Tidal circulation in Bay of Chagar Hutang, Malaysia

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Present study consists the physical characteristics of the coastal water within small bay of Chagar Hutang at Redang Island. Temperature distributions in the bay were in the range of 27.9 - 30.5°C. Surface current split into two directions, directed to northwest and southeast in diurnal timescale, while bottom current directed to northeast and southwest. Surface water maximum speed recorded was 0.48 m/s and bottom water maximum speed was 0.16 m/s. Tidal current of the study area is of mixed-diurnal tide.

[Keywords: physical characteristics, field observation, time series, current circulation, small bay]

Introduction

Chagar Hutang is a sheltered bay with the fore reef profile on the west side ¹. Due to this fact, they are predicted to possess unique characteristics compared to other coastal waters. For example, the domination of wind waves transforms the bathymetry of a bay through the shoaling, refraction and reflection processes ². Moreover, reef is defined as the centre of a dynamic bay, inducing a continuous re-circulation of the inside waters ³. Study by ⁴ indicate that the combination of the ebbing/flooding of the system together with the modulation of wave-driven currents with changes in water depth are the factors that affect the intratidal current variability on the reef area. They are consistent with the hypothesis that the circulation within coral reef systems can be driven by a number of forcing mechanisms, including surface wave breaking, tides and wind ⁵.

There had been few studies carried out involving the observational aspect of physical characteristics of a bay area. For example, ⁶ found that on the scale of days to weeks, the temperatures, salinities and currents of Lunenburg Bay have significant temporal variations which are strongly affected by the wind forcing. The same result obtained by ⁷ where on a time scale of 1–2 weeks the current fluctuations and temperature variability in Ningaloo Reef, Western Australia were driven by local wind-forcing. ⁴ on the other hand, proposed that circulation within Ningaloo Reef was dominantly driven by the effects of wave breaking, with tides playing a secondary but significant role.

Since Chagar Hutang is one of the major nesting beaches for green and hawksbill turtles in Redang Island, previous studies like ⁸ and ⁹ compiled an extensive review on the nesting biology and ecology of sea turtles. However, very limited study is done to find out the overview of physical characteristics of that area or to correlate the nesting of sea turtles with physical parameters of the sea water. The basic knowledge of physical parameters of Chagar Hutang coastal water such as tides and humidity is crucial since it can help in increasing hatching success of in situ incubation of turtle eggs while the understanding of current circulation in this area will lead to a better prediction of the dispersal of hatchlings released from Chagar Hutang ¹⁰. In terms of corals, the current circulation can enhance dissolved and particulate nutrient levels adjacent to the reef which in turn triggering local increases in pelagic primary production and increasing nutrient fluxes to reef organisms ⁷.

Therefore, the aim of this study is to determine the physical characteristics of the coastal water at Chagar Hutang, Redang Island which is expected to give more insight into how species such as sea turtles and corals will respond to the environmental changes and indirectly help in their conservation efforts. Then, this study will try to demonstrate the variation of temperature and current circulation since the compilation of temperature data will be very useful in understanding coastal water circulation mechanism which is usually complex.

Materials and Method

This study was conducted at Chagar Hutang, Redang Island (Figure 1). Chagar Hutang is an isolated beach, 350 m in length located at northernmost part of Redang Island. The study
The study site is located at 5º 48.778’ N and 103º 0.502’ E, off coast of Terengganu in South China Sea. Chagar Hutang is the project site for Sea Turtle Research Unit (SEATRU), Universiti Malaysia Terengganu (UMT) and declared as turtle sanctuary in 2005 by State Government of Terengganu.

The conservation effort of SEATRU on green and hawksbill turtles and their nesting areas began in 1993. This site has restricted access and no activity allowed after 15:00 hours to minimize disturbances on the nesting beach.

Chagar Hutang is fronted by a small bay and is bordered by rocky promontories. The distance between these two promontories is approximately 420 m while the approximate depth at this area is about 8 m. Regarding the hydrographic characteristics of this area, study reported that the mean total temperature was 30.08°C while the prevailing current direction appears to be little or no overall pattern with greatest number of currents recorded from south and because this area is situated on a shallow continental platform, they are primarily exposed to tidal currents.

