



# Short-term observations of beach Morphodynamics during seasonal monsoons: two examples from Kuala Terengganu coast (Malaysia)

Effi Helmy Ariffin<sup>1,2</sup> · Mouncef Sedrati<sup>3</sup> · Mohd Fadzil Akhir<sup>2</sup> · Mohamad Noradlan Mohd Norzilah<sup>4</sup> · Rosnan Yaacob<sup>1</sup> · Mohd Lokman Husain<sup>2</sup>

Received: 7 March 2017 / Revised: 3 June 2019 / Accepted: 8 July 2019 / Published online: 27 July 2019  
© Springer Nature B.V. 2019

## Abstract

This paper describes the morphodynamic changes that took place along Kuala Terengganu coastline over daily periods during seasonal monsoons (onset of Northeast Monsoon in October 2014 and during Southwest Monsoon in May 2015). Cross-shore beach profiles had been determined and foreshore sediments were sampled from two selected beaches; north of Kuala Terengganu at Pengkalan Maras (PM) and another to the south at Kuala Ibai (KI). Based on the beach classification scheme, PM appeared to be a spilling breaker type beach ( $\xi_b$ ) with an Intermediate state ( $\Omega$ ), whereas KI belonged to the plunging breaker type ( $\xi_b$ ) with Intermediate-Dissipative state ( $\Omega$ ). The beaches were dominated by coarse and fine sands at PM and KI, respectively. The wave hydrodynamics on the southern beach (KI) was characterised by higher  $H_b$  values, when compared to that in the north (PM). This study investigated the impact of morphodynamic changes during seasonal monsoons, regardless of the presence of coastal defence structures. Without any coastal defence structure (revetment), the PM beach exhibited attainment of equilibrium state, when compared to the KI beach. Therefore, coastal structures, such as revetments, directly modified the morphodynamics at KI beach. The PM beach displayed the tendency for occurrence of erosion during the Northeast Monsoon, while exhibited accretion during the Southwest Monsoon. This scenario differed from that noted at the KI beach, which signified erosion during both seasonal monsoons. The study outcomes may assist in formulating an effective coastal zone management plan for monsoon-dominated coasts, particularly sandy beaches.

**Keywords** Beach erosion · Hydrodynamics · Numerical modelling · Coastal defence · Coastal management

## Introduction

Kuala Terengganu beaches have sandy sediment (Rosnan and Mohd Lokman 2005), in which the foreshore or intertidal zone is a dynamic zone due to impact from human activities (structures of the coast) and natural phenomena (wind, waves,

tide) (Kumar et al. 2012). Such sandy beaches, which serve as natural sediment, tend to buffer for coastal system, along with the correlation of erosion (accretion) with high (low) energy waves (Ariffin et al. 2016). The trend of waves depends on seasonal variation; waves with low energy while calm, but high energy upon storm (Ariffin et al. 2016; Castelle et al. 2015; Prasad et al. 2009; Saravanan and Chandrasekar 2010; Vousdoukas et al. 2012). The phenomena of erosion and accretion (changes in beach) that occur due to the changing season offer data to comprehend coastal processes, thus contributing to better coastal management planning. Nevertheless, the beach morphology that alters based on season and durations (short term: hourly/tidal cycle, daily, weekly; and long term: monthly and annually) demand close observations (Davis 1985). Masselink et al. (2007) asserted that short-term observations mostly assess morphological variance in the sandy beaches due to waves and tides in micro- and meso-tidal conditions.

Stive et al. (2002) developed a storm model by observing seasonal changes, as well as estimating rapid sediments

✉ Effi Helmy Ariffin  
effihelmy@umt.edu.my

<sup>1</sup> School of Marine and Environmental Sciences, Universiti Malaysia Terengganu, 21030 Kuala Terengganu, Terengganu, Malaysia

<sup>2</sup> Institute of Oceanography and Environment, Universiti Malaysia Terengganu, 21030 Kuala Terengganu, Terengganu, Malaysia

<sup>3</sup> Géosciences Océan UMR CNRS 6538, Centre de Recherche Yves Coppens, Campus de Tohonic, Université Bretagne Sud, 56000 Vannes, France

<sup>4</sup> School of Ocean Engineering, Universiti Malaysia Terengganu, 21030 Kuala Terengganu, Terengganu, Malaysia

erosion at storm and subsequent slower accretion at post-storm. The application of this model for beaches is subject to the varied seasonal wave energies. Beach morphodynamics could be influenced by anthropogenic effect upon coastal region, including breakwater, harbours, groynes, revetments and ripraps. Investigations on modern beaches, which are linked with dense human habitation, may be applied as yardstick in identifying its morphodynamic and equilibrium conditions.

As for the case of a beach with high-wave energy located on the northern Moroccan Atlantic coast, called Charf el Akab, displayed interesting relationship between increased energetic events at winter storm and intense human activities since past several years (Taaouati et al. 2011). At the East Coast of Peninsular Malaysia, the human-dense Cherating beach is not in equilibrium due to coastal erosion caused by development of beach bar and high scarps (1–2 m). Typically, high scarps are initiated due to impact of tides and high-energy waves on modern beaches (Wong 1990).

Studies related to beaches seem to adopt the morphodynamic system model in inching towards dynamic equilibrium condition under steady force setting. Such models predict the equilibrium state by depicting beach morphology (Dean 1973; Masselink and Short 1993). These beach-system models are used in vast researches in light of coastal morphodynamics (Woodroffe 2002) ranging from three-dimensional (3D) morphology to isolated environmental parameters. Some assessed beach morphology via direct visual observations using models, which have led to categorisation of beach states: dissipative, intermediate and reflective genres. Upon linking forcing factors with observations of beach condition, Wright et al. (1985) built a non-intricate predictive model to group beach types. Gourlay (1968) proposed the dimensionless parameter called Dean's number, and was later enhanced by Dean (1973) by embedding sediment and wave features.

This present study characterised beach morphodynamics at north and south of Kuala Terengganu located in Malaysia by comparing their equilibrium states. This study is novel as it adopted short-term observations during seasonal monsoons, as other researches pertaining to Kuala Terengganu beaches mainly focused on long-term investigations (see Ariffin et al. 2016; Rosnan and Mohd Lokman 2005). The two primary morphodynamic features that define the equilibrium state of a beach are: i) surf similarity index ( $\xi_b$ ) proposed by Battjes (1974) and Galvin (1968), and ii) dimensionless fall velocity ( $\Omega$ ) proposed by Dean (1973) and Gourlay (1968).

