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Hydrodynamic Characteristics in Cu Lao Dung Mangrove Forest, Soc Trang, Vietnam

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Abstract: *Mangroves are unique ecosystems that play a crucial role in protecting coastal environments. This study was conducted in Cu Lao Dung mangrove forest area, Soc Trang, to analyze hydrodynamic conditions and the ecological role of mangroves in coastal environment. Field surveys were carried out during two monsoon seasons (Southwest and Northeast) in 2014–2015, measuring and analyzing hydrodynamic factors including water level fluctuations, wave heights, flow velocities, and suspended sediment concentration (SSC). The results indicate that flow within the mangrove forest tends to be weak and asymmetric, while wave energy significantly decreases as waves propagate into the forest, with reductions exceeding 70% for high waves. SSC shows an increasing trend from the coastal zone toward the interior of the forest, highlighting the role of mangroves in sediment deposition. Seasonal variations were also observed, with stronger hydrodynamic forces during the Northeast monsoon. These results increase the understanding of hydrodynamic mechanisms in mangrove ecosystems and provide a scientific information for the management, conservation, and restoration of mangroves, particularly in areas heavily impacted by climate change and human activities.*

Keywords: *Hydrodynamic, tidal asymmetry, mangrove forest, Cu Lao Dung*

1. Introduction

Mangroves have long been studied and highly valued for their unique ecosystem characteristics and their crucial role in protecting coastal environments. According to Vu and Mai [1], mangroves help reduce wave heights up to 85%, which not only mitigates the impacts of waves but also contributes to slowing water flow and accumulating sediment. In the context of climate change and sea level rise, mangroves act as a "green wall" that protects coastlines and inland areas from storm surges and flooding. Therefore, conducting in-depth studies on the physical processes and hydrodynamic mechanisms within tidal-influenced regions is essential to understanding the conditions necessary for the survival of mangroves [2].

Research on mangroves has predominantly focused on biology, ecology, or environmental aspects, whereas studies addressing the interactions between hydrodynamic and physical processes in mangrove ecosystems have received less attention [3]. The work of Wolanski et al. [4], which synthesizes the roles of physical processes in mangrove regions, is considered the first comprehensive study in this area. Subsequent studies have delved deeper into the role of hydrodynamics, including the influence of tides and waves on sediment distribution and flow alterations within mangrove ecosystems.

Tides have been identified as the most significant factor, affecting not only the distribution of mangrove trees but also their associated growth and the topography. Furukawa and Wolanski [5] described how tidal forces influence the transport of suspended sediments, contributing to the shaping of the mangrove environment. Additionally, field studies by Mazda et al. [6,7] revealed that wave attenuation depends on water depth and tree density, with older mangroves exhibiting a greater capacity for wave reduction. Massel et al. [8] developed a theoretical model to predict wave attenuation in mangroves based on root structure and position. The studies by Vo Luong and Massel [9] further expanded the understanding of wave-mangrove interactions, emphasizing the role of tree density and seabed topography in dissipating wave energy.

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These studies not only clarify the physical mechanisms in mangrove ecosystems but also provide scientific foundations for mangrove conservation and restoration. The present study investigates hydrodynamic factors in Cu Lao Dung mangrove forest, aiming to evaluate their characteristics and interactions in this environment. This study offers a broader and scientific information on the role of mangrove ecosystems in protecting coastlines and riverine environments from the impacts of climate change and human activities.

2. Methodology

Cu Lao Dung District, located in Soc Trang Province, lies between the Hau River and consists of various islets – forming the largest island in the Hau River, close to the East Sea. It is surrounded by water on all sides and holds a very important position in terms of socio-economic development and national defense. The district borders the Dinh An estuary in Tra Cu District, Tra Vinh Province to the east, the Hau River to the west, the East Sea to the south, and My Phuoc Islet in Ke Sach District, Soc Trang Province to the north. The islet region is directly influenced by the East Sea tides, experiencing a semi-diurnal tidal regime year-round, with tides entering the inland through the Dinh An and Tran De estuaries. Cu Lao Dung Mangrove Nature Reserve, located along the district's coastline, is characterized by a high diversity of species and biological composition.

The surveyed area is in the central part of Cu Lao Dung mangrove forest. This area has a gently sloping terrain with extended mudflats. Near the locations of the stations, a small creek remains water-filled even during low tide. The Department of Oceanography, Meteorology, and Hydrology conducted surveys during both the Southwest Monsoon season from September 21, 2014, to October 4, 2014, and the Northeast Monsoon season from March 2, 2015, to March 15, 2015. In each survey, measurement stations were established, including Station ST0 located outside the forest margin, Station ST1 set on the mudflat near the forest edge, and Stations ST2 and ST3 placed progressively deeper within the forest. (Figures 1). At these stations, instruments will be installed to record changes in hydrodynamic factors, including water level fluctuations, wave heights, flow velocities, and suspended sediment concentration (SSC) (Table 1). The survey results will be used to assess the spatial variability of these hydrodynamic factors, from the outer coastal zone to the inner mangrove area. Changes influenced by the presence of mangroves will also be examined. The surveys were conducted during two periods: September–October 2014 and March 2015, corresponding to different meteorological (SouthWest Monsoon and NorthEast Monsoon seasons) and hydrological (flood and dry seasons) conditions, which aims to account for the variations and impacts of these factors on the hydrodynamic regime in the study area.

