HYDRODYNAMICS AND PHYSICAL PROPERTIES OF SEAWATER IN DARVEL BAY, SABAH

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The Author

ABSTRACT

This study covers the hydrodynamic characteristics, wave climate and physical properties of seawater in Darvel Bay, Sabah, Malaysia. Water circulation and current patterns of approximately 17,150 km^2 were studied by generating and simulating the water current in the bay waters using Mike 21 HD module in two monsoons. The numerical simulation for northeast monsoon (NEM) was generated for the period of 03-05 December 2003 and the southwest monsoon (SWM) was generated for the period of 22-23 September 2005. Numerical model consists of bathymetric database set-up, calibration and validation of the models. Water current measurements were conducted by using two holy sock drogues tracking and current meter at the northern part of the study area. Holy sock drogues were deployed at 1 m below the water surface on 29 September 2003 and 03 December 2003 to represent the SWM and the NEM, respectively. Current velocity measurements using Aquadropp Profiler during 03-05 December 2003 was used to calibrate and verify the hydrodynamic simulation. Long-term wave climate in the study area was investigated through the model development using JONSWAP spectral analysis. Wind measurements for 5.25 years from the nearest wind station at Tawau were used for wave hindcasting. Extreme wave events for 20 years return period were calculated. Extensive field measurements were conducted in different monsoons to identify effects of hydrodynamic changes on physical properties of seawater. Temperature, salinity, pH and dissolved oxygen (DO) were measured on 05 March, 28 September and 17 December 1999 using Hydrolab. Seawater parameters were measured down to a depth of 30 m in 16 sampling stations. Vertical and horizontal profiles of measured parameters were discussed. Average current speed during ebb and flood tides from the holey sock drogues during September was 0.11 m/s and 0.12 m/s, respectively. It was reduced to 0.07 m/s during ebb tide and 0.09 m/s during flood tide in December. Both monsoon seasons showed that the holey sock drogues moved towards open sea during ebb tides and opposite direction during flood tides. The current velocity near the sea surface measured by Aquadopp Profile was almost 2 times higher than current velocity near the sea bottom. The range of current velocity during ebb tides was from 0.014 m/s to 0.18 m/s with average direction of 134°. During the flood tides current velocity ranged from of 0.011 m/s to 0.13 m/s during with average current direction of 250°. Currents simulation of 675 m resolution showed that strong current ranging from 0.05 to 0.20 m/s was detected along the northeast coastal area and moved towards Sakar Island before it turned towards Silam and Kunak areas with decreasing speed during the flood tides. Strong current were clearly shown at small passages within the islands in 75 m resolution. Wave hindcasting from the wind data showed strong wave activity from the east direction with maximum wave height of 1.58 m and wave period of 5.59 s, respectively. The impact of wave energy along the Darvel Bay coast is greatest during the SWM period. Seawater temperature is found to be varied at sea surface but slowly decreased towards 30 m of measurement. Salinity in September and December were higher compared to salinity in March. Variations of DO from surface to 30 m depth were found to be small but varied at different stations and months of sampling. Field measurement on pH depicted mostly constant value. Seasonal effects on water parameters in the study area. The findings of this research will be useful for seaweed farming, fisheries activities and coastal infrastructures development and management planning for the entire area of the Darvel Bay.

