ASSESSMENT OF WATER QUALITY STATUS OF PENANG COASTAL WATER

SITI NOOR SYAFIKA BINTI SULIMAN

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ASSESSMENT OF WATER QUALITY STATUS OF PENANG COASTAL WATER

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SITI NOOR SYAFIKA BINTI SULIMAN

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ABSTRAK

Dalam kajian ini, penilaian parameter kualiti air (suhu, pH, saliniti, konduktiviti, jumlah pepejal terlarut (TDS), kekeruhan, oksigen terlarut, jumlah pepejal terampai (TSS), keperluan oksigen kimia (COD), keperluan oksigen biologi (BOD), ammonia, ortofosfat, nitrat dan nitrit) telah dijalankan. Indeks pencemaran organik (OPI) telah diterapkan untuk menentukan status pencemaran organik di sekitar kawasan kajian. Sampel air dikutip di pesisir pantai Jambatan Kedua Pulau Pinang (Tapak A) dan Taman Negara Pulau Pinang (Tapak B) semasa air pasang anak dan air pasang perbani secara berganti - ganti selama enam bulan (Disember 2015 hingga Mei 2016). Semasa cuaca panas kesan daripada kejadian El Nino pada April 2016, suhu air laut mencecah 34.37°C di Tapak A. Dalam kajian ini, kepekatan ammonia didapati lebih tinggi di Tapak A secara signifikan terutamanya di muara Sg Keluang (4.0 mg/L) yang diukur pada bulan April 2016. Kepekatan TSS juga adalah tinggi di kedua – dua Tapak A (permukaan: 20 – 493 mg/L, dasar: 60 – 708 mg/L) dan Tapak B (permukaan: 27 – 220 mg/L, dasar: 60 – 1131 mg/L), direkodkan pada bulan April and Januari 2016, masing - masing. Pemetaan permukaan dan dasar air menggunakan perisian Surfer 12 menunjukkan bahawa ammonia dan TSS tertumpu di muara sungai di Tapak A dan di perairan menuju ke laut terbuka di Tapak B (SB11). Berdasarkan ujian t tidak bersandar, ammonia, ortofosfat, dan nitrit di Tapak A didapati lebih tinggi secara signifikan di permukaan air ($p<0.05$) manakala nitrit didapati lebih tinggi secara signifikan di dasar air ($p<0.05$) di Tapak B. Kebanyakan nutrien yang direkodkan semasa air pasang perbani lebih tinggi berbanding semasa air pasang anak mungkin disebabkan oleh kehadiran sisa arus yang lebih tinggi. Penilaian pencemaran organik berdasarkan OPI menunjukkan bahawa kebanyakan

stesen di Tapak A (terutamanya di muara Sg Keluang, Sg Jawi, dan sekitar perairan yang terletak berhampiran dengan tapak pelupusan sampah Pulau Burung) merekodkan nilai OPI melebihi 4, menunjukkan bahawa kawasan ini lebih dicemari dengan bahan organik. Nilai OPI yang direkodkan di Tapak B mempunyai nilai kurang daripada 0 menunjukkan bahawa perairan di sekitar Taman Negara Pulau Pinang kurang dicemari dengan bahan organik. Walau bagaimanapun, perairan di sekitar stesen 4, 7, dan 11 di Tapak B menunjukkan nilai OPI yang sedikit tinggi (8.62, 4.28, dan 4.28, masing - masing). Walaubagaimana pun, kepekatan BOD dan COD yang rendah yang dicatatkan dalam kajian ini bercanggah dengan nilai-nilai OPI. Ini menunjukkan bahawa nutrien tak organik terlarut paling banyak menyumbang dalam indeks pencemaran organik terutamanya ammonia. Oleh itu, dapat disimpulkan bahawa gangguan antropogen seperti kawasan industri dan penempatan yang lebih tertumpu di Tapak A berbanding di Tapak B, menyalurkan bahan tercemar ke dalam air dan menyebabkan pencemaran organik. Oleh yang demikian, setiap pembangunan di pesisiran pantai harus dipantau bagi menjamin kelestarian sumber perairan.

ASSESSMENT OF WATER QUALITY STATUS OF PENANG COASTAL WATER

ABSTRACT

In this study, the assessment of water quality parameters (temperature, pH, salinity, conductivity, total dissolved solids (TDS), turbidity, dissolved oxygen, total suspended solids (TSS), chemical oxygen demand (COD), biological oxygen demand (BOD), ammonia, orthophosphate, nitrate, and nitrite) were carried out. Organic pollution index (OPI) was determined to assess the organic pollution status around the study area. Water samples were collected at the coastal water of Penang Second Bridge (Site A) and Penang National Park (Site B) during spring and neap tides, alternately for six months (December 2015 - May 2016). During hot weather of El Nino in April 2016, the seawater temperature reached 34.37 °C at Site A. In this study, ammonia concentration was found to be significantly higher at Site A especially at the estuary of Sg Keluang (4.0 mg/L) measured in April 2016. TSS was also high at both Site A (surface: 20 – 493 mg/L, bottom: 60 – 708 mg/L) and Site B (surface: 27 – 220 mg/L, bottom: 60 – 1131 mg/L), recorded in April and January 2016, respectively. Mapping of the surface and bottom water using Surfer 12 software indicated that ammonia and TSS were concentrated at the estuaries at Site A and coastal area towards the open sea at Site B (SB11). Based on the independent t-test calculations, ammonia, orthophosphate, and nitrite were significantly higher ($p<0.05$) at the surface water of Site A, while nitrite was significantly higher ($p<0.05$) at the bottom layer of Site B. Most of the nutrients recorded during spring tide were higher compared with neap tide may be due to higher residual current present. The assessment of organic pollution based on OPI showed that most of the stations at Site A (especially at estuaries of Sg Keluang, Sg Jawi and seawater nearby the Pulau Burung landfill), recorded OPI values greater than 4 indicating that the coastal water were being polluted with organic substances. The OPI values at Site B were recorded below zero implying that the coastal water in the vicinity of Penang National Park was considered to be less polluted from organic pollution. However, the coastal waters around stations 4, 7, and 11 at Site B showed slightly higher OPI values (i.e. 8.62, 4.28, and 4.28, respectively). However, low BOD and COD concentrations recorded in this study were contradicted with the OPI values. This suggested that dissolved inorganic nutrients contributed the most in the organic pollution index especially ammonia. It can be concluded that the anthropogenic disturbances such as industrial and residential areas which were more concentrated at Site A compared with Site B, discharged pollutants and caused organic pollution. Therefore, any development surrounding the coastline should be monitored to ensure the sustainability of the coastal water resources.