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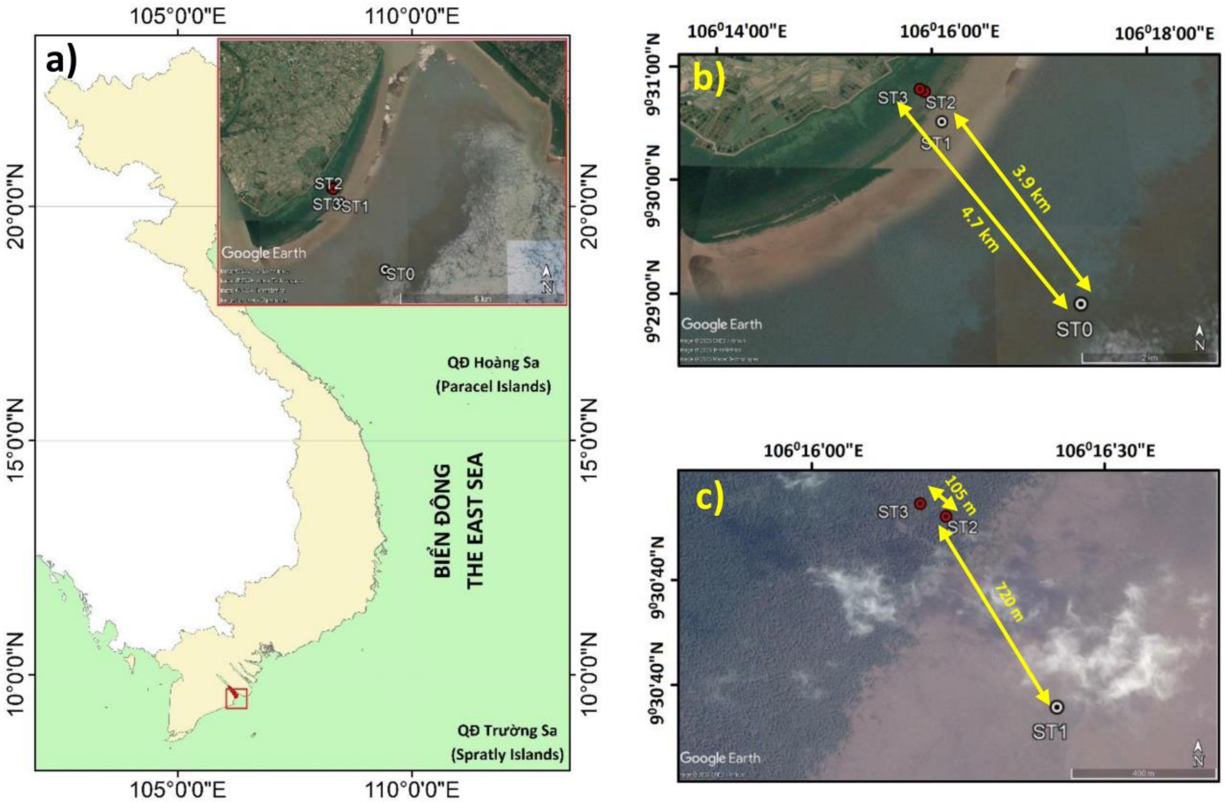

Fig. 1. Study area and location of survey stations: a) Cu Lao Dung mangrove forest area, b) Distance between ST0 – ST1 – ST3, c) Distance between ST1 – ST2 – ST3

Tab. 1. Measuring devices at stations and settings during the survey trip 09-10/2014 and 03/2015