## Description of study area

This study assessed the northern and southern Kuala Terengganu coasts located on the East Coast of Peninsular

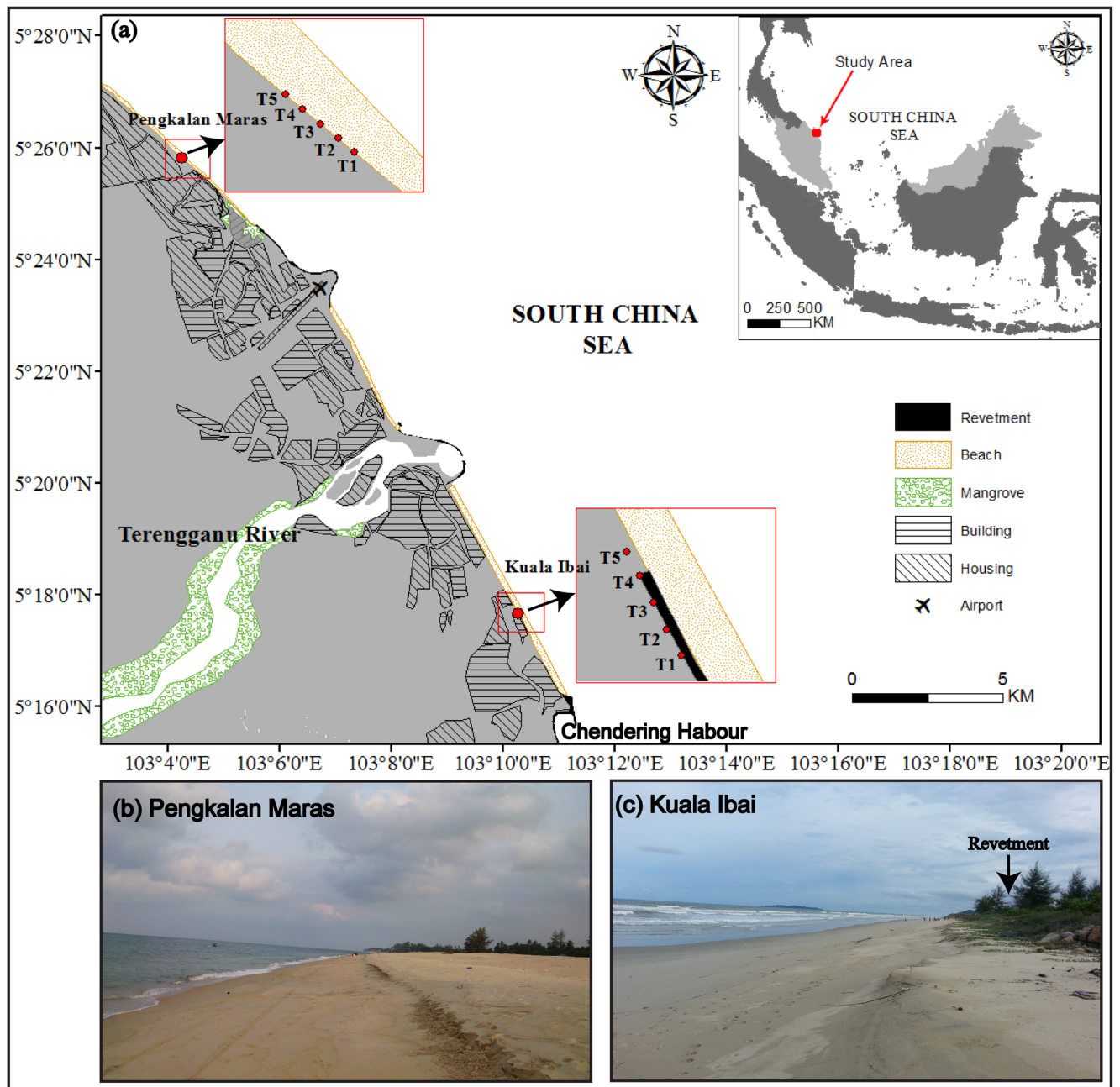
Malaysia and separated by the Terengganu River. The two sandy beaches investigated refer to Pengkalan Maras (north) and Kuala Ibai (south) (see Fig. 1) portray North-northwest to South-southeast trending. Escalating human activities exert adverse effects on these beaches and interrupt the dynamics that control their equilibrium state, which lead to further erosion. Unlike Pengkalan Maras, Kuala Ibai has a 3-m wide revetment on its berm (vegetation area), which serves as coastal defence in addressing erosion issue. The structure has substantially modified its morphodynamic features, particularly in beach slopes, apart from interrupting sediment transport system and waves.

A beach is characterised by many surficial structures formed by winds, wave processes and tides. Seasonal winds locally occur as Northeast Monsoon (between end of October and end of March), while Southwest Monsoon occurs between beginning of May and end of September (Ariffin et al. 2016). The properties of wind-generated waves depend on wind conditions (Hill 2004), with beaches being exposed to predominantly two seasons of wind waves; North-easterly winds during Northeast Monsoon and South-westerly winds during Southwest Monsoon (Kok et al. 2015).

Based on wind wave studies performed during the Northeast and Southwest Monsoons in the Kuala Terengganu area, significant wave heights ( $H_s$ ) of 1.0–2.0 m were recorded during Northeast Monsoon, while less than 0.8 m during Southwest Monsoon (Ariffin et al. 2018b; Ariffin et al. 2016; Mirzaei et al. 2013). However, the tides in this region are generally semi-diurnal and the setting can be classified as micro- to meso-tidal, with Mean High Water Spring (MHWS) of 3.28 m and Mean Low Water Spring (MLWS) of 1.12 m (Ariffin 2017).

