **(Baker and Herson, 1999)**. Coilforms are, therefore, routinely monitored by water supply authorities. Disinfection, mainly by chlorine, usually kills all the bacteria. Blue green algae (Cyanophyta) have become common to be found in the water **(USA-EPA, 1999)**. Toxins may be produced which can damage the liver and the nervous system. Removing the toxins require a special treatment and only boiling the water will not help. Lastly, parasites, a group of microorganisms which include *Cryptosporidium* and *Giardia*, can cause illness. They are often resistant to disinfection but must be filtered out of the water **(USA-EPA, 1999)**.

Coliforms bacteria are common in the environment and are generally not harmful. However, the presence of these bacteria in treated and untreated water (drinking water) indicates that the water may be contaminated with germs that can cause disease. Faecal coliforms and *E. coli* are bacteria whose presence indicates that the water may be contaminated with human or animal wastes. Many researchers in Malaysia such as **Mohd Omar** and **Nik Norulaini (2004)** have studied the water quality of Beris Dam used coliforms bacteria and *E. coli* as indicators of water quality. At the departments which take care of water in Malaysia such as DOE, MOH and PBA, faecal coliforms and *E. coli* are the important parameters and national standard use to be monitored in their water quality monitoring programmes **(DOE, 2003; PBA, 2003; MOH, 2004)**.

Phytoplankton as the primary producers play an important role forming the basis of the food chain. These assemblages exhibit excellent continuity through time and with changes in water quality **(Palumbo et. al., 2002)**. Phytoplankton are sensitive indicators of water quality where changes in their populations can provide information about water chemistry of the aquatic system **(Joy et. al., 1990; Rana, 1995)**. Changes in phytoplankton species can occur under diverse circumstances including the response to a variety of irritants **(Zmarly and Lewin, 1986)**. Fresh water phytoplankton assays are useful in the assessment of the toxicity of municipal, industrial and agricultural wastewater effluents, so investigators such as **Walsh and Alexander (1990)** used phytoplankton as indicators of water quality changes and pollution in their studies. **Rai et al. (1981)** used some algal species as indicators of heavy metals contamination because of their capability to accumulate and concentrate heavy metals.

Realizing the importance of the adverse impact of organic pollutants on aquatic biota, studies were taken to determine the present status of the water quality levels in various water bodies in the world. In Malaysia, many researchers used phytoplankton for water quality monitoring and indicators of organic and inorganic pollution. For example, **Nather Khan (1990)** studied the biological assessment of water pollution in the Linggi River Basin (Malaysia) using diatom community structure and species distribution. While **Phang et. al. (1997)** used some phytoplankton as an indicator of heavy metals.

Measurement and monitoring of other microorganisms have been used to evaluate the impacts of various anthropogenic factors, ranging from increased nutrients, to toxic contaminants, to specific pathogens. Large data bases exist on numbers and types of microorganisms and their activities. A number of microorganisms have been implicated in waterborne diseases, including protozoa, viruses and bacteria. Waterborne disease is usually acute (i.e., rapid onset and generally lasting a short time in healthy people) and most often is characterized by gastrointestinal symptoms (e.g., diarrhea, fatigue, abdominal cramps) **(Byleveld et. al., 1999)**.

Cryptosporidiosis and giardiasis are transmitted via contact with infected person or animal, recreational waters or contaminated drinking water. That represents a significant public health problem **(DWI, 2003)**. *Cryptosporidium* was thought to be the causative agent of the public water supply and swimming pool water outbreaks, indicating a continuing risk of cryptosporidiosis associated with chlorinated water supplies **(Furtado et al., 1998)**. **Kramer et al. (1998)** reported the first cryptosporidiosis outbreak in USA associated with the use of recreational water. The outbreak lasted for approximately 1 month and affected more than 2, 000 people. Exposure to lake water was found to be strongly associated with disease. It is thought that runoff and infected swimmers were the source of the organism.