	09-10/2014			**03/2015**		
	Instrument	***Measuring factor***	***Setting parameters***	***Instrument***	***Measuring factor***	***Setting parameters***
ST0	Valeport MIDAS DWR	Water level Wave Current Turbidity	Rate: 4 Hz Burst: 30 min Wave burst: 2048 samples Tide burst: 60 s	Valeport MIDAS DWR	Water level Wave Current Turbidity	Rate: 4 Hz Burst: 30 min Wave burst: 2048 samples Tide burst: 60 s
ST1	Valeport MIDAS DWR	Water level Wave Current Turbidity	Rate: 4 Hz Burst: 30 min Wave burst: 2048 samples Tide burst: 60 s	RBR TWR	Water level Wave	Rate: 4Hz Burst: 30 min Sample: 2048
				ATU75W-USB	Turbidity	Rate: 10 Hz Burst: 60 min Sample: 4800
	AEM213D	Current	Hourly, by depth	AEM213D	Current	Hourly, by depth
ST2	AWH-USB	Water level Wave	Rate: 10 Hz Burst: 30 min Sample: 4800	RBRduo	Water level Turbidity	Rate: 6 Hz Burst: 10 min Sample: 2048
	AEM-USB	Current	Rate: 10 Hz Burst: 60 min Sample: 4800	AEM-USB	Current	Rate: 10 Hz Burst: 60 min Sample: 4800

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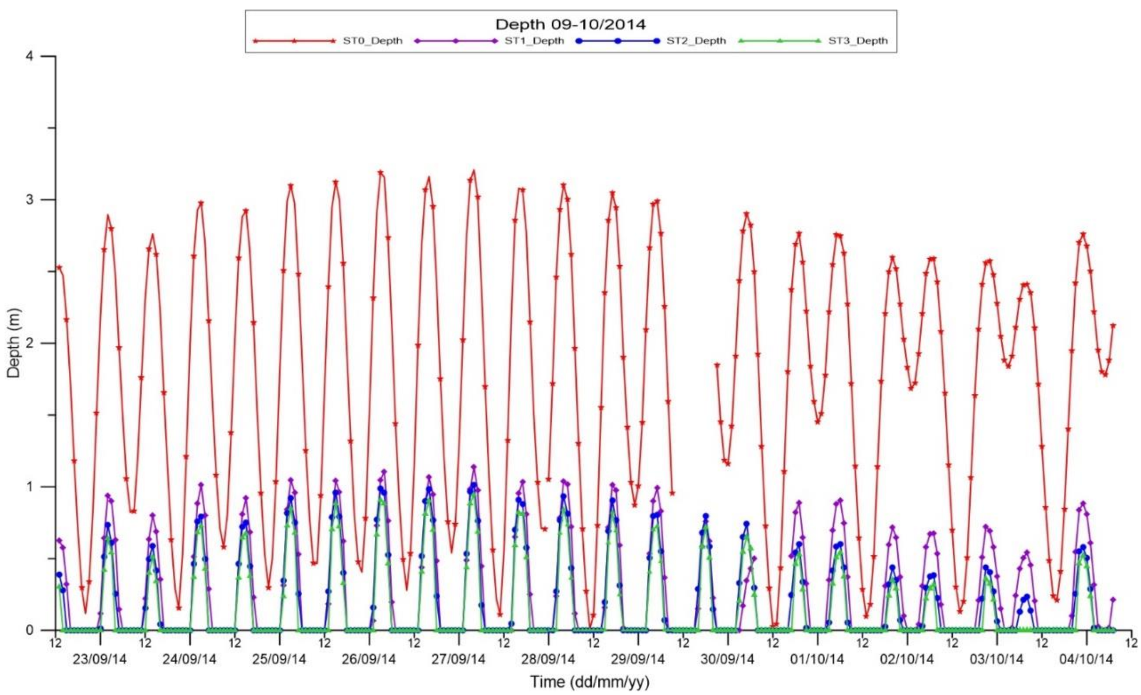
ST3	RBRduo	Water level Wave	Rate: 6 Hz Burst: 10 min Sample: 2048	AWH-USB	Water level Wave	Rate: 10 Hz Burst: 30 min Sample: 4800
				RBRduo	Water level Turbidity	Rate: 6 Hz Burst: 10 min Sample: 2048

3. Results and Discussion

The water level fluctuations in the study area exhibit an irregular semi-diurnal tidal pattern, with distinct high and low tidal phases observed at station ST0, where the tidal range is approximately 2.5 m. Stations located on the mudflat and within the mangrove forest (ST1, ST2, ST3) are exposed to low tide conditions, leaving them dry for nearly half of the tidal cycle. The water levels at the stations during the NorthEast monsoon season (03/2015) are higher than those during the SouthWest monsoon season (09-10/2014) (Figure 2).

