TIDAL EFFECTS ON PHYSICAL WATER PROPERTIES AND SUSPENDED SEDIMENT CONCENTRATION IN SALUT-MENGKABONG LAGOON

CARLOS VITTORIO DONDING

PROGRAM SAINS MARIN SEKOLAH SAINS DAN TEKNOLOGI UNIVERSITI MALAYSIA SABAH

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Saya akui karya yang bertajuk "Tidal Effects on Physical Water Properties and Suspended Sediment Concentration in Salut-Mengkabong Lagoon" ini adalah hasil kerja saya sendiri kecuali nukilan dan ringasan yang setiap satunya telah dijelaskan sumbernya.

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DIPERAKUKAN OLEH

Tandatangan

1. PENYELIA
   Dr. Md. Azharul Md. Hoque

2. KO-PENYELIA BERSAMA
   Mrs. Ejria Saleh

3. PEMERIKSA
   Mrs. Ejria Saleh

4. PEMERIKSA 2
   Ms. Zarinah Waheed

5. DEKAN
   Prof. Madya Dr. Sharif A Kadir S Omang

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ABSTRACT

Observation of tide effects were made to physical water properties and suspended sediment concentration in Salut-Mengkabong Lagoon. The physical water properties measured include current velocity, temperature, salinity, pH and dissolved oxygen in Salut Lagoon and Mengkabong Lagoon. The study was conducted during spring tide and neap tide. For each Salut and Mengkabong Lagoon, 5 stations were placed each lagoon. Physical water properties and current velocity from water samples were taken from surface, middle and bottom of the lagoon. Current velocity measurements were taken at 1-meter increment from the lagoon surface. Field measurements were taken during ebb tide and flood tide. The result of spring tide and neap tide showed differences. The measurement of physical water properties during spring tide was relatively higher than during neap tide. Same results occured during measurement of 2 neap tides in 2 different monsoons. The measurement in September was relatively higher than during January. Tides play significant role in transporting suspended sediment in coastal lagoon then waves. Ebb tide and flood tide current condition also affected current velocity, temperature, salinity, pH and dissolved oxygen in coastal lagoons. Differences were observed between the inner station and the station near the inlet of Salut and Mengkabong lagoons.

ABSTRAK

Pemerhatian tentang kesan pasang surut telah dibuat ke atas parameter-parameter fizikal air dan pepejal terampai di Lagun Salut-Mengkabong. Parameter-parameter fizikal yang diukur termasuk kelajuan arus, suhu, salinity, pH dan oksigen terlarut di Lagun Salut dan Lagun Mengkabong. Kajian dilakukan ketika air pasang anak dan air pasang purnama. Terdapat 5 stesen telah ditetapkan di setiap lagun. Bagi pengukuran suhu, saliniti, pH, oksigen terlarut dan pepejal terampai, 3 bacaan dan sampel air diambil pada kedalaman permukaan, pertengahan dan dasar lagun tersebut. Manakala bagi kelajuan arus, bacaan diambil pada pertambahan kedalaman setiap satu meter dari permukaan air. Sampel dan bacaan diambil pada ketika air surut dan air pasang. Semasa kajian dilakukan, perbandigan antara pasang anak dan pasang punama menunjukkan perbezaan. Bacaan parameter bagi pasang purnama adalah lebih tinggi berbanding dengan pasang anak. Begitu juga dengan perbadingan antara dua pasang anak yang diambil pada dua monsun yang berbeza. Bacaan ketika monsun pada bulan September adalah lebih tinggi berbanding dengan bulan Januari. Oleh kerana ombak tidak dijana dalam lagun, air pasang dan surut memainkan peranan yang penting dalam menyebarkan pepejal yang terampai. Air pasang dan air surut juga mempengaruhi kelajuan arus, suhu, saliniti, pH dan oksigen terlarut didalam lagun persisiran pantai. Perbezaan juga dapat dilihat pada stesen yang terletak pada kawasan terdalam lagun Salut-Mengkabong dengan stesen yang berdekatan dengan teluk lagun.

