Effect of Monsoons on Beach Morphodynamics in the East Coast of Peninsular Malaysia : examples from Kuala Terengganu coast

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EFFECT OF MONSOONS ON BEACH MORPHODYNAMICS IN THE EAST COAST OF PENINSULAR MALAYSIA: EXAMPLES FROM KUALA TERENGGANU COAST

(EFFETS DES MOUSSONS SUR LA MORPHODYNAMIQUE DES PLAGES DE LA CÔTE EST DE LA MALAISIE PÉNINSULAIRE: EXEMPLES DU LITTORAL DE KUALA TERENGGANU)

Effi Helmy Bin Ariffin

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Je dédicace cette thèse de doctorat à mon épouse et mes fils bien-aimés,

à mes parents que j'aime,

et aussi, aux adorables membres de ma famille, avec tout mon amour

I dedicate this PhD thesis to my beloved wife and sons,

my lovely parents

and also my adorable family members with lots of love

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ABSTRACT

Effect of Monsoons on Beach Morphodynamics in the East Coast of Peninsular Malaysia: Examples from Kuala Terengganu coast

28 September 2017

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In Southeast Asia, coastal dynamics are governed by a special equilibrium between northeast and southwest monsoons. In the context of sea-level rise and climate change, the monsoon regimes create an adaptation of the coastal dynamics. This situation gives rise to erosion phenomena along the coastline. However, public authorities have attempted to mitigate the problems of erosion by the construction of coastal defence structures. Unfortunately, the implementation of these structures is insufficient to protect the coast, and may have a more negative impact on its evolution. Hence, coastal structures have a strong influence on the configuration of the shoreline. However, artificial structures can affect the wave regime, hydrodynamic circulation and sediment transport, thus reducing the ability of the shoreline to respond to natural forcing factors (such as with double monsoon season regimes) and also fragmenting the coastal space. The present thesis explores the problems of erosional phenomena, shoreline evolution and beach morphodynamics along the Kuala Terengganu shoreline on the East Coast of Peninsular Malaysia, with the aim of understanding the natural versus anthropogenic factors. This study was conducted in three phases to address the following topics: i) shoreline evolution from 2006 to 2014; ii) mid-term surveys (bi-monthly) involving data collection from July 2013 until June 2015 and; iii) short-term surveys (twice daily) with data collection during northeast and southwest monsoons. In 2008, Kuala Terengganu was officially proclaimed a City and was transformed into an economic powerhouse of the east coast regions. Since then, Kuala Terengganu International Airport has developed its runway with a 1-km extension out into the sea. Subsequently, the hydrodynamic and sediment transport in this zone has totally changed, especially in the northern sector of the Kuala Terengganu coast. Hence, from an analysis of the results, erosion is observed north of the airport and accretion to the south, while the rest of the Kuala Terengganu coast appears to be quite stable. Based on a morphodynamic model for simulating seasonal processes, erosion is found to dominate most of the stations during northeast monsoons, while accretion or beach recovery is observed during southwest monsoons. By contrast, only the beach south of the airport shows the seasonal changes simulated by the morphological model, exhibiting accretion and erosion during northeast and southwest monsoons, respectively. Furthermore, the Batu Rakit beach (to the north) is located far away from coastal development, and can be designated as a natural beach compared to other beaches. Kuala Terengganu beach is classified as an Intermediate beach. Hence, an increase and decrease takes place in the seasonal beach state during northeast and southwest monsoons, respectively.

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CHAPTER ONE: INTRODUCTION

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1.1 Regional Perspective

Processes affecting coastal systems are often so complex that this leads to non-linear morphodynamic changes. The effects of erosion and deposition on beach morphology often involve long-term recovery processes which interact with the removal and supply of sediment. These recovery processes are clearly related to natural as well as anthropogenic factors. Natural phenomena such as storms clearly represent factors that contribute to erosion along the coasts of many countries, while beaches are found to build up during calm conditions. Many studies show that, in the case of undeveloped beaches (without anthropogenic pressures), swell waves on a flat sea surface during the summer are observed to build up the berm or beach dune. However, during the winter period, high steep storm waves erode the beach face and transport the sediment seawards, thus creating long-shore bars (Darsan, 2013; Hapke *et al*., 2013; Lucrezi *et al*., 2016).