(a)



b)

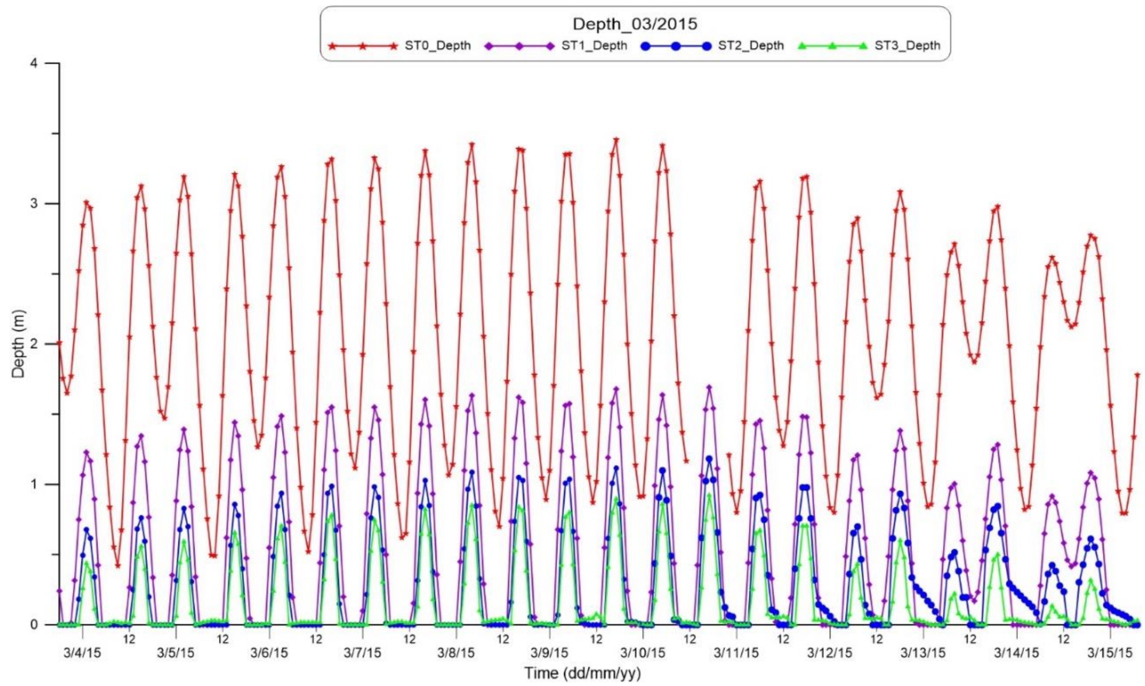


Fig. 2. Water level at the stations: a) in 09-10/2014, b) in 03/2015

Flow velocity results indicate a strong dependence on tidal water level fluctuations, with peak flow velocities typically occurring during flood and ebb phases, while lower velocities generally align with low and high tide. At station ST0, the current flow during flood tide tends to be higher than during ebb tide, reaching a maximum of approximately 0.5 m/s during the NorthEast monsoon season. In the mangrove forest, however, the flow velocity shows a different variation pattern, often being higher during ebb tide with a maximum of around < 0.2 m/s (Figure 3).

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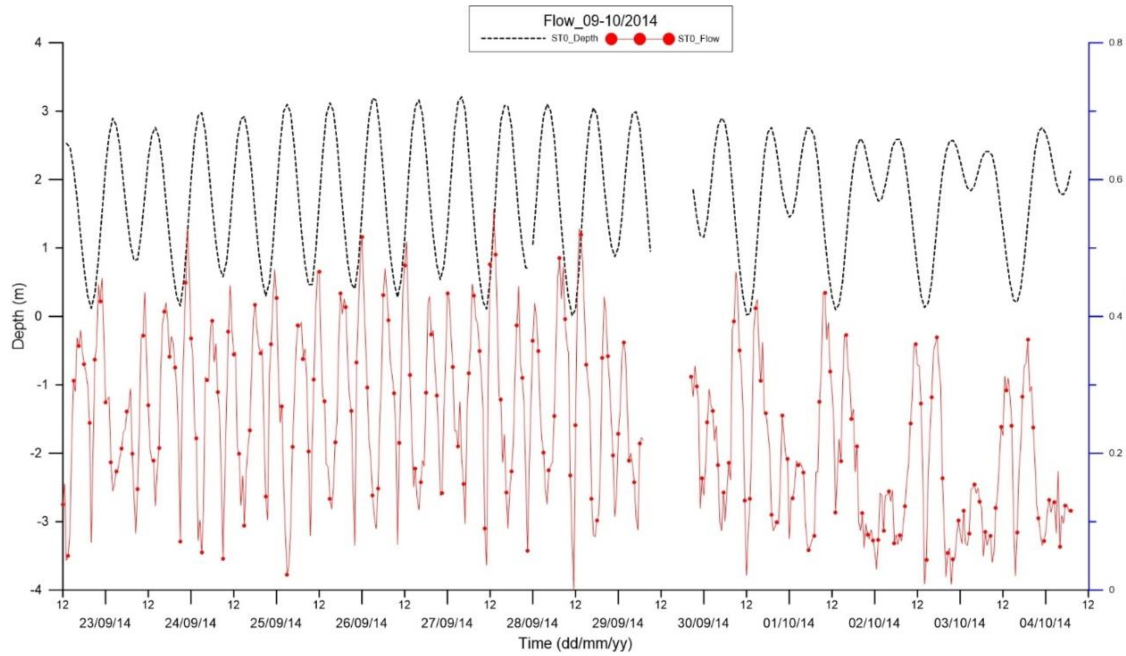
(a)



b)