## Methodology

This present study was conducted along the Kuala Terengganu coastline, namely Pengkalan Maras (PM, north) and Kuala Ibai (KI, south), during Northeast Monsoon (late October 2014), and Southwest Monsoon (late May 2015). Beach profiles and wave parameters were analysed to record the morphodynamic features of the selected beaches. Wave parameters were recorded on October 2014 and May 2015 by using the wave modelling (DHI 2011) modules (Mike-21 – Spectral Wave Flexible Mesh). This wave modelling system had been employed to retrieve the morphodynamic features from the selected beaches during the stipulated monsoons. The breaking wave height ( $H_b$ ) was predicted using wave height data ( $H_o$ ) in deeper waters. As the subtidal zone displays a broadly constant slope on the shoreface of Kuala Terengganu, the breaking wave height was calculated by



**Fig. 1** Study area showing (a) two selected beaches on the Kuala Terengganu coast, namely; (b) Pengkalan Maras (PM) to the north and (c) Kuala Ibai (KI) to the south of the Terengganu River, respectively. Each beach comprises five transects (T1 to T5)

using the formula proposed by Komar and Gauhan (1972), as given in Eq. 1:

$$H_b = 0.39g^{0.2} (TH_0^2)^{0.4} \tag{1}$$

where  $H_b$  denotes breaking wave height,  $g$  represents acceleration due to gravity,  $T$  refers to wave period, and  $H_0$  reflects wave height in deep waters.

The morphodynamics are characterised using various parameters (environmental parameters) based on the model built by Masselink and Short (1993) under maximum wave

conditions. Most studies applied environmental parameters in estimating beach morphodynamics (e.g. beach state and type of breaker) in accordance with beach slope, wave height and wave period. Commonly, type of breaker is predicted using the surf similarity index ( $\xi_b$ ) (Battjes 1974; Galvin 1968), expressed in Eq. 2:

$$\xi_b = \frac{\tan\beta}{(H_b/L_0)^{0.5}} \tag{2}$$

where  $\tan\beta$  is beach slope, while  $L_0$  is wave length; calculated in Eq. 3 as:

$$L_0 = gT^2/2\pi \quad (3)$$

On a uniformly sloping beach, the breaker type is estimated by spilling ( $\xi_b < 0.4$ ), plunging ( $0.4 < \xi_b < 2$ ) and surging ( $\xi_b > 2$ ) (Battjes 1974; Galvin 1968). Wright and Short (1984) introduced a criterion to estimate the state of beach based on sediment grain size and wave height by applying the dimensionless fall velocity ( $\Omega$ ) proposed by Dean (1973) and Gourlay (1968), as depicted in Eq. 4:

$$\Omega = \frac{H_b}{w_s T} \quad (4)$$

where  $w_s$  is sediment fall velocity. Based on the models developed by Dean (1973) and Gourlay (1968), the dimensionless fall velocity distinguishes reflective beaches ( $\Omega < 1$ ) from intermediate beaches ( $1 < \Omega < 6$ ) and dissipative beaches ( $\Omega > 6$ ).

Beach profile surveys were conducted for five days (28th October - 1st November 2014), and four days (28th May - 31st May 2015). The sample beaches were covered by five transects with 50-m spacing between the lines of transect (see Fig. 1). These beach profiles were measured from the berm (vegetation area) to the low-tide mark using Total Station instruments (Topcon GPT-3100 N). The readings were adjusted to DTGSM datum level, using beach volume and slope values obtained from monitored profiles, which were analysed with the Profiler 3.2 XL program (Cohen 2016).

This present study exclusively assessed the changes in bed level solely for Transect 3 with collection of sediment sample from middle of the beach. The mean grain size ( $D_{50}$ ) of sediment, which was calculated via GRADISTAT V4.0 program (Blott and Pye 2001), was applied to calculate sediment fall velocity ( $w_s$ ) that heavily relied on size of grain (Gibbs et al. 1971).

## Results and discussion

The study outcomes are presented in two sections; wave characteristics and beach morphodynamics. Characteristics of wave contain types of wave breaker and wave height, both relating to beach morphodynamics. The mean sediment grain size ( $D_{50}$ ) is essential in determining the behaviour and morphodynamics of beach. In determining the effect of short-term beach morphodynamics on PM and KI during monsoon season, the following aspects were analysed: profile, gradients, volumes and state of beaches, as well as changes in level of bed and types of breaker. In comprehending the impact on coastal management, changes in beach morphodynamic are briefly discussed in light of adaptation of coastal defence subject matter.

## Wave characteristics

The selected beaches displayed higher wave heights in October 2014, when compared to the start of Northeast Monsoon, while lower values were recorded in May 2015 during Southwest Monsoon. The essential wave heights ( $H_s$ ) during storms were below 3 m from near shore, but decreased up to 2 m (see Fig. 2) during Northeast Monsoon (Ariffin et al. 2018b; Ariffin et al. 2016; Mirzaei et al. 2013). Although no sign of storm was noted for the monsoons, Fig. 3 illustrates significant wave heights with a normal pattern and escalated reading for Northeast Monsoon (Ariffin et al. 2016; Mirzaei et al. 2013). These findings are in agreement with data retrieved for breaking wave height ( $H_b$ ) that displayed lower values for Southwest Monsoon than for Northeast Monsoon (see Table 1).

The survey at PM beach in October 2014 recorded 0.52 m and 0.68 m for average and maximum  $H_s$ , respectively. In May 2015, the average and maximum  $H_s$  were 0.16 m and 0.21 m, respectively. The KI beach exhibited near similar pattern of PM beach in October 2014, with 0.52 m and 0.66 m as average and maximum  $H_s$  reading, respectively. The  $H_s$  readings for KI beach in May 2015 were higher than those for PM beach (PM: 0.23 m and 0.30 m for average and maximum  $H_s$  values).

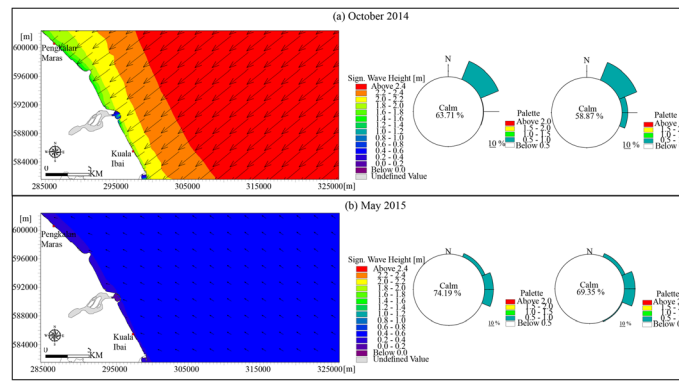
The highest energy-wave patterns noted at KI beach in May 2015 displayed beach disequilibrium, when compared to PM beach that portrayed low-energy wave trend. Calmer waves seemed to be more intense in KI than that noted in PM for both monsoon events (see Fig. 2). Such variance is attributable to the presence of revetment on berm that altered the foreshore hydrodynamics (Kaliraj et al. 2013; Masselink and Short 1993). In parallel to this, both beaches had near similar breaking wave ( $H_b$ ) values (see Table 1), but substantially differing values for  $H_s$ .