**In-situ Data Collection**

5 weeks field experiment was conducted during October and November 2012. The bottom mounted Acoustic Doppler Current Profiler (ADCP) and conductivity, temperature and depth (CTD) were deployed at the opening of Chagar Hutang bay approximately 200 m from the beach line. ADCP was located on the seafloor of 8 m water depth and measured the current profiles every 10 min. The CTD was co-located with the ADCP during the same sampling period to record the temperature data directly at a 10-min interval. Although the sampling period exceed one month, however, the ADCP returned useful data records of only 11 days (2nd Oct–12 Oct, 2012); due to insufficient power source.

The data collected of this study was analyzed for two parameters; temperature and current. The first step in analysis was the data tabulation of all the physical parameters involved. Data obtained from the ADCP and CTD was sorted and arranged according to their categories and units of measurement. From the recorded CTD data, a set of observations of temperature was plotted, compared and analyzed to identify the variations. Vertical profiles of current speed and direction obtained from ADCP were first plotted to provide an insight of current circulation in that area. Apart from that, 3 m and 7 m current profile data were used to represent the surface layer and bottom layer of coastal water. From the calculated orthogonal velocities \( u \) and \( v \), the amplitudes and phases of two tidal constituents; semidiurnal tides: \( M_2 \) and diurnal tides: \( K_1 \) were estimated using MIKE 21 Toolbox. Then, the current velocities were used to plot progressive vector diagram (PVD) which is really helpful in showing the movement of current in water parcel. Finally, the
dominance of tidal cycle was confirmed with spectral density plot.

**Result**

The CTD measurements at the entrance of the bay showed persistent hydrographic features during the sampling periods. Surface temperature at the study site during October-November was recorded in the range between 27.9 - 30.5 °C (Figure 2a). The lowest temperature record was 27.87 °C on 17th October 2012 while the highest temperature recorded during the study period was 30.48 °C on 2nd October 2012. Closer examination of these fluctuations (Figure 2b) revealed some synoptic variability, but dominant diurnal fluctuations. The daily pattern was persistent throughout October until early November and ranges up to 0.6 °C differences. Diurnal variability dominated the small bay of Chagar Hutang with the temperature record featured rapid warming approaching afternoon (0800-1000) and rapid cooling in the late evening (1500-1600). Water temperature remained constant between 2200 to 0400h during a period of approximately 6 hours.

The currents flow during October between the surface and bottom water were found in opposite directions represented by contour plot (Figure 3) of diurnal current direction of water column drawn at the entrance to the bay. In surface water, there were two main directions of currents flow which were to northwest and southeast direction (Figure 4a). For bottom water, the currents flow was directed to northeast and southwest (Figure 4b). Surface currents were dominant compared to bottom currents where strong northwestern currents can be seen on surface water where the currents reached up to 0.48 m/s (Figure 5a). However, the strongest bottom water current is only 0.16 m/s (Figure 5b). Diurnal variability of the current characteristics can be observed where the pattern of the current speed showed the same cycle for each 24 hours. The ADCP data confirmed that the variability of both surface and bottom layers were dominated by a diurnal signal.
Figure 3: Contour plot of current direction.

Figure 4: The current direction at (a) surface (b) bottom.

Figure 5: Current speed at (a) surface and (b) bottom.
During the sampling period, the surface current showed the dominant current movement was in northwards direction away from the coast with the N-S component speed of ~0.5 m/s while the bottom current, demonstrate a clear picture of the bottom circulation with smaller N-S component velocity range between 0-0.16 m/s, and the current lean towards the coast (Figure 6). Progressive vector diagrams (PVDs) at sampling site from 2nd October until 12th October 2012 was shown in Figure 7. Progressive vector for surface water showed southwestward background flows with a mean speeds of 0.12 m/s while in the bottom water the background flows was southeastward with a mean speeds of 0.04 m/s. The movement of meandering curves of PVD at the surface was approximately 30 m and 50 m for bottom.