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g/L gram per liter

g/m^3 gram per meter cube

CHAPTER 1

INTRODUCTION

1.1 Introduction

Coastal lagoons are critical for the survival of many species. Tremendous species of fishes and other wildlife depends on coastal lagoon as a place to live, breed and feed. Many species of shellfish and fishes rely on the sheltered water for spawning and as nursery ground. Hundreds of marine organisms especially species that have commercial potential, depend on coastal lagoon at some point during their development.

Besides serving as important habitat for wildlife, the wetlands that fringe many coastal lagoons also perform many valuable services. Water draining from the uplands carries sediments, nutrients and other pollutants. As the water flows through fresh and salt marshes, much of the sediments and pollutants are filtered out. This filtration process creates clearer and cleaner water, which benefits both people and marine life. Wetland plants and soils also act as a natural buffer between the land and ocean, absorbing floodwaters and dissipating storm surges. This protects upland organisms as well as valuable real estate from storm and flood damage.

Among the cultural benefits of coastal lagoon are recreation, scientific knowledge, education and aesthetic values. Boating, fishing, swimming, surfing and bird watching are just a few of the numerous recreational activities people enjoy in coastal lagoons. As transition zones between land and water, coastal lagoons are invaluable laboratories for scientists and students, providing countless lessons in biology, geology, chemistry, physics, history and social issues.

Furthermore, the tangible and direct economic benefits of coastal lagoon should not be overlooked. Tourism, fisheries, and other commercial activities thrive on the wealth of natural resources coastal lagoon supply. The protected coastal waters of estuaries also support important public infrastructure, serving as harbours and ports vital for shipping, transportation and industry.

Unfortunately, this increasing concentration of people is upsetting the natural balance of coastal lagoon ecosystems and threatening their integrity. The urban development around the lagoon places increasing pressure on the sensitive system (Icely, 1987) and compromises the water quality in the lagoon (Durham, 2000). Channels have been dredged, marshes and tidal flats filled, waters polluted, and shorelines reconstructed to accommodate human housing, transportation, and agriculture needs. Stresses caused by overuse of resources and unchecked land use practices have resulted in unsafe drinking water, beach and shellfish bed closings, harmful algal blooms, unproductive fisheries, loss of habitat, fish kills, and wildlife, and a host of other human health and natural resource problems. Thus, this study is very important to examine the effect of tidal variation in coastal lagoon. The effect of tides to physical water properties and suspended sediment can show how many the changes in the coastal lagoon due to the stresses mention above. The role of the present study is to describe some of the physical and ecological aspects of the Salut-Mengkabong lagoon as well as detailing new data of the temperature and salinity regimes.

Coastal lagoons are often associated with wetlands and native fisheries of conservation value. Conservancies are involved in advocacy on water values, coastal management and wetland management. It relates to the opening and closing of the gravel coastal barriers controlling the water levels and water exchange in these lagoons. However, sediment type, backshore form and wave regime different in the inlet and the lagoons area.

The establishment of guidelines must proceed from understanding of the nature and trends of physical coastal processes that have been formed and that continue to modify coastal lagoons. As part of a major study of the lagoon system, the temperature and salinity regimes are investigated at timescale ranging from tidal to annual.

1.2 Objectives

1. To study the effects of tidal variation on physical water properties in Salut-Mengkabong Lagoon.
2. To identify the effects of tidal variation on suspended sediment concentration in Salut-Mengkabong Lagoon.
3. To investigate the variation of studied water parameter during southwest monsoon and northeast monsoon.

CHAPTER 2

LITERATURE REVIEW

4.1 Coastal Lagoon

Coastal lagoons account for 13% of all coastal environments (Barnes, 1980). Typically, coastal lagoons are common along coasts with wide and flat coastal plains (Emery, 1995) and are separated from the ocean by a barrier. Coastal lagoons occur all over the world except Antarctica (Nichols and Boon, 1994). For building the lagoon barrier, abundant of sediment supply associated with wave action exposure is necessary. Lagoons naturally grade into others types of wetland habitat including semi-enclosed marine bays, freshwater lakes and estuaries (Barnes, 1980).