Another important factor leading to erosion arises from various anthropogenic modifications and structures along the coast. Although most of these structure (e.g. revetments, ripraps, seawalls, groynes and breakwaters) are designed to control erosion, it is interesting to note that they can actually cause erosion in many cases. In groyne systems, for example, structures associated with the reclamation of land from the sea have an impact on coastal sedimentary processes and shoreline changes (Bunicontro *et al*., 2015; Escudero *et al*., 2014; Hsu *et al*., 2007; Kaliraj *et al*., 2013; Mohanty *et al*., 2012; Vaidya *et al*., 2015).

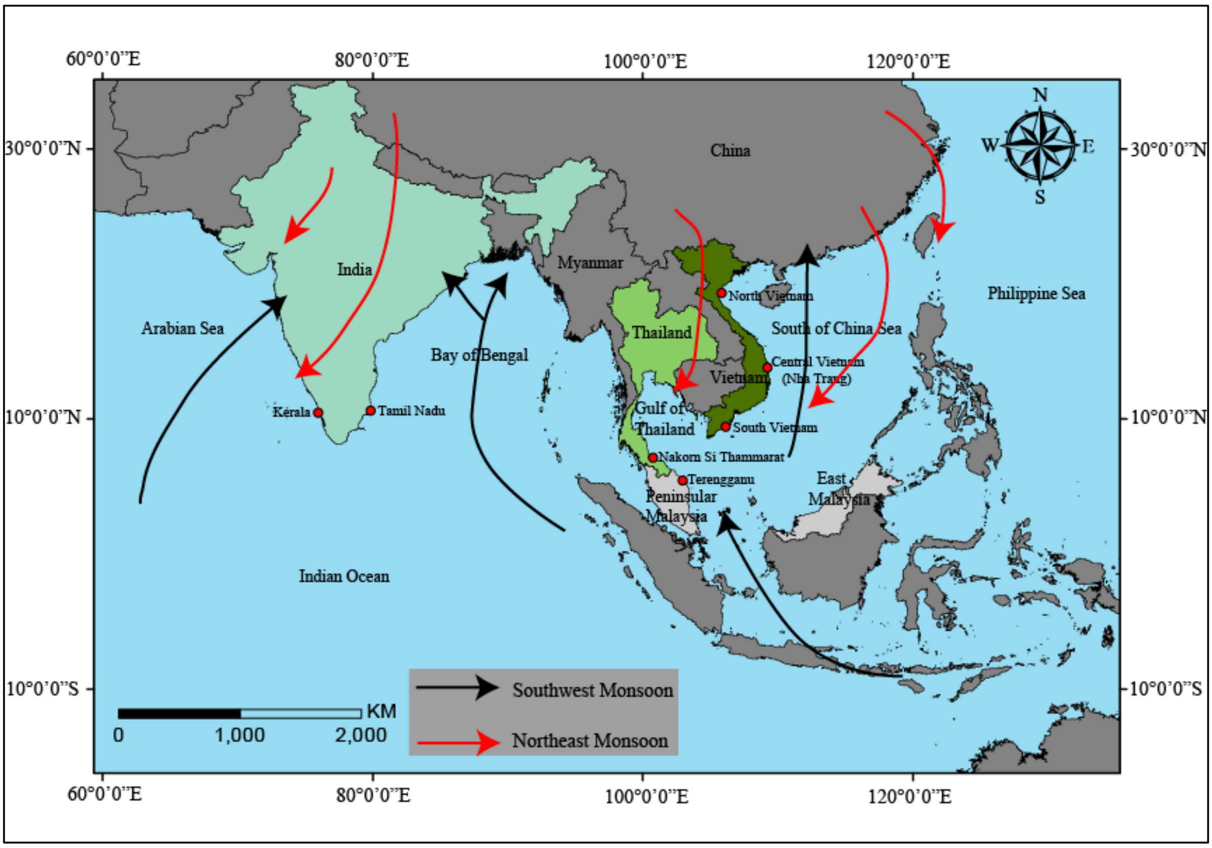

Figure 1.1: Asian monsoons in integrated regional studies.