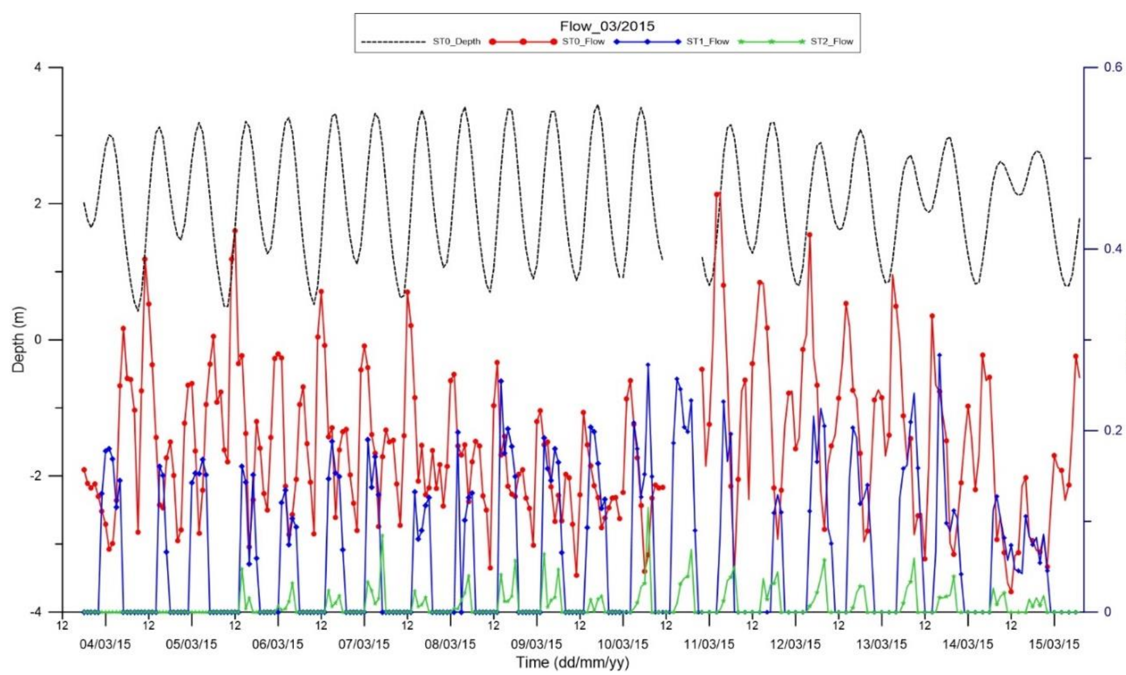


Fig. 3. Flow velocity at the stations: a) in 09-10/2014, b) in 03/2015

Observed wave height also correlates closely with water level fluctuations, increasing as the water level rises and decreasing as it falls. At station ST0, the significant wave height (Hs) reaches a maximum of about 0.45 m in the SouthWest monsoon season and approximately 0.8 m during the NorthEast monsoon season. The maximum Hs decreases to around 0.4 m and 0.55 m at the mudflat station, corresponding to each season. Within the mangrove forest, the maximum Hs decreases further, reaching about 0.1 m during the SouthWest monsoon and 0.2 m during the NorthEast monsoon at station ST2 (Figure 4).

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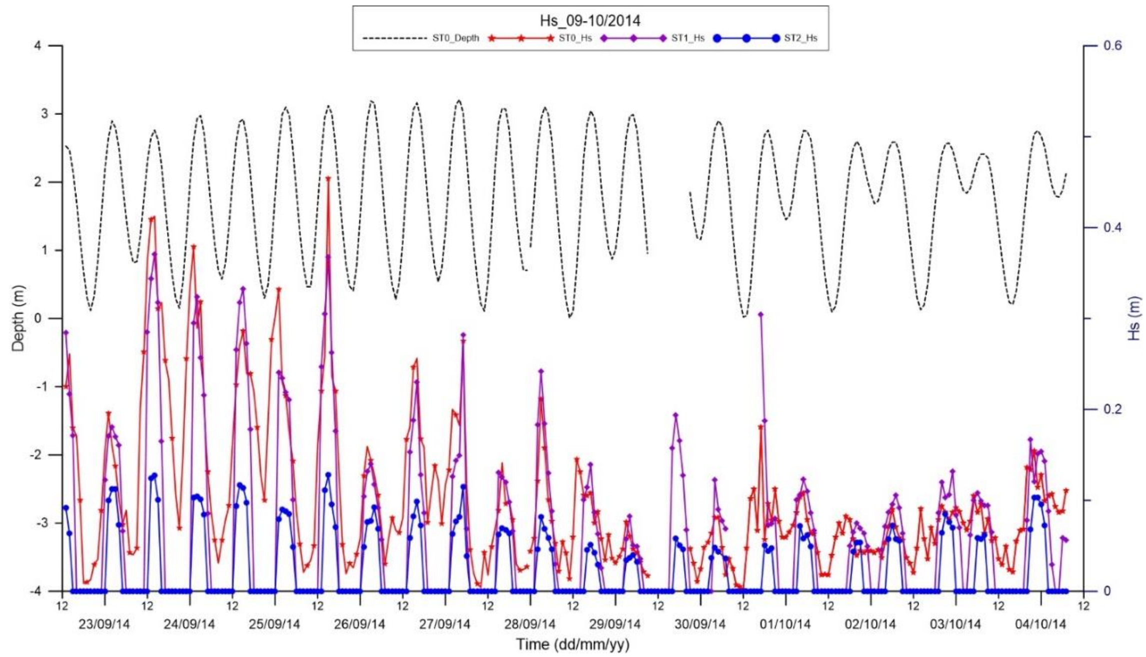
(a)