Coastal lagoons usually are shallow water bodies running parallel to the coastline and connected to open sea with an outlet (Reineck, 1996). Rivers may discharge into a lagoon thereby forming estuarine areas. There are many controversies from the previous definition. Not all coastal lagoons follow the shoreline-parallel pattern. They are parallel to the coast when they originated from wave-built barrier. A submerged river valley can be positioned normal to the shoreline (Phleger, 1981).

The latest definition indicated that coastal lagoons are inland water bodies usually oriented parallel to the coast. They are separated from the ocean by a barrier, connected to the ocean by one or more restricted inlets and having depths seldom exceed a couple of meters (Kjerfve and Magill, 1989). Micro tidal coasts are the most favourable for barrier beach built by waves and for consequent lagoon containment (Nichols and Boon, 1994). In direct contrast, macro tidal environments exhibit few barrier-lagoon systems because of stronger tidal currents.

Coastal lagoons can be divided into three types, depending on the degree of water exchange between lagoon and ocean (Kjerfve, 1994). Typically, coastal lagoon can be divided into leaky lagoon, choked lagoon and restricted lagoon.

Leaky lagoons have wide tidal channels, fast currents and unimpaired exchange of water with the ocean. Choked lagoons occur along high energy coastlines and have one or more long narrow channels. The long narrow channels restrict the water exchange between the lagoon and ocean. Circulation within this type of lagoon is dominated by wind patterns. Restricted lagoons have multiple channels and well defined exchange with the ocean. They tend to show a net seaward transport of water. Wind patterns in restricted lagoons can also cause surface currents to develop, thus helping to transport large volumes of water downwind (Kjerfve, 1994).

Many restricted lagoons tend to be well mixed because they are heavily influenced by wind patterns. Winds enhance vertical mixing in the water column and influence surface currents that insure lateral mixing of estuarine water. This results in a vertical profile of the water column where virtually no change in salinity is observed from the surface to the bottom. In contrast, salinity in well-mixed estuaries does decrease horizontally with distance from the ocean.

4.2 Tidal Fluctuation

Coastal lagoons are estuaries maintained by tidal currents with a vertical mixing. The effects of tides control the different water bodies (Hayes *et al*., 1984). Tidal inlets have a minimum flow area in relation to the lagoon tidal prism. The degrees of water exchange affect the tides in coastal lagoon. Tidal movement is one of the driving forces in the coastal lagoon circulation. The most important movement is the horizontal axis.

Although fluctuations in mean sea level should correlate with a variation in the inlet's throat, some inlets do not represent this pattern (Fitzgerald *et al*., 2002). Based on laboratory tests, waves superimposed on tides reduce 40% of small inlets cross-sectional area, suggesting that waves cause a net transport toward the inlet that reduces its area.

Tides also sustain the presence and geometry of tidal deltas. Typically, micro tidal inlets have flood tidal deltas, while a meso tidal and macro tidal coast ebb deltas and sand ridges are important (Hubbard *et al*, 1979). Maximum currents occur at the inlets and channels. At the inlet, there is a segregation of flows. While on the inner mouth, the reverse is true for major flood channel and lateral ebb-channels.

The tide in the lagoon is visible in current, salinity, turbidity and other physical properties of seawater. Typically, the tides will reach maximum speed in either direction at mid-tide and will reach a minimum of zero at about the change of the tides. The resuspension and deposition of the sediment in the lagoon is affected by the tidal fluctuation. The constituents of the water column are also affected by the spring-neap tide cycle. Large variation of suspended matter load has been observed between spring and neap tide situations (Hubbard *et al*, 1979).