## Morphodynamics and behaviour of beaches

In October 2014 (Northeast Monsoon), the beach volume signified accretion in PM, while erosion in KI. In this period, which reflects the onset of Northeast Monsoon, the PM beach underwent recovery based on the sediment volume accretion at post Southwest Monsoon in 2014 (Ariffin et al. 2016). In May 2015 (Southwest Monsoon), the PM beach displayed slight reduction in volume of sediment attributable to the effect of Northeast Monsoon in 2014–2015. Ariffin et al. (2016) and Rosnan and Mohd Lokman (2005) claimed that beaches begin its recovery during Southwest Monsoon (calm season) and rely on the volume of sand available.

The beach volume for KI beach in October 2014 showed that only Transect 4 (end of revetment) displayed some accretion (see Fig. 1). Transect 5 exerted the worst erosion as it was placed further from the end of revetment. Masselink and Short





**Fig. 2** A numerical model of significant wave height and direction with wave rose plotting **(a)** in October 2014 and **(b)** in May 2015

(1993) asserted that sea walls or revetments (any artificial structure) alter shoreline by discarding sediments from the coast. Nonetheless, the KI beach volume displayed slight reduction in its erosion during Southwest Monsoon in May 2015 (only Transect 2 had accretion). It is also during this particular monsoon that the beach starts its recovery process by relying on the sand volume (see Fig. 4). Rosnan and Mohd Lokman (2005) highlighted that erosion in beaches is a primary source of sediment to supply long-shore transport system in Terengganu coastal.

The beach gradient ( $\tan \beta$ ) for October 2014–May 2015 survey duration (no storm) at PM and KI beaches displayed minor variation (see Table 1). The KI beach had steeper slope than the PM beach as the revetment on berm altered the morphodynamics of beach at the foreshore zone (Kaliraj et al. 2013).

To define the morphodynamic state from the quantitative stance, both surf similarity index ( $\xi_b$ ) and Dean number  $\Omega$  were calculated for each survey period (see Table 1). Jackson et al. (2005) reported that increment in  $H_b$  led to higher Dean number  $\Omega$ . Therefore, the  $H_b$  values were higher for Northeast Monsoon, in comparison to Southwest Monsoon, upon reduction in this parameter ( $\Omega$ ).

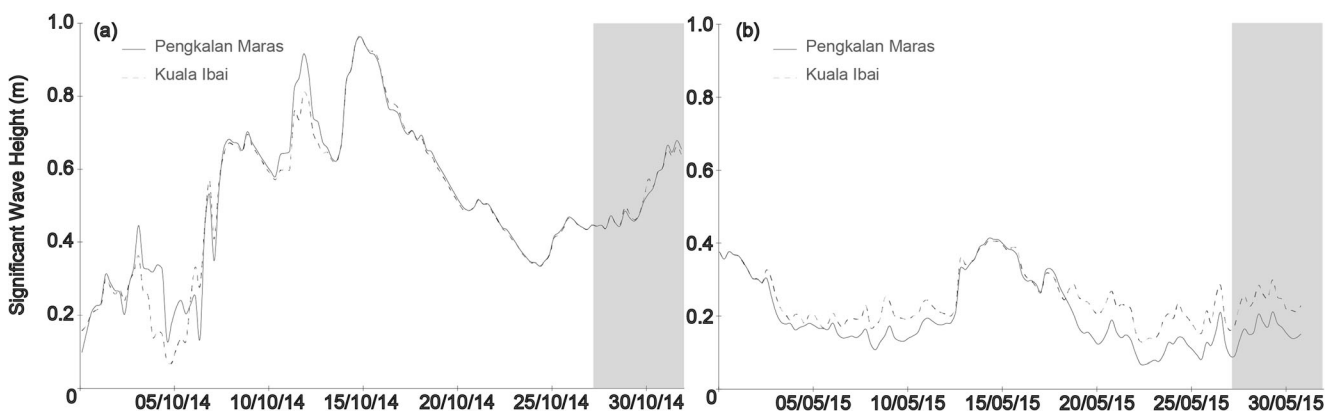
Nevertheless, different patterns of morphodynamic states were observed at both selected beaches. The

morphodynamic state of PM beach was because of low slope values, spilling breakers, and intermediate beach state (low  $\Omega$  readings). On the contrary, the surf similarity index ( $\xi_b$ ) at KI beach had been due to plunging breakers caused by intermediate-dissipative beach state (higher  $\Omega$  readings) and higher slope values.

In comparing the two monsoon seasons, the  $\xi_b$  and Dean number  $\Omega$  values increased and decreased, respectively, for PM beach. In KI beach, the comparison between the monsoon seasons signified a decrease in both  $\xi_b$  and Dean number  $\Omega$  values. Taouati et al. (2011) and Aagaard et al. (2005) mentioned that no major changes were noted in  $\xi_b$  and  $\Omega$  values for beaches with gentle slopes despite the presence of substantially high-energy waves.

Nevertheless,  $\Omega$  values at KI beach escalated in October 2014, when compared to that recorded in May 2015 (PM: lower  $\Omega$  value). This is in line with Masselink and Pattiaratchi (2001), who reported higher  $H_s$  and  $\Omega$  values for stormy conditions. At calm conditions, both  $H_s$  and  $\Omega$  values were lower.