CHAPTER 1 - INTRODUCTION

Estuarine and coastal marine ecosystem are often recognized as hydrologically and spatially complex systems (Smith, 2003). As a convergence zone of freshwater and marine water, estuary exhibits unique physical, chemical, biological community leading to high productivity. One of the major problems faced by estuaries and coastal waters around the world is nutrients overenrichment. Rapid increase in human activities such as aquaculture activities which may discharge aquaculture wastes (Cao et. al., 2007), eco-tourisms, reclamation (Salwa, 2008), industrialization and urbanisation (Maizatun & Mariani, 2011) and also establishment of solid waste landfills (Carpenter et al., 1998) due to increase waste production resulted from population growth that are often focused along the shores dramatically multiplies the impact towards these environment.

The coastal water quality is much dependent on land-used human activities within the vicinity. Any sort of pollutants from land alteration, such as from agricultural leachate (Mendiguchía et al., 2007), sewage discharge and aquaculture effluent (Trott & Alongi, 2000; Bellos et. al., 2004; García-Pintado et. al., 2007) have profound effects on the water quality of our coastal ecosystem. Various sources from human activities eventually contributing to the devastation of marine water quality; all of which resulted in the degradation of marine habitats and loss in biodiversity (Mosley & Aalbersberg, 2003). Subsequent receptions of nutrient input from coastal human activities makes coastal waters vulnerable to nutrient pollution (Folke et al., 2004), eutrophication and water quality degradation.

Most of the pollutants from land based activities will flow into the coastal water via river and estuaries, and the pollutants concentration will be elevated at the open sea (Liu et al., 2011). Rapid urbanization along the coastal water of Penang plays an important role in the increase of point source (PS) and non-point source (NPS) pollution loading. Domestic sewage, waste from animal husbandary areas and industrial wastes were identified as the main sources of pollution at Sg Pinang river basin. Apart from that, soil erosion from construction site and urban runoff will also elevated from the river basin to the coastal and open sea (Farah Naemah et al., 2008). This situations put Penang coastal waterways vulnerable to pollution threats. Urbanization refers to the concentration of human populations in discrete areas, leading to transformation of land for residential, commercial, industrial and transportation purposes (Pelling & Blackburn, 2014). The increasing developing areas within the river basin increases pollution loading (Zhang et al, 2014). Alteration and changes of water quality pose a hazard to the marine ecosystems and directly towards endangered sensitive marine species. Changing in quality of water used for recreation, fish industries, drinking and tourisms reduces the value of water bodies.

In general, coastal zones are vulnarable towards slightest changes of physical, chemical, and biological properties. Non-point sources of pollutants are runoff which originated from agricultural residue, animal stocks, sub-urban development, forest, houses, city and all others, which are eventually assimilated by rain water and brought to the sea as runoff, whereas point sources of nutrients comes from ships, pipes and effluents (EPA, 2005). The toxic substance and other fertilizer-based nutrients may spread over the coast. However, these sources are more difficult to manage, because the source is widespread over a range of spectrum in the marine environment.

Primary nutrients considered as non-point pollutants are nitrogen and phosphorus which are essential for plant growth, however if too much are being introduced into the environment it can leads to a very serious effect of eutrophication. Eutrophication is the overproducing of organic matter that results in the blooming of microscopic algae (Bricker et al., 2008). Excessive blooming of algae near the water surface blocks sunlight needed by native bottom-dwelling organisms and plants. As higher concentration of the algae and bottom-dwelling plants die, they sink to the bottom and decomposition by oxygen-consumed bacteria take place. Oxygen taken up by this bacteria eventually reduces dissolved oxygen in the water bodies. Decomposition by bacteria and fungi released the nutrients together with carbon dioxide and energy. Aquatic plants that serve as primary producers consume phosphorus and nitrogen for growth. When there is abundance of these nutrients in the water bodies, a situation called algal bloom occurs. This will lead to anoxia or depletion of oxygen, whereas concentration of H_2S as a product of sulphate as electron acceptor in the sediments increases (Theede, 1973). Aquatic fish, shellfish and benthic organisms cannot live in this low oxygen water conditions (Childress & Seibel, 1998).

Deterioration of coastal water quality has triggered the initiation of serious management efforts in many countries. Most acceptable ecological and social decisions are difficult to make without careful modelling, prediction/forecasting, and analysis of seawater quality especially coastal water quality for typical development scenarios. Water quality prediction enables a manager to choose an option that satisfies a large number of identified conditions. For instance, water quality variables, such as salinity, temperature, nutrients, dissolved oxygen (DO), and chlorophyll-*a*, in coastal water describe a complex process governed by a considerable number of hydrologic, hydrodynamic, and ecological controls that operate at a wide range of spatiotemporal scales (Whitehouse et al., 1997). Sources of the admixtures often cannot be clearly identified, and the locally influenced complex mass exchange between the variables may not be known. Due to the correlations and interactions between water quality variables, it is interesting to investigate whether a domain-specific mechanism governing observed patterns exists to prove the predictability of these variables. The identification of such forecast models is particularly useful for ecologists and environmentalists, since they will be able to predict seawater pollution levels and take necessary precaution measures in advance.

