Journal of Sustainability Science and Management
Volume 15 *Number* 4, June 2020: 120-129

eISSN: 2672-7226

THE IMPACT OF SEASONAL MONSOONS ON THE MORPHOLOGY OF BEACHES PROTECTED BY BARRIER ISLANDS IN SETIU, TERENGGANU, MALAYSIA

NOOR IZAM ISMAIL[1], EFFI HELMY ARIFFIN*[1,2], ROSNAN YAACOB[1], MOHD LOKMAN HUSAIN[2] AND NOR BAKHIAH BAHARIM[1]

[1]Faculty of Science and Marine Environment, [2]Institute of Oceanography and Environment, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia.

**Corresponding author: effihelmy@umt.edu.my*

Submitted: 5 September 2019 Accepted: 10 April 2020 http://doi.org/10.46754/jssm.2020.06.012

Abstract: The beach is a complex system area where many natural and anthropogenic factors may influence the coastal processes. These processes include erosion and accretion, which may pose a significant problem. Understanding their causes is, therefore, essential not only for researchers but also the community, especially in mitigating the effects of monsoons and executing coastal development plans. Hence, this study tried to understand the natural impact and changes at a coastal stretch in Terengganu, Malaysia, which was affected by the Northeast Monsoon. This study determined the profile of four beaches on the stretch through cross-shore transects in monthly intervals. Beach surface sediment samples were also collected at four sampling stations facing several islands off the coast for particle size analysis. Besides that, the significance of the wave height was illustrated. Most beaches where the sampling stations were located had been affected by erosion. However, some did experience accretion during the Northeast Monsoon. The sediment sizes ranged from very coarse to fine sand. The beach morphology changes were essential in executing coastal management plans. Therefore, this study could provide clearer information for future coastal developments, especially in beaches along Terengganu.

Keywords: Beach morphology, beach erosion, mean particle size, Island, anthropogenic.

Introduction

Beaches have an active environment and their dynamics are unstable (Hole & Grant, 2001; Thampanya *et al*., 2006; Moses & Robinson, 2011) continually changing shape and shifting position in response to winds, waves, tides, relative sea level, and human activities. The most significant changes occur seasonally and following storms. During summer, beaches are generally higher and sandier than they are in winter. During the winter, the 'missing' sand moves from the beach to nearshore areas to form sandbars. This happens as a result of changing wave shape due to more intense storm activity. During spring and early summer, or following a storm, the sand in the nearshore region moves back toward and eventually attaches to the beach. Once on the beach, the finer sand grains are moved by wind action to form higher, wider sand dunes. These seasonal and storm related interactions and changes in the form, volume, and position of beaches, dunes, and nearshore areas produce what is known as 'dynamic equilibrium'. They are among places that are vulnerable to natural phenomenas and anthropogenic activities. Beaches do not only provide essential sustenance to the local population, but they are also essential for people who live far away or at non-coastal areas (Ariffin, 2016; Ratnayake, 2016; Ratnayake *et al*., 2018; Amalan *et al*., 2018). For example, the population growth in a country will increase its human activity, which will consequently apply high pressure on the processes the affect beach profilling and sedimentology (Ariffin *et al*., 2016; Ratnayake *et al.,* 2018; 2019).

However, the movement of sediments may be influenced by the presence of islands. According to Sousa *et al*. (2013), a set of islands located nearby the coast or each other may directly affect beach morphodynamics. The beaches, due to their location (near capes) or with protective measures built on them, may reduce the wave energy of the sea and diffract the initial phenomena (Aragonés *et al*., 2016) the accuracy of these models is vital to optimize the costs of coastal regeneration projects. Planning of such interventions requires methodologies that do not generate uncertainties in their interpretation. A study and comparison of mathematical simulation models of the coastline is carried out in this paper, as well as elements that are part of the model that are a source of uncertainty. The Islands also help to stabilize the beach profile by slowing down the speed of the waves to achieve a state of equilibrium of the beach. The equilibrium of the beaches may be estimated via grain size analysis and beach profiling (Dora *et al*., 2014).

The processes of beach profilling and sedimentology in the coast of Terengganu are usually influenced by annual monsoons in Peninsular Malaysia, i.e., the Northeast Monsoon from November until March, and the Southwest Monsoon from May until September (Ariffin *et al*., 2016; 2018; 2019). The Northeast Monsoon significantly affects beach profile and sedimentology in Terengganu because it brings storms and heavy rainfall directly from the South China sea, which is adjacent to the state.

