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BEACH MORPHODYNAMIC CLASSIFICATION IN DIFFERENT MONSOON SEASONS AT TERENGGANU BEACHES, MALAYSIA

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Abstract: Wave climate, topography and sediments are the main forcing factors that influence beach morphodynamics. This paper characterise beach morphodynamic classification along the Terengganu coast during seasonal monsoons (the onset of southwest monsoon in June 2009 as calm conditions and northeast monsoon in December 2009 as storm conditions). Two main morphodynamic characteristics are used to define reflective, intermediate and dissipative beaches such as the surf similarity index (ξb) and the dimensionless fall velocity (Ω). In order to estimate morphological changes, repetitive beach profiles were acquired and averaged. The morphodynamic characteristics are also supported with wave data collected from the European Centre for Medium-Range Weather Forecasts (ECMWF) database and modeled in Spectral Wave Flexible Mesh of Mike-21 module, in order to investigate the wave propagation along the Terengganu coast. According to the beach morphodynamic classification scheme, the southern Terengganu coast showed a reflective beach state with high wave energy and coarser sand. In contrast the northern part with low wave energy, due to sheltering by many islands, demonstrated an intermediate beach state and finer sediment. However, the trend of sediment mean grain size (D_{50}) reveal finer to coarser during southwest and northeast monsoons respectively. The results of this study are helpful in formulating and preliminary observation on effective coastal zone management plan for monsoon-dominated coast especially in sandy beach.

KEYWORDS: Beach characteristic, coastal defence, anthropogenic, numerical model, South China Sea

Introduction

Beaches play a major environmental role as buffers of wave energy and storm (Aleman *et al.,* 2015). The Terengganu coast, characterise by sandy beach, behave as a dynamic zone affected by natural events (i.e., waves, winds and tides) as well as human activity (i.e., impact of coastal structures) (Ariffin *et al.,* 2016; Rosnan & Mohd Lokman, 2005). By understanding the dynamics of beaches (beach morphodynamic), the information can be used to create a model of coastal processes based on seasonal observations, which predict the rapid erosion of beaches during storms and their subsequent slower accretion during post-storm periods (Aleman *et al.,* 2015; Stive *et al.,* 2002).

This model can also be applied to natural areas (on beaches) subject to a seasonally variable wave energy regime. In term of the beach morphodynamic and classification, the beach consisted of a narrow and steep of slope and can be considered as reflective because of the influence of high energy conditions and storm impact. According to Mohd Zaini *et al.* (2015), the strong collapsing breakers to the beach-face during northeast monsoon and created the reflective beach type. However, beach morphodynamics may also be affected by anthropogenic impacts (e.g., harbours, riprap or revetments, groynes and breakwaters) and natural coastal landforms (e.g., headlands and rocky shore) with making a narrow and steeper beach. In contrast, calm condition create a low energy environment and classify as intermediate beach (Horn & Walton, 2007).

Many beach studies have adopted the model of a morphodynamic system evolving towards a state of dynamic equilibrium (under steady forcing conditions) (Anfuso *et al.,* 2007; Ariffin *et al.,* 2016; Masselink & Short, 1993; Merlott *et al.,* 2014). This has led to a classification of beach states into dissipative, intermediate and reflective types. By relating beach state observations to forcing factors, Wright *et al.* (1985) developed a simple predictive model to classify beach forms. Dean's number is a dimensionless parameter first proposed by Gourlay (1968), and then rewritten by Dean (1973), which incorporates the wave and sediment characteristics.

The aim of this study is to characterise beach morphodynamics along the Terengganu coast for a comparison of equilibrium states. Two main morphodynamic characteristics are used to define an equilibrium beach, the surf similarity index (ξ_b) proposed by Battjes (1974) and Galvin (1968), and the dimensionless fall velocity (Ω) proposed by Dean (1973) and Gourlay (1968).