Population growth and increasing demand of resources are driving factors; water resources among Asian countries are facing serious and are under intense pressure. Population of Penang as reported by Department of Statistics Malaysia (DOS) (2016) is approximate1y 1.72 million where over half of the populations populated the island. The island is divided into two districts; the northeast district which is highly developed and compacted where the city centre located and the southwest district where we can still see forest-covered areas with hilly terrains. Penang Island is known as Silicon Valley of the East due to its growing industries.

Penang is the most urbanized and economically important state therefore the rapid development results in increasing pressure that is directly brought to the coastline and neighbouring areas. Liu et al., (2011) carried out a study of water quality using the organic pollution index in the coastal waters of Bohai Sea, China found out that pollutants loads from industrial sewages have stronger impact on the coastal waters. Thus, organic pollution index is adopted, modified and will be proposed as an early warning or signal of eutrophication and algal bloom. The determination of organic pollution level using the concentrations of inorganic nutrients, dissolved oxygen and chemical oxygen demand to reflex the contamination degree. Any unusual level of nutrients concentrations which essential for phytoplankton growth can be determined and removed from the water body before the algal could possibly bloom and polluted the water body.

Both selected coastal areas differ in anthropogenic activities, water uses and coastal role. Coastal water of Batu Kawan and Batu Maung extends until Sg Jawi vicinity are observed to have higher risk of being affected by anthropogenic activities and development. Big scale aquaculture cages can be observed at the coastal areas as we pass the Second Penang Bridge, growing and getting bigger since 1974 where it started with 128 cages as reported by Tan et al. (1985). Rapid development, urban buildings, factories and recreational areas near the seashore can also be seen at this study site. The estuaries and coastal areas are also the spot for artisanal fishing. Meanwhile, Penang National Park was gazetted on April 2003 as national park under the National Park Act 1980 No. 226. All activities were kept at minimum level, but artisanal fishing activities are still taking place. There are also boat services to take visitors to the beach but they can also trek through the national park forest. Visitors are allowed to set up camp at the beach, but with fewer disturbances to the nature. In order to maintain its status as national park, any development that can jeopardise its sustainability is prohibited.

1.1 Problem statements

Coastal and inland anthropogenic activities around Penang as well as the development along the coastline significantly impact the surrounding environments. The main focus of this study was to point out the impact of rapidly developing coastal region on the coastal environment of Penang.

1.2 Importance of the study and research aims

Water quality and organic pollution were determined in this study to assess the current status of Penang coastal waters and to detect any changes or trends in water quality over time and space. Thus, this study aimed to identify the pollution sources contributing to the spatial and temporal variations. Water quality monitoring can be applied to design specific pollution prevention or remediation programs. This study also highlighted the organic pollutin index as rapid pollution assessment.

1.3 Research hypothesis

(a) Water quality parameters are significantly different between disturbed and less disturbed area which are influenced by the land and sea based activities.

(b) Area with high anthropogenic activities discharge higher pollutants which increase the organic pollution level.

(c) The effects of anthropogenic activities on water quality status are proportional to the pressure results from human activities.

1.4 Research objectives

(a) To determine the water quality status of selected Penang coastal areas.

(b) To assess and map the concentrations of selected parameters in Penang coastal waters to determine the area with high anthropogenic disturbances which discharge higher pollutants.

(c) To determine the organic pollution level based on modified Organic Pollution Index.

CHAPTER 2 - LITERATURE REVIEW

2.1 Environmental characteristics of Penang Island

Penang is located on the north western coast of Peninsular Malaysia between latitudes 5º 7’ N and 5º 35’ N, and longitudes 100º 9’ E and 100º 32’ E (Chan, 1998). Penang State had a population of 1.66 million in 2013 and projected to grow to 1.75 milion in 2017 (DOS, 2016). The 362 hectare or 295 km² island is the most populated island in Malaysia other than Langkawi Island in Kedah. The eastern part of island facing the mainland is highly urbanised with industrial, commercial and residential areas, whereas the western portion is rugged and less developed area.

Year 2016 was the most hottest year in Malaysia’s history with an average air temperature of 27.66 °C, higher than the latest temperature recorded during El Nino in 1998 (27.6 °C). Climate change was the effect of El Nino phenomenon that surged Malaysia till half of the year of 2016 (Pusat Iklim Nasional, 2016).

Hot or drought period occurred starting from January 2016 and peaked in March and April 2016. During this period, Penang and other parts of Malaysia still received an average rainfall but areas like Johor, Pahang, and some parts of Sabah received about 20-40% less than average rainfall. The highest value is recorded in wet season which usually occurs from June to December. Another study by Wan Ruslan (2000) reported that low rainfall was recorded in Penang Island in January while high evaporation recorded in October. For the year 2016, rainfall was the highest in July with value 200.8 mm.

