A LIMNOLOGICAL STUDY OF TEMENGOR RESERVOIR WITH SPECIAL REFERENCE TO THE APHOTIC ZONE

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A LIMNOLOGICAL STUDY OF TEMENGOR RESERVOIR WITH SPECIAL REFERENCE TO THE APHOTIC ZONE

by

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LIST OF UNITS AND ABBREVIATION

C^o = Celcius

g/L = gram per litre

ha = hectare

Hz = Hertz

km/hour = kilometre per hour

L = litre

m = metre

m^2= metre squared

m^3= metre cubic

mg/L = milligram per litre

mm = millimetre

mS/cm = milliSiemens

OD = optical density

s.d = standard deviation

KAJIAN LIMNOLOGI DI TASIK TEMENGOR DENGAN RUJUKAN KHAS KEPADA ZON AFOTIK

ABSTRAK

Kajian bulanan terhadap kesan perubahan musim dan kedalaman ke atas proses fizikal dan kimia air tasik di Tasik Temengor telah dijalankan dari bulan November 2011 sehingga Jun 2012 untuk meliputi musim kering (Disember 2011, Januari 2012, Febuari 2012 dan Jun 2012) dan musim panas (November 2011, Mac 2011, April 2012 dan Mei 2012) berdasarkan data taburan bulanan hujan. Dalam kajian ini, parameter fizikal telah diukur secara *in-situ* manakala parameter kimia, sampel air diambil dari kedalaman yang berbeza (permukaan air, kedalaman Secchi, 5 m, 10 m, 15 m dan 20 m) di lima stesen kajian. Berdasarkan keputusan yang diperolehi, purata kedalaman Secchi berjulat 2.01 m sehingga 2.31 m. Dalam kajian ini, parameter fizikal seperti suhu air berjulat 29.8ºC sehingga 30.0ºC, kandunganoksigenterlarutberjulat 6.8 sehingga 7.6 mg/L dan pH berjulat 7.82 sehingga 8.76. Secara kasarnya, bacaan untukketiga-tiga parameter ini adalah tinggi di permukaan air tetapi berkurangan secara beransur-ansur dengan kedalaman. Manakala, konduktiviti berjulat 0.033 sehingga 0.039 mS/cm, paras pepejalterlarutberjulat 0.019 sehingga 0.023 mg/L, kandungan ortofosfatberjulat 0.022 sehingga 0.059 mg/L, nitrat-nitrogen berjulat 0.015 sehingga 0.028 mg/L, nitrit-nitrogen berjulat 0.0006 sehingga 0.0016 mg/L dan klorofil *a* berjulat 1.55 sehingga 3.52 mg/L. Keenam-enam parameter ini adalah rendah di permukaan air dan semakin meningkat apabila kedalaman air bertambah. Parameter fizikal yang diukur kecuali suhu (ºC) adalah lebih rendah semasa musim hujan manakala parameter kimia yang diukur adalah lebih tinggi semasa musim kering kecuali

kepekatan nitrat-nitrogen. Kajian batimetrik dijalankan untuk memetakan kedalaman dasar lima stesen kajian di TasikTemengor. Kedalaman maksima yang direkod adalah di Stesen 3 dan Stesen 4 sedalam 80 meter. Berdasarkan keputusan parameter fizikal dan kimia yang diukur dalam kajian ini, Tasik Temengor boleh diklasifikasikan sebagai tasik mesotrofik. Asas ekologi yang kukuh dapat memastikan Tasik Temengor beroperasi secara optimum. Penambaikan kajian yang lebih mendalam tentang proses eko-hidrologi di TasikTemengor dapat dijadikan sebagai asas untuk merangka program pengurusan, pemulihan dan konservasi yang lebih baik.

A LIMNOLOGICAL STUDY OF TEMENGOR RESERVOIR WITH SPECIAL REFERENCE TO THE APHOTIC ZONE

ABSTRACT

A monthly study was conducted to analyze the influence of seasonal change and water depths on physical and chemical processes in the water column of Temengor Reservoir from November 2011 until June 2012 to cover the dry (December 2011, January 2012, February 2012 and June 2012) and wet season (November 2011, March 2012, April 2012, and May 2012) based on the monthly rainfall distribution obtained. In this study, the physical parameters were taken *in-situ* whereas for chemical analysis, water samples from different depths (surface water, Secchi depth, 5 m, 10 m, 15 m and 20 m) of five sampling stations were collected. Based on the results, mean of Secchi depth ranged from 2.01 m to 2.31 m. For physical parameters such as water temperature, it ranged from 29.8 to 30.0ºC, dissolved oxygen ranged from 6.8 to 7.6 mg/L and pH ranged from 7.82 to 8.76. Roughly, the values for these three parameters were high at surface water but decreased gradually with depths. On the other hand, conductivity ranged from 0.033 to 0.039 mS/cm, total dissolved solids level ranged from 0.019 to 0.023 mg/L, concentrations of orthophosphate ranged from 0.022 to 0.059 mg/L, nitrate-nitrogen ranged from 0.015 to 0.028 mg/L, nitrite-nitrogen ranged from 0.0006 to 0.0016 mg/L and chlorophyll *a* ranged from 1.55 to 3.52 mg/L. These parameters were low at surface and increased with deeper water depths. The measured physical parameters except temperature (ºC) were slightly lower during wet season whereas the measured chemical parameters except nitrate-nitrogen were slightly higher during the dry season. Bathymetry study was conducted to map the benthic elevation of five

sampling stations in Temengor Reservoir. The maximum depth recorded was at Station 3 and Station 4 with 80 metres. Based on the findings of measured physical and chemical parameters from this study, Temengor Reservoir can be classified as a mesotrophic lake. A solid ecological foundation can achieve the utmost operation of Temengor Reservoir. Improvement of in-depth research works studying the eco-hydrological process of Temengor Reservoir would provide a basic tool necessary to frame a better management, restoration and conservation programme.