Furthermore, South Asia is influenced by the same factors as other regions subject to monsoon regimes as well as anthropogenic pressures. Monsoon storms act in combination with the existing coastal structures, often inducing morphodynamic changes from an equilibrium state (Mishra *et al*., 2011; Mohanty *et al*., 2012; Saengsupavanich, 2012; Saravanan and Chandrasekar, 2010; Vaidya *et al*., 2015). The term monsoon is derived from an Arabic word meaning season, indicating an annually reversing wind and precipitation system (Goswami, 2005).

Hence, the Asian Monsoons have an effect on precipitation, wind and wave direction that influences the seasonal variation of coastal morphodynamics. Normally, the South Asian Monsoon regimes in countries such as India, Vietnam, Thailand and Malaysia are represented by northeast and southwest monsoons (Figure 1.1). However, the geography of the monsoon regime can differ across South Asia, with some regions experiencing stronger southwest monsoons compared to the northeast monsoon and *vice versa*.

In this situation, India is subject to storms during the southwest monsoon because the region is directly influenced by southwesterly winds. On the contrary, during northeast monsoons, there is a return to calm conditions with northeasterly winds blowing from China which are blocked by mountainous relief over Myanmar and Thailand (Figure 1.1). However, the rainy season in India is represented by the southwest monsoon each year from May to October. Furthermore, the northeast monsoon is associated with calmer conditions occurring from November to February each year (Saravanan and Chandrasekar, 2015; Wilson *et al*., 2014).

India has the world's second largest population and also suffers from a coastal erosion problem. Coastal erosion is a global problem because it is linked to anthropogenic pressures, hence; coastal erosion has become a major concern for the future socioeconomic development of coastal cities in India. This point of view is supported by Black *et al*. (2008) and Saravanan & Chandrasekar (2010), who show erosion along the Kerala coastline and accretion along the Tamil Nadu coastline, with annual mean sediment erosion and accretion volumes of -60.0 m^3/m (Kerala) and +76.04 m^3/m (Tamil Nadu), respectively. The Kerala coast is more eroded compared to the Tamil Nadu coast because the former is directly influenced by the southwest monsoon (see Figure 1.1 for location).

However, as observed in other regions, coastal structures formed within the monsoon environment tend to erosion in the north and accretion in the south, in view of the longshore sediment transport which conditions the natural coastal dynamics (Kudale, 2010). Coastal processes in India are developed according to the monsoonal morphodynamic model, with erosion (Kerala and Tamil Nadu) during the southwest monsoon and accretion during the Northeast monsoon (see Figure 1.1 for location).

Vietnam is divided into three geographical regions (Northern, Central and Southern) showing different degrees of influence from the monsoon (Figure 1.1). Vietnam is the unique region where the monsoon activity reflects a transition between two distinct subsystems of the Asian monsoon: the southwest and northeast monsoons. Northern Vietnam is generally warm and sunny from October to December, with a cold winter in January and February. The temperature begins to rise again in March, while the summer maximum occasionally reaches 40 °C between May and August, which also corresponds to the rainy season.

In Central Vietnam, the monsoon pattern reverses under the influence of the Northeast Asian Monsoon (November to February) and the area tends to be subject to typhoons. During the dry season from June to September, temperatures reach their maximum. Lastly, Southern Vietnam tends to develop its dry season from December to April, while the Southwest Asian Monsoon season starts in May and continues to October (Abramson, 2016; Pham *et al*., 2010).