4.3 Coastal Lagoon Processes

4.3.1 Limited Freshwater Input

Very little freshwater enters from the catchments, which itself may be very small. The quantity of freshwater input can vary seasonally, depending on regional climatic conditions. In tropical region, the average rainfall is large and the narrow channel is permitting the transport of freshwater during rainy season. Many coastal lagoons lack distinct river or creek channels, and receive freshwater from sheet runoff only. Groundwater input may also be significant (Harris *et al.*, 2003).

4.3.2 Limited Exchange with the Ocean

Some exchange of marine and estuarine water occurs through the entrance of the coastal lagoon, although this can be restricted by a narrow channel. Entrances of coastal lagoons tend to be intermittently open and closed, and many tend to remain closed for long periods, only opening during floods (Ranasinghe *et al.*, 1999). Sub-surface exchange of marine and estuarine water through the permeable barrier may also occur during periods of closure. Coastal lagoons and strand plain-associated coastal creeks that are permanently closed to the ocean exhibit a long-term balance between freshwater inputs, barrier over washing, rainfall, outputs via evaporation and seepage (Cooper, 1993).

4.3.3 Internal Circulation

Internal circulation within coastal lagoons is typically driven by wind-induced currents and internally generated waves. Internal circulation patterns may be altered during extreme high-flow events, and periods of entrance opening. Because the entrance to coastal lagoons and strand plain-associated coastal creeks is usually intermittently or permanently closed, ocean wave and tidal influence is negligible inside the basin (Harris *et al.*, 2003).

4.3.5 Mixing

Salinity can vary significantly depending upon the amount of freshwater input, climate and the frequency and duration of entrance opening. Stratification is common during periods of freshwater input, except during significant internal wind-induced wave activity. Systems with low barriers are more often well mixed and contain saline water due to frequent wash-over by waves, and landward percolation of seawater through the barrier at high tide (Oliveira-Esquerre *et al.*, 2004). Some coastal lagoons and strand plain-associated coastal creeks contain elevated water levels in the basin. If the barrier in these systems is breached, the basin can almost completely drain, resulting in near complete sub aerial exposure. As the average depth of coastal lagoons tends to be above the wave base, they tend to be well mixed by wind waves and currents.

4.4 Physical Water Properties

Five physical property variables are considered for the tidal dynamics in Salut-Mengkabong Lagoon. These variables are salinity, temperature, dissolved oxygen (DO), pH and current velocity.

4.4.1 Salinity

Coastal lagoons are transitional zones in which the chemical composition varies from that of freshwater to marine. Salinity is a key determinant in the distribution of lagoons flora and fauna, especially for benthic invertebrate communities (Tenore *et al*, 2006).

Measurement of the ionic strength of estuarine and marine waters is typically made using salinity. Salinity may be defined as the total solids in water after all carbonates have been converted to oxides, all bromide and iodide have been replaced by chloride and all organic matter has been oxidized. Typically, salinity is reported as grams per kilogram or parts per thousand.

Salinity is most commonly measured electronically using a salinometer probe as part of a conductivity-temperature-depth meter (CTD) unit. A related measure of the ionic strength of water samples is the conductivity, which is the ability of an aqueous solution to carry an electric current. This ability depends on the presence of ions, their total concentration, mobility, valence, relative concentrations and on the temperature of measurement.

4.4.2 Temperature

Temperature is an important determinant of the rate of chemical reactions and biological processes. Dissolved oxygen saturation is a function of water temperature. Temperature influences the spatial and seasonal distribution of benthic in fauna, microbial process rates and temporal and spatial distributions of fishes. Because most lagoons are shallow, there can be considerable diurnal and seasonal temperature variation. Lagoon temperature also varies with air temperature and depth, leading to vertical temperature gradients. In addition to the potential influence of natural temperature variations on aquatic biota and chemical reactions, anthropogenic thermal inputs can lead to significant modifications of estuarine and coastal marine biological communities.