On the other hand, the Southwest Monsoon is relatively calm because it blows in from the west coast of the peninsula, where rain and storms may have dissipated inland. This monsoon helps the recovery process on the beach profile and sedimentology in Terengganu by maintaining its equilibrium. However, beach erosion is one of the major problems that usually occur in Terengganu and is not only caused by natural phenomenas, but also anthropogenic factors. Therefore, this study tried to understand the natural impact and changes brought on by seasonal monsoons on several shores in the state by determining the beach profile and particle size analysis. The beach morphology changes are essential in coastal management plans and this study may provide clearer information for future developments in Terengganu, especially along the coastal areas.

Study Area

The study area was a 20 km coastal stretch facing the South China Sea in the northern district of Setiu in Terengganu, Malaysia. It included several popular beaches and picnic spots, from Pantai Penarik to Merang. The sampling stations were established in places where the highest rainfall was recorded during the Northeast Monsoon (Rosnan & Lokman, 2005). Tides at the study areas were semi-diurnal and covered from microtidal to mesotidal. The Terengganu coast had wet equatorial climate, which experienced high temperatures throughout the year. Heavy rainfall usually occurred during the Northeast Monsoon, with an average annual reading of 2,990 mm. In contrast, the average annual rainfall during the Southwest Monsoon was only 740 mm (Ariffin *et al*., 2016). Some parts of the study area were near tourist islands like Pulau Redang, Pulau Bidong and Pulau Perhentian, and served as launchpoints for boats to commute to the islands.

The four stations in this study are shown in Figure 1. Station One (St 1) was in Pantai Penarik, which is a tourist attraction. There were several restaurants and the population lived near the coastline. Station Two (St 2, Pantai Bari Kecil) was situated about five km from St 1, and was a remarkable area in this study. The jetty building in front of the sampling area was being constructed while the study was conducted. The building of the jetty began in June 2015. After its completion, natural resources (silica) were transported to a nearby island. Station Three (St 3, Pantai Telaga Papan) was near Merang, and approximately 15 km from Pantai Penarik. This station was surrounded by undergrowth and coconut trees in a backshore area. There was also a natural berm. Station Four (St 4, Pantai Merang) was located in the northern part of Merang district and it was also a famous beach in Terengganu. Many tourists visited this area as there was a jetty that linked it to nearby islands. The beach was also located near an estuary.

Methodology

The survey was conducted throughout 2015, starting in the middle of the 2014/2015 Northeast Monsoon from January 2015 (referred to as the base of the beach profile) to March, followed by the Southwest Monsoon from June until September. The 2015/2016 Northeast Monsoon began again in November, but the study was terminated in December 2015. Beach profiling and sediment analysis were carried out at the four sampling stations.