*Cryptosporidium* oocysts and *Giardia* cysts can be found commonly in the aquatic environment including raw and treated water **(Medema et. al., 1998)**. In Malaysia, human cryptosporidiosis **(Lai, 1992; Kan and Shekhar, 1993)** and giardiasis **(Kan, 1988; Che Ghani, 1993; Norhayati, 2003; Wahab, 2004; Hakim et al, 2007)** have been reported, but none published data are available about the sources of fresh water especially in treated and untreated water. *Cryptosporidiu*m and *Giardia* were studied In Malaysia in stool samples from January, 2000 to April, 2004 by **Nissapatorn et al. (2005)**. They found that eleven of the 1,350 stool samples were positive for *Cryptosporidiu*m and *Giardia* infections; one of the 5 cases was clinically diagnosed as gastrointestinal cryptosporidiosis, while 6 cases were of giardiasis.

The human pathogen *Cryptosporidium parvum* and *Giardia duodenalis (lamblia)* are ubiquitous in the surface waters **(LeChevallier et. al., 1991a**; **Walker et. al., 1998)**, and its transport in surface waters must be understood in order to protect the safety and integrity of water supply systems.

*Cryptosporidium parvum* and *Giardia duodenalis (lamblia)* are of particular public health interest because it can persist for long periods in the environment **(Robertson et. al., 1992)**. It is difficult to disinfect it in water treatment plants **(Korich et. al., 1990)**, and it has been implicated as the cause of many waterborne disease outbreaks **(Roefer et. al., 1996)**.

All the research works done by Malaysian scientists showed their enthusiasm to conserve and sustain the Malaysian freshwater habitats. The chemical, physical and biological components are different from headwater streams to rivers and in the reservoir. It has a strong influence on the ecosystem and the distribution of aquatic life forms at different areas **(Payne, 1986)**. The information obtained is very important to determine the status and quality of a freshwater system. Monitoring and management studies in Malaysia plan to prevent the occurrence of water contamination and eutrophication phenomena **(Ho and Kumarasivam, 1994; Yusoff, 1996; Tong and Goh, 1997)**. It is important to better understand these small reservoirs, especially with regard to changes in water quality as a result of run off or human activities. Therefore, the present focus is on the study of the physico-chemical and biological characteristics of Teluk Bahang Reservoir and Batu

Ferringhi Treatment Plant waters as, to date, no such research has been done on drinking water of these places.

## 1.2 Objectives

The present study looks at the possibility of using microorganisms (*Giardia* cysts, *Cryptosporidium* oocysts, faecal coliforms and *E. coli* and phytoplankton) and physico-chemical parameters as indicators for water quality of the water from Teluk Bahang Reservoir, pump house station (raw water) and treated water (drinking water) from Batu Ferringhi Treatment Plant and may be elucidated with the following objectives.

(1) To obtain specific information on quality and quantity of water from Teluk Bahang Reservoir, raw water (pump house station) and treated water from Batu Ferringhi Treatment Plant based on the results of identified and enumerated microorganisms and concentrations of physico-chemical parameters.

(2) To determine the correlation between the microorganisms' assemblages associated with the physico-chemical parameters, and how this interaction influences on the water quality.

(3) To use the microorganisms as biological indicators of changes in Teluk Bahang Reservoir and Batu Ferringhi Treatment Plant waters.

(4) To identify the parameters that are most important in the evaluation of changes in water quality of Teluk Bahang Reservoir Water.

(5) To evaluate the treatment efficiency and the quality status of treated water (drinking water) in Batu Ferringhi Treatment Plant based on the results of raw and treated water as well as Drinking Water Quality Standards in Malaysia.

# CHAPTER 2

# Literature Review

## 2.1 Man-made Lakes

### 2.1.1 Introduction

Lakes are lentic ecosystem. They are usually deep with little or no sunlight reaching the bottom. They are either man made or formed due to natural tectonic or volcanic processes (**Stanley and Alpers, 1975)**. Lakes with good water quality are used for drinking or recreational purposes like swimming, fishing, boating and picnic area, etc.

The freshwater only makes up to a tiny proportion of water on Earth which is less than 3% of the total water and the rest of about 97% is ocean **(Jeffries and Mills, 1990)**. Freshwater aquatic habitat such as rivers and lakes covered a very small area of the world's landscape. Streams and rivers are the main water source and are called the lotic habitats. The lotic habitat refers to the moving or running water environment, where the physical, chemical and biological components are dominated by strong or weak flow (**Payne, 1986)**. Erosion and disposition are the dominant process of this flowing water environment. Flowing water will carry eroded substrate, organic and inorganic matter into the lakes. The input of these substrates created a different physical and chemical environment of a lake. The standing water environment or lentic habitat has a deeper water depth, higher water capacity, different aquatic macrophytes, and nutrients accumulation compared with the lotic habitat. So, the ecology of lotic habitats differs from lentic systems by the dominance of linked flow, erosion deposition and substrate process **(Goldman and Horne, 1983)**.