ABSTRAK

HIDRODINAMIK DAN CIRI-CIRI FIZIKAL AIR LAUT DI TELUK DARVEL, SABAH

Kajian ini merangkumi hidrodinamik, iklim ombak, dan ciri-ciri fizikal air laut di Teluk Darvel, Sabah, Malaysia. Pergerakan air dan corak arus yang meliputi kira-kira 17,150km^2 dikaji dengan kaedah simulasi numerik menggunakan model perisian hidrodinamik Mike 21 semasa monsun timur laut (NEM) pada 03-05 Disember 2003 dan monsun barat daya (SWM) pada 22-23 September 2005. Model numerik terdiri dari pengisian data asas batimatri, kalibrasi dan validasi model. Arus air diukur menggunakan 2 buah 'holey sock' dan meter arus yang kedua-duanya dipasang di bahagian utara kawasan kajian. 'Holey sock' dihanyutkan 1 m dari permukaan air pada 29 September 2003 dan 03 Disember 2003 bagi mewakili SWM dan NEM. Pengukuran halaju arus dibuat dengan menggunakan meter arus Aquadopp Profiler pada 02-05 Disember 2003. Data-data yang diperolehi dari meter arus digunakan untuk kalibrasi simulasi hidrodinamik. Iklim ombak di kawasan kajian dikenalpasti dengan menggunakan analisa JONSWAP spektral. Data harian angin selama 5.25 tahun yang diperolehi dari Stesen Tawau digunakan untuk mengetahui unjuran ombak. Kejadian ombak lampau untuk jangka masa 20 tahun juga turut dikira. Pengukuran terhadap suhu, saliniti, pH dan oksigen terlarut (DO) air laut dilapangan pada dua monsun yang berlainan dijalankan untuk mengenal pasti kesan perubahan hidrodinamik terhadap parameter fizikal air laut. Pengukuran dilakukan pada 05 Mac, 28 September dan 17 Disember 1999 dengan menggunakan Hydrolab. Parameter air laut diukur 1 m dari permukaan sehingga 30 m kedalaman air di 16 stesen kajian. Perbincangan dibuat berdasarkan profil vertikal dan taburan horizontal bagi setiap parameter air yang diukur. Purata halaju arus diukur menggunakan 'holey sock' pada bulan September adalah 0.011m/s semasa air surut manakala 0.12m/s semasa air pasang. Pada bulan Disember, halaju berkurang kepada 0.07 m/s semasa air surut dan 0.09 m/s semasa air pasang. Kedua-dua monsun menunjukkan air bergerak ke arah laut terbuka semasa surut dan bergerak ke arah bertentangan semasa pasang. Bacaan dari Aquadopp Profile mendapati halaju arus pada bahagian permukaan adalah 2 kali lebih tinggi dari bahagian dasar. Julat halaju semasa air surut adalah diantara 0.014 m/s -0.18 m/s dan bergerak pada purata arah 134^o. Semasa air pasang pula julat halaju arus adalah diantara 0.011 m/s - 0.13 m/s dan bergerak pada purata arah 250^o. Simulasi arus pada 675 m resolusi menunjukkan halaju arus semasa air pasang di pesisir pantai bahagian timur laut teluk adalah di antara 0.05 m/s hingga 0.20 m/s dan bergerak ke arah Pulau Sakar sebelum ke kawasan perairan Silam dan Kunak. Arus deras jelas kelihatan di antara pulau-pulau pada 75 m resolusi. Unjuran ombak adalah kuat dari arah timur dengan ketinggian maksimum 1.58 m dan masa ombak adalah 5.59 s. Kesan tenaga ombak adalah ketara di sepanjang pantai utara Teluk Darvel semasa SWM. Suhu air adalah tidak sekata di bahagian permukaan dan semakin berkurangan sehingga 30 m kedalaman. Saliniti pada bulan September dan Disember adalah lebih tinggi daripada saliniti bulan Mac. Nilai DO tidak menunjukkan perbezaan yang ketara di antara permukaan sehingga kedalaman 30 m bagi setiap stesen dan bulan pensampelan manakala nilai bacaan pH didapati paling konstan diantara parameter air yang diukur. Hasil kajian ini dapat memberi manfaat bagi aktiviti pengkulturan rumpai laut, perikanan dan perancangan pengurusan bagi keseluruhan kawasan Teluk Darvel.