Morphology of Study Area

The coast of Terengganu facing the South China Sea (in east coast of Peninsular Malaysia) with the coastline extending for 244 km (Nor Hisham, 2006). The Terengganu coastline commences from Kuala Besut in the Besut region in the north, near the state of Kelantan (KLN), while, terminating at Mak Nik and Kuala Kemaman in Kemaman region near the southern boundary of the state of Pahang (PHG). This study distinguishes Besut, Setiu and Kuala Terengganu as northern regions while, Marang, Dungun and Kemaman as southern regions. Distinguished by regions, ten stations are selected based on coastal landforms and anthropogenic beaches (Figure 1 & Table 1).

On the other hand, a beach is characterise by many surficial structures formed by winds, wave processes and tides. According to Akhir (2014), reversal of wind systems cause the direction of circulation to change according to the monsoon seasons. Seasonal winds locally occur as the northeast monsoon (between the end of October and the end of March), while the southwest monsoon occurs between the beginning of May and the end of September (Ariffin *et al.,* 2016). The properties of wind-generated waves are dependent on wind conditions (Hill 2004), with beaches being exposed to predominantly two seasons of wind-waves, i.e., north-easterly winds during the northeast monsoon and southwesterly winds during the southwest monsoon (Kok *et al.,* 2015). Furthermore, the type of tides on the Chendering, Kuala Terengganu (main tide station) coastline is semi-diurnal and micro to meso-tidal, with a Mean High Water Spring (MHWS) of 3.28 m and Mean Low Water Spring (MLWS) of 1.12 m (Ariffin, 2017).