When rivers are impounded or dammed to store the freshwater for human utilization, an artificial lake is created. This man-made lake is known as a reservoir. Scientists have defined the man-made lakes as “freshwater bodies created or enlarged by the building of dams, barriers, or excavations” **(Fels and Keller, 1973)**. The design of a reservoir is greatly influenced by its function which includes hydropower generation, flood control, irrigation, industrial consumption, urban water supply, aquaculture and also recreational usage. The environmental characteristics, social and economic aspects are well studied before rivers are impounded **(Petts, 1984)**.

When the reservoir begins to fill, a new physical structure is established. The physical, chemical and biological components change as a result of the transformation of flowing water to a standing water environment. These changes include increases in water residence time, temperature, stratification and reduction in turbulence; decreased in particles and turbidity and sometimes an increase of autochthonous primary production **(Friedl and Wüest, 2002)**. Reservoir is a complex hybrid ecosystem that demonstrates a mixture of characters of both lentic and lotic environment. There are few different aspects between reservoirs and natural lakes. Reservoirs usually have larger drainage basin and surface area compared to natural lakes. Nutrients and sediment loads are much higher in reservoirs than natural lakes. The continued activity of water discharges creates an unstable physical and chemical characteristic in the reservoir **(Ryding and Rast, 1989)**. The water losses are small in natural lake compared to the man-make lake. The man-made lakes environment is influence by water discharge of human activity. Therefore, the understanding of the structure, function and dynamics of a reservoir ecosystem is very important to its future management **(Ryding and Rast, 1989)**.

Rivers are the most important source of freshwater in Malaysia. Rivers and streams with or without impounding reservoirs contribute around 99% of the raw water for water supply in Malaysia with the remaining 1% of raw water coming from groundwater **(Pillay et al., 2001)**. The physical and chemical characteristic have been reported for Gombak River **(Bishop, 1973)**, rivers in Taman Negara **(Mushrifah et al., 1994)** and the Kelang River **(Law et al., 1997)**

Reservoirs in tropical areas are special aquatic ecosystems where physico-chemical characteristics and biological features are strongly controlled by the input of water from rivers and periodic dewatering from which it is structurally different **(Thornton et al., 1990)**. Reservoirs in Asia are very rare, if ever, built for fishery purposes, despite the substantial benefit in fisheries from reservoir damming **(De Silva, 2000)**. In Malaysia, there are over 50 reservoirs that have been built **(Ali, 1997)**. In Penang State, three major impounding dams have been built. Teluk Bahang Dam is one of them. It is in the category of the second largest of Penang's three key dams which supply Penang state the drinking water. These dams supply Penang about 20% of the required raw water. The main source of raw water (≈80%) of Penang is Sungai Dua which flows into Seberang Perai on the main land. Since Penang has a limited total water catchment area of only 61.4 $km^2$, these dams has been constructed to serve as strategic reserves during the annual dry seasons when stream flows drop in Sungai Dua and other rivers. The combined storage capacity of these dams is 46,013 million litres **(PBA, 2003)**. Among reservoirs in Malaysia, Tasik Bukit Merah which was built in 1909 is the oldest man-made lake in Malaysia with a surface area of 3250 ha **(Verdegem, 1999)**. Kenyir Reservoir is currently the largest man-made lake in Malaysia with surface area of 36,900 ha and was built in 1983. Most of the reservoirs in Malaysia also have become recreational and fishing attractions for the local people.

### 2.1.2 Reservoir Characteristic

A reservoir has the characteristics of a lake system. Both reservoir and natural lake tend to gain water from inflowing streams and rivers as well as direct rainfall. However, the water is lost differently between natural lakes and reservoirs. Natural lakes lose water at the surface through evaporation and via rivers **(Payne, 1986)**. The loss of water is usually slow and changes of water level in natural lakes are seldom extreme compared to reservoirs.