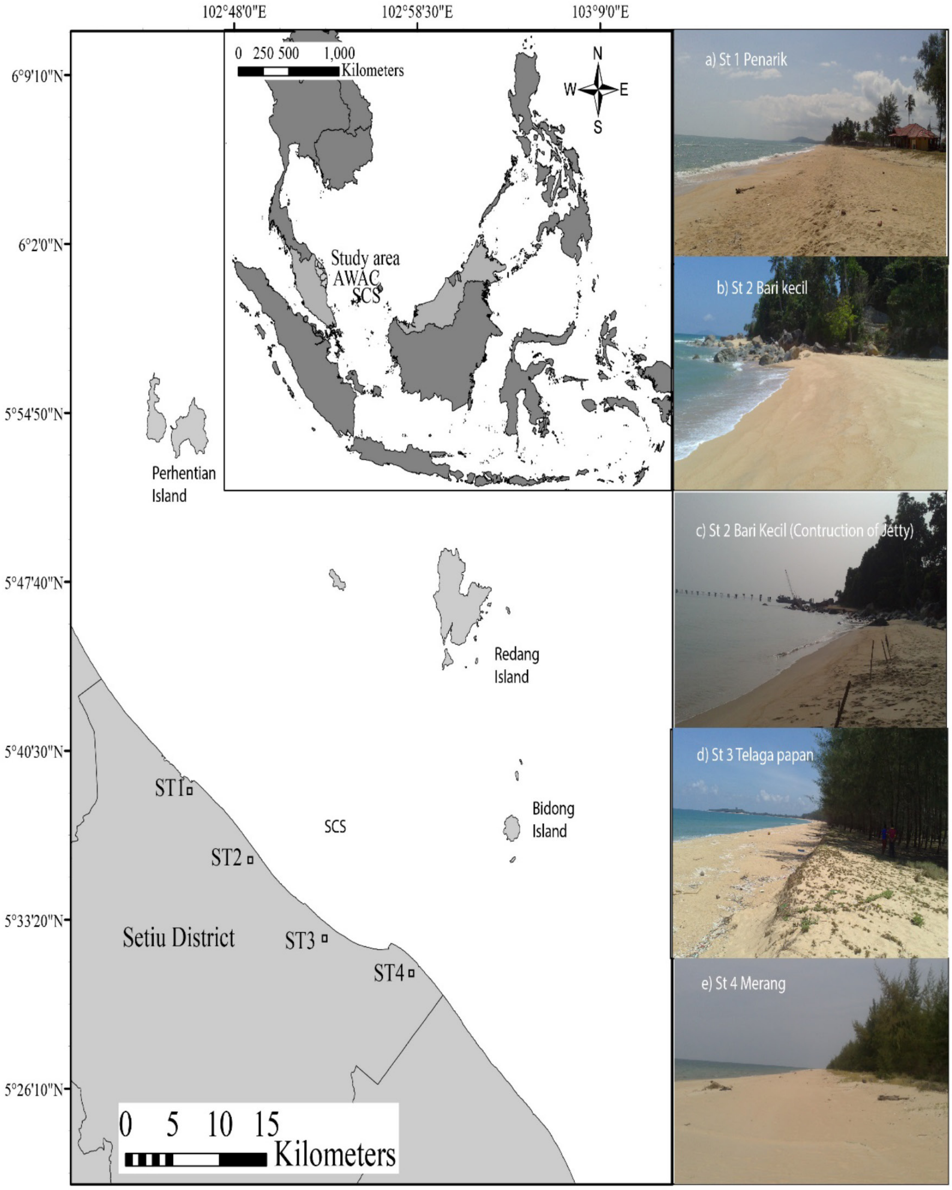

Figure 1: The locations of the four sampling stations of this study in Setiu district, Terengganu, Malaysia, which were adjacent the South China Sea

*note: Acoustic wave and current profiler (AWAC) located in the study area are for validation of numerical modeling.

Beach profile was measured using a Topcon Non-Prism Total Station GPT-3100N theodolite (Topcon, Tokyo, Japan), starting at the beach dunes as the benchmark and ending about 0.5 m into the water (during low tide) with the average beach width between 27 m to 60 m. The beach profile data was analysed using Profiler 3.0XL to determine volume output. However, for beach morphology processes, the surface sediment samples were collected from the dune until low tide with 10 m intervals. Dry sieve analysis was carried out and the mean particle size was calculated using the GRADISTAT program (Blott & Pye, 2001). The sieves were arranged consecutively finer downwards at 0.5 phi intervals ranging from 4000 µm until 63 µm. The sieves were shaken for about 20 minutes for each sample.

The wave model was simulated for 13 months and constrained with three significant factors: wind, tides and density — six-hourly wind data extracted from the European Centre for Medium-Range Weather Forecasts (ECMWF) database. Wave measurements (in-situ data) were recorded with a directional wave system Acoustic Doppler Wave and Current Profiler (AWAC), deployed on a bottom-mounted frame in sub-tidal zones at 10 m depth. In the earlier step, the model validation was performed using field measurement data to check the simulation output. The root mean square error (RMSE) was calculated using the significant wave height field, together with the modelled data. The calibration was done using the value suggested by DHI (2011) using formula in Equation 1.

$$\text{RMSE}=\sqrt{\sum \frac{(H_{s\,InSitu} - H_{s\,Model})^2}{N}}, \qquad \text{(Eq. 1)}$$

where, H_s is the significant wave height and N is the number of significant wave height readings.

The RMSE in this study was 0.284, as presented in Figure 2. The results of the models were validated with one month of AWAC wave height data recorded in the nearshore of Kuala Terengganu. The AWAC measurements were available in six-hourly intervals covering the period from April 2015. The wave modelling was generated by Mike 21 to estimate wave patterns during the survey period. The Spectral Wave (SW) Flexible Mesh was calibrated by testing the influence of bottom friction and its influence on wave breaking at the AWAC measurement location (Figure 1). As stated by Ariffin *et al*. (2016), the combination of adjustable parameters led to the best agreement between the measured and the calculated data sets.