Figure 5 shows the changes in morphodynamic for bed level and beach profile noted at PM. The trend for October 2014 (Northeast Monsoon) was Accretion-Accretion-Erosion-Accretion on the second, third, fourth and fifth day of observations, respectively. In May 2015 (Southwest



**Fig. 3** Significant wave height **(a)** in October 2014 and **(b)** in May 2015; grey boxes represent beach profile survey periods

**Table 1** Beach morphodynamic parameters

Month	$D_{50}$ (mm)		$H_b$ (m)		$\tan \beta$		$\xi_b$		$\Omega$	
	PM	KI	PM	KI	PM	KI	PM	KI	PM	KI
Oct-14	0.51	0.22	1.36	1.37	0.03	0.15	0.21	1.08	2.01	6.75
May-15	0.54	0.22	0.53	0.56	0.04	0.17	0.25	0.84	1.54	5.34
Mean Grain Size	Coarse Sand	Fine Sand	–	–	–	–	–	–	–	–
Breaker type	–	–	–	–	–	–	Spilling	Plunging	–	–
Beach state	–	–	–	–	–	–	–	–	Intermediate	Intermediate-Dissipative

Monsoon), only the fourth day of observation displayed Erosion-Accretion-Erosion pattern. Based on the changes in bed level from 28 October until 1 November 2014, a plateau was noted for the beach profile with active region at 25 m distance. However, the conditions appeared to be more dynamic for 25 m – 50 m distance interval, mainly because the zone lies between MHWS and MLWS tide levels.

Meanwhile, the morphodynamic changes in KI differed from those reported for PM, especially in terms of bed level during similar monsoon periods (see Fig. 6). Changes in bed level for October 2014 (Northeast Monsoon) and May 2015 (Southwest Monsoon) signified Erosion-Erosion-Accretion-Erosion on the second, third, fourth and fifth day of observation (in May 2015, similar pattern with October 2014). By observing the change in bed level from 28 until 31 May 2015, the beach profile with active region corresponded to dynamic zone that started at a distance of 15 m from the revetment (i.e. MLWS tide level) and further extension to 30 m.

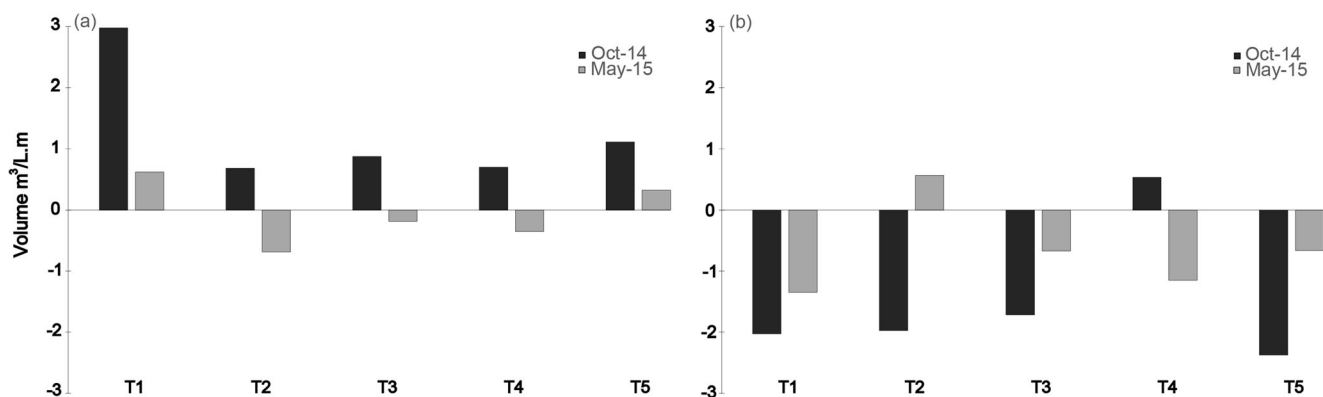
From the recorded bed level change and beach state, the PM beach displayed the tendency to be at equilibrium state, along with low constant beach gradient and natural high-energy wave conditions. Nevertheless, disequilibrium state was noted for KI beach due to constant bed level changes trend, constant erosion, and nil beach recovery for both monsoon seasons. The hydrodynamics for KI beach was altered

due to the presence of revetment, which resulted in higher  $H_s$  value for Southwest Monsoon (Kaliraj et al. 2013; Masselink and Short 1993).

Minor variances was discovered for October 2014–May 2015 in terms of sediment size ( $D_{50}$ ), with fine and coarse sands noted at KI (south) and PM (north) beaches, respectively (see Table 1). These outcomes contradicted the reported distribution of sediment size by Rosnan and Mohd Lokman (2005), wherein fine and coarse sands were observed at northern and southern sites, respectively. In 2005, the northern studied area had no compact coastal structures or development, in comparison to years after 2010 upon the noted progression (Muslim et al. 2011).

### Adaptation of coastal defence

An inclusive coastal management system is of paramount importance, primarily because the beach erosion phenomenon has become an uprising issue. The objective in adaptation of coastal defence is crucial to protect the coastlines from devastating erosion. In order to implement coastal defence, it is pertinent for a coastal engineer to understand, initially, the behaviour of beach morphodynamic prior to implementing any structural plan. In fact, a number of successful adaptation of coastal defence have been reported, such as that in Greece (Alexandrakis et al. 2015), England (Karunarathna et al.



**Fig. 4** The cumulative beach volume at a) Pengkalen Maras beach and b) Kuala Ibai beach during October 2014 and May 2015