The outflow of water in reservoir is controlled by human, compared to the natural lake where water is discharged naturally. The water stored in reservoir is discharged or released based on the function of the reservoir. The discharge of water for hydroelectric power generation is continuous and high flow of tons of water is needed to generate electricity. Reservoir purposely built for rice irrigation will release water during the rice planting activity. The floodplain reservoirs store more water during the rainy season to protect the downstream area from flood damage **(Ryding and Rast, 1989)** and the water level was increased during this period. Therefore, the water level fluctuations are much greater in reservoirs compared to natural lakes. The timing of water discharge and volume also affect the reservoir's characteristic in terms of flora and fauna, biological production, nutrient dynamics, *etc.* **(Thornton et al., 1990)**.

The solar radiations differed with latitude. The solar radiation is important to sustain the ecology of a reservoir in two aspects **(Jeffries and Mills, 1990)**. First, the heating of the water body resulting in the differences in temperature of water mass, mixing and chemical alterations. This will affect the suitability of habitats to the temperature tolerances of aquatic wildlife. The second aspect is to provide light for photosynthesis by plants, either the microscopic algae or the macrophytes.

The different wavelengths of light are differentially absorbed by the water. In the shallow water bodies, the light may penetrate to the bottom and provide sufficient light for photosynthesis **(Petts, 1984; Payne, 1986)**. The reservoir however has a deeper depth and the light compensation is different throughout the whole reservoir. The light penetrating the water attenuates with depth in a reservoir and results in the physical and chemical alterations **(Goldman and Horne, 1983)**.

Light intensity decreases exponentially with depth. When the light strikes the surface of water, it is first refracted, then greatly reflected, absorbed and scattered by the water **(Jeffries and Mills, 1990)**. Thus the light intensity diminishes rapidly below the surface water. The light is rapidly absorbed by the water and only a small portion is available to the phytoplankton for photosynthesis. Therefore, very little light is able to penetrate to the deeper layer of the water column.

The penetration of light into water is called water transparency which can be measured using a Secchi disc **(Goldman and Horne, 1983)**. It is a disc with black and white paint. The disc is lowered into the water until it disappeared from the eye sight. At this level, the photosynthesis rate may equal to the respiration rate and is called the compensation level. The water transparency varies with seasons and changes of the water turbidity. Above this compensation depth is the euophotic zone and below is the aphotic zone **(Jeffries and Mills, 1990)**. The higher light intensity at the euphotic zone enhances the photosynthesis compared to the aphotic zone. The differences in light intensity alter the physical and chemical components at both euphotic and aphotic zone.

The surface water is heated by the sun, therefore the water temperature is higher. Water in the aphotic zone is usually cooler than euphotic zone **(Goldman and Horne, 1983)**. This is due to very little light and heat penetrates to the aphotic zone. The depletion of light intensity from euphotic zone to aphotic zone created a thermal stratification especially in temperate reservoirs **(Payne, 1986)**. The water temperature influenced by the distinct season changes in the temperate which easily establishes a thermocline layer. On the other hand, tropical reservoirs receive more sunlight and heat throughout the year and thermocline is usually observed in the deeper lakes. The diurnal changes also influence the distribution of aquatic organisms and their tolerance of water temperature within the reservoir **(Payne, 1986)**.

Dissolved oxygen is very important to aquatic organisms. Phytoplankton is the main producers of oxygen in the reservoir **(Jeffries and Mills, 1990; Thornton et al., 1990)**. At the euphotic zone, photosynthesis is enhanced by the higher light intensity compared to the limited light in the aphotic zone. Therefore, oxygen concentration is higher at the euphotic zone. Oxygen diffuses into the water under atmospheric pressure and also depends on the surface water turbulence **(Reid, 1961)**. Oxygen concentrations in lakes are related to the lake productivity and lake depth **(Jeffries and Mills, 1990)**. In the upper euphotic zone, oxygen concentrations are higher due to higher lake productivity. In the aphotic zone, most oxygen is consumed for decomposition process and lowered the oxygen level. Factors such as mixing, turbulence, photosynthesis and respiration influence the concentrations of dissolved oxygen in the water **(Jeffries and Mills, 1990)**.

Nutrients are referring to nitrogen, phosphorus, silicon, calcium magnesium and other compounds that are consumed by plants and animals for metabolism process **(Goldman**

**and Horne, 1983)**. In freshwater ecosystem, rivers load the dissolved substances into the reservoir and increase the nutrient concentrations. The ionic substances accumulate in deeper water due to the biological turnover and interaction with the sediments **(Payne, 1986)**. The sinking organic matters in aphotic zone increase the decomposition rate and release more ionic substances in this level. Therefore, oxygen is exhausted from the decomposition process and creates an anoxic condition in the aphotic of reservoir.