Central Vietnam is influenced by more storms during the northeast monsoon because the northeasterly winds blow straight from the South China Sea. Hence, the central sector of the Vietnamese coast is more intensely eroded because of the influence of a typhoon regime. For example, the Nha Trang beach (see Fig. 1.1 for location) in Central Vietnam shows accretion from May to October. After mid-October, significant erosion occurs, probably due to the Northeast wave regime associated with the Northeast Asian Monsoon. However, during mid-November 2013, Nha Trang beach underwent intense erosion linked to the impact of high waves generated by the passage of Typhoon Haiyan (Lefebvre *et al*., 2014).

Thailand has two coastal provinces, with the West Coast being influenced by storms associated with the southwest monsoon (Thampanya *et al*., 2006) and the East Coast tending to be affected by the northeast monsoon (Phantuwongraj *et al*., 2013). In Thailand, the southwest and northeast monsoons tend to occur in May to October and in October to February, respectively.

Over the past two decades, coastal areas on the Gulf of Thailand have been progressively eroded in a sector extending from the neighbouring East Coast of Peninsular Malaysia to the southeastern tip of Thailand. These coastal areas have seen the development of villages, resorts, saltworks, shrimp ponds and mangroves, but are now beneath sea level. At present, the intensity and rate of coastal erosion are continuing without any sign of slowing down (Prinya, 1996). From studies carried out on the Nakorn Si Thammarat coast of Thailand from 1974 to 1975, Saengsupavanich *et al*. (2009) have shown that the coastline is tending to erode with a maximum retreat of approximately 100 m (or roughly 5 m per year on average) due to the influence of anthropogenic pressures along the coast (see Fig.1.1 for location).

To address the erosion problem, the Thai government has taken measures to build T-head groyne systems to protect the coastline. Incorrectly configured coastal structures have accelerated erosion on this coastline. According to Phantuwongraj *et al*. (2013), during the Northeasterly Storm in November 2009, beaches in Southern Thailand were preserved from strong wave attack by pine trees. Normally, natural structures of features are the best type of protection for the coastline.

Malaysia has two regions bordering the South China Sea: Peninsular Malaysia or West Malaysia, which is geographically the southernmost part of the Asian continent, and East

Malaysia, which occupies the northern and western parts of Borneo (Figure 1.1). Malaysia has developed urbanization along the coastal strip. Erosion is taking place on this coastline, particularly under the influence of the double monsoon regime (Nor Hisham, 2006). Seasonal wind regimes in Malaysia can be divided into northeast and southwest monsoons. The East Coast of Peninsular Malaysia (Noraisyah *et al*., 2015; Rosnan and Mohd Zaini, 2009) and East Malaysia (Borneo) (Koiting *et al*., 2015) are subject to northeast monsoons, while the West Coast of Peninsular Malaysia is subject to southwest monsoons (Mokhtar and Ghani Aziz, 2003; Nor Hisham, 2007).

For example, one of the longest coastlines in the region is located in Terengganu State on the East Coast of Peninsular Malaysia facing the open South China Sea (see Fig. 1.1 for location). Each year, the monsoon season on the Terengganu coast is governed by the northeast monsoon (October to March) and the southwest monsoon (May to September) (Akhir *et al*., 2014; Mohd Lokman *et al*., 1998; Rosnan and Ariffin, 2010; Rosnan and Mohd Lokman, 2005; Sultan and Shazili, 2009). The northeast monsoon produces more storms, along with stronger waves and currents, compared to the southwest monsoon, which is associated with calmer and more stable conditions (Mohd Lokman *et al*., 1995; Rosnan and Mohd Lokman, 2005). Hence, the increase of urbanization on the Terengganu coast has brought about serious changes in the natural environment especially as regards coastline retreat (Mohammad Fadhli *et al*., 2014; Muslim *et al*., 2011).