4.4.3 Dissolved Oxygen

Dissolved oxygen (DO) is a basic physiological requirement for nearly all aquatic biota and for the maintenance of balanced populations. Most lagoon populations can tolerate short exposures to reduced DO concentrations without adverse effects. Extended exposures to DO concentrations less than 60% oxygen saturation may result in modified behaviour, reduced abundance and productivity, adverse reproductive effects, and mortality.

Low DO conditions can also increase the vulnerability of benthos to predation as they extend above the sediment surface to obtain more oxygen. DO concentrations throughout the water column can vary widely with tide, time of day, wind patterns and biological activity. Low DO in these shallow lagoons may be highly variable both spatially and temporally (Sanford *et al*., 1991). These conditions can lead to misclassification of the ecological condition of estuaries with respect to hypoxia.

Goals of the analyses comparing DO measurement approaches were to determine the best measure for representing DO exposure to evaluate the stability of DO over the sampling period and to determine if the characteristics of exposure to extreme low DO can be predicted from short-term continuous DO records (Oliveira-Esquerre, 2004).

4.4.4 pH

Another important indicator of the chemical condition of coastal lagoons and coastal marine waters is pH. In lagoons, pH will usually be controlled by the mixing of seawater solutes with those in the fresh water inflow. A major factor influencing the pH of estuarine waters is the carbon dioxide solubility, which is a function primarily of salinity and secondarily of temperature.

Surface seawater pH usually ranges between pH 8.1 and 8.3. River waters usually contain a lower concentration of excess bases than seawater; this shifts the carbonate buffering system toward a higher concentration of free carbon dioxide and lower pH in the upper reaches of rivers. Freshwater inflow to lagoons is typically much less buffered than seawater, thus greater variation in pH is observed in the less saline portions of lagoons than near their mouths. The range of pH values observed in the upper reaches of lagoons can be 7.5 – 9.0 (Fitzgerald *et al*, 2002).

REFERENCES

Barette-Bekker, J., Duursma, E. and Kuipers, B. (Eds), 1998. *Encyclopedia of Marine Sciences.* Springer Verlag, Berlin, 357 pp.

Barnes, R. S. K., 1980. *Coastal Lagoon.* Cambridge University Press, 106 pp.

Christiansen, T., Wiberg, P. L. and Miligan, T. G., 2000. Flow and sediment transport on a tidal salt marsh surface. *Estuarine, Coastal and Shelf Science* **50** (3), 315-331.

Cooper, J. A. G., 1993. Sedimentation in the Clift-bound, microtidal Mtamvuna estuary. South-Africa. *Journal of Marine Geology* **112**, 237-256.

Dal Monte, L. and Di Silvio, G., 2004. Sediment concentration in tidal lagoon. A contribution to long-term morphological modeling. *Journal of Marine Systems* **51**, 243-255.

Day, J. W., Scarton, F., Rismondo, A. and Are, D., 1998. Rapid deterioration on salt marsh in Venice Lagoon, Italy. *Journal of Coastal Research* **14** (2), 583-590.

Durham, L. R., 2000. *A kinematic study of the Ancao Basin in the Ria Formosa Lagoon, Algarve.* University of Wales, Bagor, 45 pp.

Dworak, J. A. and Gomez-Valdes, J., 2003. Tide-induced residual current in a coastal lagoon of the Gulf of California. *Estuarine, Coastal and Shelf Science* **57**, 99-109.

Eisma, D. and Irion, G., 1988. Suspended matter and sediment transport. In: Salomons, W., Bayne, B., Duursma, E., and Forstner, U. (Eds.) *Pollution of the North Sea – an Assement.* Springer-Verlag, Berlin, 20-35.

Emery, K. O., 1995. Coastal lagoon processes. In: Kjerfve, B. (Ed.) Elsevier Science B.V., Amsterdam. *Marine Geology,* **123** (2), 118-119.

Fitzgerald, D. M., Buynevich, I. V., Davis, R. A. and Fenster M. S., 2002. New England tidal inlets with special reference to riverine-associated inlet systems. *Geomorphology* **48**, 178-208.