CHAPTER 1

INTRODUCTION

1.1 General introduction

Limnology refers to the study of inland aquatic systems involving freshwater ecosystems which include reservoirs, rivers, streams, ponds and wetlands. Basic ecological study covers the physical, chemical, biological and geological characteristics of an ecosystem. Comprehension on the complex reactions between these basic attributes of inland waters is vital as they can be viewed as important factors that will manage an ecosystem by providing and maintaining the available conditions (Wetzel, 2001). In order to maintain the sustainability of a reservoir, basic ecological information is necessary. Data regarding water quality and nutrient levels are essential to develop a wise management plan.

A new aquatic ecosystem is developed due to the technology of dam construction. Generally, when a dam is constructed, changes will occur resulting in transformation of a free-flowing river ecosystem to a reservoir habitat (Wetzel, 1983; Haas *et al.*, 2010). Besides, it also causes the terrestrial habitat to turn into aquatic and lotic habitat turns into lentic with significant hydrological changes such as water flow, water volume and depth. Thus, the biodiversity of an aquatic system may be altered due to changes in physical forces (Bunn and Arthington, 2002). Construction of a dam also influences the local people who live surrounding the area especially in terms of its social economic. It has numerous socio-economic benefits and in many places, it has undoubtedly contributed to economic development.

In a tropical reservoir, water column is usually divided into two major zones known as photic and aphotic (dark) zone. Photic zone is the layers that receive enough light penetration to perform photosynthetic activity whereas aphotic zone is the lower layers of water column that receive no light penetration (Lokman, 1992). Therefore, planktonic microalgae from nutrient-rich deep water may be separated due to stratification. Consequently, their ability to harvest light photosynthetically is impaired.

Geographical location plays a major role in determining the limnological character of lakes and reservoirs and it has been long recognized and well-documented (Horne and Goldman, 1994; Jorgensen, 2005; Tranvik *et al.,* 2009). Generally, climate is divided into two main regions which are temperate and tropical areas. Climatic conditions play major role in regulating the physical characteristics of lakes in terms of light duration and intensity, wind activity and atmospheric temperature (Sigee, 2005). A tropical lake shows several similar characteristics to temperate lakes in summer. In tropical areas, seasonal climatic changes are reduced and show seasonality in terms of rainfall (Jorgensen *et al.*, 2005).

Geographically, Malaysia is located near the equator, 5º on the north side. The average wind speed ranges from a high 8 m/s during Monsoon and a low 3 m/s in between the Monsoon (Nor *et al.,* 2014). Due to its geographical location, Malaysia receives abundant of sunlight every year. Monsoon dominates the climate of this country, also known as tropical wet and dry season marks the seasonal differences. There are two main seasons in Malaysia which is wet and dry season (Abd Hamid, 2012).

A shift in species abundance and composition of the flora and fauna is an inevitable effect due to the impoundment of a water body (Agostinho *et al.,* 1999). The ecological characteristic of the reservoir is significantly influenced by the sediment transport and deposition (Thornton *et al.*, 1990). Sedimentation is enhanced due to formation of a reservoir which will reduce the flow velocity (McCartney, 2009). According to Kimmel and Groeger (1986), unique characteristics of a dam such as the ratio of the catchment area to surface area, nutrient loadings and high sedimentation rate will cause the dam to experience degradation much faster than natural lakes. This situation negatively affects the water body and its relationship with other ecosystem.

Bathymetric study is vital to obtain better understanding on the impacts of land processes on the hydrology of lakes. It is an integral part in ecohydrological knowledge of surveying and charting bodies of water. Accelerated eutrophication and sedimentation of inland water is now greatly discussed all over the world (Setiawan, 2012). Application of remote sensing technique can provide spatial distribution of water quality distribution

Vertical profiling studies could provide a sturdy tool in order to obtain a better understanding of limnology and hydrogeochemical processes (Dodson, 2005). One of the significantly important gradients for biological and chemical processes is oxidation and reduction (Agostinho *et al.*, 1999). A process which involves organic materials breaking down in waterways, increase in water temperatures or night-time respiration by dense algal blooms in nutrient-rich waters will eventually lead to oxygen depletion (Müller *et al.*, 2012).

Limnological study of the lentic systems in Malaysia had been carried out for more than forty years (Ho, 1994). Inland water in Malaysia is governed by various sectors (Sharip and Zakaria, 2008). Clean water is made sure to be provided as local supply. Therefore, few agencies were established in the efforts to manage water withdrawals. The enforcement of laws such as Environmental Quality Act 1974 (EQA), Environmental Quality (Prescribed Activities) (Environmental Impact Assessment) Order 1987, Fisheries Act 1985 (Fisheries Maritime Regulations 1967; Amended 1987 and Fisheries: Marine Culture System Regulation) and National Forestry Act 1984 were implemented (Sharip and Zakaria, 2008).