Coastal erosion and reclamation in Malaysia can be linked to the demands and impacts of development in the coastal zone, where 70% of the Malaysian population is situated. Coastal erosion problems usually stem from anthropogenic intrusions into the dynamic zones of coastal areas. More worryingly, erosion may also occur due to the inefficient selection of coastal protection procedures due to an inadequate understanding of the erosion problem as such (Nor Hisham, 2006). Understanding the influences and effects of monsoons is important for predicting changes in the coastal geomorphology and sedimentary environment.

This study addresses two main issues: i) monsoon storm development and its impact on morphodynamic changes, ii) the way in which beach systems recover from these effects. On the other hand, coastlines possess many anthropogenic structures which may affect the sensitive coastal equilibrium. This fragile equilibrium consists of erosion during northeast monsoon storms and recovery during the southwest monsoon (Ariffin *et al*,, 2016; Rosnan and Ariffin, 2010; Rosnan and Mohd Lokman, 2005; Rosnan *et al*., 2003).

1.2 Previous Research

Open beaches are dynamic zones which function as a natural sediment buffer for coastal systems. Periods of erosion and accretion of this sediment buffer are correlated with high- and low-energy wave conditions. Shoreline recession is caused by long-term and short-term processes, which correspond to natural (monsoon storm impact) and anthropogenic effects, respectively (Coco *et al*., 2014; Corbella and Stretch, 2012; Stive, 2004; Zhang, *et al*., 2004).

In general, significant wave heights of 0.35 m and 1.5 m are observed on the West Coast of Peninsular Malaysia during northeast and southwest monsoon, respectively (Mokhtar and Ghani Aziz, 2003; Nor Hisham, 2007). By contrast, the East Coast of Peninsular Malaysia is exposed to the South China Sea and significant wave heights of between 2.7 m to 4.8 m are recorded in Terengganu, which leads to a coastline recession during northeast monsoons (Nor Hisham, 2006). In Pahang, Malaysia (south of Terengganu), the significant wave height along the coastline is 2.0 m and 0.5 m during northeast and southwest monsoons, respectively (Mohd Zaini, *et al*., 2015).

The northeast monsoon storms generate high-energy hydrodynamic conditions along the East Coast of Peninsular Malaysia, especially in Terengganu and Pahang. In contrast, storms occur on the West Coast during the southwest monsoon. During a storm event, the beach is eroded and the natural buffer between the land and the ocean is reduced. For example, the Kuala Terengganu coastline (Terengganu province) is mostly eroded during the northeast monsoon and recovers/ undergoes accretion on natural beaches during the southwest monsoon (Rosnan and Ariffin, 2010; Rosnan and Mohd Lokman, 2005; Rosnan *et al*., 2003).

Furthermore, Kuala Terengganu was less developed before 2005, without any coastal structures along the coastline (Mohd Lokman *et al*., 1998; Rosnan and Mohd Lokman, 2005; Rosnan *et al*., 1994). In 2008, the district of Kuala Terengganu was upgraded by the Malaysian Government to the status of a city to spur construction and touristic development along the Kuala Terengganu coastline. The main examples of artificial structures on the coastline (construction started in 2008) include the (tarmac) runway extension at Kuala Terengganu airport, and a breakwater at the mouth of Terengganu River. As result, about 60 m of coastline has been eroded north of the airport area (Mohammad Fadhli *et al*., 2014).

Another factor affecting erosion on the Kuala Terengganu coast is the decline in suspended sediment transport (Jonah, 2015), since the major sediment supply comes from the Terengganu River (Rosnan and Mohd Lokman, 2005; Sultan *et al*., 2011). In 2010, the breakwater at Terengganu River mouth was fully completed, leading to a decrease in the supply of river sand. According to Muslim *et al*. (2011), the coast north of Terengganu River mouth is undergoing erosion, mainly due to the interruption in sediment transport. This hypothesis is supported by the study of Black *et al*. (2008), which shows a change in dynamic equilibrium because of the absence or reduction of sediment supply.

