TEMPORAL VARIABILITY OF SELECTED PHYSICO-CHEMICAL PARAMETERS
AND PRIMARY PRODUCTIVITY IN ESTUARINE WATER OF KUCHING

Liaw Sze Chieng

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Temporal Variability of Selected Physico-chemical Parameters and Primary Productivity in Estuarine Water of Kuching

LIAW SZE CHIENG

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Department of Aquatic Resource Science and Management
Faculty of Resource Science and Technology
UNIVERSITY MALAYSIA SARAWAK
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Declaration

I hereby declare that no portion of the work referred to in this thesis has been submitted in support of an application for another degree of qualification to this or any other university of institution of higher learning.

___________________________
(Liau Sze Chieng)
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Temporal Variability of Selected Physico-chemical Parameters and Primary Productivity in Estuarine Water of Kuching

Liaw Sze Chieng
Aquatic Resource Science and Management
Faculty of Resource Science and Technology
Universiti Malaysia Sarawak

ABSTRACT
Remote sensing is an important technology for broad-scale aquatic related researches. Unlike in situ methods, satellite data can provide synoptic data for a large study area. This study describes the results of temporal changes of chlorophyll a, temperature datasets and phytoplankton composition in estuarine waters as well as the validation of satellite chlorophyll a and temperature datasets with in situ datasets in estuarine Case 2 waters of Kuching for seven months. This study was carried out in Samariang and Santubong estuaries from 21st September 2011 until 2nd April 2012. The physico-chemical water parameters, phytoplankton abundance and composition, chlorophyll a (Chl-a) concentration and Total Suspended Solids (TSS) were studied. Based on the study, the in situ chlorophyll a mean concentration was 2.30±1.84 mg/m³ for Samariang estuary and 2.35±1.19 mg/m³ for Santubong estuary. There was no validation possible in Samariang and Santubong estuaries as the satellite instrument errors were too high. While for Bako estuary, the satellite derived Chl-a datasets were significant different with the in situ datasets on 16th November 2011 (r² = 0.8602) but not significant different on 19th November 2011 (r² = 0.2239). This study concludes that the accuracy of satellite derived Chl-a datasets to validate in situ datasets was depending on the water turbidity. There are limitations to validation during this study of which data of nearby overhead passes were often not available due to land masking, cloud cover and large errors near coastal waters.

Keywords: Temporal changes, Data validation, Chlorophyll a, Temperature, Case 2 estuarine waters

Liaw Sze Chieng
Aquatic Resource Science and Management
Faculty of Resource Science and Technology
Universiti Malaysia Sarawak

ABSTRAK
Penderiaan jauh merupakan teknologi yang penting dalam penyelidikan berskala luas dalam bidang aqualit. Tidak seperti kaedah in situ, data satelit boleh menyediakan data sinoptik bagi kawasan kajian yang besar. Kajian ini telah menerangkan hasil perubahan bagi dataset klorofil-a suhu and Komposisi fitoplankton yang diperolehi di perairan muara dari segi masa serta pengesahan dataset satelit untuk klorofil-a dan suhu dengan dataset in situ dalam kes 2 perairan muara sungai di Kuching selama tujuh bulan. Kajian ini telah dijalankan di Muara Samariang dan Santubong dari 21st September 2011 until 2nd April 2012. Parameter fiziko-kimia air, jumlah dan komposisi fitoplankton and kepekatan klorofil-a serta jumlah pepejal terampai telah dikaji. Berdasarkan kajian ini, kepekatan klorofil-a in situ untuk Muara Samariang adalah 2.30±1.84 mg/m³ dan untuk Muara Santubong adalah 2.35±1.19 mg/m³. Suhu yang direkodkan untuk Muara Samariang adalah 28.64±1.70 °C manakala untuk Muara Santubong adalah 28.84±1.35 °C. Pengesahan data tidak dapat dijalankan di Muara Samariang and Santubong disebabkan oleh kesilapan alat satelit yang terlalu tinggi. Manakala bagi Muara Bako, dataset Klorofil-a terbitan satelit pada 16th telah menunjukkan perbezaan yang ketara dengan dataset in situ (r² = 0.8602) manakala tidak menunjukkan perbezaan yang ketara antara dataset satelit and dataset in situ (r² = 0.2239). Kajian ini telah menyimpulkan bahawa ketepatan dataset satelit klorofil-a untuk pengesahan data in situ adalah bergantung kepada kekeruhan air. Terdapat batasan pengesahan data semasa kajian ini di mana data "overhead pass" yang berhampiran tidak mudah didapat kerana masalah liputan awan, liputan tanah dan kesilapan yang tinggi.