b)

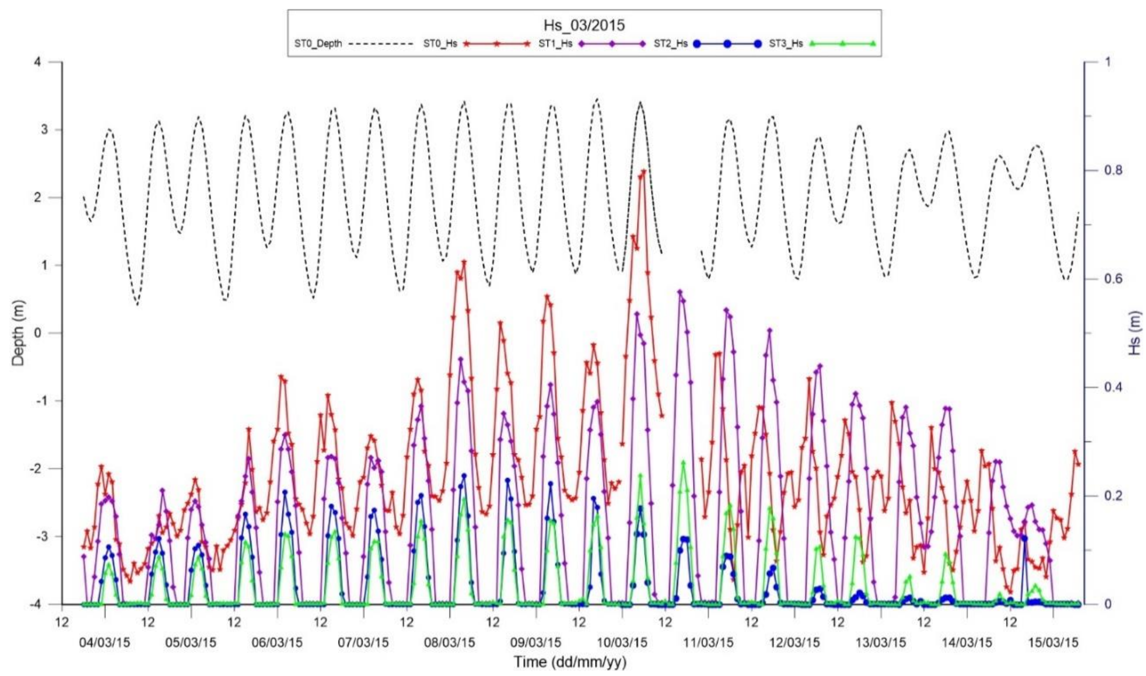


Fig. 4. Significant wave height (Hs) at the stations: a) in 09-10/2014, b) in 03/2015

Survey results for suspended sediment concentration (SSC) indicate an increasing trend from the outside into the mangrove forest. At station ST0, the maximum SSC is less than 600 mg/l, while within the mangrove forest, it is significantly higher, reaching up to 1500–1800 mg/l. Variation patterns differ as well; outside the forest, SSC is typically higher at high or low tide, whereas within the mangrove forest, SSC tends to be lower at high tide (Figure 5).