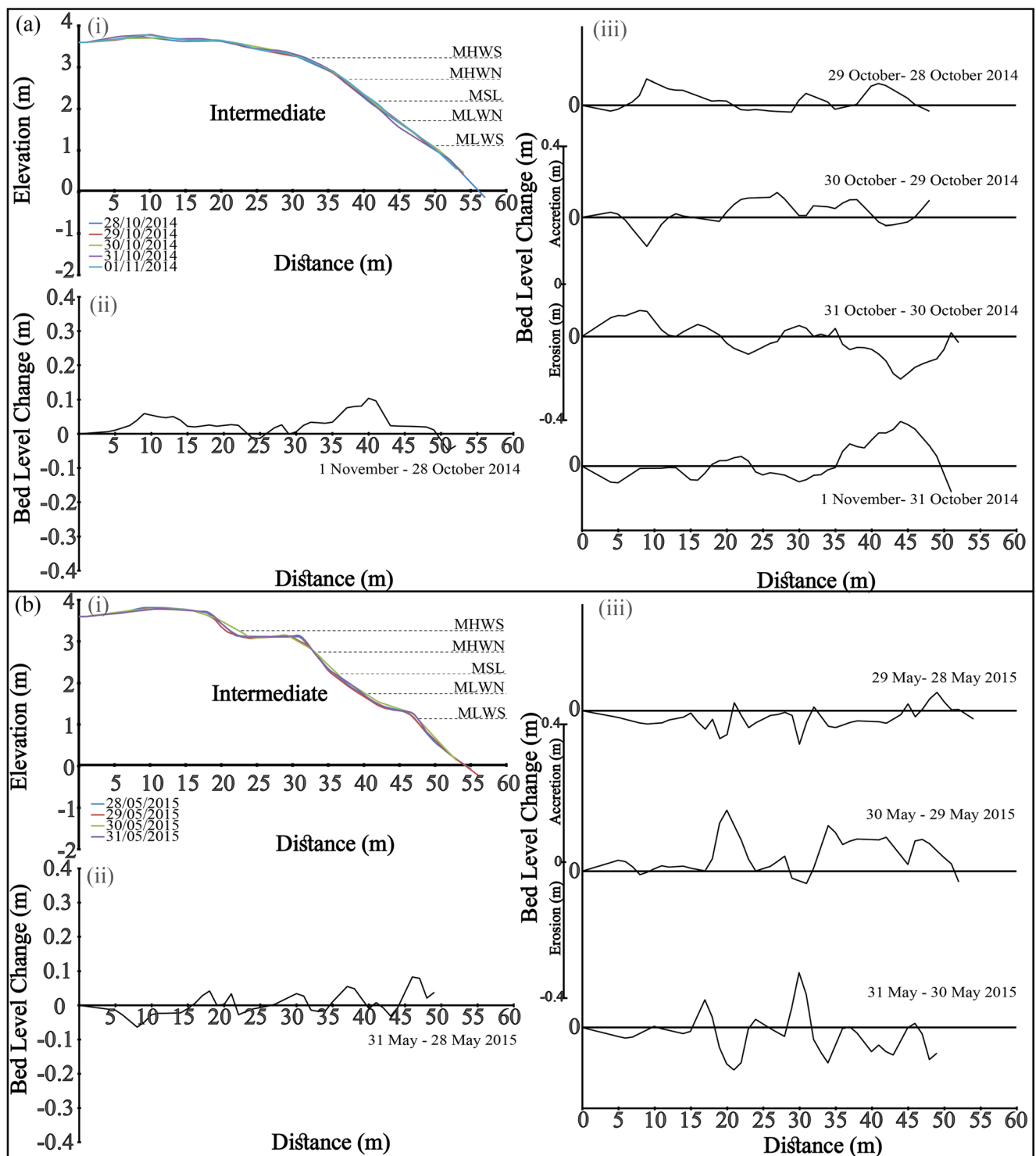
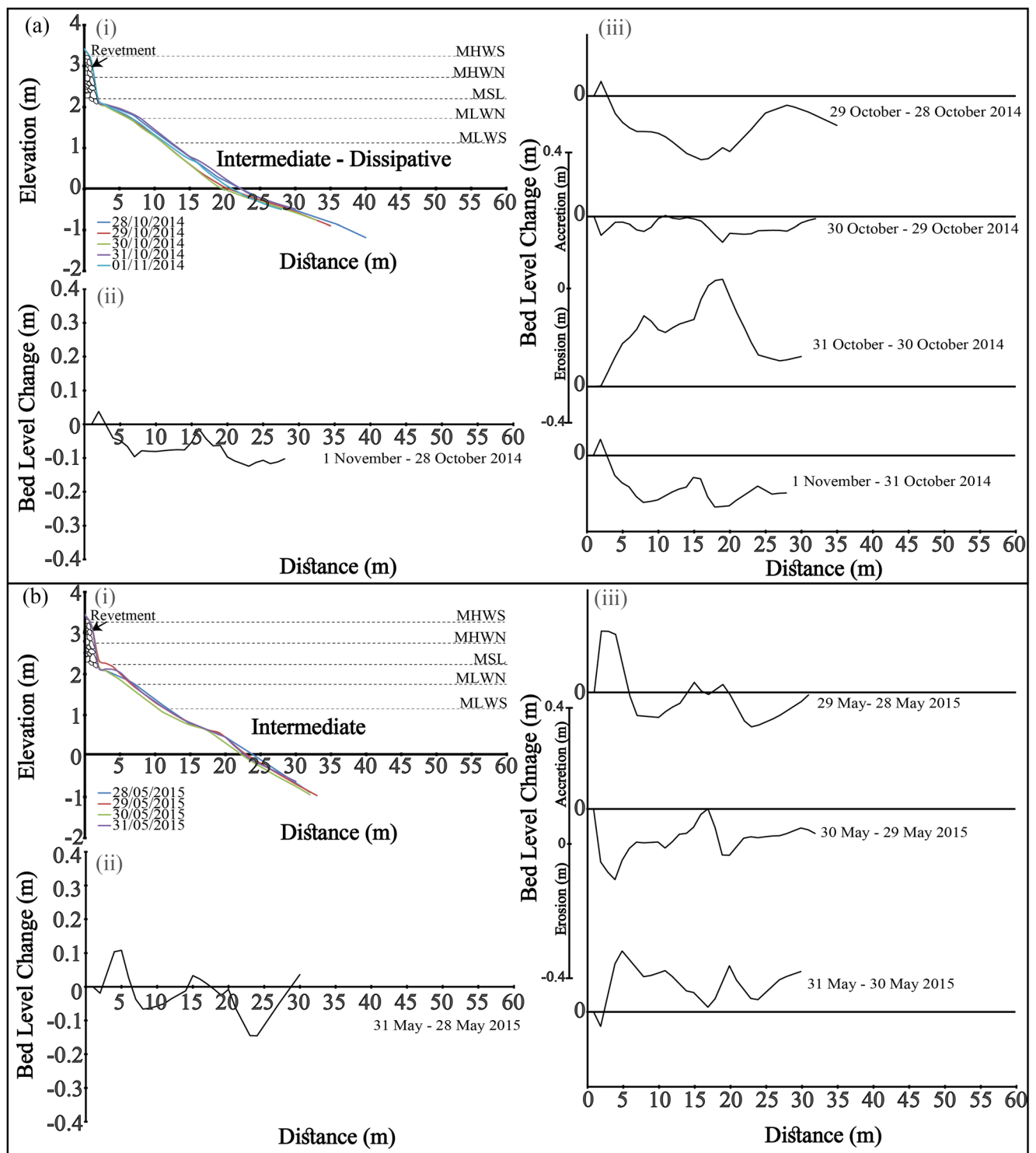