Kata Kunci: Perubahan dari segi masa, Pengesahan data, Klorofil-a, Suhu, Kes 2 Pengairan Muara

1
1.0 Introduction

Present day, remote sensing is more widely used in monitoring and conservation purposes. No doubt, it is a useful technology for broad scale aquatic related research such as for water quality monitoring, chlorophyll \(a\) monitoring, coral reef management and phytoplankton monitoring (Richardson & Ledrew 2006). Besides that, unlike \textit{in situ} methods, the data for satellite methods provide synoptic data for a large area for the particular study. However, either \textit{in situ} methods or satellite applications alone are not sufficient for a large scales survey (Giardino et al. 2010).

MODIS (Moderate Resolution Imaging Spectroradiometer) and MERIS (MEedium Resolution Imaging Spectrometer) are two (2) common remote sensing instruments for use in aquatic studies. According to Prasad and Singh (2010), the MODIS instrument is commonly used for chlorophyll \(a\) and surface temperature monitoring. MERIS is widely used in chlorophyll \(a\) and suspended solids monitoring (Lacroixa et al. 2007; Gonsa, Auer \& Effler 2008; Cui at al. 2010).

With the improvement in the satellite instruments, the demand for satellite data in aquatic research increases. However, there is a lack of comparison and validation of satellite chlorophyll \(a\) and temperature data with the \textit{in situ} data especially in Sarawak waters. In Sarawak, the waters are mostly categorized as Case 2 waters which mean that they are mainly influenced by the inorganic suspended solids, dissolved organic matters, and detritus which can be from many human activities and runoff (Kuchinke et al. 2009). Both suspended solids and chlorophyll \(a\) will contribute to the spectral results for satellite imagery (MERIS Product Handbook 2006). This event will always mislead researchers making estimation using ocean colour products which have not been validated.
*In situ* water quality parameters are important in studies of temporal changes of phytoplankton. However, there are lack of previous work utilizing satellite derived products to determine temporal change in chlorophyll \( a \) and temperature in estuarine waters of Kuching. In order to get the accurate satellite derived datasets, both the *in situ* water parameters and phytoplankton abundance should be obtained to correlate with the satellite datasets (Cui et al. 2010).

The purposes of this study were:

- To determine the temporal changes of chlorophyll \( a \) and temperature in estuarine waters of Kuching from *in situ* water quality parameters sampling and satellite derived chlorophyll \( a \) and temperature datasets.

- To compare and validate the satellite derived chlorophyll \( a \) and temperature dataset with *in situ* datasets in estuarine Case 2 waters of Kuching.

- To determine the temporal changes of phytoplankton abundance and composition in the estuarine waters of Kuching.
2.0 Literature Review

2.1 Remote Sensing

Remote sensing is the application of using electromagnetic radiation to obtain information about Earth’s surface without direct contact with it (Martin 2004). The benefits of remote sensing are: 1) provide synoptic datasets, 2) provide quantitative datasets and 3) offer repeat sampling for the researchers (Richardson & Ledrew 2006).

![Figure 1: The electromagnetic spectrum shows the spectral window used for remote sensing (Taken from Robinson & Guymer 2002)](image)

The Figure 1 above is the electromagnetic spectrum which shows the spectral window used for remote sensing. It ranges from shortest gamma rays to longest radio waves. In most remote sensing applications, the common electromagnetic bands used are visible bands, infra-red and microwave (Robinson & Guymer 2002). The visible bands are the light that we can see with our naked eyes which primarily involves blue, red and green spectrums. The range for visible bands are from 0.4 to 0.7 µm. Infra-red have a longer wavelength than the red spectrum of visible bands which can be divided into near-infrared, mid infrared and thermal infrared. These bands were ranging from 0.7 – 1.3 µm, 1.3 – 3.0
µm and 3.0 – 14.0 µm, respectively. Microwaves are the longest wavelengths that apply in remote sensing which range from 1 mm to 1 m (Aggarwal 2003).

![Diagram showing sensors and measurements](image)

**Figure 2:** The schematic shows the visible and infra-red sensors with the primary measurements and the derived parameters (Adapted from Robinson & Guymer 2002)

![Diagram showing measurements of water](image)

**Figure 3:** The two primary measurements of water which can be made in satellite oceanography. (a) Ocean Colour (OC) – sun energy passes through and scattered under water surface then transmits to the visible waveband multi-spectral radiometer; (b) Sea Surface Temperature (SST) – thermal emission from water surface have been sent to infra-red radiometer and microwave radiometer. (Adapted from Robinson & Guymer 2002)

Remote sensing used sensors to receive data from the ground. According to Robinson and Guymer (2002), there are several classes and types of sensors that used in remote sensing. Figure 2 above shows the schematic for visible and infra-red sensors with
the primary measurements and derived parameters for remote sensing. Both of the sensors are passive sensors which mean that the sensors work with the naturally occurring energy. Visible sensor is used for Ocean Colour (OC). OC is the water colour reflected from the phytoplankton pigments, suspended sediments and organic particulates. Infra-red sensor is used to detect Sea Surface Temperature (SST). Figure 3 above shows the primary measurements applied in satellite oceanography. There are some differences between the transmission routes. For OC, sun energy passes through and scattered under water surface then transmits to the visible waveband multi-spectral radiometer while for SST, thermal emission from water surface have been sent to infra-red radiometer and microwave radiometer (Robinson & Guymen 2002).