2.2 Demographic information of Penang

Around 2.06 million of vehicle populations in Penang Island was reported in 2013. The second Penang Bridge, The Sultan Abdul Halim Muad’zam Shah (SAHMS) bridge with total length 24 km (16.9 km over water) was constructed to overcome congestions problem. Batu Kawan located at south of Seberang Perai on the mainland and Batu Maung located at south west of The Island is connected. The construction of second Penang bridge started in November 2008 and was completed in February 2014 and open to public on 1st of March 2014. The construction of this facility is expected to stimulate the growth of land use and economic development of Batu Maung, Bayan Lepas and Bandar Cassia. These changes are believed to pose positive impact such as urbanisation, industrialization, economic expansion, increase in income, and expanded infrastructures, but somehow can also bring negative effects especially towards the environment i.e pollution, over-population, high fuel consumption, trafic congestion, migration, and reduction of resources (Siti Nadia & Ahmad Hilmy, 2015).

2.3 Penang coastal water

Coastal waters are defined as water zones between inland high water mark and the edge of continential shelf before the deep sea region. Coastal waters extending approximately 20 nautical miles which is approximately 37 km. Coastal water is part of coastal zones that also includes estuaries, deltas, bays, lakes, and rivers (Al Gahwari, 2003). Coastal zones in Malaysia experiencing the most intense pressure where many human activities such as population settlement, aquaculture, industries, port, fishing, agriculture, and construction programs concentrated at this region thus jeoperdising its sustainability.

Pollutant load from human activities such as growing of housing areas, industrial areas and aquaculture activities that could lead to coastal water degradation and thus will affect the marine organisms population. In order to evaluate the water quality of aquatic systems, many countries have introduced a plan to monitor and assess the pollution effect (Pesce & Wunderlin, 2000; Štambuk-Giljanović, 1999;

Avigliano & Schenone, 2016) based on organic pollution index and eutrophication index (Liu et al., 2011; Wang et al., 2015) that focused on the organic-based pollutants.

2.4 Impact of human activities on coastal water

2.4.1 Aquaculture activities

Coastal area of Pulau Jerejak, Pulau Aman, Sg Chenam and Penaga had been developed as aquaculture areas by the Penang State Government as an initiative of the growing demand of this industry. A study in Pulau Aman, Penang by Roziawati et al. (2015) shows that potentially toxic and harmful microalgae i.e *Alexandrium* spp., *D. caudata*, and *Pseudonitzchia* spp. were commonly found at Pulau Aman . Roziawati et al. (2015) also stated that salinity, pH and temperature are the most influencial environmental parameters in regulating the harmful microalgae. Other than that, phosphorus, carbon, and nitrogen originated from food wastes, excretion, and respiration products were introduced into the water column from aquacultural activities (Wu, 1995). Water discharged from a fish farm contains vitamins, protein, lipid and carbohydrates (Boonyaratpalin, 1997) from food waste, fish excrement and detritus deoxygenate the waters and increase the levels of suspended solids and ammonia (Choo, 1994). Significant effects of fish farming is the enrichment of aquatic bodies with copper, organic matter and nutrients which decreases dissolved oxygen, lead to hypoxia and anoxic conditions (Hall et al., 1992; Leung et al., 1999; Holby & Hall, 1991) and coastal water quality degradation. Aquaculture and fish farming activities can harm the biodiversity (Goldburg & Triplett, 1997), which is believed to caused genetic alteration cause by favaourable condition of selective and pre-matured breeding (Hulata, 2001). Polyploidy and hybridisation caused infertility and decreased natural competition (Hulata, 2001).

2.4.2 Domestic and urban wastes

Beach areas in Malaysia are one of the biggest contributors in the eco-tourisms sector (Hamimah & Nezakati, 2014). Early human settlements were found near the water resources (Beckham, 1995). Rapid development along coastal areas, growing population and pressure from land activities runoff puts marine environment in danger. Usage of soap and detergents, food residue, oils, urine, and excrement products (Schaffelke et al., 2005) that originates in river and streams will then increase the risk of coastal and marine pollution.

The biggest water pollutants from land comes from untreated sewage effluents i.e wastewater and agricultural run-off (Islam, 2003). Disposal of untreated or improper treated effluents threatens the ecosystem (Adepelumi et al., 2005). Untreated sewage is slightly acidic, contains bacteria, parasites , viruses and high nurients concentrations (South et al., 1994). Increase in nutrient concentrations being channeled into the river ecosystem will increase the risk of eutrophication in the coastal waters. From 2010 - 2012, the number of excellent and good marine coastal waters decreased whereas the moderate marine water stations increased in terms of Marine Water Quality Index (MWQI) (DOE, 2012).

An approximate of 25 % faecal coliform loading of sewage discharge was reported in Jelutong outfall (Koh et al., 1997). Department of Environment Malaysia (DOE) (2003) reported Penang coastal water with highest *E. coli* contamination (89%), oil and grease (34.7%), and suspended solids (72.1%) pollutants. This situation continued in 2004. High level of these contaminant especially *E.coli* caused skin rashes, contamination of seafood, increase health problem, and decrease water value (DOE, 2003).

2.4.3 Reclamation and coastline development

Rapid economic expansion and industrial growth have attracted and increase population settlements near the coast. Coastal areas in Malaysia are known of its richness in resources and thus become the center for domestic and economic development. Coastal zones had been utilized for variety of purposes such as housing, transportation, recreation, fisheries, communication, and oil & gas exploration (Kaparawi and Abd latif, 1996). Rapid urbanisation and development effect from high demand lead many reclamation projects and coastal development projects to be implemented. Human population growth however had been threatening this valuable zone.

There has been an increase in reclamation practices in coastal areas of Malaysia specifically in Penang. Reclamation practices in Penang first started in coastal areas of Koay jetty of Clan Jetty, Georgetown in 1970s, Bayan Baru industrial estate in 1980s and1990s, Jelutong land for coastal highways in 1990s, recently in Queensbay and Gurney Drive (Salwa, 2008; Nadzhirah et al., 2015; Yin & Kwang, 2016).