There are many studies conducted by Malaysian scientist with interest to conserving and sustaining the diversity of Malaysia freshwater habitats. Information obtained from these research works is very important in determining the status and quality of freshwater system (Chong *et al.,* 2010; Lim *et al.,* 2011; Shah *et al.,* 2012; Székely, 2012; Karim and Mansor, 2013; Bhuiyan *et al.,* 2014; Wan Maznah and Makhlough, 2014; Zakeyuddin *et al.,* 2014).

Reservoirs in Malaysia were mainly built to meet the high demand of clean water supply for domestic needs, irrigation and especially generation of hydroelectric power (Ali, 1997; Ismail and Najib, 2011; Kamaruddin *et al.,* 2011; Pillay and Zullyadini, 2014). Lake Bera and Lake Chini located in Pahang are the only natural lake in Malaysia, with Lake Bera studied intensively under the International Biological Programme/Productivity of Freshwater Communities (IPB/PF) Program (Sharip and Zakaria, 2008). Kenyir Lake is the largest man-made lake in Malaysia with surface area of 37, 000 ha (Ho, 1994).

A number of studies in Temengor Reservoir were recorded over the recent years. Most of the earliest researches were focused on aquatic pollution and water quality, biodiversity of the reservoir as well as water resource development and management (Ali, 1996; Grinang, 1998; Akhir, 1999). However, a number of studies conducted mainly focused on the photic zone of the water body. One of the early attempts of limnological study in Temengor Reservoir was done by Grinang (1998). His work provided useful information on the use of aquatic insect as water quality indicator at the catchment area in Temengor Reservoir.

1.2 The scope of the study

This study covered two parts; water quality and bathymetry at five sampling stations. For water quality chapter, physical and chemical parameters at photic and aphotic zone were measured. Bathymetric mapping of five stations was conducted to determine the current maximum depths as comparison to previous study.

1.3 The importance of the study

Various works on the health quality of freshwater system were reported over the recent years (Othman, 2009; Hashim *et al.*, 2012; Karim and Mansor, 2013; Che Salmah *et al.*, 2014). With this in consideration, this study was conducted to investigate the water quality status of Temengor Reservoir for better management and monitoring plans. Information on the topography of Temengor Reservoir is important in order to understand hydrological processes effects on biological and chemical interactions. Therefore, benthic elevation of selected areas in this reservoir could be provided as supportive baseline data for future studies related to bathymetry and sedimentation. Knowing the current status of Temengor Reservoir especially the lake floor will hence initiate a better and effective management plan to be designed in order to govern its sustainability.

1.4 Objectives

This limnological study of Temengor Reservoir was conducted to obtain the current status of the physico-chemical parameters of water column especially in the aphotic zone and to gain new information such as the benthic elevation of the lake floor.

Hence, the objectives of this study are as follows:

a) To determine the physical and chemical parameters at five sampling stations.
b) To identify the seasonal changes in physical and chemical parameters at five sampling stations.
c) To map the bathymetry of five sampling stations.

CHAPTER 2

LITERATURE REVIEW

2.1 Reservoir characteristics

Reservoir is man-made water body which is formed by the construction of a dam across a river or stream, resulting in the impoundment of the water behind the dam structure whereas lakes occurred naturally which was over geologic time. (Wetzel, 2001). Nevertheless, both lakes and reservoirs experience processes such as exchange of gas across the air-water interface, predator-prey interaction, primary production and internal mixing (Thornton *et al.,* 1990).

Reservoirs range in size from pond-like to large lakes, and share some characteristics with natural lakes. Generally, all reservoirs are governed for water quality requirements concerning to a variety of human uses. A thorough understanding of the physical, chemical and biological interactions acting within the system is essential for a detailed analysis (Kopp *et al.,* 2009).

Determination of lake and reservoir's shape and structure is based on how they are formed. Both systems undergo distinct physical, biological and chemical process in terms of the interactions of the biotic and abiotic components. In contrast to natural lakes, reservoirs and the dams that impound them are engineered system operated to meet specific needs (Van Looy *et al.,* 2014).

In order to meet specific uses, an engineered system of reservoirs and impounding dam is designed. As a reliable water supply, reservoir is important in providing water to meet a spectrum of economic, social and environmental needs (Kennedy and Walker, 1990). Reservoirs which play important role in the economy of many nations require great management and protection plan as they are prone to the impacts of loadings of silt, nutrients and organic matter (Cooke *et al.*, 2005).

With today's advanced and improved technology, reservoirs are built for different purposes such as generating hydroelectric power, irrigation and as part of transportation to name a few (Mekonnen and Hoekstra, 2010; Raje and Mujumdar, 2010; Rangel *et al.*, 2012). According to Sharip and Zakaria (2008), in addition to functioning as storage basins for domestic and industrial water supply, some reservoirs were constructed to control flood by acting as a buffer to regulate different flow during dry and wet season. Besides that, lakes and reservoirs also uphold important ecosystem that harbours biodiversity of rare, endemic and endangered species.

Connections between the requirement to construct a reservoir at a location and the manner in which they are effectively operated provide insight to their limnological character. Understanding these connections provides an improved knowledge of reservoir limnology and proposes the means to develop and implement efficient management strategies (Kennedy, 1999). Limnological approach to study the characteristics of a reservoir is usually similar to analysis conducted for natural lakes (Thornton, 1990).

According to Jorgensen *et al.* (2005), a reservoir is generally similar and as important as natural lake. Findings obtained from studies on reservoir would usually be explained in such of a lake manner. Structures and functions of a lentic ecosystem are greatly discussed in various studies such as Limnology (Wetzel, 1983), Restoration and Management of Lakes and Reservoirs (Cooke *et al.*, 2005), Lake and Reservoir Management (Jorgensen *et al.*, 2005) and Lake Ecosystem Ecology

(Likens, 2010). Internal process such as water mixing, change of gas at the surface and exchange of heat through the trophic level occurred in both lake and reservoir ecosystem were discussed in these writings.