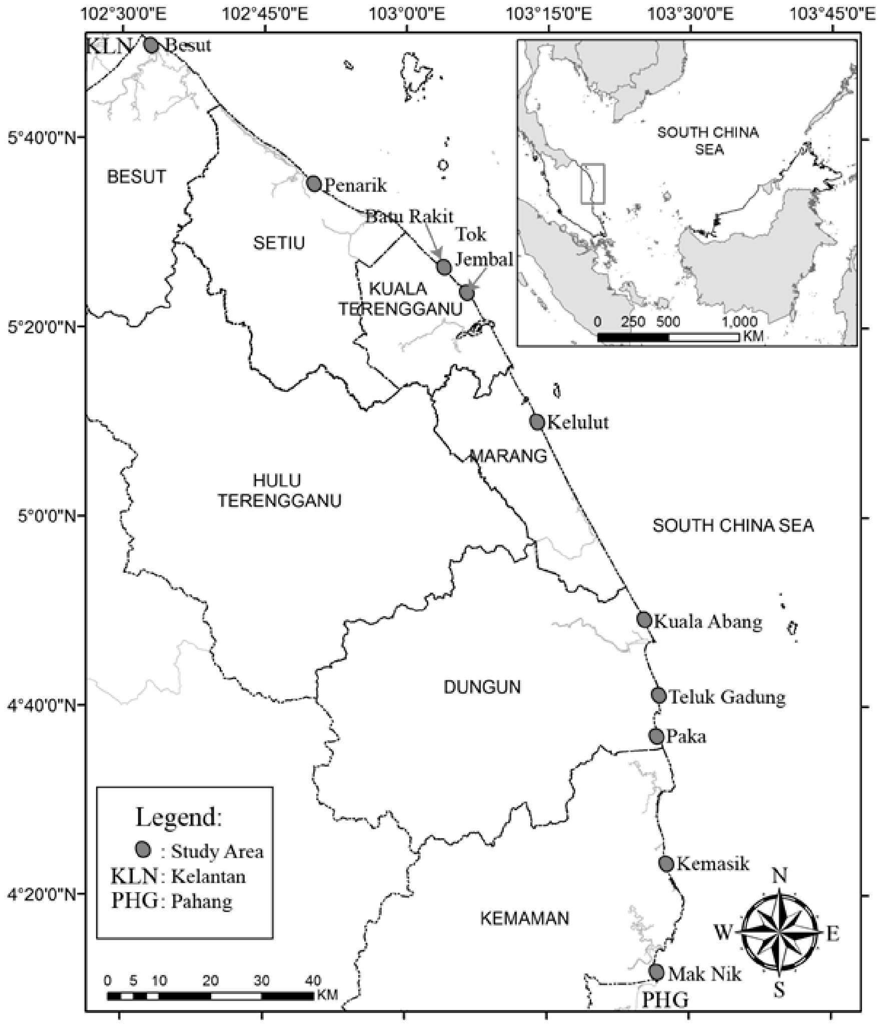


Figure 1: Study area of Terengganu coast with eleven stations along the coastline.

Table 1: Coastal landforms and anthropogenic at Terengganu coast.

Stations	**Regions**	**Environments**
Besut	North	Nearest river mouth
Penarik	North	Short beach
Batu Rakit	North	Wide beach
Tok Jembal	North	Nearest coastal structure (airport runway extension)
Kelulut	North	Short beach and in front island
Kuala Abang	South	Nearest headland
Teluk Gadung	South	Nearest headland and short beach
Paka	South	Nearest oil refining and port
Kemasik	South	Short beach
Mak nik	South	Nearest headland

Materials and Methods

Numerical model

Wave modeling was carried out with Mike-21 module – Spectral Wave Flexible Mesh (DHI, 2011) to estimate the wave parameter along the Terengganu coast during June (southwest monsoon) and December (northeast monsoon) 2009. The bathymetry was generated based on GEBCO input with the average depth ranging from -0.5 to -30.0 m (coast – offshore). The wave model was forced by a series of wind data extracted from European Centre for Medium-Range Weather Forecasts (ECMWF, 2017) sources located offshore.

Wave Climate

The wave parameters were extracted from the wave model in June (southwest monsoon) and December (northeast monsoon) 2009. This wave modeling system was used to obtain the morphodynamic characteristics of the studied beach areas during both monsoons. The breaking wave height (H_b) was estimated using the wave height (H_o) data in deeper waters. Since the subtidal zone exhibits a broadly constant slope on the shoreface of Kuala Terengganu. The breaking wave height can be calculated using the formula proposed by Komar and Gauhan (1972), as expressed in equation i:

$$H_b = 0.39\, g^{0.2}\, (TH_0^2)^{0.4} \qquad \text{(i)}$$

where; H_b = breaking wave height, g = acceleration due to gravity, T = wave period and H_0 = wave height in deep waters.

In addition, morphodynamics can be characterized by different parameters (environmental parameters) according to the model of Masselink and Short (1993) under maximum wave conditions. Most studies use environmental parameters to predict the beach morphodynamics (e.g., breaker type and beach state) based on wave heights, wave period and beach slope (Battjes, 1974; Black *et al.,* 2008; El Mrini *et al.,* 2012; Galvin, 1968; Masselink & Pattiaratchi, 2001). The breaker type is usually estimated by the surf similarity index (ξ_b) (Battjes, 1974; Galvin, 1968), equation ii:

$$\xi_b = \frac{\tan\beta}{(H_b/L_0)^{0.5}} \qquad \text{(ii)}$$

where; tan β = beach slope and L_0 = wave length, which is calculated in equation iii:

$$L_0 = gT^2/2\pi \qquad \text{(iii)}$$

On a uniformly sloping beach, the breaker type is estimated by spilling (ξ_b<0.4), plunging (0.4<ξ_b<2) and surging (ξ_b>2) (Battjes, 1974; Galvin, 1968). Additionally, Wright and Short (1984) provide a criterion for predicting beach state based on wave height and sediment grain size using the dimensionless fall velocity (Ω) proposed by Dean (1973) and Gourlay (1968), equation iv:

$$\Omega = \frac{H_b}{w_s T} \qquad \text{(iv)}$$

where; w_s is the sediment fall velocity.