Other studies involving sediment grain-size analysis indicate that sediments to the north of the Terengganu River are moving to the north-west, while south of the river, they are moving towards the south-east (Rosnan and Mohd Lokman, 2005; Rosnan and Saadon, 1989). Nearshore sea floor sediments do not show any significant change in grain-size distribution, with fine sand particles dominating all the year round (Rosnan *et al*., 2003).

Studies on the coastal area of Tanjung Piai in Johor State (located at the southernmost tip of Peninsular Malaysia) show that erosion is caused by coastal development such as land reclamation, artificial islands, dredging of port channels and the building of coastal defence structures (breakwaters) (Awang *et al*., 2014). Hence, ineffective coastal management combined with poor scientific information has led to a risk of coastal erosion (Appeaning Addo *et al*., 2008). However, coastal management is fraught with uncertainties because the main concern is over the use of coastal resources (Cooper *et al*., 2008). According to Jonah (2015), an effective management strategy needs to be implemented based on a knowledge of the historic trends in coastline evolution and hydrodynamic influence.

For example, in coastal management, beach recovery depends on sediment supply and the severity of the erosion event in question (Houser *et al*., 2008). As we know, beach recovery follows the transport of sediment by offshore-directed undertow during an erosion event. This sediment load is then slowly reworked back towards the shore under calm conditions associated with wave shoaling and refraction effects (Corbella and Stretch, 2012; Gracia *et al*., 2002). However, beach recovery not only depends on wave shoaling and refraction effects but also on geography and coastal landforms (Corbella and Stretch, 2012). For example, fluvial sources are important contributors to sediment supply on coastlines that show a balance between morphodynamic model processes (beach cycle) (Black *et al*., 2008; Chandramohan *et al*., 1992; Dora *et al*., 2014; Saengsupavanich *et al*., 2009).

1.3 Objectives of the Research

Many studies around the world show that beaches are affected by natural and anthropogenic factors, including the East Coast of Peninsular Malaysia. Strong currents, wave surges, wind and tidal action are among the natural factors (Monsoon Effect), while anthropogenic factors involve the construction of groynes, breakwaters and concrete structures. Hence, natural and anthropogenic factors act in parallel and have a major impact on coastline evolution. To understand the beach morphodynamics of the East Coast of Peninsular Malaysia, the Kuala Terengganu coast can be used as an example illustrating the processes in terms of a monsoonal morphodynamic model (beach cycle) taking account of the impact of natural or anthropogenic factors.

The study aims to understand beach rotation processes based on morphological variables (beach profiles and sedimentology) and temporal/spatial variations derived from survey data and sample collection. These data are supported by climate information (effect of monsoons and physical parameters) from various sources which is used to assess morphodynamic mechanisms in the study area.

In view of the above considerations, the study sets out to meet the following specific objectives:

i. To determine the morphodynamics of seven beaches in diverse settings subject to different hydrodynamic conditions.
ii. To understand the impact of the monsoon period and associated changes on beach morphodynamics.
iii. To identify vulnerable coastal areas affected by intensive erosion and specify the causes of this critical situation.

1.4 Thesis Outline

The thesis consists of eight chapters. Chapter 1 presents an introduction to the study, including regional perspectives and previous research, as well as the objectives of the thesis work. Chapter 2 discusses the literature on coastal environments in the Kuala Terengganu region, including the geological and geographical characteristics, as well as the atmospheric and ocean influence. Chapter 3 gives a detailed account of the methodology, through the analysis of multiple parameters. The three main chapters of the thesis (4 – 6) describe the beach morphodynamics of the East Coast of Peninsular Malaysia (Kuala Terengganu region).

In more detail, Chapter 4 presents an assessment of the impact of artificial coastal structures in Kuala Terengganu, while Chapter 5 provides some insights into the significance of morphodynamic changes during the seasonal monsoons, which are responsible for the beach erosional regime in Kuala Terengganu. Chapter 6 discusses the effect of storms on short-term morphodynamic changes. The material presented in Chapter 7 is also treated in the general discussion section of the study. Finally, Chapter 8 sets out a conclusion and recommendations for further research, along with a clear restatement of the main findings of the study.