2.2 Reservoir zonation

Lake and river ecosystem is generally differentiated by its habitat based on the movement of water flow (Goldman and Horne, 1983). Lake ecosystem is lentic where there is relatively no water flow or stagnant and the physical, chemical and biological characteristics are low in variation. On the other hand, for river ecosystem, these characteristics will fluctuate due to the movement of water or also known as lotic habitat (Sigee, 2005). Identification of reservoir zonation is of great practical importance to design an efficient plan for reservoir managing and utilization. Different zone shows different sensitivity to eutrophication. Accordingly, a specific methodology and standards for nutrient assessment should be constructed for each zone respectively (Shao *et al.*, 2010).

Lake is divided vertically into three major zones depending upon the amount of light penetrating through; littoral zone, limnetic zone and aphotic or profundal zone (Figure 2.1). The littoral zone refers to the area closest to the shore. Shallow water in littoral zone allows light penetration to the sediments. Therefore, this area is characterized by the presence of beds of submerged and emergent macrophytes vegetation that are able to survive strong wave action. In addition, littoral zone has a rich microbial community and high biological diversity with large numbers of aquatic organisms (Sigee, 2005; Sorf and Devetter, 2011).

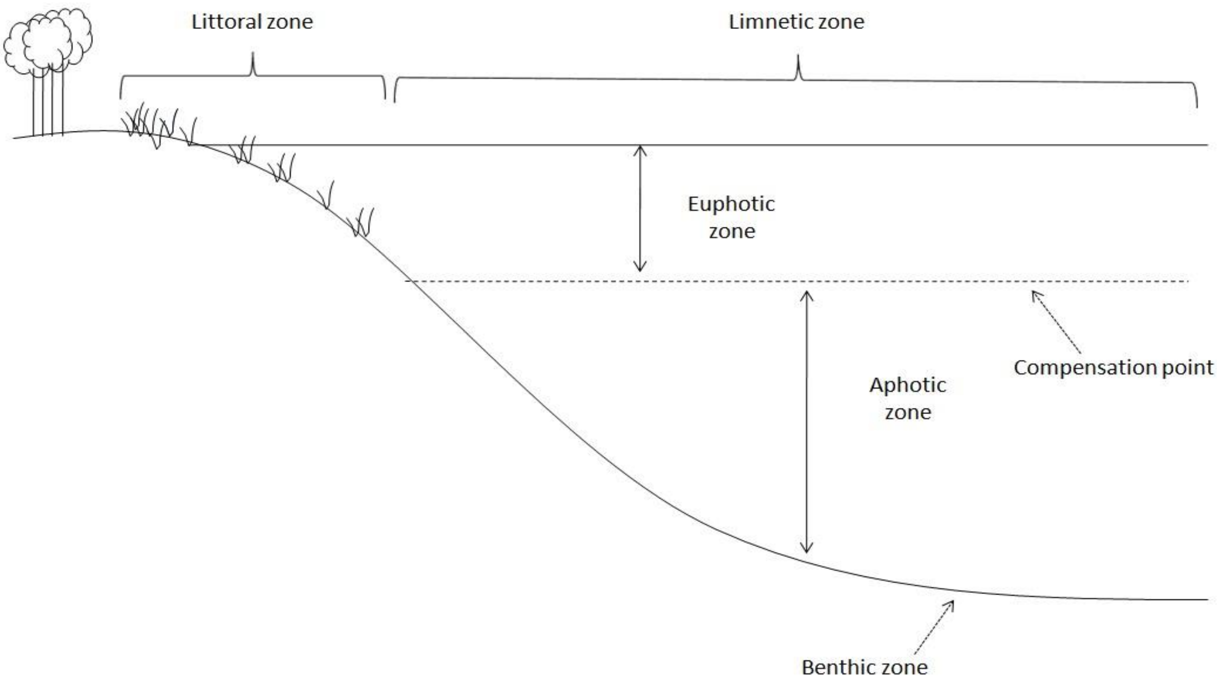

Figure 2.1 Definite zones which are determined by the distance from shore gradients and depth in reservoir (Sigee, 2005).

Limnetic zone is the area that has limited light penetration and receives no influence from the shore. Free-floating organisms such as plankton dominated this zone where it comprises of a vertical water column with an air-water interface at the top and lake sediments at the bottom. The water column is closely related to the sediment in terms of nutrient cycling and interchange of aquatic populations. The primary producer in this ecosystem is planktonic algae (Sigee, 2005). As one descends deeper in the limnetic zone, the amount of light penetration decreases until a depth is reached where photosynthetic gain is equal to respiratory loss, also known as light compensation level. Bacteria are particularly important in sediments that receive no light (aphotic zone) and no oxygen (anoxic) in the limnetic zone (Sazak and Sahin, 2012).

Aphotic or the profundal zone is the water zone beyond the layers receiving effective light penetration, thereby it accepts insufficient or no amount of light to carry out photosynthesis. Besides that, level of dissolved oxygen in this zone is low also has low dissolved oxygen content (Agrawal, 1999). A large population of bacteria and fungi dominated this zone where decomposers break down the organic matter subsided from top layer of water column and subsequently releasing inorganic nutrients for recycling. This zone has negative net photosynthesis or negligible total photosynthesis due to no light penetration (Likens, 2010).