According to the model of Dean (1973) and Gourlay (1968), the dimensionless fall velocity can be applied to differentiate between reflective beaches (Ω<1), intermediate beaches (1<Ω<6) and dissipative beaches (Ω>6).

Beach Morphology and Sediment

To support the wave climate calculation, beach slopes were extracted from beach profiles and sediment mean grain size (D_{50}) was analysed to characterise the sediments. Beach profile surveys were carried out in June (southwest monsoon) and December (northeast monsoon) 2009. The beach profile were measured from the berm (vegetation area) to the low tide mark using total station instruments (Topcon GPT-3100N). The readings were adjusted to the DTGSM datum level, using the beach volume and slope values obtained from monitored profiles that were analysed with the Profiler 3.2 XL program (Cohen, 2016).

The mean grain size (D_{50}) of sediments was determined using the GRADISTAT V4.0

calculator (Blott and Pye 2001). This value was then used in the calculation of the sediment fall velocity (w_s), which strongly depends on grain size (Gibbs et al., 1971).

Results and Discussion

The main findings of this study are discussed in two sections, the first dealing with wave parameter and second with beach morphodynamics and classification. The results from the wave characteristics study include information on significant wave height and wave breaking type, which can be linked to beach morphodynamics and classification. The study of beach morphodynamics and classification also involves the measurement of mean sediment grain size (D_{50}). It also describes beach gradients, breaker types and beach states, as well as beach profile, which are analysed to understand the dynamic along Terengganu coast during typical seasonal monsoons.

Wave Parameter

Wave height in the study area generally show lower values during the southwest monsoon, in contrast, the highest wave height experienced in the northeast monsoon during storm conditions (Table 2 & Figure 2). It is also noteworthy that the highest energy wave patterns are observed in the southern regions. In contrast, in the northern regions, especially at Besut and Penarik, lowest energy wave patterns during northeast storm events are observed because of the obstruction effect of several islands in these regions.

Table 2: Significance wave height (maximum) along Terengganu coast during southwest and northeast monsoons of 2009.

Stations	Southwest Monsoon Maximum of Significant Wave Height (H_{smax})	Northeast Monsoon Maximum of Significant Wave Height (H_{smax})
Besut	0.45	1.75
Penarik	0.48	1.76
Batu Rakit	0.70	2.44
Tok Jembal	0.70	2.35
Kelulut	0.65	2.44
Kuala Abang	0.69	2.64
Teluk Gadung	0.46	2.28
Paka	0.55	2.52
Kemasik	0.48	2.17
Mak Nik	0.48	2.32

The existence of multiple islands in these regions obstructs wave propagation resulting in a reduction of H_s (Mirzaei *et al.,* 2013). In contrast, with many anthropogenic activities at Tok Jembal beach gave the high energy phenomena during southwest and northeast monsoons (Ariffin *et al.,* 2016). Extreme waves at anthropogenic regions lead to coastal erosion (i.e. Ariffin *et al.* 2016 define coastal slope) that in turn induces catastrophic damage to infrastructure such as roads and buildings, and essentially poses a threat to fishermen operating at sea (Ariffin *et al.,* 2018; Muhammad *et al.,* 2016).

Furthermore, the significant wave heights (H_s) during storms are around 2 - 5 m offshore (Nor Hisham, 2006) and around 2 m or more on the Terengganu coastline, as observed by us, during the northeast monsoon (Ariffin *et al.,* 2016; Mirzaei *et al.,* 2013). This is also supported by the data for H_b (breaking wave height), which show higher values during the northeast monsoon (3.23 m) as compared to the southwest monsoon that depicts values of 1.26 m.