![Figure 4: Worldwide Chlorophyll a concentration (left) and Sea surface temperature (right) map (Taken from http://earthobservatory.nasa.gov/GlobalMaps/view.php?d1=MY1DMM_CHLORA, 11th October 2011)](image)

OC and SST datasets can provide several advantages. The most practical one is the large scale coverage which was previously not possible without satellites. Figure 4 above shows an example of the worldwide chlorophyll concentration and SST map. Chlorophyll is the main photosynthetic component in phytoplankton. In order to study the phytoplankton abundance in water column, chlorophyll concentration will be estimated. As mention earlier, OC involves the transmission and scattered sunlight energy. So, it used to observe chlorophyll concentration due to the ability of chlorophyll pigment to scattered the
visible bands back to the sensors. In this example, the chlorophyll concentration in dark blue colour shows the lowest chlorophyll concentration and green - yellow colour indicates the highest chlorophyll concentration. The same figure shows most coastal areas have high concentration of chlorophyll. In SST map, the dark violet colour indicates the coolest waters and lightest pink colour show the warmers waters.

Figure 5: SeaWIFS Image shows the chlorophyll map (left) and suspended solid map (right) which arise from different atmospheric correction algorithms on year 1999 in Gulf of Finland (Adapted from Bukata 2005)

The Figure 5 above shows the SeaWIFS image for chlorophyll and suspended solids concentration in Gulf of Finland (an example of Case 2 waters) in year 1999. The image is important to show that Case 2 waters are influenced by both phytoplankton and suspended solids (Bukata 2005).

2.1.1 The Relationship of Chlorophyll a (Chl-a) with Phytoplankton and its Biomass

Phytoplankton are a group of tiny, single celled drifting photosynthetic organism which are also known as “grasses or plants of the sea” (Rissik & Suthers 2009). Most phytoplankton are photo-autotrophic and important as the base of aquatic food web (Khenari et al. 2010). According to Nasrollahzadeh et al. (2008), the growth of phytoplankton depend on sunlight, carbon dioxide (CO₂), nutrients such as nitrogen and phosphorus as well as other in situ
environmental conditions such as water temperature, pH, turbidity, dissolved oxygen and grazers (zooplanktons).

The plant-like phytoplankton community need Chlorophyll $a$ (Chl-$a$) to convert sunlight into organic compounds (Satpathy et al. 2010). This process is called photosynthesis. Chl-$a$ concentrations in water can be used to estimate the algae biomass. This is because Chl-$a$ is essential in photosynthetic organisms. Besides that, Chl-$a$ is the indicator for phytoplankton biomass (Alvain, Duforêt-Gaurier & Loisel 2011). The excessive concentration of Chl-$a$ indicates the presence of algal blooms. The unconsumed algae then sink to the bottom and decay. This can cause the oxygen depletion in the deeper waters.

Diatoms and dinoflagellates are the two main groups that made up phytoplankton and can be divided according to their size. (Redden et al. 2009). Phytoplankton lives in aquatic ecosystem and can be found in pelagic zones of both freshwater and saltwater bodies. According to Carreto et al. (2008), the satellite chlorophyll $a$ and SST datasets were used to indicate the algal communities. In their study, the microscopy works were done to examine the different types of algae that occupied in the water bodies. Besides that, it help in monitoring the harmful algal (HA) in water column. Moreover, the cell count and identification is important to keep track of the temporal changes of phytoplankton taxa in water bodies especially in estuarine water which have high environmental variability. Lastly, the manual cell count and identification data can be used to correlate and validate the satellite datasets in order to get more trustable and convincing data.

2.1.2 Sea Surface Temperature (SST)

Sea Surface Temperature (SST) is the water temperature near ocean’s surface which range from 0.001 to 20 m below water surface (EOS Data Product Handbook 2000). The
monitoring of SST as well as Chl-\textit{a} concentration which explained in part 2.1.1 is needed because both are important to ocean productivity (Alvain et al. 2008).