Dam areas are usually explained in three zones based on a longitudinal cross section from the water source that flows into dam structure known as the lacustrine zone which resembles the lentic habitat, riverine zone which resembles the river ecosystem and transition zone (Figure 2.2) (Thornton *et al*., 1990). All these three zones have unique physical, chemical and physical characteristics that differentiate the limnology of a dam from one another (Ford, 1990; Wang *et al.,* 2011).

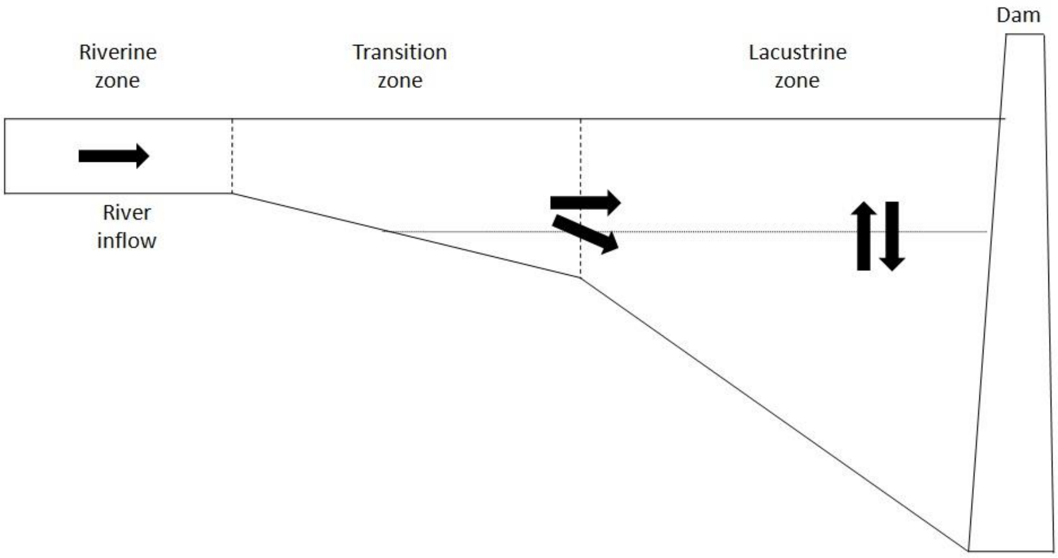

Figure 2.2 Longitudinal cross section view showing three distinct zones defined by the slope of a dam (Thornton *et al.*, 1990).

Riverine zone in general is situated away from the outlet and is also the main source for water inflow from the parent river or watershed into the dam area. This zone is relatively shallow, narrow and showing well mixing of water thus it maintains an aerobic environment. Due to the narrow structure of the channel, the water velocity is in high rate but however, decreasing as it moves towards the dam area. The physical and chemical attributes shown in this zone is similar to lotic system (Kimmel *et al.,* 1990; Smoot and Findlay, 2001).

Transition zone is situated in between the riverine and lacustrine zone in the dam area. This area is a deeper and broader basin. The borders between riverine and lacustrine zone often changes depending on the water level and water inflow from the riverine zone (Kimmel *et al.,* 1990). This zone has decreased water flow and decreased abiotic turbidity resulting in a greater photic layer (Smoot and Findlay, 2001). The productivity of this zone depends more on concentration of allochthonous (Thornton*et al.,* 1990; Lind and Barcena, 2003).

Lacustrine zone resembles the ecosystem of a lake where the water body can be divided into a number of layers that are characterized by water mixing. The rate of organic production is usually higher than rate of decomposition thus creating a potential where nutrient will be the limiting factor in this zone. The organic matter in this zone is basically from the death or senescence of aquatic organisms (Kimmel *et al.*, 1990). This zone has lentic properties including seasonal stratification and lower nutrient concentration (Smoot and Findlay, 2001).

2.2.1 Lentic physical structure

Lentic ecosystem is generally divided into three layers which are epilimnion, metalimnion and hypolimnion (Figure 2.3) due to stratification (Payne, 1986). It is created due to temperature-density differences (Boulton *et al.*, 2014). The layers are situated in the limnetic zone and created due to temperature fluctuations influenced by water movement and heat distribution (Goldman and Horne, 1983). Heat exchange from the atmosphere to the water body causes the imbalance of temperature distribution, where the temperature will be high in the upper layer of water column and the values decrease with depth. Therefore, warmer water column which are less in density will be on the surface and higher density colder water column will be below it. Changes in temperature will cause density differences hence influencing the physical process in standing water (Boulton *et al.*, 2014). The thermal stratification dictates a control on the vertical fluxes due to partitions in the water column (Yeates and Imberger, 2003).

Epilimnion is characterized by warmer and less in density water column with essentially uniformed temperature. In many lakes, the growth of phytoplankton mainly occurs in this area as it receives enough light penetration for photosynthetic activity. Consequently, this leads to severe nutrient depletion and limited replenishment from the hypolimnion.