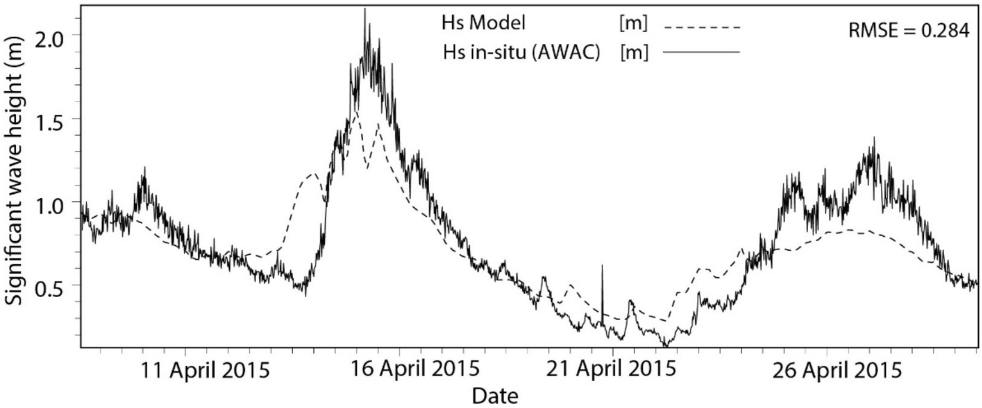

Figure 2: The validation of significant wave height (H_s) with the root mean square error (RMSE)

Results

The beach morphology changes, including beach profile and particle mean size are shown in Figure 3. The beach morphology changes were classified into the Northeast and Southwest Monsoons. The changes were determined in one complete cycle in 2015 that showed very different dynamics between all stations. The essential results of this research were as follows:

Station One

The graph in Figure 3 presents January 2015 as the base of the beach profile. Accretion was observed to occur in this area in March during the ending phase of the Northeast Monsoon (storm conditions). This was proven by the volumetric changes in Table 1 that showed an increase in the volume of sediment compared to January. In June (during the Southwest Monsoon), erosion was observed in the profile as the sediment volume became less than the previous sampling. In September, erosion was still detected before accretion occurred again in December, which was the onset of the new Northeast Monsoon.

The beach sediments in this area were categorised as medium to very coarse sand. In January, the areas around the station seemed to be filled with coarse sand. In March, the sand came between medium and very course. By June, the sand became medium coarse and in September, coarse sand was dominant in the area. By the end of the study, the sand in the area was observed to be medium coarse, which was the same as in June.

Station Two

Accretion was observed in this area in March. The sediment volume also increased compared to January and, in June, the rate had been reduced to the lower part of the profile due to the jetty construction. However, erosion occurred in the dune area. In September, the dune experienced accretion until December, when erosion reoccurred again. St 2 was dominated by coarse sand during the sampling period. The beach sediments were categorised from medium to very coarse sand. While medium sand was found during September, very coarse sand began appearing in January and December.

Station Three

The area around this station underwent accretion in March as indicated by the increased in sediment volume. However, between the Southwest Monsoon in June and its transition period in September, erosion occurred in this study area. Less sediment volume was found in June, and the volume decreased more when measured again in September. Then, in December, when the Northeast Monsoon was peaking, accretion began to reoccur. The beach sediments were categorised from medium to very coarse sand. In January, very coarse sand was found at the last three sampling points. In March and June, medium sand dominated the last point. From September to December, all sediments were classified as coarse sand.

Station Four

During the tail of the Northeast Monsoon (March), accretion occurred at this area. In June, the volumetric changes and beach profile showed erosion happening, where a loss of volume was detected. In September, accretion happened in this study area until December, when erosion happened again. St 4 was dominated by medium and fine sand in December, especially at point four, which was the swash zone. During January, March, June and September, at all the points, only medium sand was found. However, in December, fine sand was observed.

Table 1: Volumetric changes in the study areas

St	January 2015	March 2015	June 2015	September 2015	December 2015
1	171.82	191.53	186.62	180.82	194.15
2	127.34	132.74	132.65	133.91	119.78
3	111.12	114.54	112.16	110.01	126.09
4	152.45	153.57	127.34	152.67	148.64