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LIST OF ABBREVIATIONS

ADCP	Acoustic Doppler Current Profiler
CERC	Coastal Engineering Research Centre
E	East
eq	Equation
ETM	Enhanced Thematic Mapper
FAO	Food and Agriculture Organization
GIS	Global Information System
GPS	Global Positioning System
HD	Hydrodynamic
ICZM	Integrated Coastal zone Management
JONSWAP	Joint North Sea Wave Project
JPS	Jabatan Pengairan dan Saliran
K_1	Principal lunar-solar diurnal for diurnal
Kg	Kampung
M_2	Principal lunar for semi-diurnal
MHWS	Mean high water spring
MHWN	Mean high water neap
MLWN	Mean low water neap
MLWS	Mean low water spring
MSL	Mean sea level
mth	Month
N	North
NE	Northeast
NEM	Northeast monsoon
O_1	Principal lunar diurnal for diurnal
RM	Ringgit Malaysia
S_2	Principal solar for semi-diurnal
Sg	Sungai
SMB	Sverdrup-Munk-Bretschneider
St	station
SE	Southeast
SWM	Southwest monsoon

LIST OF SYMBOLS

%	Percent
a.m	*Ante meridiem* (before midday)
cm	Centimetre
ha	Hectare
hr	Hour
kg	Kilogram
km	Kilometre
km/hr	Kilometre per hour
km^2	Square kilometre
m	Metre
m/s	Meter per second
m^3	Cubic meter
mCD	Meter above Chart Datum
mg	Milligram
mm	Millimetre
mm/mth	Millimetre per month
mm/yr	Millimetre per year
mt	Metric tonne
mth	Month
o	Degree
°C	Degree Celsius
p.m	*Post meridiem* (past midday)
psu	Practical salinity unit
sec	Second
Sv	Sverdrups (1 Sv= 10^6 m^3 s^{-1})
yr	Year

CHAPTER I

INTRODUCTION

1.1 Introduction

Darvel Bay, the largest bay in the east coast of Sabah, is connected to the Pacific Ocean through Sulawesi Sea. Lahad Datu and Kunak are two important growing towns around the Bay. Sabah Economic Development Corporation (SEDCO) has announced to implement a SEDCO Industrial Estate with a cost of RM13 million surrounding 5 km from Lahad Datu town centre which covers 40 ha of land. Currently, coastal areas around Lahad Datu and Silam towns are already threatened by urban construction and reclamation activities for harbor and road expansion. According to Cem and Assim (1996) and De Silva *et al.* (1999b), increasing pressure of coastal development activities and destruction of marine ecosystems by growing population are the main threat to the marine ecosystem of Darvel Bay. As part of Malaysian Coastal Zone, coastal development surrounding the bay is often carried out without any detailed study of the dynamic processes including coastal erosion, sedimentation and depletion of water quality (Othman and Lee, 1991). These could worsen coastal processes and coastal environments after a few years if no action is taken. Understanding of hydrodynamic processes is the primary importance to other studies in bay ecosystem. Detail and accurate information of hydrodynamic characteristics generated by tides, winds and waves patterns are also important for implementing any conservation and management plan of the area.

Darvel Bay is located within the area of most biological diverse marine environments in the Indo-Pacific region. About 80 percent of the local communities are depending on marine resources as a source of livelihood. Related fisheries production particularly dried prawns and salted fish are it's significant economic activities. Also, Darvel Bay is categorized as one of the richest shrimp fishing grounds in Sabah (Kan, 2003). Kunak and Lahad Datu areas are the third and fifth districts respectively in terms of marine fish landing by Districts in Sabah (Department of Fisheries, 2004).

Most of the coastal fishermen operations are limited to the coastal area and destructive fishing methods are widely used in the pas such as fish bombings which contributed to over-fishing and created great adverse impact to the marine life and coastal ecosystems. Loss or disturbance of the natural coastal ecosystems by the destructive fishing methods may affect not only the abundance of associated marine organisms but also its role as a buffer zone and finally leads to serious coastal hydraulic modification and change of wave patterns (Carter, 1995). Conservation planning of marine ecosystems and enrichment of any marine organisms program required detail information of the hydrodynamic and wave energy profile in the Darvel Bay.