Metalimnion exists between these two layers and is characterized by the rate of sudden change in water temperature with depth. The sudden decrease in water temperature creates a slope that shows a slant in a vertical profiling of water temperature. Metalimnion, a also known as thermocline acts to separate the warmer and colder water column. According to (Wetzel, 1983), thermocline exists where

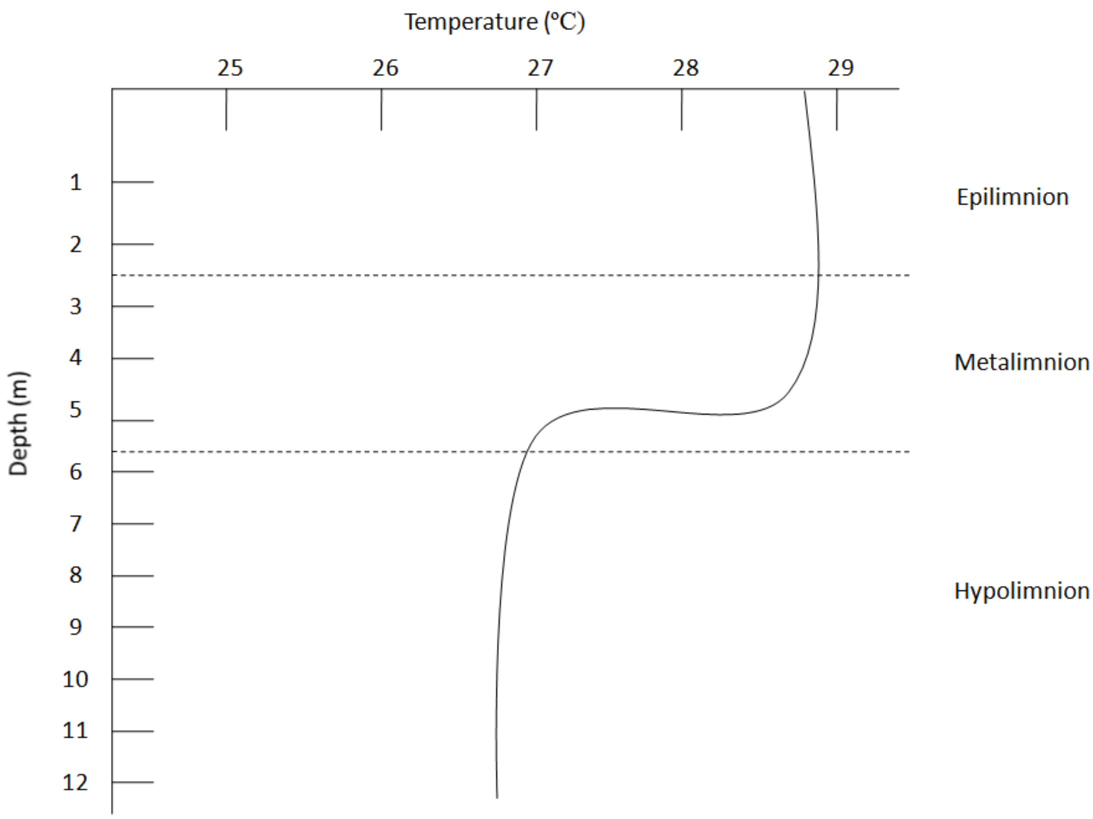

Figure 2.3 The thermal stratification of a tropical reservoir (Payne, 1986).

there the temperature change is more than 1ºC in every 1 m depth of water column. Thermocline functions as a physicochemical barrier to water circulation and nutrients passage and reduces the exchange of oxygen between surface and deep water (Wetzel and Likens, 1991).

Hypolimnion is situated near the bottom layer of water column and has colder water and is more densed. The dissolved oxygen level decrease in the deeper depths of water column (Henry, 1999). Decomposition of organic material such as dead phytoplankton that sinked through metalimnion usually occurred at this part of water column. Thus, it is usually cold and photosynthetic production is minimal (Sigee, 2005).

Freshwater ecosystem is frequently altered to due to climatic changes (Brooks *et al.*, 2011). World climate changes based on latitudes as well as solar radiation which are highly correlated to latitude and also one of the main factors that control the changes in physical, chemical and biological process in water body (Eum and Simonovic, 2010). Therefore, varieties of patterns in temperature change vertically and pattern of water mixing according to latitudes. According to Lewis (1987), this is important as the different temperature of water mass, mixing and chemical alteration will influence the competency of habitats to tolerate temperature for the survival of aquatic organisms. The importance of climate and geomorphology which has influence on the limnology and geochemical characteristics in a reservoir is well discussed in previous studies (Dodson, 2005; Mwaura, 2010; Ashraf *et al.*, 2012).

Generally, climate is divided into two main areas which are temperate and tropical. Tropical areas which are located near the equator are differentiated by having high humidity and rainy seasons, temperature which is high and stable relatively and small change of season. On the other hand, the characteristics of a temperate area are rotation of four seasons and obvious temperature change between the seasons. Variance in temperature in different season generated by solar radiation is considered as the main factor controlling biotic and abiotic interactions in an aquatic ecosystem (Thornton *et al.,* 1990). Seasonal fluctuations in mean temperature, hydrology, nutrient delivery, utilization and retention have significant impacts for nutrient management (Bukaveckas and Isenberg, 2013) and considered as most important variables which determine plankton abundance (Offem *et al.,* 2011).

In a tropical area, light intensity and period of solar radiation increase during dry season. Light wavelength that is not reflected will be absorbed by water surface until a known depth and spread in the form of heat (Sanderson and Taylor, 2003). Some of the solar energy will also be absorbed by algae and other suspended particles (Reynolds, 1984). Light intensity decreases exponentially with depth. Water surface will be warmer and low in density due to the absorption of the light. Water layers that do not receive solar radiation will have higher temperature and more dense which stay at the bottom of the water body (Sigee, 2005).