The reservoir stratification usually reduces the substrate exchange between surface and deep water, eventually leading to anoxic conditions **(Friedl and Wüest, 2002)**. Nitrate, hydroxides, ammonium and hydrogen sulfide are usually accumulated in the deeper anoxic water **(Petts, 1984; Bellanger et al., 2004)**. The flooded soil and vegetation act as the major source of nutrients at the early stage of impoundment because it begins to decompose and deplete oxygen level in a reservoir. The decomposition can continue for several years and even up to 20 years for tropical reservoirs **(Jeffries and Mills, 1990)**.

The formations of reservoirs through impoundment of rivers also change the biological components and processes **(Goldman and Horne, 1983)**. The changing of flowing water habitat into a standing water environment causes the riverine flora and fauna to adapt to the new environment. There are changes of species composition in the new habitat during the succession process. The riparian plants along the rivers will be replaced by the submerged plants and establishments of lentic species, such as *Salvinia* sp. and *Eichhornia* sp. **(Petts, 1984)**. When flowing water is blocked, fish migration will be interrupted. Fish diversity decreases and their compositions are species which can adapt to live in the reservoir. According to **Thornton et al. (1990)**, the fish production is high at the beginning years after the impoundment. This was due to the higher benthic fauna productivity and greater habitat had brought many effects to its drainage basin area. The reservoir biotic community is low in diversity compared to the river ecosystem and the ecosystem succession rate is greatly influenced by human manipulations and management of the drainage basin **(Ali and Kamaruzzaman, 1996)**.

### 2.1.3 Reservoir Production

In aquatic ecosystems, all the organisms interact with each other from a distinct structure and function at different trophic levels. The organisms that produce their own organic matter are called ‘autotrophs’ (producer, in contrast to ‘heterotrophs’ which use the organic matter produced by other organisms. The autotrophs transform light to chemical energy and the energy transfer from plant to herbivore and to carnivore. At the same time, there is a continuous loss of energy from each population or trophic level through mortality, respiration and execration. The incorporation of new energy and materials into the organisms constituting the biomass is termed production **(Payne, 1986)**. The rate of production is not necessarily related to the size of the organisms or its biomass.

Photosynthesis is the process by which the autotrophic organisms transform absorbed light into energy and organic compounds, which present the primary production. The photosynthetic organisms capture light energy by means of certain pigments such as chlorophylls, and use this energy to fix carbon dioxide into organic compounds **(Lewis and Wang, 1997; Graham and Wilcox, 2000)**. The reaction can be summarized as:

Light Fluorescence

↓ ↑

Chlorophylls

$$nCO_2 + nH_2O \rightarrow nCH_2O + nO_2$$

Not all the light energy is transformed into organic compounds; some may be used for respiration. Thus, the energy produced from photosynthesis is only the gross production. Net production is the remaining material after respiration has been accounted. There is always a small proportion of gross primary production may be lost as excretory or extra products **(Payne, 1986)**. The net production will be either grazed by the first consumer or lost to the decomposer after death.

The primary producers in reservoirs are planktonic algae (phytoplankton), attached algae (periphyton), and rooted macrophytes **(Thornton et al., 1990)**. The attached algal and rooted macrophytes communities are restricted at the littoral zone and thus phytoplankton is the main contributor to reservoir's primary production due to high density. The distribution of phytoplankton depends on wind effect and its mixing between the upper and lower depth.

Light irradiation is important to inhibit photosynthesis process of phytoplankton **(Reynolds, 1984; Kifle and Belay, 1990)**. Surface water receives higher light intensity and certain wave band tends to inhibit the photosynthesis process. Light intensity decrease exponentially with depth and the optimum light occurs at a lower depth. Respiration may also reach a peak at the similar depth as the densities of aquatic organisms may be highest at this level. There is a progressive decline in both net and gross production as light becomes attenuated below the maximum production point. The depth at which oxygen production just equals to oxygen utilization is the compensation point. Thus the production rate is higher at the epilimnion layer. The peak of production is commonly found at some intermediate depth **(Payne, 1986; Barnes and Mann, 1991)**. Lake Lanoa, Philippines showed the same phenomenon where the maximum productivity was recorded at 2 m depth and decreased drastically at the deeper depth **(Lewis, 1974)**.