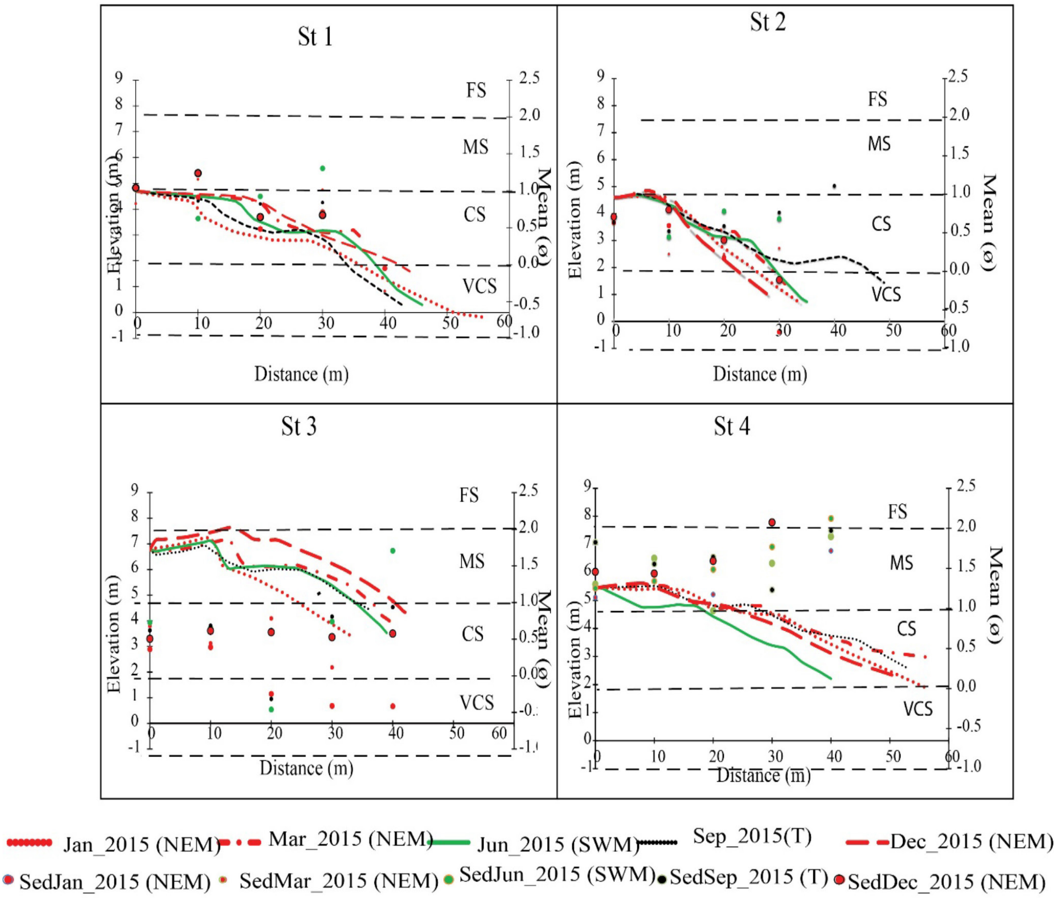

Figure 3: The morph-sedimentological graph of the study area in January, March, June, September, and December 2015

*Note: FS-Fine Sand; MS-Medium Sand; CS-Coarse sand; VCS-Very Coarse Sand.

Figure 4 represents the responses observed by the modelled waves in this study. The monsoon started from December 2014 to March 2015, and three significant storms took place during that season. The first and second storms were in December 2014, and the third occurred in January 2015. The most substantial wave height was 2.28 m, while the other two storms generated waves up to 1.8 m high. The Southwest Monsoon was mild and did not produce any storms or rough seas. The average significant wave height was less than 0.4 m.