2.1.3 MODIS (Moderate Resolution Imaging Spectroradiometer)

According to Xiong et al. (2009), MODIS serve as the key instrument on the Terra and Aqua satellites under NASA (National Aeronautics and Space Administration). The spatial resolutions for MODIS are 250 m, 500 m and 1000 m with 36 spectral bands. The wavelength range for MODIS is from 0.4\textmu m to 14.4\textmu m. The temporal resolution for MODIS instrument to view Earth’s surface is one (1) to two (2) days. The product data which can be obtained from MODIS instruments are Chl-\textit{a} concentration and SST.

2.1.4 MERIS (MEdium Resolution Imaging Spectrometer)

MERIS instruments on board the European Space Agency (ESA) satellite Envisat. The spatial resolutions for MERIS are 300 m and 1200 m. MERIS consist of 15 spectral bands. MERIS is mainly use in ocean colour monitoring. It used to observe the chlorophyll \textit{a} concentration and suspended solid concentration (MERIS Product Handbook 2006).

2.2 Case 1 Waters and Case 2 Waters

Case 1 waters refer to mid-ocean waters which are known as ‘clear waters’. Basically, the optical properties for Case 1 waters are influenced by water molecules and phytoplankton. Case 2 waters mainly refer to inland and coastal waters. The optical properties for Case 2 waters are influenced by inorganic suspended solids, dissolved organic matters, phytoplankton and detritus (Bukata 2005).

2.3 Estuarine Waters

Estuarine waters are semi-enclosed body of water which connect freshwater and sea water. Besides that, it is influenced by tidal movement. The mixing of freshwater and saltwater has caused the high fluctuation of salinity and influence the nutrient content in water. The
nutrient content can be affected by the discharged from river and run off (Anderson, Glibert & Burkholder 2002). In estuarine water, phytoplankton growth are mainly regulated by the flushing or run off, salinity level, light intensity and nutrient concentration (Ferreira et al. 2005).

2.4 Water Quality Parameters

2.4.1 Temperature

Water temperature is an important parameter in aquatic systems which can affect the efficiencies of chemical reactions, photosynthesis and metabolic rates of other aquatic organisms (Genevieve & James 2006). Generally, the rate of photosynthesis increases with increase of temperature. However, it will decline sharply as the optimum point reached (Sampathkumar & Anathan n.d.). Generally, phytoplankton can tolerance the temperature with a range 15 – 31 °C. But, it is species specific which mean each species of phytoplankton have their optimum growth in certain temperature range. Temperature, together with illumination can influence the phytoplankton composition and diversity in estuarine water (Baumert & Petzoldt 2008; Lassen et al. 2010).

2.4.2 Salinity

According to Flöder et al. (2010), salinity is the saltiness of water body. It expressed in practical salinity unit (PSU) and is an important ecological factor which can influence the type of phytoplankton found in estuarine water (Lemaire et al. 2002). Estuaries are a dynamic ecosystem affected by the freshwater discharge and tidal movement from the sea. Generally, diatom can adapt better to the salinity variation in estuarine water, i.e. Skeletonema sp. can tolerate with the salinity range from 11 – 40 PSU (Sampathkumar & Anathan n.d.) which show Skeletonema sp. is a euryhaline phytoplankton. On the other hand, dinoflagellate such as Ceratium sp., Peridinium sp. and Prorocentrum sp. can adapt
with narrow salinity range. These show difference taxa of phytoplankton have their own optimum range to adapt the salinity changes (Buchanan et al 2005).

2.4.3 Turbidity and Total Suspended Solids (TSS)

Turbidity is the measurement of the clarity of water, while Total Suspended Solids (TSS) are the particles that affect the turbidity of water. Turbidity can also be caused by the abundance of phytoplankton in water bodies. Water turbidity can influence the phytoplankton abundance in the water (Shen et al. 2011). In high turbidity water, there is less light can penetrate through water (Hotzel & Croome 1999). This leads to less photosynthesis process can occur due to light limitation and directly affects the productivity of phytoplankton in the water bodies. This is an important parameter that need to be take into account when study the Chl-a concentration and phytoplankton communities in estuarine water.

2.4.4 pH

The pH is the measurement of the acidity and alkalinity of water (Genevieve & James 2006). For example, seawater usually high in pH level (approximately 8.1) which indicates the seawater is alkaline. pH level in water can affect the nutrient content in water bodies due to the changes of water chemistry (Water Quality for Ecosystem and Human Health 2006). Besides that, this can change the phytoplankton growth rate and distribution, especially in estuarine water which subjected to drastic variability in pH (Chakraborty et al. 2011). This can directly affect the aquatic food web because phytoplankton serves as the base of the aquatic food web.

2.4.5 Dissolved Oxygen (DO)

Each water molecule contains an oxygen atom which serves as an important component in aquatic systems. Aquatic organisms need the oxygen for aerobic metabolisms (Genevieve