Hayes, O., Davis, J. R. and Richard, A., 1984. What is a wave-dominated coast? *Journal of Marine Geology* **60**, 313-329.

Harris, P. T., Heap, A., Passlow, V., Hughes, M., Daniell, J., Hemer M. and Anderson, O., 2003. Tidally incised valleys on tropical carbonate shelves: An example from the northern Great Barrier Reef, Australia. *Journal of Marine Geology* **220**, 181-204.

Hubbard, D. K., Oestel, G. and Nummedal, D., 1979. The role of waves and tidal currents in the development of tidal inlet sedimentary structures and sand body geometry: example from North Carolina, South Carolina and Georgia. *Journal of Sediment Petroleum* **49**, 1073-1092.

Icely, J. D., 1987. *The Dangers of Development to Natural Reserve: The Ria Farmosa, Portugal.* Rolex Awards for Enterprise. Project No. 4/C 11178.

Kausch, H., 1990. Biological processes in the estuarine environment. In: Michaelis, W. (Ed.) *Estuarine Water Quality Management. Coastal and Estuarine Study.* Springer Verlag, Berlin **36**, 353-361.

Kjerfve, B., 1994. Coastal Lagoon Processes. *Elsevier Oceanography Series 60.* Elsevier, Amsterdam, 577 pp.

Kjerfve, B. and Magill, K. E., 1989. Geographic and hydrodynamic characteristics of shallow coastal lagoons. *Journal of Marine Geology* **88**, 187-199.

Lima, C. and Vale, C., 1977. *Ria Formosa Lagoon: Physical, chemical and biological aspect.* Secretary Estard Press, Lisbon, 21 pp.

Nichols, M. N. and Boon, J. D., 1994. Sediment transport processes in coastal lagoons. In: Kjerfve, B. (Eds.) Coastal lagoon processes. *Elsevier Oceanography Series 60.* Elsevier, Amsterdam **7**, 157-220.

Oliveira-Esquerre, K. P., Seborg, D. E., Bruns. R. D. and Mori, M., 2004. Application of steady-state and dynamic modeling for the prediction of the BOD of an aerated lagoon at a pulp and paper mill: Part I. Linear approaches. *Chemical Engineering Journal* **104**, 73-81.

Phleger, F. B., 1981. Foraminifera ecology and marine geology. *Journal of Marine Geology* **1**, 16-43.

Ranasinghe, R., Pattiaratchi, C. and Masselink, G., 1999. A morph dynamic model to simulate the seasonal closure of tidal inlets. *Coastal Engineering* **37**, 1-36.

Reineck, H. E., 1996. Tidal signatures in modern and ancient sediments. *Journal of Sedimentary geology* **105**, 111-112.

Rolinski, S. and Umigiesser, G., 2005. Modelling short term dynamics of suspended particulate matter in Venice Lagoon, Italy. *Estuarine, Coastal and Shelf Science* **63**, 561-576.

Sand-Jensen, K., 1998. Influence of submerged macrophytes on sediment composition and near-bed flow in lowland streams. *Freshwater Biology* **39**, 663-679.

Sanford, L. P., Panageotou, W. and Halka, J. P., 1991. Tidal resuspension of sediment in Northern Chesapeake Bay. *Marine Geology* **112**, 237-256.

Tenore, K. R., Zajac, R. N., Terwin, J., Andrade, F., Blanton, J., Boynton, W., Carey, D., Diaz, R., Holland, A. F., López-Jamar, E. et al., 2006. Characterizing the role benthos plays in large coastal seas and estuaries: A modular approach. *Journal of Experimental Marine Biology and Ecology* **330**, 392-402.

Yang, S. L., Zhang, J. and Zhu, J., 2004. Response of suspended sediment concentration to tidal dynamics at a site inside mouth of an inlet: Jiaozhou Bay (China). *Hydrology and Earth System Sciences* **8**(2), 170-182