Characteristics explained will change in temperate area based on the amount of solar radiation received (Wetzel, 1983). For tropical areas, stratification is stable due to high solar radiation all year except for ecosystem that is located on a higher altitude (Lewis, 1996). Besides absorption of the solar energy, stratification also occurs due to thermal conduction or diffusion, turbulent thermal conduction and inflow and outflow thermal transfer from the system (Ford, 1990; Boehrer and Schultze, 2008).

Dissolved oxygen is an important element that involves in chemical and biological reactions in aquatic environment (Goldman and Horne, 1983). Water quality of a dam usually depends on dissolved oxygen as the existence of this element will be the catalyst to degradation process that occurs in water. The concentration of dissolved oxygen in aquatic system presumably indicates more about their metabolism than any other assessment (Rankovic *et al.,* 2010).

The distribution of dissolved oxygen in a water column is influenced by a few factors which are temperature, current, morphology of a dam, wind movement, photosynthesis and respiration (Cole and Hannan, 1990). Photosynthesis process which is carried out by phytoplankton is enhanced at euphotic zone due to higher light intensity thus contributes to a higher oxygen concentration as compared to the aphotic zone which received limited light penetration (Lokman, 1992).

Additionally, wet and dry seasons also influence the distribution of dissolved oxygen. In a study conducted by Uzoukwu *et al.* (2004), it was stated that dissolved oxygen levels were higher in wet season as compared to dry season. Catchment areas that receive heavy rainfall would cause strong water turbulence and therefore affects the concentration of dissolved oxygen. Generally, most water body in tropical areas have lower dissolved oxygen level due to a higher concentration of organic components as compared to temperate areas (Dudgeon, 2008).

2.3 Nutrient dynamics

Both natural lake and reservoirs receive extensive quantity of organic matter (Forbes *et al.,* 2012). Quantity and quality of external nutrient loadings mainly regulate the water quality and productivity of a reservoir (Kennedy and Walker, 1990). Nutrients are elements which are consumed by plants and animals for metabolism process and highly influence the primary production of a water body (Goldman and Home, 1983). Nutrients such as ammonium, nitrite, nitrate and orthophosphate exist in water column as inorganic nutrients which are elements that can be dissolved (Qualls, 2000).

Inflow of nutrients to water is divided into two; either naturally from the ground or as a result of human activities. Additionally, other nonpoint sources such as pollution, agricultural activity, urban runoff and wastewater also contribute to the enhancement of nutrients contents in the water body. An increase in the nutrient input would boost lake productivity leaving detrimental impacts to other trophic levels (Wan Maznah, 2002; Søndergaard *et al.,* 2003). Phosphorus and nitrogen are the most important nutrients prior to eutrophication (Smith, 2003).

Eutrophication is a phenomenon of nutrient enrichment over time and is considered as an aquatic ecosystems response to nutrient loading, which can cause naturally or accelerated by human factors. Natural eutrophication is the process by which lakes gradually become aged and more productive, whereas excess nutrients from human activities are called "cultural eutrophication" (Sheela *et al.,* 2011). Enhancement of nutrient availability would augment the growth of phytoplankton. Consequently, water turbidity will increase which then impoverish the light condition (Balali *et al.,* 2013).

Tropical systems are more sensitive to eutrophication than temperate systems, given the higher propensity to hypoxia in the deeper depths, therefore making it essential to exercise stricter control of nutrient loads (Rangel *et al.,* 2012). Accordingly, these changes contribute to the loss of aquatic animals such as fish kills due to irregular oxygen content and high content of toxic compound (Hart *et al.,* 2002). Eutrophication is a serious problem since it contributes to environmental problems world-wide as the status of eutrophication is more than 60% in Malaysia (Malek *et al.,* 2011). The enhancement of nitrite and nitrate concentration in an aquatic ecosystem will influence the water quality. Impacts such as toxic algal bloom, death of phytoplankton and other aquatic wildlife, promoting the decomposition process by the microbes, occurrence of objectionable taste and odour events and the decrease in dissolved oxygen level will lead to diseases and fish kill (Shanmugam *et al.,* 2007; Jeppesen *et al.,* 2012).

2.3.1 Phosphorus

Phosphorus is unique compared to nitrogen due to its cycle in water which does not involve any oxidation process but remains permanent in P-O form both organic and inorganic in particles or dissolved phase. It can be found in soil, water and sediments in the form of chemical compound and is identified as a limiting factor nutrient for algal growth in lakes and reservoirs (Hanrahan *et al.,* 2002; Carey and Rydin, 2011).

Bostrom et al. (1988) explained few forms of phosphorus that exist in water. Phosphorus in particle phase includes live and dead plankton, condensed phosphate, absorbed phosphorus in suspended particles and amorphous phosphorus. Dissolved phosphorus is divided into organic and inorganic phosphorus. Phosphorus found in natural water is usually in form of (PO_4^{3-}). Some dissolved phosphorus is restored to the surface layers when aquatic organisms die and sink to the bottom through upwelling and some are buried in sediments (Round, 1981; Krohne, 2001).

Phosphate is among the nutrients that influence the productivity of a lentic body. Orthophosphate is the main component of phosphate that influences lake productivity. It is the only form of phosphorus that can be used up directly by planktonic algae and bacteria (Smith, 2003) and easily assimilated to organic phosphate and other living cellular organism component (Sigee, 2005).