The dominance of a diurnal frequency in the variability of current circulation was confirmed by the computed spectral density. From Figure 8, we could assume that the diurnal constituent, $K_1$ was dominant at both surface and bottom compared to semidiurnal constituent, $M_2$. Spectral density plot had shown for the period of 24 hours, both level recorded the highest density of current which indicate diurnal fluctuations were larger than those produced by semi-diurnal tides. Tidal cycle in this study area could be classified as mixed tide with dominant diurnal because apart from major diurnal forcing there were also manifested appreciable variations at other frequencies of 8h, 12h and 60h.

Figure 6: Current direction at (a) surface and (b) bottom.
Discussion

Since this study is the first attempt to observe the physical characteristics at small bay of Chagar Hutang, the period of this study seemed to provide a very limited representation of the dynamics of the water properties distribution. Even though shorter period was involved, but clear pattern for the physical variables of the water column could be observed. The mooring records allowed examination of the mechanisms responsible for the variations of water temperature. From the temperature distribution pattern in Figure 2, the data provided evidence for strong diurnal fluctuation in the coastal water. These daily fluctuations were associated with solar heating of the surface layer since the surface of the water column began to heat up after sunrise. This is because, heating of the surface layer will create a thin surface mixed layer as discussed in 14. Furthermore, 14 also indicate that this process could and should be present in a variety of coastal systems including bay area.

For the current profiles, stronger currents up to ~0.5 m/s could be observed in surface water. This could be influenced by the local tidal current or wind. However, there is no direct correlation between the current circulation and wind (data...
The dominance of diurnal tide during the sampling period was in accordance with previous study by 18. Apart from that, water level variability and the current speed record in Figure 9 confirmed the diurnal forcing during the period of study. However, in our research site, instead of dominant diurnal tides, mixed tides characteristics could be observed. 19 also recorded the same finding where Terengganu area is characterized with mixed tide with dominant diurnal tide. The phase of the diurnal flow at the entrance of the bay showed variability coherent with the tidal influence (Figure 10). The flows in each of surface and bottom layers moved in opposite directions. Water inflow occurred during high tide through bottom layer however, during low tide there was water inflow of the bay through surface layer. This revealed the unique characteristic of a bay which possessing estuarine-like circulation. The same result obtained by 18 where they found that with near-surface net outflow and near-bottom net inflow, they represent the presence of an estuarine-like circulation over certain portions of the bay.

Although this study involved shallow water area, but it is possible to have different flow patterns for surface and bottom layers. Previous study by 20 agreed and proposed that even in the shallow waters; near-surface flow can be quite different from near-bottom flow. Moreover, the geomorphology of the bay is believed to be the causative factor for the formation of estuarine-like flow. 3 stated that even though the dominant forcing factors of a bay circulation is whether the wind or the tides, however, the presence of a particular type of bathymetry is most important in creating this mode of circulation. Inner bay of Chagar Hutang is shallow with the bottom bathymetry composed of material like coral reefs and rocks 10 which could contribute in shaping the...
bay circulation. However, further study need to be carried out in this area to evident this point.

![Figure 10: Time series of (a) water level (b) current speed at surface (black) and bottom (red) (c) current direction at surface (black) and bottom (red).](image)

**Conclusion**

Two main aspects of the analysis that have been emphasized in this study were the hydrographic characteristics and current circulation at Chagar Hutang, Redang Island during the pre-northeast monsoon. This study managed to analyze the influence of local setting of Chagar Hutang bay on temperature distribution and current circulation. Temporal variations of temperature were produced mainly by solar heating due to clear skies. Diurnal variability was indicated by the distribution of the temperature at the entrance of the bay as depicted by the moored records.

The current profiles revealed that the basic circulation in Chagar Hutang Bay was separated into two layers. During high tide, there was inflow of water occurred through bottom layer meanwhile during low tide inflow of water occurred through surface layer. Tidal flow showed estuarine-like flow of the bay. Both the surface and bottom layers were dominated by diurnal variability from tidal forcing, however the influences was more dominant at surface layer compared to bottom layer. Apart from diurnal forcing, mixed tide characteristic was also recorded. In general, the overall results provided a very useful overview of the physical characteristics of Chagar Hutang coastal water which can be used as a reference for future study.

**References**


10 Joseph, J., personal communication