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(a)

b)

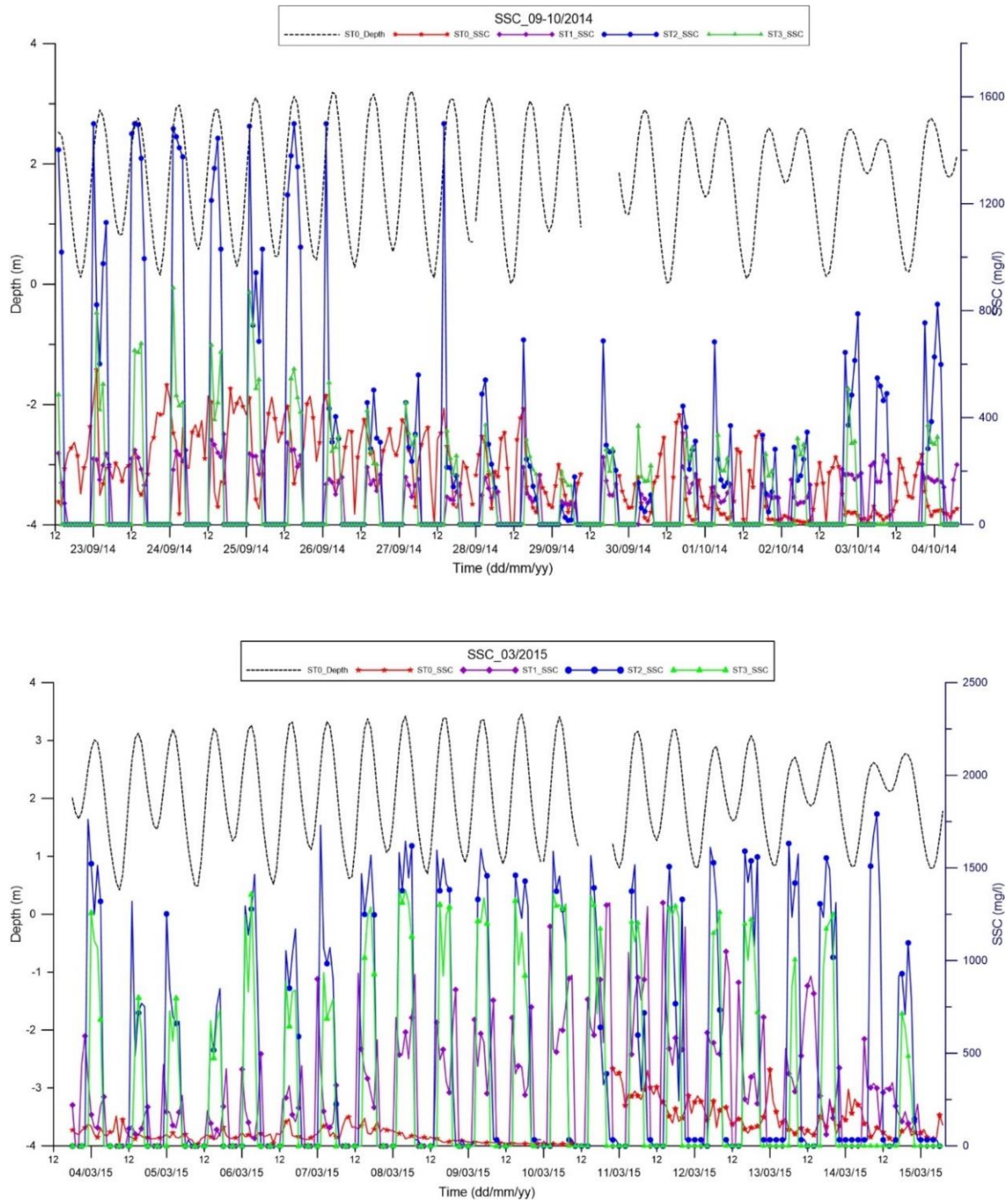

Fig. 5. Suspended sediment concentration (SSC) at the stations: a) in 09-10/2014, b) in 03/2015

Comparing water depth observations shows that as the tide propagates from the outside into the mangrove forest, the tidal fluctuations remain mostly undistorted. The distance from the outer station ST0 to the inner station ST3 is less than 5 km, and the area's relatively gentle topography does not show significant phase shifts in the tidal patterns observed.

The flow velocities across survey stations shows that flow within the mangrove forest is relatively weak, with velocity magnitudes significantly lower than those at the mudflat and offshore stations. Additionally, the flow velocity at station ST2 exhibits asymmetry between the flood and ebb phases, particularly pronounced during the period of 03/ 2015. According to the theory proposed by Mazda et al.

[10], this could be due to the phase lag of flow velocity components within the mangrove forest, hindered by the tree trunks and roots. The asymmetry of the flow can create favorable conditions for the growth of mangrove species while maintaining the stability of bottom sediments. However, this may also affect the exchange of water and nutrients between the mangrove forest and the surrounding marine environment, particularly during periods of weak flow (slack tide).