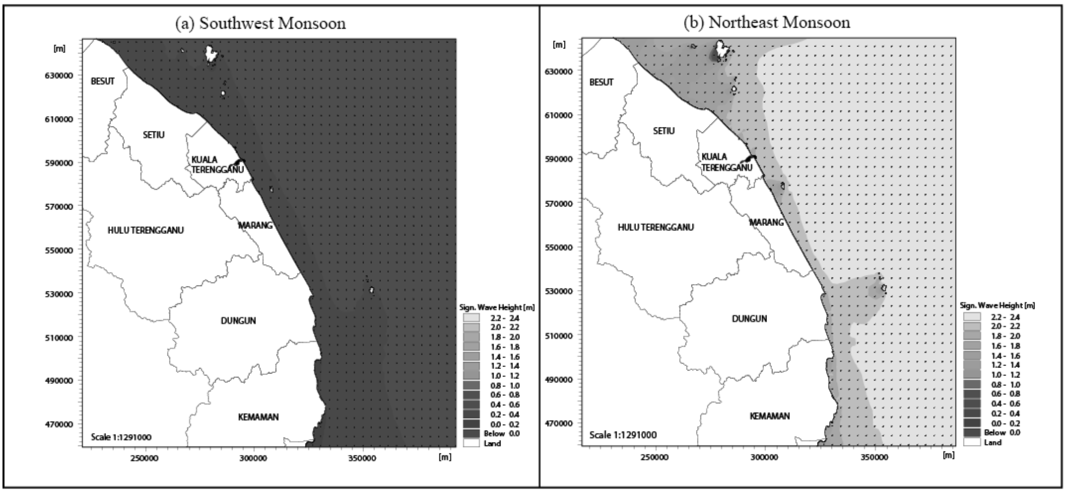


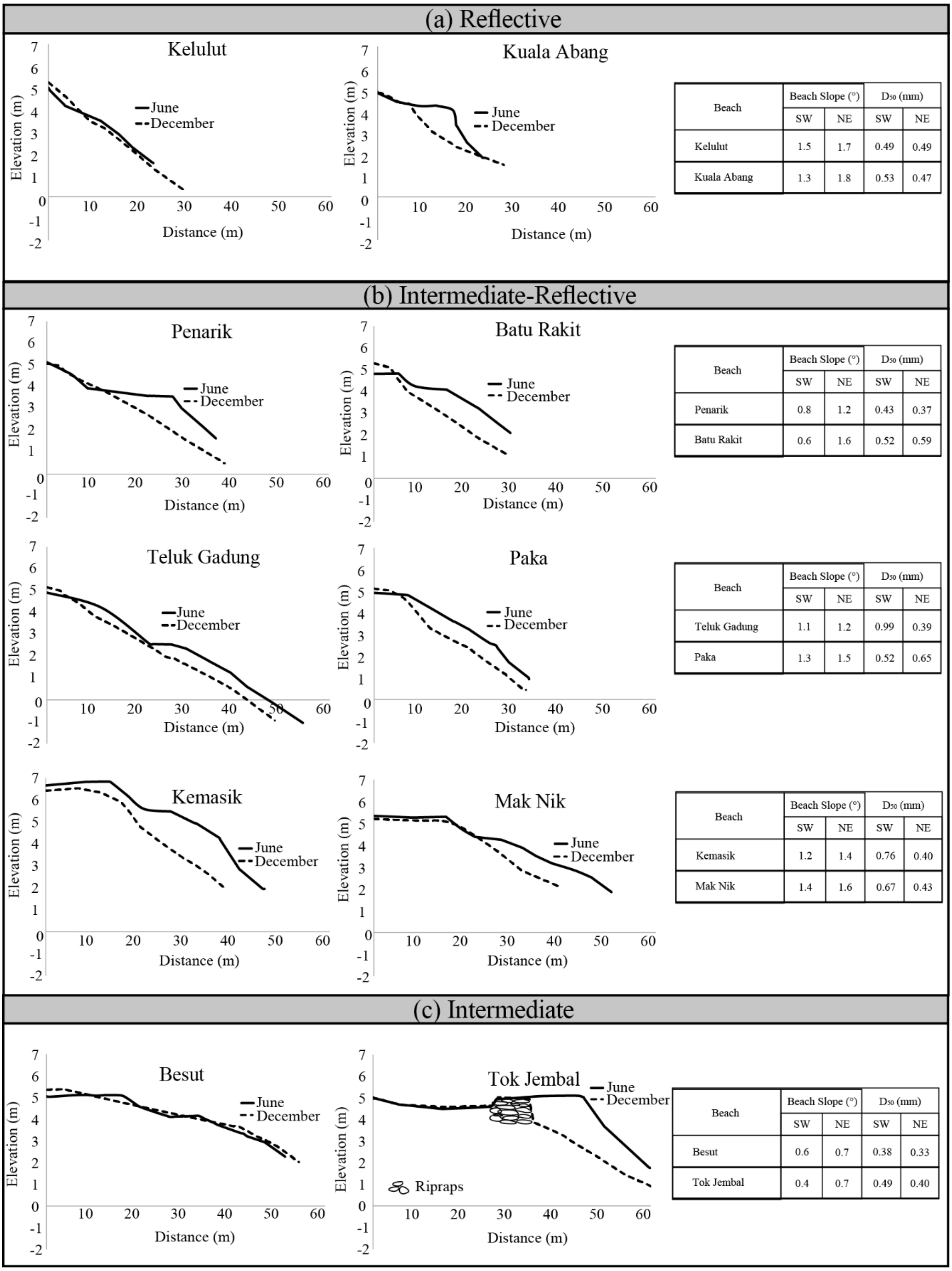
Figure 2: Significant wave height and direction along Terengganu coast during a) southwest monsoon and b) northeast monsoon of 2009.