Nutrients availability is another factor to the photosynthesis process. Even with high light intensities, photosynthesis will be restricted with short supply of nutrients. According to **Payne (1986)** the availability of nutrients is dependent upon two factors; the recycling rate of nutrients between phytoplankton and other components within the system, and the effectiveness and frequency of mixing processes from deeper water to upper layer. Nutrients enrichment may limit the growth rate of phytoplankton and thus influence the reservoir production. Therefore, nutrients, especially nitrogen and phosphorus are the limiting factor in primary production **(Perin et al., 1996)**. Nitrogen is commonly the limiting factor in tropical reservoir, whereas in temperate, phosphate is the principle limiting factor of production **(Payne, 1986)**.

Availability of carbon dioxide also plays an important role in determination of the production. Carbon dioxide is transformed into glucose during photosynthesis. Thus the amounts of carbon dioxide influence the photosynthesis rate of phytoplankton. Photosynthesis will alter the amount of carbon, either soluble carbonic acid or bicarbonate content in the water and change the pH in the reservoir **(Palmer, 1980)**. The rapid rate of production is usually associated with phytoplankton densities. However, under algal blooms conditions, where the densities of phytoplankton are very high, photosynthesis capacity may be lower **(Payne, 1986)**. This is because the competition of light irradiance and nutrients uptake is very high when the phytoplankton populations are denser in the water. The efficiency of nutrients recycling in the reservoir will also be affected.

Lake eutrophication is now a world-wide concern. The main manifestation of this process is a very strong development of primary producers in the euphotic zone and very low oxygen concentration in deep layers of the lake. In highly eutrophic lake, phytoplankton is often dominated by cyanobacteria **(Zohary and Breen, 1989; Lindholm and Eriksson, 1990)**. These organisms form water blooms at the surface which strongly reduce light penetration in the water column; most cyanobacteria species are toxic, their massive development compromise drinking water production and leisure activities. The observations in Lake Östra Kyrksundet as reported **by Lindholm and Eriksson (1989)** and previous work on eutrophic freshwater reservoirs (with fish and bird kills associated with cyanobacterial blooms) raise some general questions concerning water quality criteria and the monitoring of toxic cyanobacteria in lakes and reservoirs.

The productivity at the tropical reservoirs is always higher than temperate **(Lewis, 1974; Ryding and Rast, 1989)**. The constant water temperature ensures the stable growth rate of phytoplankton in tropical compared to the temperate. Small and shallow lakes tend to have higher net production because phytoplankton biomass is more concentrated **(Perin et al., 1996)**. Therefore, the absorption of light and nutrients is higher and the production rate is increased. The distribution of phytoplankton, light intensity, nutrients enrichment, phytoplankton density and interaction of physical and chemical components are the controlling factors of reservoirs production **(Lewis, 1974; Reynolds, 1984)**.

The study of reservoir's productivity had been reported at Temenggor Reservoir **(Hashim and Ali, 1999; Meii and Ali, 2000)**, at Muda and Pedu Reservoir **(Ishak, 1996; Othman, 1996),** at Timah Tasoh **(Ali, 2002)** and Chenderoh Reservoir **(Meor et al., 2002)**. The production rate was influenced by the phytoplankton populations in the reservoir. The reports also stated that high abundance of phytoplankton decreased the light penetration and thus lowered the production rate.

One of the early attempts of limnological study was done by **Lai and Chua (1980)** on Muda and Pedu Reservoir. The work provided useful information on water quality status and fish diversity of the reservoirs. The physical and chemical characteristics also have been studied in Kenyir Reservoir **(Jalal et al., 1999; Yussof and Ambak, 1999)**, and Temenggor and Bersia Reservoir **(Ali, 1996)**. The ecological characteristic of the reservoir is significantly influenced by the sediment transport and deposition **(Thornton et al., 1990)**. The effects of soil erosion and sedimentation on Malaysia water resources also had been reported **(Rahaman and Ismail, 2002)**.