Reclamation, restoration, dredging and pumping of sea sands in estuarine and coastal areas hugely affect the marine ecosystem and environment. These practices caused alteration in the coastal structures and habitats. One of the main impact of reclamation activities is the increase in deposited sediments which then leads to increase in suspended solids and water turbidity as well as disturbances to biological functional groups (Lu et al., 2002). Increase in suspended solids will increase turbidity which will block sunlight penetration and reduce growth. Other than that it also causes loss of estuarine habitats such as wetlands and mangrove areas (Valdes, 1999), reduction in richness, abundance and biomass of benthic organisms such as mollusc (Naser, 2011), and impaired sesile benthic organisms growth (Essink, 1999).

Although the condition of coastal and marine structure will somehow recover but the process will take a long time. Prat et al. (1999) reported a slow recovery of aquatic ecosystem after reclamation process in Spain. Coastal areas are very unique therefore any development that needs to be carried out at these areas should follow Integrated Coastal Zone Management (Sano et al., 2010).

2.5 Evaluating marine water quality

Coastal water pollution has been a problem in many developed as well as developing countries. Until today, Marine Water Quality Index (MWQI), and Marine Water Quality Criteria and Standard (MWQCS) have been widely used in monitoring marine water other than biotic indices. MWQI was used to reflex marine water quality status and category, developed from seven main parameters, which include dissolved oxygen, ammonia, faecal coliform, total suspended solids, oil and grease, nitrate and phopshate. Water bodies are classified into 4 categories under MWQI according to the values from calculation (Table 2.1).

Table 2.1 Range and classification of Marine Water Quality Index (MWQI) (DOE, 2016).

MWQI value	MWQI Category
90 – 100	Excellent
80 – <90	Good
50 – <80	Moderate
0 – <50	Poor

On the other hand, MMWQCS is also developed and has been used as guideline with correspond to the MWQI values with four different classes (Class 1, 2, 3 and E) with different beneficial uses (Table 2.2). Class 1 and Class 2 in the MWQCS require MWQI values equal to or greater than 80 and are categorized at least as ‘good’ water quality. The Class 3 waters of the MWQCS are generally within the moderate category of the MWQI.

Table 2.2 Malaysian Marine Water Quality Criteria and Standard (MMWQCS) classes and its beneficial uses.

MMWQCS	Beneficial uses
Class 1	Preservation, Marine Protected Areas, Marine Parks
Class 2	Marine Life, Fisheries, Coral Reefs, Recreational and Mariculture
Class 3	Ports, Oil & Gas Fields
Class E	Mangroves Estuarine & River-mouth Water

2.5.1 Organic Pollution Index (OPI)

Apart from that, it is important to have an index that evaluates the degree of organic pollution as nutrient is one of the major accelerator of eutrophication problem. Researchers from China have constructed an organic pollution index that focuses on organic matter pollution and its impact. This index accounts for the effects of chemical oxygen demand, dissolved oxygen, dissolved inorganic nitrogen and dissolved inorganic phosphorus (Liu et al., 2011). This index was first established by Zhou et al. (1983) later had been modified by Lan (2011) and widely applied by China for instance at Yangtze Delta (Quan et al., 2005), Guangzhou Bay (Peng & Jia, 2007) and Jiaojiang Estuary (Wang et al., 2015).

Therefore, OPI is a comprehensive index that highlight the organic pollution constituents as the main focus. These include the effects of COD, dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP), and dissolved oxygen (DO)

(Liu et al., 2011). Dissolved inorganic nitrogen (DIN) was the sum of nitrate, nitrite and ammonia (The National Water Quality Monitoring Council, 2007). DIN is the most abundant and bioavailable form of nitrogen and is easily transported by the river into the coastal water (Veuger et al, 2004) and essential for phytoplankton growth and also responsible for algal bloom. Caffrey et al. (2007) stated that orthophosphate on the other hand was the dissolved inorganic form of phosphorus (DIP).

Excessive nutrients accumulation in coastal water is the major factor that contributes to eutrophication and algal blooms. This index can be adopted as early warning detection of high nutrients presence in the water body that can directly signal eutrophication and can be used as guideline for an assessment of marine ecosystem health status.

2.6 Physico-chemical characteristics of an estuarine and coastal water

2.6.1 Temperature

Temperature of tropical seawater ranges from 28°C - 32°C (Bong and Lee, 2008). Metabolic rate and reproductive activities of these aquatic lives is governed by temperature, which increases the oxygen demand of the organism. Increase in temperature will eventually decrease the solubility of dissolved oxygen for aquatic species. About 7% of increase in temperature will decrease 13% of ability of the gases to dissolve in the water body (Sébastien et al., 2013). Temperature plays an important role which influences the chemical, biochemical and biological functions of the water body (Manjare et al., 2010). Water temperature is influenced by air temperature, season, monsoons, topography, altitude, and humidity. El Nino which results in hot weather enhances the sea temperature that affects fisheries, caused coral bleaching, drought, forest burning, health issues and others (Academy of

Science Malaysia, 2016). Sea surface temperature anomalies greater than 2 °C at east-central equatorial Pacific Ocean during hot period of ENSO (El Niño–Southern Oscillation) causes an impact on Malaysia (Academy of Science Malaysia, 2016).