Beach Morphodynamic and Classification
Reflective Beaches

Reflective beaches are characterised by a steep slope and an abrupt profile with the absence of a berm crest with high wave and strong collapsing breakers to the beach-face (Merlotto et al., 2014; Mohd Zaini *et al.,* 2015). This type of beach states is only observed at the Kelulut (beach slope 1.5° to 1.7°) and Kuala Abang (beach slope 1.3° to 1.8°) beaches (Mohd Zaini *et al.,* 2015). The median diameter of sediment (D_{50}) at Kelulut during southwest and northeast monsoon present 0.49 mm. However, Kuala Abang beaches shows 0.53 mm and 0.47 mm during southwest and northeast monsoons respectively (Figure 3a).

Intermediate-Reflective Beaches

Most of the Intermediate-Reflective beaches are observed in the southern regions of the Terengganu coast because of direct exposure to the South China Sea, a lack of islands to shelter the region and a number of headlands that cause rapid changes to beach morphodynamics beach (Horn & Walton, 2007). Examples of this beach state can be seen in Teluk Gadung, Paka, Kemasik and Mak Nik beaches with beach slopes ranging from 1.1° to 1.4° during seasonal monsoons (Figure 3b). These results similar study with Rosnan *et al.* (2018) as mentioned beach morphology changes reflected a great seasonal variation caused by monsoon wave actions. While similar classification is noticed in the northern region of Batu Rakit and Penarik beaches, intense anthropogenic activity causes enhanced hydrodynamic energy in this zone with increasing the beach slope (Ariffin *et al.,* 2016). Furthermore, the trend mean grain size of sediments in this beach shows coarse to very coarse sands during southwest monsoon to northeast monsoon (Rosnan & Mohd Zaini, 2009).