CHAPTER TWO: STUDY AREA

Contents:

2.1 Environmental and Geological Setting

The regional geology of the land adjacent to the coast is relevant to the investigation as well as the interpretation of the results. This is because sediments are transported and deposited in a given area depending on the nature of the bordering terrains. The geology of Peninsular Malaysia records a Phanerozoic history [without major gaps] from the late Cambrian to the late Triassic. During the Triassic, sedimentation took place mainly in a continental environment, while older deposits are primarily marine. The Triassic is also characterized by the eruption of the Pahang Volcanic Series, which is found mainly in Kelantan, Terengganu and Pahang (Ghani, 1980; JMG, 1985).

The Jurassic and Cretaceous succession is less complete, while the overlying formations of probable late Tertiary age have a very limited distribution. The mountain chains in the western part of Peninsular Malaysia developed with major intrusive activity associated with the emplacement of tin-bearing granitic batholiths during the late Jurassic and early Cretaceous. The process of mountain building led to the development of a double orogen consisting of two parallel mountain arcs: the East Coast Range and the Main Range (Tjia and Fujii, 1992; Vijayan, 1993).

Quaternary deposits are extensive and economically important. Alluvium brought down by the rivers gave rise to widespread sedimentation along the coasts, especially in the western part of Peninsular Malaysia during the Quaternary. During this period, the drop in sea-level caused by glaciations led to recession of the coastline, which exposed much of the submerged shelf as dry land. Peninsular Malaysia is composed of a great variety of rock types reflecting a spectrum of environments in space and time. This diversity is typical of a continental margin that has experienced a complex series of geosynclinal, orogenic, and post-orogenic events (JMG, 1985; Vijayan, 1993).

Quaternary geological formations (1 to 4) are composed of continental and marine deposits with unconsolidated sands of mainly marine origin (Garba *et al*., 2015). The beaches of the east coast of Peninsular Malaysia are covered by 90 % sandy sediment which is constantly being nourished by sediment loads from several major rivers such as the Pahang, Kelantan and Terengganu (Nor Hisham, 2006).

Coastal superficial deposits, especially sandy soils, are extensively found along the east coast of Peninsular Malaysia. The coastal soils are characteristically different from inland soils. These sandy soils, which are locally known as bris soils, include some spodosols (soils with organic-rich spodic horizons in the topmost 2 m) and some entisols (Anizan, 1992). Owing to the strong coastal currents in the South China Sea, only sand can be brought into this area, with the weathering products of granite becoming the main source of the sediment.

According to Garba *et al*. (2015) these superficial deposits are underlain by 10 geological formations, as shown in Figure 2.1:

i. Quaternary (1): continental and marine deposits with mainly unconsolidated marine sand.
ii. Quaternary (2): continental and marine deposits with unconsolidated silt and clay (mainly).
iii. Quaternary (3): continental and marine deposits with unconsolidated humic clay, peat and silt.
iv. Quaternary (4): marine and continental deposits with unconsolidated clay, silt, sand and gravel undifferentiated.
v. Cretaceous-Jurassic (10): thick, cross-bedded sandstone with metamorphic and sedimentary rocks of sandstone type.
vi. Permian (20): shale, slate and phyllite with subordinate schist and sandstone; limestones are developed throughout the succession.
vii. Permian (21): same as Permian (20), but with unconsolidated ignimbrite.
viii. Carboniferous (25): phyllite, slate and sandstone; argillaceous rock is commonly carbonaceous. Locally prominent development of limestone.
ix. Carboniferous (26): same as Permian (20), but with metamorphic and sedimentary rocks of sandstone type.
x. Acid intrusives (38): undifferentiated igneous rocks, mostly granitic.