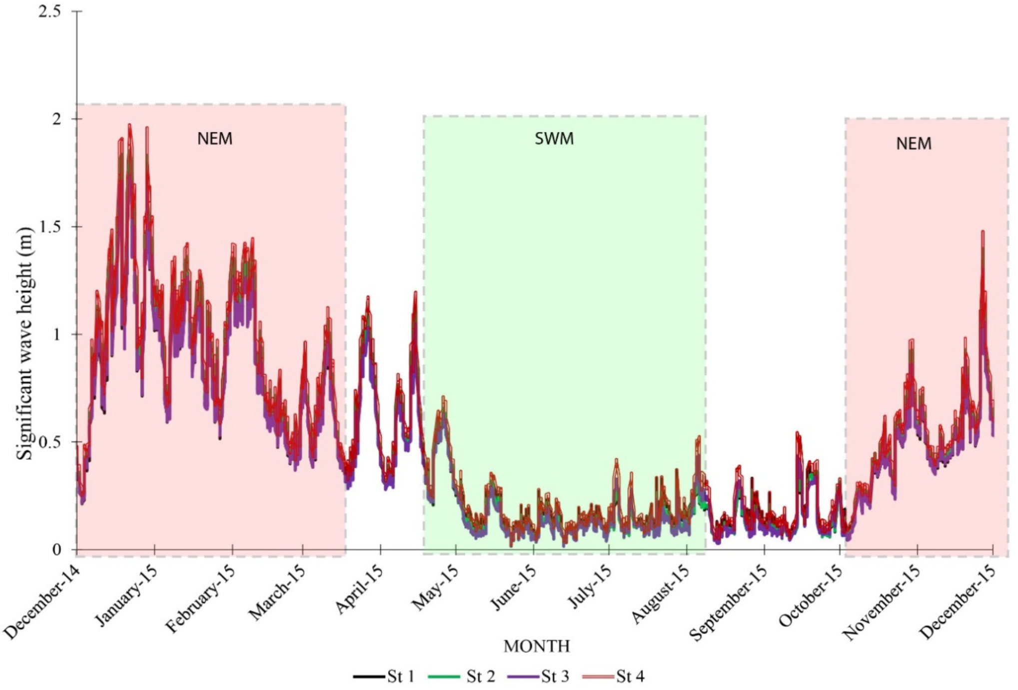

Figure 4: The significant wave height of the study areas from December 2014 to December 2015

The values of 16.91 % (Figure 5) was recorded during the 2014/2015 Northeast Monsoon and 20.08 % during the following 2015/2016 season. The rates of accretion were also the highest. During the Southwest Monsoon, the calm condition recorded was 24.49 %. At all sampling stations, sediments moved from the sea towards the coast, and there were two wave directions during the monsoon.

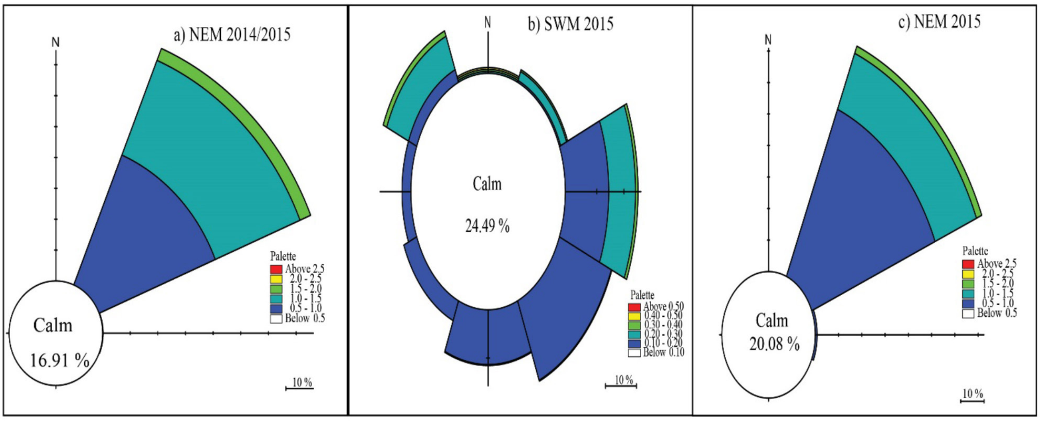

Figure 5: Rising waves in the study areas during the Northeast Monsoons of 2014/2015 and 2015/2016, and the Southwest Monsoon of 2015

Discussion

The nature of the beach profile changes revealed that erosion was accompanied by storms that occurred during the Northeast Monsoon, while recovery/accretion took place during the Southwest Monsoon (Ariffin *et al*., 2016; 2018; 2019). However, generally, based on the results, the accretion also happened at some sampling stations during the Northeast Monsoon, which contradicted the natural processes of the beach morphology during the storm season. The beach morphology changes could be attributed to their location near some islands. The islands might have protected the study areas from being directly influenced by the Northeast Monsoon. Additionally, according to Phantuwongraj *et al*. (2013), the overwash sediment deposited at the beach dunes in the east coast of Thailand during the same monsoon had led to the formation of several barrier islands. In contrast, erosions happened in most stations of this study during the Southwest Monsoon.

However, in the case of St 2, erosion was observed at the beach near the jetty during the 2015/2016 Northeast Monsoon According to Lin *et al*. (2015) and Walton and Dean (2011), the wave height distribution was very dynamic along the beaches nearest to the jetty. The construction of the jetty allowed had slowed down the sediment movement. This concurred with the fact that human activities could be a factor that changes the beach morphology. For example, construction of coastal structures, beach nourishment, sand mining and tourism could cause beaches to become eroded (Gujar *et al*., 2011; Jonah, 2015; Rangel-Buitrago *et al*., 2015).