Beach	Beach Slope (°) SW	Beach Slope (°) NE	D_{50} (mm) SW	D_{50} (mm) NE
Kelulut	1.5	1.7	0.49	0.49
Kuala Abang	1.3	1.8	0.53	0.47

Beach	Beach Slope (°) SW	Beach Slope (°) NE	D_{50} (mm) SW	D_{50} (mm) NE
Penarik	0.8	1.2	0.43	0.37
Batu Rakit	0.6	1.6	0.52	0.59

Beach	Beach Slope (°) SW	Beach Slope (°) NE	D_{50} (mm) SW	D_{50} (mm) NE
Teluk Gadung	1.1	1.2	0.99	0.39
Paka	1.3	1.5	0.52	0.65

Beach	Beach Slope (°) SW	Beach Slope (°) NE	D_{50} (mm) SW	D_{50} (mm) NE
Kemasik	1.2	1.4	0.76	0.40
Mak Nik	1.4	1.6	0.67	0.43

Beach	Beach Slope (°) SW	Beach Slope (°) NE	D_{50} (mm) SW	D_{50} (mm) NE
Besut	0.6	0.7	0.38	0.33
Tok Jembal	0.4	0.7	0.49	0.40

Figure 3: Beach morphodyamic classification observed; a) reflective, b) intermediate-reflective and c) intermediate.

Intermediate Beaches

This classification of beach state is observed at Tok Jembal and Besut beaches. Tok Jembal beach is in disequilibrium due to the construction of an extension of the airport runway (Ariffin *et al.,* 2016) bringing about changes in beach morphology (Anfuso *et al.,* 2007). However, the beach state shows intermediate beach because ripraps cover the entire beach Figure 3.c. Unfortunately, the attempt was not a satisfactory since the rock-size of the ripraps was too small to resist high waves in the foreshore area during the northeast monsoon. In Saengsupavanich *et al.* (2009) study, the project was a failure because the dimensions of the rocks used were not adequate protect the beach. The back shore and slope remains unchanged, while, the D_{50} changes from medium sand to coarse sand (Figure 3c). On the other hand, the Besut beach is in equilibrium having an intermediate beach state classification and present no large changes on the beach slope and D_{50}.

Monsoon Seasonal of Beach Morphodynamics Classification

In order to perform beach morphodynamic classification, seasonal changes, especially monsoon changes, should be thoroughly cognized to understand beach cycle processes (Aleman *et al.,* 2015; Stive *et al.,* 2002). This study shows two regions of the Terengganu coast showing varying beach morphodynamics. The northern region maintains an Intermediate–Intermediate and Intermediate–Reflective state during southwest monsoon to northeast monsoon and can be summarised as Intermediate beaches. In contrast, the southern region maintains a Reflective–Reflective and Intermediate–Reflective state during southwest monsoon to northeast monsoon and can be summarized as Reflective beaches. According to Mohd Zaini *et al.* (2015) are studies at nearby to Terengganu regions, north of Pahang regions reveal as reflective beaches which same environment at south of Terengganu. On the other hand, mostly beaches along Pahang coast are categorise as intermediate beaches and companion at Terengganu coast.

It is because these two regions are influenced by the wind-waves from the offshore, i.e., north-easterly winds during the northeast monsoon and south-westerly winds during the southwest monsoon (Ariffin *et al.,* 2016; Kok *et al.,* 2015; Mirzaei *et al.,* 2013). Along the Terengganu coast, the disparity in wave configuration between the northern and southern regions is due to the wind-wave distribution and variation in coastal landforms and anthropogenic structures (Nor Hisham, 2006).

Conclusion

This study emphasises that beach morphodynamics can be modified whenever there is some interference due to the presence of coastal landform (headland) or artificial structures. When comparing the two regions (north & south) of the Terengganu coast, the northern region displays intermediate beach and southern region demonstrates reflective beach (not protected by many islands and headlands). In summary, during the southwest monsoon, calm conditions are prevalent, whereas, storm conditions are observed during the northeast monsoon that results in erosion due to a higher wave energy environment. In the same phenomena, the mean sediment size revealed finer to coarser during southwest to northeast monsoon respectively. However, the results of this study can be helpful in formulating an effective coastal zone management plan using coastal processes model (preliminary studies) in beach morphodynamic classification for monsoon-dominated coasts with sandy beaches.

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