According to a spokesman from Cheng Xin Technology Development Corporation in Taipei, Taiwan, Sabah is one of the best places in the world to undertake open sea cage fishes farming due to pollution-free sea waters off the Sabah coast (Borneo Post, 2003). In line with that, Agriculture and Food Industry Minister, Datuk Abdul Rahim Ismail mentioned that marine area between Semporna and Lahad Datu are two areas that had been earmarked by the Sabah State Government of 70,000 ha as suitable for fish farming activities and also an area that would be gazetted as the Aquaculture Industrial Zone (AIZ) (Daily Express, 2003). The state government has

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strived to bring various AIZ related projects and encouraged investors to come and venture in aquaculture-based projects in this area. Aquaculture activities in Darvel Bay area include mangrove earthen ponds, floating cages, pens and oyster farms in Pulau Bohayan. The biggest fish pens are located at Pulau Sampir, Kunak. Sheltered locations in Darvel Bay lead this area to be a potential aquaculture activity. Aquaculture activities in bays or coastal areas change physico-chemical water properties because nutrient and organic wastes, in dissolved and particulate forms, stemming from uneaten food and excreta generally affect the seawater properties. The sustainability of the aquaculture activities also depended on the water quality and physical water properties, which were governed by wave energy profiles, water circulation, hydrodynamic characteristics and water exchange. Monsoonal variations also have substantial effects on seawater properties. During the northeast monsoon (NEM), heavy rainfall would change the salinity distribution in the coastal area and high suspended sediment discharges from rivers would reduce the sunlight penetration in the water column. At present, there are no detail documented records of physical properties of seawater in Darvel Bay. So as a first step of planning any aquaculture activities, horizontal and vertical profiles as well as monsoonal variations of seawater properties of Darvel Bay should be studied.

Darvel bay area was identified as a great potential for the development of local seaweed industry. During the site survey conducted in 2004, seaweed culture mainly of *Gracilaria sp.* was actively carried out in the sea flats in Kunak District and provided additional livelihood resources for the coastal fishermen. Ibrahim (2002), reported that Pangi, Madai and Pangkalan villages in Kunak District produced about 53,189.90 kg of dried seaweed worth RM 78,541.35 in 2000. However, the activity was not permanent and tends to be seasonal due to seaweed diseases and bad weather (De Silva *et al.*,

1999a). The successes of mariculture and aquaculture activities are not only dependence on seasonal fluctuation of seawater parameters but also on hydrodynamic changes and long-term wave climate which need to be studied to maximize the production.

Marine tourism in Sabah has gained popularity over the years and will continue to be one of the main attractions in boosting the state tourism industry. New Sabah Times (2003), reported that tourism industry is one of the three priority sectors in the Halatuju–Sabah's Economic Development Agenda. According to Picher (1996), magnificent marine life is found around the islands of Darvel Bay to the southeast of Semporna District while, Picher and Ridzwan, (1996) highlighted tourism activities such as coastal resort development and sports recreation for yachting, treasure hunts, fishing, island cruises and diving can be promoted due to fresh air, clear blue water and clean white sand on most of the islands in Darvel Bay. Gua Madai, Hot Spring Lakes and Pulau Batik Kulambu in Kunak District are some of the existing natural tourist attractions in Darvel Bay while Tabin wildlife, Danum valley and Borneo Paradise Resort are currently recognized as major tourist attractions. Strategic location and good marine environment have already attracted several companies to invest in new projects based on eco-tourism. For example, the proposed tourist and recreation centre at Timbadu, Lahad Datu which is based on sustainable exploitation of the natural environment and serves as an educational centre (Panglima Fajar Sdn. Bhd., 1997). The nearshore processes (such as coastal erosion, deposition etc.) are governed by waves and hydrodynamics affecting some part of the bay. So a detailed study on hydrodynamics and long-term wave climate in Darvel Bay will provide useful information for designing any development projects in the study area.