According to Ariffin *et al*. (2018) and Dora *et al.* (2014), the mean particle size of beach sand was an indicator of beach morphology dynamics. The sand might be presented as coarse due to erosion and fine due to accretion. Based on the beach morpho-sedimentary results, St 4 was categorised as the most stable beach due to its gentler elevation, sediment transport distance and fine to medium sand. According to Rosnan & Mohd Zaini (2009), the finer sediments indicated areas affected by low-energy forces that subtly affected the beach morphology, especially the slopes.

The wave diffraction from the sea could be reduced if there was natural protection, such as islands or headlands, or coastal structures (breakwater) built near or parallel along the coastline. A previous study by Aagaard and Hughes (2017) in Agadir Bay, Morocco, found that breakwaters along the beach could reduce wave diffraction. The beach profile slope was maintained even after 40 years since the breakwaters were built. However, the authors also stated that there was sufficient supply of sediment sources along the coastline.

Conclusion

The monsoons of Peninsular Malaysia had critical effect on specific coastlines and their associated changes of beach profiles and sediment transport. Changes in beach profile and sedimentological characteristics depended on natural factors and the human activities, including the intensive erosion seen at vulnerable coastal areas. The tourist islands located near the sampling stations acted as natural barriers to several beaches that protected them from erosion, especially during the Northeast Monsoon, when there was a stronger hydrodynamic factor compared to other periods.

Acknowledgments

This research was supported by Malaysian Education Ministry under the Fundamental Research Grants Scheme (FRGS) [UMT/RMIC/FRGS/1/2018/59513(1). The authors like to thank the Coastal Gamer team and staff from the Laboratory of Physical Oceanography and Geology, and Faculty of Science and Marine Environment, UMT, especially Mr. Roslan Latif, Mr. Sainol and Mr. Raja, for their assistance at the sampling stations and not to forget Miss Rabitah and Mr. Adlan during sampling. Special thanks, too, to Mr. Ismail and Mr. Syukri for transporting the team to the study locations and Nasihin Seth for editing this paper.

References

Aagaard, T., & Hughes, M. G. (2017). Equilibrium shoreface profiles: A sediment transport approach. *Marine Geology*. https://doi.org/10.1016/j.margeo.2016.12.013

Amalan, K., Ratnayake, A. S., Ratnayake, N. P., Weththasinghe, S. M., Dushyantha, N., Lakmali, N., & Premasiri, R. (2018). Influence of nearshore sediment dynamics on the distribution of heavy mineral placer deposits in Sri Lanka. *Environmental Earth Sciences, 77*(21)*,* 737.

Aragonés, L., Serra, J. C., Villacampa, Y., Saval, J. M., & Tinoco, H. (2016). New methodology for describing the equilibrium beach profile applied to the Valencia's beaches. *Geomorphology*, *259,* 1–11.

Ariffin, E. H., Mathew, M. J., Yaakob, R., Akhir, M. F., Shaari, H., Zulfakar, M. S. Z., … Awang, N. A. (2018). Beach morphodynamic classification in different monsoon seasons at Terengganu beaches, Malaysia. *Journal of Sustainability Science and Management*, *13*(5), 65–74.

Ariffin, E. H., Sedrati, M., Akhir, M. F., Daud, N. R., Yaacob, R., & Husain, M. L. (2018). Beach morphodynamics and evolution of monsoon-dominated coasts in Kuala Terengganu, Malaysia: Perspectives for integrated management. *Ocean and Coastal Management*, *163,* 498–514.

Ariffin, E. H., Sedrati, M., Akhir, M. F., Mohd Norzilah, M. N., Yaacob, R., & Husain, M. L. (2019). Short-term observations of beach morphodynamics during seasonal monsoons: two examples from Kuala Terengganu coast (Malaysia). *Journal of Coastal Conservation*, *In Press*. https://doi.org/10.1007/s11852-019-00703-0

Ariffin, E. H., Sedrati, M., Akhir, M. F., Yaacob, R., & Husain, M. L. (2016). Open Sandy Beach Morphology and Morphodynamic as Response to Seasonal Monsoon in Kuala Terengganu, Malaysia. *Journal of Coastal Research*, *75*(sp1), 1032–1036.

DHI. (2011). Mike-Hydrodynamic Module User Guide. Denmark.