Generally, nutrient cycles in an aquatic system involve exchange activity of organic and inorganic materials back to the production of living matter. In a lentic system, nutrient flux between the areas will create a vertical and horizontal profiling of nutrient species (Kennedy and Walker, 1990). Temperature and concentration of dissolved oxygen are among the main factors that influence nutrients in few phases of nutrient cycles. These biotic factors will give a vertical profiling of nutrient concentration in a lentic system for both shallow and deep water.

2.3.2 Nitrogen

Nitrogen makes up about 78% of atmospheric gas (Krohne, 2001). Nitrogen in water exist in few forms which are dissolved gaseous molecules (N_2), inorganic ammonia ion (NH_4^+), nitrate (NO_3^-) and nitrite (NO_2^-), as well as organic nitrogen element (Riley *et al.*, 2001). Ammonia and nitrate are the elements used up by plant for biological process. Nitrate however is a vital element for growth consumed by aquatic plants especially algae (Pidwirny, 2006).

Assimilation from aquatic plants and mineralisation from bacteria species towards existing nitrogen component are part of the cycles that will determine the composition of nitrogen found in water column. Decomposition process carried out by the heterotrophic bacteria and nitrogen gas accumulation by bacteria species will release ammonia. Nitrification process that used up oxygen carried out by microbes will oxidize ammonia to nitrate. This process is important to control the form of nitrogen in a lake or dam ecosystem. (Qualls, 2000; Pidwirny, 2006; Moss, 2008).

On the other hand, denitrification process will change nitrate to gas and loss of this important nutrient for lake productivity will be balanced by accumulation of nitrogen. *Nitrosomonas* and *Nitrosospira* are the best-known aerobic ammonia oxidizers and *Nitrobacter* and *Nitrospira* are well known nitrite oxidizers (Sliekers *et al.*, 2002).

2.3.3 Chlorophyll *a*

Chlorophyll *a* is the major photosynthetic pigment in a lot of phytoplankton in an aquatic system. Chlorophyll *a* is frequently used as an indicator of algal blooms. High algal growth in a reservoir indicates high lake productivity. An increase in Chlorophyll *a* concentration indicates eutrophication in lakes, subsequently associated with low biodiversity and therefore deprives the aquatic environment of sufficient ecosystem services. Chlorophyll *a* is considered one of the main factors that contribute to turbidity in aquatic ecosystem (Ndungu *et al.,* 2013).

2.4 Lake trophic state

Lakes can be classified into three states based on the available nutrients which will determine the lake fertility. More nutrients are found in more fertile lakes and therefore more plants and algae. A eutrophic lake is a well-nourished lake with high nutrients and high plant growth. Oxygen is low in a eutrophic lake since it has so much biomass. On the other hand, an oligotrophic lake has low nutrient contents and low plant growth. In an oligotrophic lake, high level of oxygen is found at surface layer. Mesotrophic lakes behave differently than oligotrophic lakes in that they stratify especially in tropical areas. In addition, it also has medium amount of nutrient content (Lee *et al.,* 1995; Cako *et al.,* 2013) (Appendix A).

2.5 Bathymetric study

A detailed knowledge of wide scale distribution patterns of population, communities and habitats of the seafloor is fundamental for impact assessment, conservation and studies of ecological patterns and processes (Sandwell and Smith, 1999; Hewitt *et al.*, 2004). In many lakes, bottom sediments consist of materials from precipitation of chemical and biological processes.

According to Golterman *et al.* (1983), characteristics of sediment may differ slightly under various climatic conditions but however may be used on a worldwide basis. Determination of component concentrations in bed sediments is a broadly used approach to monitor and assess contaminant distributions in streams (Feltz, 1980; Groot *et al.*, 1982).

Prior to having a better knowledge on the effects of land processes on the hydrology of lakes and to obtain a clearer indication of environmental changes, the information on multitemporal bathymetric on lakes is essentially needed. In hydrology and sediment studies, lake morphometry parameters gives beneficial information to determine lake life expectancy, residence time, water balance and sedimentation rate (Yesuf *et al.*, 2013).

The topography of lake surface area and morphometrical parameters are discussed in various studies such as Moreno and Garcia-Berthou (1989), Lawniczak *et al.* (2011) and Zhang *et al.* (2011). According to Sharif and Mahmud (1995), the slow production of different types of hydrographic surveying products in Malaysia is due several reasons such as lack of skilled and qualified organization, the application of aged method and unsophisticated equipment as well as shortage of appropriate hydrographic surveying coaching.

CHAPTER 3

MATERIALS AND METHODS

3.1 Study site

Temengor Reservoir is situated in the north of West Malaysia between N 05º32.595', E101º20.454' and 263 m above sea level. It is the second largest man-made lake after Tasik Kenyir as it covers approximately 15,200 ha of area. This reservoir was created by the impoundment of a dam to store water and generate hydroelectric power.

This study site is situated on the upper elevation of Sungai Perak and surrounded by pristine tropical forest that harbours variety of endemic and rare species of flora and fauna. The maximum depth of Temengor Reservoir was recorded to be 90 metre deep. In addition to generating hydroelectric power, the reservoir supplies water to nearby human settlement, as well as playing a major role in flood control.

The main inflows of the reservoir are from three water catchment area known as Belum Reserve Forest (134, 167 ha), Grik Reserve Forest (37, 220 ha) and Temengor Reserve Forest (148, 870 ha) which received an average annual rainfall of more than 2000 mm (Davidson *et al.,* 1995). Sungai Kejar, Sungai Sara, Sungai Singor and Sungai Tiang are several of the rivers flowing into the reservoir.