2.6.2 pH

Most of the chemical and biochemical reactions that take place in the water body are affected by the pH value. The pH value refers to the alkalinity and acidity of the water body. Air temperature and rate of photosynthesis are some factors that bring about the changes of the pH value. Optimum pH for phytoplankton grow is 5.0 - 8.5 (Umavathi et al., 2007). pH increases with salinity until the water reach $CaCO_3$ saturation. pH recorded in the study by Gasim et al. (2013) at areas of reclamation and coastal alteration in Tanjung Tokong and Gurney Drive in Penang were more alkaline with pH 8.0 and 7.48 respectively. Ecological function is affected when pH is more acidic, which is below 6. Hönisch and Hemming (2005) showed that the pH value reduced when marine productivity was increased. Increase in pH (greater than 9) can cause rapid toxicity of ammonia (Eddy, 2005). Domestic wastes and effluents also increase the acidity of coastal water (Akpan, 2004). Inorganic fertilizers that contain mixture of chemicals also decrease pH values (Karuppiah & Gupta, 1996). Ocean acidification impact due to increase in carbon dioxide emission will also decrease pH in ocean.

2.6.3 Salinity

Salinity is the amount of salts present in the seawater, which mainly comprises by sodium and chloride ions. Salinity varies according to the rate of freshwater-seawater flow, high tide and low tide events, precipitations, and evaporation due to increase in temperature. Generally, salinity is higher at the bottom of the estuary compared to the surface because saline water is more condensed than freshwater (Gao et al., 2008). Average seawater salinity is between 30 – 35 psu and it is an optimum salinity for many biological and chemical functions. Study at Penang National Park recorded the average salinity of 28.50 – 32.00 psu (Chuah, 2012). Other than that, salinity in the range of 26.5 to 31.5 psu and 15.2 – 32.4 psu were recorded by Choh et al. (2006) and Siddiquee et al. (2011) at southern part of Malaysian coastal waters respectively.

2.6.4 Conductivity

Conductivity of the seawater is the ability of the water to conduct electricity. Conductivity level of the seawater is higher than estuary or freshwater due to the presence of ions such as sodium ions, chloride ions, sulphate ions, magnesium ions and others. Conductivity is always related to salinity and dissolved solids except it measures the water ability to conduct electricity. Conductivity level at estuary and river increases during high tide and spring tide (Moore, 1999). Conductivity level of seawater is usually similar and constant but the conductivity level during high tide is higher than low tide due to high concentration of ions (EPA, 2012). Another study by Kaur (2012) showed that level of conductivity recorded in marine water is between 55600 and 58600 µS/cm. Conductivity level is also influenced by the rate of precipitation.

2.6.5 Turbidity

Turbidity measures the intensity of light scattered by suspended solids that include clay, silt, organic matters and plankton (EPA, 2012). Turbidity will fluctuate in the event of strong current, high precipitation and human disturbances such as fishing boats. Turbidity at Sg. Fetes, Tanjung Tokong, and Gurney Drive in Penang were 73.9, 21.4, and 1750.8 NTU, respectively (Gasim et al., 2013). Reclamation increases the level of turbidity. Dumping and dredging enhanced sediment deposition that increase the turbidity, risking benthos community and habitats (Lu et al., 2002). High turbidity affect fish feeding and growth rate (Gasim et al., 2013). Gills function in some fish may be impaired.

2.6.6 Total dissolved solids

Total dissolved solids (TDS) is the measures of amount of inorganic and organic materials include metal and ions in the water bodies. TDS measures similar substances as conductivity like dissolved ions but it also includes dissolved uncharged materials like silt and organic substances. In areas of heavy rainfall and less bedrock, TDS level may be low (Kent and Landon, 2013). TDS is classified under urban runoff (Shanmugam et al., 2007). Source of TDS into the coastal waters are from urban effluents, agricultural runoff, acidic rainfall that come from industrial factories, weathering and dissolution of minerals (Yap et al., 2011). Sedimentations will also increase TDS and turbidity, and also nutrients loading that causes decrease in dissolved oxygen.

2.6.7 Total suspended solids

Total suspended solids (TSS) at the seabed are higher than the surface during neap tide, due to the presence of the substrate at the bottom of the seawater. TSS increases when pH (Sanderson & Taylor, 2003; Mendiguchia et al., 2007), salinity (Sanderson & Taylor, 2003) and dissolved oxygen (Mendiguchia et al., 2007) decreases to a minimum level. High TSS indicates the impairment of the water bodies (Holbeck-Pelham and Rasmussen, 1997). TSS is 7 times higher during low tide than high tide (Park, 2007). Organic matter from aquaculture cages deposited at seabed increase TSS at that area. TSS recorded at fish cages at Batu Uban, Penang was in the range of 73 – 83 mg/L (Class III according to Malaysia Marine Water Quality Criteria and Standard) (Choo, 1994).

2.6.8 Dissolved oxygen

Dissolved oxygen (DO) is essential for aquatic species such as fish, other aquatic organisms, and microorganisms' respiration. Amount of dissolved oxygen is influenced by water temperature, wind action for gases exchange or aeration, rate of respiration and decaying process, and also rate of photosynthesis carried out by aquatic plants (Best et al., 2007). There is more dissolved oxygen in cold water than the warm water as increase in water temperature decrease the solubility of gases. DO recorded at coastal waters of southern Malaysia ranges widely between 2.2 to 12.03 mg/L (Yap et al., 2011). DO level at 4 mg/L is optimum for aquatic organisms (class 4 MMWQCS) (Miltner, 2010). DO below than the standard level (4 mg/L) will give impact towards aquatic life. According to MMWQCS of Class 2, DO at 5 mg/L is beneficial for marine life, fisheries coral reefs, recreation and mariculture. High concentrations of nutrients and organic matter decreases dissolved oxygen.