Although the Darvel Bay is an important component of the east coast of Sabah in terms of both ecosystem and natural capital, the physical coastal processes of the bay are yet to be documented. There were only a few studies done on Darval Bay, which were again mostly concerned with the marine biological aspects. Understanding of hydrodynamics and physical properties of seawater in semi-enclosed waters is the primary importance to other related studies of the bay ecosystem. As an example, the water exchange through the inlet of the bay governs the spatio-temporal distribution of hydro-geomorphologic characteristics and physico-chemical water properties, which are important for the description of productivity and carrying capacity of the bay. The flow of water current made some natural flushing to maintain good water circulation and for mixing of physical properties of seawater, such as the salinity, and temperature. So the knowledge in hydrodynamics and properties of seawater are important for sustainable management of the bay ecosystem. The Sulawesi Sea, facing the Darvel Bay is governed by the strong surface wind and corresponding ocean response during the southwest and northeast monsoon period, for which the monsoonal variations of studied parameter should also be investigated. The major aim of this work is to study the hydrodynamic characteristics, wave climate and physical properties of seawater in Darvel Bay through computational model simulation and field measurement.

1.2 Objectives

Motivated by the need to assess the hydrodynamics and physical properties of seawater governed by the complex interactions of bay profile, wave energy, tidal flow, wave-current interactions in the Darvel Bay, the primary objectives of this research were as follows:

1. To study the water circulation pattern in Darvel Bay through model calculation and validation.
2. To calculate long-term extreme wave conditions in Darvel Bay.
3. To study the temporal and spatial distributions of physical properties of seawater (temperature, salinity, pH and dissolved oxygen).
4. To investigate the effects on monsoonal variations on hydrodynamic characteristics, wave climate and physical properties of water.

1. 3 Significances of the Study

1.3.1 Impacts of Land Use Changes on Marine Ecosystems

Land use changes on both catchment and coastal areas of Darvel bay can alter the pattern of stream flow and disturb its natural equilibrium between lands, estuaries and coastal lines. Ongoing deforestation for large scale oil palm plantation and urban development mainly contributed high suspended sediment concentration included organic loads, nutrients, bacteria and toxic substances into nearshore area of Darvel Bay. Rivers surrounding the bay (Figure 2.1) were primary transport mechanism of soil sediment, industrial effluents and sewages into coastal area (Cem and Assim, 1996). Even though some nutrients and sediment are needed to support aquatic organism's life, too much of such pollutants that wash into rivers and ultimately drain into coastal marine habitats may contribute to eutrophication and change the physico-chemical of properties of seawater (Kunzmann, 2002). Higher effects of eutrophication occurred in the coral

reef areas prevent sunlight penetrated deeper in the water column (Guzman, *et al.,* 1990). Furthermore, great concentration of chemical residues from the land could go to food web and may kill most of the aquatic life.

Some streams and rivers that used to flow all year round were now drying up during dry period while water level of rivers drastically increased during heavy rain. As an example, on 29 December 2003, Tabanak River, a small river near Lahad Datu was overflowed and washed away many houses and other properties along the river after only three hours of continuous rainfall (Chong, 2003). Flash floods or reduced freshwater discharge would cause change of existing natural processes in the bay along with economic losses and would increase health risks to local community.

Malaysia has spent thousands of ringgit on the protection and restoration of marine ecosystems including maintenance of navigation channels, dredging and dredged material relocation. Most problems were related to sedimentation, accumulation and transportation of sediments processes and relatively dependent on the movement of tidal currents, littoral drift and wave climate in that area (Abdullah, 1999). Detailed studies of waves and hydrodynamics characteristics could provide initial background data to determine some of the coastal processes including sediment transport and coastal pollutants distribution in Darvel Bay. These would help to overcome some of the coastal management strategy problems especially for the Integrated Coastal Zone Management (ICZM), the selection of resources used and management options.