## 2.2 Water Treatment

### 2.2.1 Natural impurities in raw water

In nature, water contains some impurities. As water flows in streams, sits in lakes, and filters through layers of soil and rock in the ground, it dissolves or absorbs the substances that come in its contact. Some of these substances are harmless. Some contaminants come from erosion of natural rock formations. While other contaminants are substances discharged from human activities such as applied to farmlands, or used by consumers in their homes **(Viessman & Hammer, 1998)**. Sources of contaminants may be in close neighborhood or may be many miles away.

The impurities present in the water source can be in the form of dissolved and colloidal natural organic and inorganic matter, as dissolved salts, and as suspended material such as clay, silica, microbial cells as algae **(Palumbo et al., 2002)**. Some of the more commonly found natural components containing organic materials are, in decreasing size order, zooplankton, phytoplankton, bacteria, parasites, viruses, clay-humic acid complexes, humic acids, proteins, polysaccharides, fulvic acids, and very small species such as fatty acids, carbohydrates, amino acids, and hydrocarbons. They are formed by the biological degradation of organic life substances **(Thurman, 1985)**, and include highly coloured compounds. Inorganic salts of natural origin are also present to some degree.

Dissolved organic compounds, defined as those which will pass through a membrane having pores of 0.45 μm size, when measured as dissolved organic carbon (DOC), have levels in the range 0.10–115.00 mg/l, with 5.75 mg/l being reported as a global average for streams **(Boggs et al., 1985)**. DOC poses a problem for the water treatment industry for a number of reasons. Apart from the aesthetic problems of colour, taste and odour, its presence poses a health hazard because of the formation of potentially carcinogenic chlorinated hydrocarbons when the water is disinfected with chlorine—the well-known problem of disinfection by-products (DBPs). Furthermore, DOC exacerbates the deterioration of the microbiological water quality in distribution systems, fouls membranes and ion-exchange resins, interferes with the oxidation of dissolved iron and manganese to insoluble easily removed forms, and can encourage corrosion, especially of copper, but not always of iron **(Broo et al., 1999)**. It can also block the pores of activated carbon filters, hindering adsorption of trace organic contaminants such as taste and odour compounds **(Ding et al., 2006)**. Humic substances are troublesome materials in that they have quite variable properties, in terms of acidity, molecular weight (MW) (several hundred to tens of thousands) and molecular structure (mostly phenolic and carboxylic acid functionalities, but also alcohol, quinone, ether, ester, and ketone groups). They behave as negatively charged colloids or anionic polyelectrolytes at natural pH levels and have surface-active properties, but can interact via their hydrophobic aromatic and aliphatic regions with non-polar pollutants such as pesticides and polychlorinated biphenyls. Humic substances are often present as stable complexes with metal ions. These variable properties influence reactivity, which as mentioned changes spatially and temporally. If the smaller charged organic molecules are first removed from raw water by ion exchange, as proposed in one full-scale plant **(Bourke and Slunjski, 1999)**, a subsequent alum clarification stage is greatly facilitated: larger flocs are formed that settle three times more rapidly, far less organics are left in the product water, and only 25% of the original alum dose is required in a conventional clarification process **(Bursill et al., 1985)**.

Suspended particulate matter is an important component of all natural waters. Particles can range from 10 μm or more down to sub-micron colloidal size **(Thurman, 1985)**. Such material needs to be removed from potable supplies because it supplies a surface onto which microbes can adsorb and be protected from disinfection chemicals by a coating of slime, or the particles themselves may be actual bacteria or oocysts and cysts of protozoa such as *Cryptosporidium* and *Giardia*. Typical suspended solids levels are 2–200 mg/L, although they can be higher than 50,000 mg/L in flooding rivers. The particles have a substantial organic and biological content, typically 1–20%, but are mainly inorganic materials like silica, aluminosilicates and iron and manganese oxides. The charge on the particles is controlled by an adsorbed layer of natural organic matter, as well as by the salinity and the concentration of divalent cations in the water **(Beckett and Le, 1990)**. Humic substances can adsorb onto the particles via surface metal cations. The surface potential of the particles is an important parameter influencing coagulation and adsorption behaviour. It can be monitored via particle microelectrophoresis, and in natural systems is invariably negative, irrespective of the nature of the primary particle **(Beckett and Le, 1990)**. The coating of organics has a strong impact on the amount of coagulant required and the rate of coagulation, slowing the rate markedly at low salinities, but having less of an effect as the salinity increases **(Gibbs, 1983)**.