2.6.9 Chemical oxygen demand

Chemical oxygen demand (COD) is the amount of dissolved oxygen needed to carry out chemical functions including the reaction that take place during decomposition (Nayan et al., 2012). Increase in COD and biological oxygen demand (BOD) indicates an increase in oxygen demand, then leads to hypoxia, which in turn leads to eutrophication (Shanmugam et al., 2007). According to National Water Quality Standard for Malaysia, COD value greater than 100 mg/L (>100) is consider as high faecal contaminants (DOE, 2011).

2.6.10 Biological oxygen demand

Biological oxygen demand (BOD) on the other hand is the amount of dissolved oxygen needed by microorganisms to carry out decomposition of organic matter. Therefore, BOD is an important indicator in accessing organic loads in the water body. Any sudden increase in organic matter, which may come from agriculture and aquaculture practices will increase organic pollution. BOD is used to demonstrate the degree of organic pollutions (Dogan et al., 2009). It is defined by the amount of oxygen required for the aerobic microorganisms present in the sample to oxidize the organic matter to a stable organic form (Chapman and WHO, 1996). Nayan et al. (2012) stated that the BOD level at coastal water of Perak decreased with average value of 3 mg/L except at Manjung (8.22 mg/L). Study at Penang National Park by Chuah (2012) showed that BOD reading was in the range of 0.38 to 3.19 mg/L.

2.6.11 Nutrients

Nitrogen and phosphorus are the two macronutrients controlling eutrophication in the estuaries and marine ecosystem (Camargo and Alonso, 2006). Ammonium, nitrate, nitrite, ortho-phosphate are forms of nitrogen and phosphorus which present in inorganic nutrients which are dissolved and very essential for phytoplankton growth (Qualls, 2000; Jaffe, 2000). Bacteria and archaea are the two types of microbes that fixes nitrogen into nitrates and nitrites. Nitrifying bacteria (*Nitrosomonas*, *Nitrobacter*, and *Nitrospira sp*) are also responsible in nitrification (conversion of ammonia into nitrate) process (Voss et al., 2013).

Based on a study by Aminot and Kérouel (1995), concentrations of ammonia at the temperate European seawater increased gradually every year by 0.05- 0.07 µM. Concentrations of ammonia from land activities and riverbank practices which include organic substances from animal wastes (Jaffe, 2000), untreated domestic sewage (Panda et al., 2006; Morgan et al., 2007), fertilizers runoff from agricultural practices (Ngoye & Machiwa, 2004), atmospheric nitrogen fixation which fixed N_2 into inorganic form of nitrogen (Ngoye & Machiwa, 2004; Panda et al., 2006; Jaffe, 200), rainfall (Eyre & Balls, 1999; Qualls, 2000; Jaffe, 2000), and lightning (Jaffe, 2000) that end up into the sea increases ammonia concentrations. These anthropogenic activities highly contribute to the increasing of ammonia concentrations.

Recent finding showed that input and output of ammonium into marine ecosystem was significantly imbalanced (Gruber and Galloway, 2008). Moreover there was discovery of a new nitrification process by a new bacteria reported i.e anaerobic ammonia oxidation (anammox), and denitrification process by eukaryotic species such as foraminifera (Risgaard-Petersen et al., 2006). Nitrification process is favored when there is a normal dissolved oxygen level in the water body whereas denitrification process only occurrs when dissolved oxygen is in low level, which is less than 4 mg/L. Increase in nitrite level will increase the toxicity of fish (Kemp and Dodds, 2002).

Nutrients enrichment in marine ecosystem at some point can be beneficial. In moderate level it can be useful as this condition promotes high primary productivity by phytoplankton, and lead to increase fish population and harvesting (Nixon, 1995) due to the presence of optimum dissolved oxygen. Despite that, at some condition, even a slight fluctuation of nutrients can damage that particular ecosystem such as coral reef. Over enrichment of nutrients will harm many marine structures. Nitrogen accumulation will accelerate eutrophicaton (Howarth and Marino, 2006; Nixon, 1995; Paerl, 1997). Over enrichment of nutrients lead to unfavoured and unhealthy conditions towards the marine ecosystem.

Unlike ammonia, nitrite, and nitrate, orthophosphate is less mobile. Therefore water runoff from agriculture and urban sewage that flow into the river and then into the seawater contain less concentrations of orthophosphate (Howell, 2010).

Weathering of rockbeds and other substrate at the seabeds forms inorganic phosphorus, orthophosphate. Orthophosphate is the limiting factor that controls primary production of phytoplankton in freshwater lotic lake but not in marine ecosystem (Carpenter et al., 1998).

Eutrophication is excessive richness of nutrients that increase the primary productivity (Khan & Ansari, 2005), leading in excessive accumulation of organic materials that later lead to hypoxia. Release of nutrients,mainly phosphate and nitrogen into aquatic ecosystem stimulates the primary production and lead to algal biomass bloom and alters the trophic structure of the water body (Abdel-Raouf et al., 2012).

CHAPTER 3 – MATERIALS AND METHODS

3.1 Sampling locations

Penang coastal waters were selected as the study site because of its growing land-based and sea-based activities that might give out negative impact to the marine and estuarine ecosystems. Two sites were selected i.e. at south-west which stretches from Batu Maung until Batu Kawan, further to Sg Jawi waters and north-western part from Teluk Bahang until Pantai Kerachut (Figure 3.1). The study was conducted from December 2015 to May 2016. Water samples were collected once a month, alternately during two tidal events i.e neap and spring tide based on the tide table according to Kedah Pier Port tidal prediction (National Hydrography Centre, 2015 and 2016).

Site A comprised of Penang Second Bridge coastal water, included Batu Maung, Batu Kawan, Pulau Aman, and estuaries of Sg Jawi, Sg Tengah and Sg Kerian, were observed with various land as well as sea based activities. Along with natural causes, may give out high pressure to the ecosystem in this area.