The comparison of significant wave heights shows a decrease in magnitude as waves propagate from outside into the mangrove forest area. From the outer station ST0 to the mudflat ST1, wave heights reduce by 30-40%, while from the mudflat to the mangrove forest ST2, wave heights can decrease by 60-70%, and for larger waves, the reduction can exceed 75%. The significant reduction in wave height as waves propagate from the coastal zone into the mangrove forest highlights the energy dissipation capability of the mangroves. This is particularly important during the NorthEast Monsoon season when wave intensity is high. The dissipation of wave energy reduces wave pressure on the interior area, protecting the forest and mudflats from erosion.

Suspended sediment concentration (SSC) tends to increase gradually from the outer station ST0 into the mangrove forest stations ST2 and ST3. The SSC variation trend within the mangrove forest differs from that at the mudflat and offshore. At station ST0, SSC generally increases with the rising tide, peaking around high tide and gradually decreasing during the ebb. In contrast, at stations within the mangrove forest, SSC tends to be lower around high tide, with two peaks observed during the flood and ebb phases. This survey result may reflect the dynamics of fine sediment deposition on the surface, influenced by tidal flows entering and exiting the forest.

Tab. 2. Statistics of dynamic factors at stations in the study area during the NorthEast and SouthWest monsoon seasons

Season	**NorthEast**				**SouthWest**			
Station	***ST0***	***ST1***	***ST2***	***ST3***	***ST0***	***ST1***	***ST2***	***ST3***
H_s average (m)	**0.25**	**0.15**	**0.05**	**0.04**	**0.1**	**0.15**	**0.07**	**-**
H_s max (m)	**0.8**	**0.55**	**0.2**	**0.25**	**0.45**	**0.4**	**0.1**	**-**
Average flow velocity (m/s)	**0.2**	**0.15**	**0.05**	**-**	**0.25**	**-**	**-**	**-**
SSC average (mg/l)	**-**	**450**	**790**	**1008**	**280**	**205**	**910**	**470**
SSC max (mg/l)	**400**	**1300**	**1800**	**1360**	**580**	**340**	**1500**	**885**

In general, the dynamics during the NorthEast monsoon season are stronger than those in the SouthWest monsoon season in the study area of Cu Lao Dung. Waves during the NorthEast monsoon season offshore can reach a maximum height of 0.8 m, decreasing to 0.55 m at the mudflat and further down to 0.2

m within the forest. Meanwhile, in the SouthWest monsoon season, waves are significantly reduced, with a maximum height of only 0.45 m offshore and 0.1 m within the forest. The flow velocity in both seasons is nearly the same, while the distribution of suspended sediment concentration (SSC) at the stations varies. Due to the stronger dynamics during the NorthEast monsoon, SSC is also higher than in the SouthWest monsoon. SSC is highest within the mangrove forest, followed by the mudflat and then the shallow waters outside. SSC is transported along with the currents and waves, carrying a large amount of sediment from offshore into the mudflat and mangrove forest. Due to the relatively gentle seabed topography here, the SSC dynamics and transport processes are not greatly hindered by the terrain and gradually decrease when water levels are sufficiently low or when waves break. Therefore, sediment accumulation gradually increases from the mudflat to the mangrove forest. These results indicate substantial sediment deposition in the mudflat and mangrove forest areas, highlighting the role of mangroves in trapping sediment in the surveyed area of Cu Lao Dung.

Overall, the interaction between water level fluctuations, currents, waves, and SSC forms a distinct hydrodynamic regime in Cu Lao Dung mangrove forest area. Currents and waves play a key role in transporting sediments into the mudflat and mangrove areas, while the complex structure of the mangroves facilitates sediment retention. The large tidal range and weak flows within the mangroves enhance sediment deposition, contributing to the accretion of mudflats and mangrove forests.

4. Conclusion

The survey conducted by the Department of Oceanology, Meteorology, and Hydrology during the SouthWest monsoon (09-10/2014) and the NorthEast monsoon (03/2015) has partially revealed the characteristics of the hydrodynamic regime in the mangrove forest area of Cu Lao Dung, Soc Trang. Through analysis of the results, it can be seen that:

Firstly, tidal propagation into the mangrove forest is not significantly distorted, indicating stable water level fluctuations in the area. Secondly, the flow within the forest shows asymmetry between the flood and ebb phases, reflecting the influence of the mangrove forest on flow patterns. Thirdly, waves diminish substantially as they enter the mangrove forest, especially for larger waves, demonstrating the important role of this ecosystem in dissipating wave energy. Lastly, the variation in suspended sediment concentration (SSC) between the mangrove forest and the outer area shows a distinct difference, underscoring the mangroves' significant impact on sediment distribution and accumulation along the coast.

To further clarify the distinctive characteristics of the hydrodynamic regime in Cu Lao Dung mangrove forest, Soc Trang, more detailed analysis of the variations and interconnections among the factors tides – currents – waves – sediment is needed. Additionally, combining these findings with other regional studies would help to create a more comprehensive evaluation.

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