Fig. 5 Levelling surveys along Transect 3 of beach profile at Pengkalan Maras, (a) during October 2014 and (b) during May 2015, showing (i) beach profile; (ii) bed level change between 28 October and 1 November 2014; and (iii) bed level change between respective daily observations

2011), and Colombia (Rangel-Buitrago et al. 2017). Only a handful have probed into the monsoon event, such as that portrayed in India (Thiruvenkatasamy and Baby Girija 2014), and Thailand (Saengsupavanich 2013).

As for the case in Malaysia, proper planning for adaptation of coastal defence through implementation of a series of breakwater along the coastline has been carried out. Such adequate planning has been installed after the failure of an



**Fig. 6** Levelling surveys along Transect 3 of beach profile at Kuala Ibai, (a) during October 2014 and (b) during May 2015, showing (i) beach profile; (ii) bed level change between 28 October and 1 November 2014 and; (iii) bed level change between respective daily observations

ad-hoc project (i.e. ripraps and revetments) that was conducted to mitigate beach erosion (Ariffin et al. 2018b). After weighing in the sandy beach environment and the dynamic challenge of the direct exposure of the coastline to the open South China Sea (Ariffin et al. 2018a),

adaptation of coastal defence demands comprehensive details and careful understanding. Thiruvencatasamy and Baby Girija (2014) asserted that coastal defence implementation generates heavy accretion near to the northern and southern of breakwater. This study reveals



the successful approach based on the intensive study of beach behaviour under monsoon environment implemented in India.

This study recommends that both short- and long-term analyses should be performed with cooperation of the government and several related research organisations. Hence, good cooperation with many stakeholders emerges as the best approach to mitigate programs in line with the present implementation across many countries in the world (Alexandrakis et al. 2015; Ariffin et al. 2018b; Ariza et al. 2014; Rangel-Buitrago et al. 2017; Saengsupavanich 2013; Saengsupavanich et al. 2009; Thia-Eng 1998; Thiruvenkatasamy and Baby Girija 2014).

## Conclusion

This study looked into the morphodynamics of beach, which could be altered due to presence of interrupting artificial structures. Upon comparison, Pengkalan Maras appeared to be closer to equilibrium than Kuala Ibai, which displayed revetment at the backshore zone. The Kuala Ibai hydrodynamics had higher energy waves during the Northeast Monsoon, when compared to that in Pengkalan Maras that portrayed calmer climate. Additionally, disruption in the recovery process was noted along Kuala Ibai beach due to the Southwest Monsoon. Thus, in order to overcome poor beach recovery issues, building of revetments or ripraps or coastal defence is hindered, while favouring vegetation or berm-based development at the coastal region. Despite the extended time consumption to gain benefit, such development does not adversely affect morphodynamics around the region, but contributes to beach recovery at a normal pace.

**Acknowledgements** This research was supported by Ministry of Education Malaysia under the Fundamental Research Grants Scheme (FRGS) [UMT/RMIC/FRGS/1/2018/59513(1)]. We would like to thank the Laboratory of Physical Oceanography and Geology, Institute of Oceanography and Environment, Universiti Malaysia Terengganu, Kuala Terengganu, Malaysia for providing the physical data. Thanks are also due to Ms. Nurul Rabitah Daud who helped carry out the beach profile surveys. We are also grateful to Mr. Mohd Raihan Shah Abdullah and Dr. M.S.N. Carpenter for their support in developing our project. Dr. Thavamaran Kanesan post-edited the English style and grammar.