Site B was located at Penang National Park (PNP) coastal water, which was gazetted as national park in April 2003. This area has minimum anthropogenic activities and disturbances and also less developed. Site B was treated as reference site.

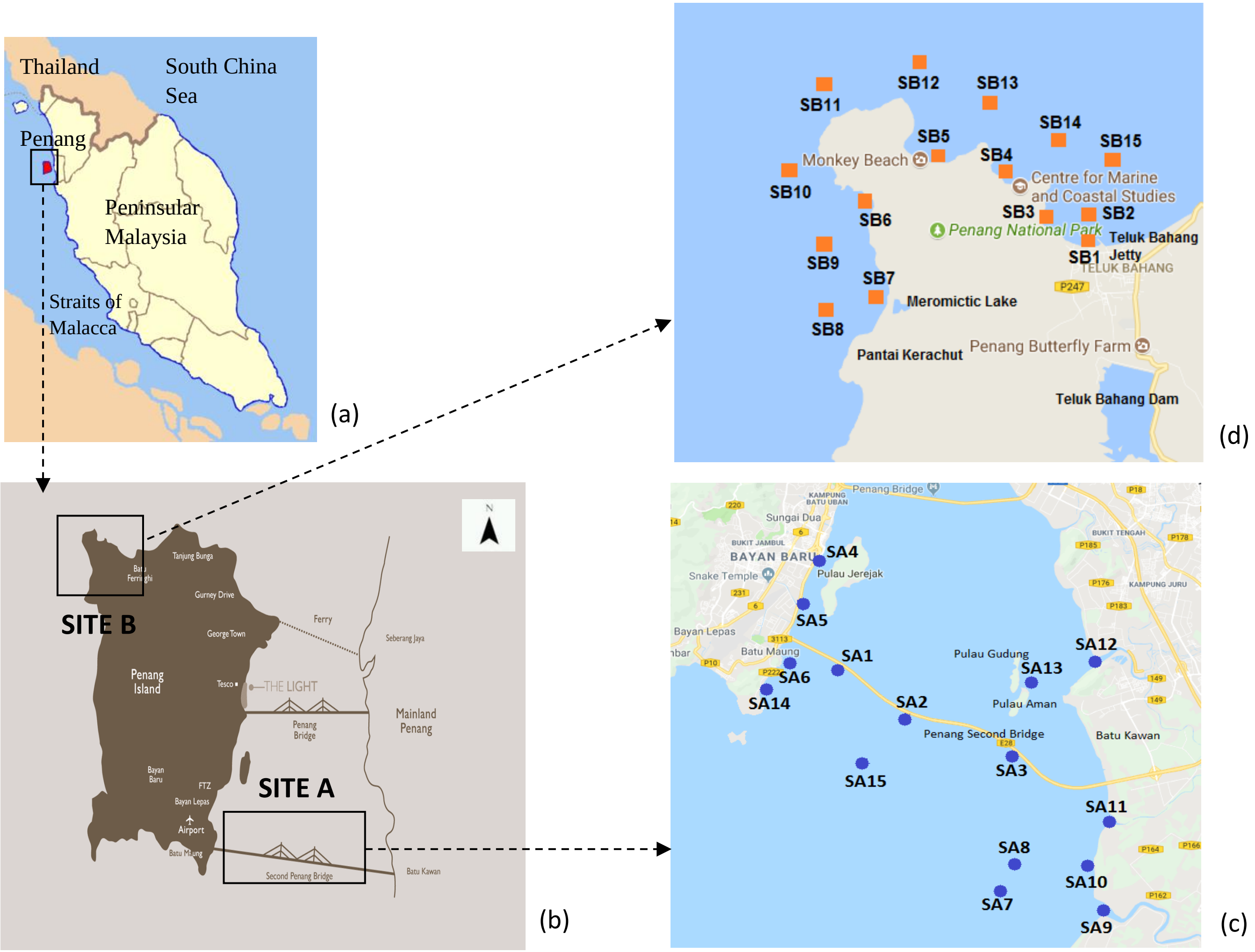

Figure 3.1 Location of Penang in Malaysia (a), study sites (b), and sampling stations at Site A (c) and Site B (d) (Scales shown are not the exact distance between sampling stations).

3.1.1 Site A

Penang coastal areas of Site A were observed with high disturbances such as landfills (Plate 3.1), settlements and fish landing area (Plate 3.2), many floating fish cages at Pulau Aman and Penang Second Bridge (Plate 3.3 and 3.4 respectively), land reclamation (Plate 3.5), boat activities (Plate 3.6), and industrial premises (Plate 3.7). These anthropogenic activities will have a serious impact on the marine environment as Penang is developing into a high industry thus when the domestic, industrial, agro-industrial effluents will be discharged they will eventually end up in the sea.

Water samples were collected from 15 stations along the coastal waters of Site A including the estuaries of Sg Nibong Kecil (SA4), Sg Keluang (SA5), Sg Kerian (SA9), Sg Tengah (SA11), and Sg Jawi (SA12) (Figure 3.1(c)). Three stations were taken underneath the Sultan Abdul Halim Muadzam Shah Bridge (Second Penang Bridge) which were SA1 which is 12 meters in depth, the deepest compared with the other stations, SA2 and SA3 at Pillar 25, 133 and 243, respectively. Other four stations were taken at the aquaculture floating cages namely SA6, SA7, SA8 and SA13. SA10 was at the inshore water of Pulau Burung landfill area. SA15 is a reference station, located 2 km from Pillar 97, to the right side of the bridge, extending towards the open sea. The reference station located far from the human activities. The Global Positioning System (GPS) coordinates of the sampling stations for Site A was listed in Table 3.1.