Dora, G. U., Kumar, V. S., Vinayaraj, P., Philip, C. S., & Johnson, G. (2014). Quantitative estimation of sediment erosion and accretion processes in a micro-tidal coast. *International Journal of Sediment Research*, *29*(2), 218–231.

Gujar, A. R., Ganesan, P., Iyer, S. D., Gaonkar, S. S., Ambre, N. V., Loveson, V. J., & Mislankar, P. G. (2011). Influence of morphodynamic variability over seasonal beach sediments and its probable effect on coastal development. *Ocean & Coastal Management*, *54*(7), 514–523.

Hole, W., & Grant, S. (2001). Beach and Dune Profiles. *Marine Extensión Bulletin*, 1-6. https://seagrant.whoi.edu/wp-content/uploads/sites/106/2015/01/WHOI-G-01-001-Sea-Grant-Beach-and-Dune-Pr.pdf.

Jonah, F. E. (2015). Managing coastal erosion hotspots along the Elmina, Cape Coast and Moree area of Ghana. *Ocean and Coastal Management*, *109,* 9–16.

Lin, L., Demirbilek, Z., Ward, D., & King, D. (2015). Wave and hydrodynamic modeling for engineering design of Jetties at Tangier Island in Chesapeake Bay, USA. *Journal of Marine Science and Engineering*, *3*(4), 1474–1503.

Moses, C., & Robinson, D. (2011). Chalk coast dynamics: Implications for understanding rock coast evolution. *Earth-Science Reviews*, *109*(3–4), 63–73.

Phantuwongraj, S., Choowong, M., Nanayama, F., Hisada, K. I., Charusiri, P., Chutakositkanon, V., & Chabangbon, A. (2013). Coastal geomorphic conditions and styles of storm surge washover deposits from Southern Thailand. *Geomorphology*, *192,*43–58.

Rangel-Buitrago, N. G., Anfuso, G., & Williams, A. T. (2015). Coastal erosion along the Caribbean coast of Colombia: Magnitudes, causes and management. *Ocean and Coastal Management*, *114*, 129–144.

Ratnayake, A. S. (2016). Evolution of coastal landforms during the Holocene Epoch along the west and southeast coasts of Sri Lanka. *Interdisciplinary Environmental Review, 17,* 60-69.

Ratnayake, A. S., Ratnayake, N. P., Sampei, Y., Vijitha, A. V. P., & Jayamali, S. D. (2018). Seasonal and tidal influence for water quality changes in coastal Bolgoda Lake system, Sri Lanka. J*ournal of Coastal Conservation, 22,* 1191-1199.

Ratnayake, N. P., Ratnayake, A. S., Keegle, P. V., Mallawa Arachchi, M. A. K. M., & Premasiri, H. M. R. (2018). An analysis of beach profile changes subsequent to the Colombo Harbor Expansion Project, Sri Lanka. *Environmental Earth Sciences 77, 24*(2018). https://doi.org/10.1007/s12665-018-7234-8.

Ratnayake, N. P., Ratnayakem, A. S., Azoor, R. M., Weththasinghe, S. M., Seneviratne, I. D. J., Senarathne, N., Premasiri, R., & Dushyantha, N. (2019). Performance analysis of the beach nourishment and breakwater construction to control the coastal erosion at Uswetakeiyawa, Sri Lanka. *SN Applied Sciences 1*, 52(2019). https://doi.org/10.1007/s42452-018-0050-7.

Ratnayake, N. P., Ratnayake, A. S., Keegle, P. V., Mallawa Arachchi, M. A. K. M., & Premasiri, H. M. R. (2018). An analysis of beach profile changes subsequent to the Colombo Harbor Expansion Project, Sri Lanka. *Environmental Earth Sciences, 77*, *24* (2018). https://doi.org/10.1007/s12665-018-7234-8

Thampanya, U., Vermaat, J. E., Sinsakul, S., & Panapitukkul, N. (2006). Coastal erosion and mangrove progradation of Southern Thailand. *Estuarine, Coastal and Shelf Science*, *68*(1), 75–85.

Walton, T. L., & Dean, R. G. (2011). Shoreline change at an infinite jetty for wave time series. *Continental Shelf Research*, *31*(14), 1474–1480.

Yaacob, R., & Mustapa, M. Z. (2010). Grain-size distribution and subsurface mapping at the Setiu wetlands, Setiu, Terengganu. *Environmental Earth Sciences*, *60*(5), 975–984.