## References

- Aagaard, T., Kroon, A., Andersen, S., Sørensen, R. M., Quartel, S., & Vinther, N. (2005). Intertidal beach change during storm conditions; Egmond, The Netherlands. *Marine geology*, 218(1–4), 65–80
- Alexandrakis, G., Manasakis, C., & Kampanis, N. A. (2015). Valuating the effects of beach erosion to tourism revenue. A management perspective. *Ocean Coast Manag*, 111, 1–11, 1
- Ariffin, E. H. (2017). Effect of monsoons on beach morphodynamics in the East Coast of peninsular Malaysia: examples from Kuala Terengganu coast. *Universite de Bretagne-Sud*
- Ariffin EH, Sedrati M, Akhir MF, Yaacob R, Husain ML (2016) Open sandy beach morphology and morphodynamic as response to seasonal monsoon in Kuala Terengganu, Malaysia. *J Coast Res* 75(Special Issue):1032–1036
- Ariffin EH, Mathew MJ, Yaacob R, Akhir MF, Shaari H, Zulfakar MSZ, Sedrati M, Awang NA (2018a) Beach morphodynamic classification in different monsoon seasons at Terengganu beaches, Malaysia. *J Sustain Sci Manag* 13(5):65–74
- Ariffin EH, Sedrati M, Akhir MF, Daud NR, Yaacob R, Husain ML (2018b) Beach morphodynamics and evolution of monsoon-dominated coasts in Kuala Terengganu, Malaysia: perspectives for integrated management. *Ocean Coast Manag* 163:498–514
- Ariza E, Lindeman KC, Mozumder P, Suman DO (2014) Beach management in Florida: assessing stakeholder perceptions on governance. *Ocean Coast Manag* 96:82–93
- Battjes, J. A. (1974). Surf similarity. In *Proceedings of of the 14th international conference on coastal engineering, ASCE* (pp. 466–480)
- Blott SJ, Pye K (2001) Gradistat: a grain size distribution and statistics package for the analysis of unconsolidated sediments. *Earth Surf Process Landf* 26:1237–1248
- Castelle B, Marieu V, Bujan S, Splinter KD, Robinet A, Sénéchal N, Ferreira S (2015) Impact of the winter 2013–2014 series of severe Western Europe storms on a double-barred sandy coast: beach and dune erosion and megacusp embayments. *Geomorphology* 238: 135–148
- Cohen, O. (2016). *Profiler 3.2 XL: Mode d'emploi*. New Caledonia
- Davis JRA (1985) *Coastal sedimentary environments*, 2nd edn. Springer Verlag, New York
- Dean, R. (1973). Heuristic models of sand transport in the surf zone. In *Proceeding of engineering dynamics in the surf zone* (pp. 208–214). Sydney, Australia
- DHI. (2011). *Mike-hydrodynamic module user guide*. Denmark
- Galvin CJ (1968) Breaker type classification on three laboratory beaches. *J Geophys Res* 73(12):3651–3659
- Gibbs R, Matthews M, Link D (1971) The relationship between sphere size and settling velocity. *J Sediment Petrol* 41(1):7–18
- Gourlay M (1968) *Beach and dune erosion tests*. Delft, Netherland
- Hill M (2004) *Coasts and coastal management*. Grey Publishing, Kent
- Jackson DWT, Cooper JAG, Del Rio L (2005) Geological control of beach morphodynamic state. *Mar Geol* 216(4):297–314
- Kaliraj S, Chandrasekar N, Magesh NS (2013) Impacts of wave energy and littoral currents on shoreline erosion/ accretion along the south-west coast of Kanyakumari, Tamil Nadu using DSAS and geospatial technology. *Environ Earth Sci* 71:4523–4542
- Karunarathna H, Horrillo-Caraballo JM, Spivack M, Reeve DE (2011) Analysis of key parameters in a diffusion type beach profile evolution model. *Cont Shelf Res* 31(2):98–107
- Kok PH, Akhir MF, Tangang FT (2015) Thermal frontal zone along the east coast of peninsular Malaysia. *Cont Shelf Res* 110:1–15
- Komar, P. D., & Gauhan, M. K. (1972). Airy wave theory and breaker height prediction. In *Proceedings of of the 13th international conference on coastal engineering, ASCE* (pp. 405–418)
- Kumar SV, Johnson G, Udhaba Dora G, Chempalayil SP, Singh J, Pednekar P (2012) Variations in nearshore waves along Karnataka, west coast of India. *J Earth Syst Sci* 121(2):393–403
- Masselink G, Pattiaratchi CB (2001) Seasonal changes in beach morphology along the sheltered coastline of Perth, Western Australia. *Mar Geol* 172:243–263
- Masselink G, Short AD (1993) The effect of tide range on beach morphodynamics and morphology: a conceptual beach model. *J Coast Res* 9(3):785–800
- Masselink G, Auger N, Russell P, O'Hare T (2007) Short-term morphological change and sediment dynamics in the intertidal zone of a macrotidal beach. *Sedimentology* 54(1):39–53

- Mirzaei A, Tangang F, Juneng L, Mustapha MA, Husain ML, Akhir MF (2013) Wave climate simulation for southern region of the South China Sea. *Ocean Dyn* 63(8):961–977
- Muslim, A. M., Ismail, K. I., Razman, N., Zain, K., & Khalil, I. (2011). Detection of shoreline changes at Kuala Terengganu, Malaysia from multi-temporal satellite sensor imagery. In *34th International Symposium on Remote Sensing of Environment - The GEOSS Era: Towards Operational Environmental Monitoring*. Sydney, Australia
- Prasad KVSR, Arun Kumar SVV, Venkata Ramu C, Sreenivas P (2009) Significance of nearshore wave parameters in identifying vulnerable zones during storm and normal conditions along Visakhapatnam coast, India. *Nat Hazards* 49:347–360
- Rangel-Buitrago N, Williams A, Anfuso G (2017) Hard protection structures as a principal coastal erosion management strategy along the Caribbean coast of Colombia. A chronicle of pitfalls. *Ocean Coast Manag* 156:58–75
- Rosnan Y, Mohd Lokman H (2005) The relationship of sediment texture with coastal environments along the Kuala Terengganu coast, Malaysia. *Environ Geol* 48:639–643
- Saengsupavanich C (2013) Detached breakwaters: communities' preferences for sustainable coastal protection. *J Environ Manag* 115:106–113
- Saengsupavanich C, Chonwattana S, Naimsampao T (2009) Coastal erosion through integrated management: a case of southern Thailand. *Ocean Coast Manag* 52(6):307–316
- Saravanan S, Chandrasekar N (2010) Monthly and seasonal variation in beach profile along the coast of Tiruchendur and Kanyakumari, Tamilnadu, India. *J Iber Geol* 36(1):39–54
- Stive MJ, Aarninkhof SGJ, Hamm L, Hanson H, Larson M, Wijnberg KM, Nicholls RJ, Capobianco M (2002) Variability of shore and shoreline evolution. *Coast Eng* 47(2):211–235
- Taaouati M, Nachite D, Benavente J, Elmrini A (2011) Seasonal changes and morphodynamic behavior of a high-energy mesotidal beach: case study of Charf el Akab beach on the North Atlantic coast of Morocco. *Environ Earth Sci* 64(5):1225–1236
- Thia-Eng C (1998) Lessons learned from practicing integrated coastal Management in Southeast Asia. *Ambio* 27(8):599–610
- Thiruvenkatasamy K, Baby Girija DK (2014) Shoreline evolution due to construction of rubble mound jetties at Munambam inlet in Ernakulam-Trichur district of the state of Kerala in the Indian peninsula. *Ocean Coast Manag* 102:234–247
- Vousdoukas MI, Almeida LPM, Ferreira Ó (2012) Beach erosion and recovery during consecutive storms at a steep-sloping, meso-tidal beach. *Earth Surf Process Landf* 37(6):583–593
- Wong PP (1990) The geomorphological basis of beach resort sites—some Malaysian examples. *Ocean and Coastal Management* 13(2):127–147
- Woodroffe C (2002) *Coasts: form, process and evolution*. University Press, Cambridge
- Wright L, Short A (1984) Morphodynamic variability of surf zones and beaches: a synthesis. *Mar Geol* 56:93–118
- Wright L, Short A, Green M (1985) Short-term changes in the morphodynamic states of beaches and surf zones: an empirical predictive model. *Mar Geol* 62:339–364

**Publisher's note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.