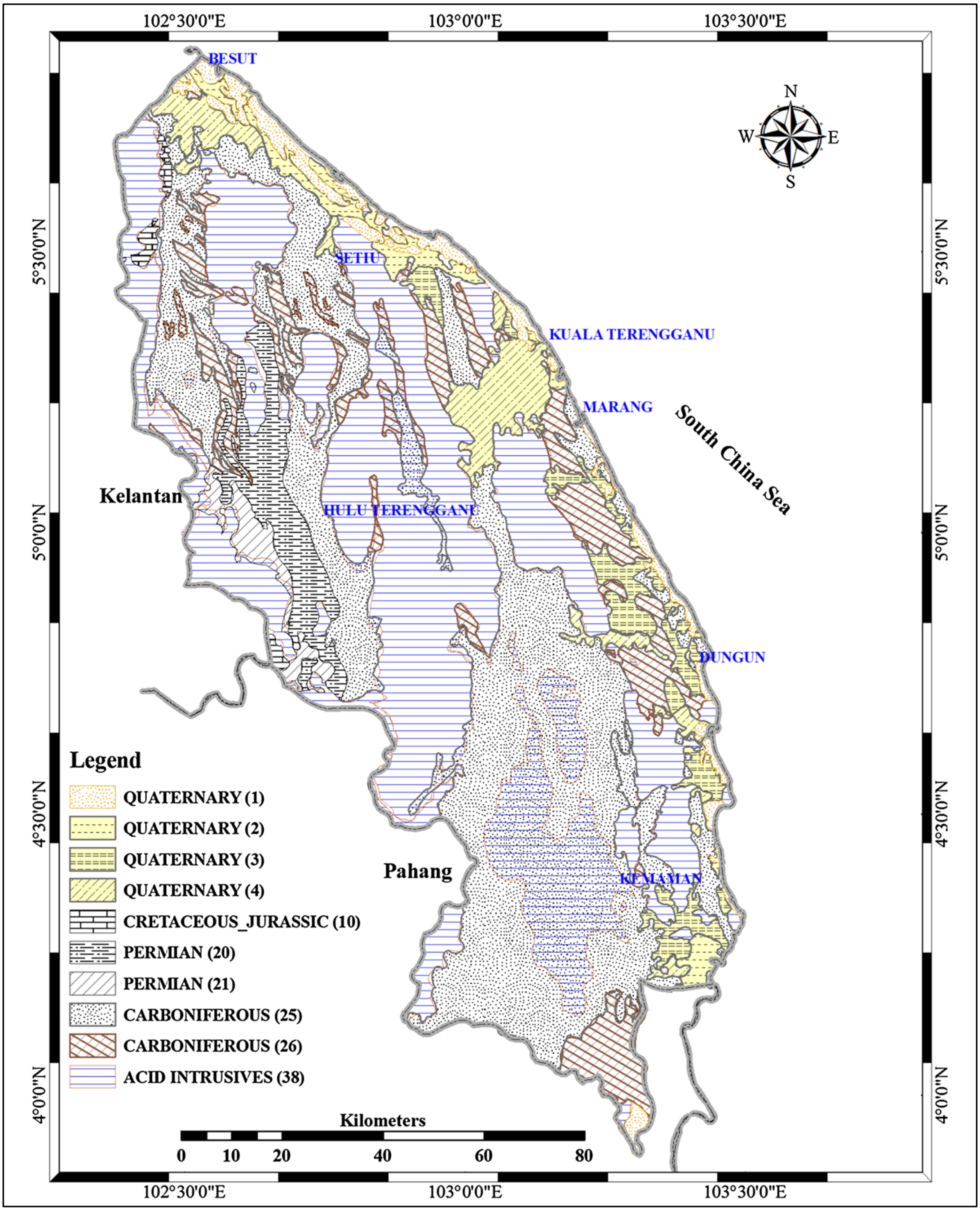

Figure 2.1: Geological formations in Terengganu State. The numbers in brackets refer to classification according to the Department of Geology Survey, (1982). (Source: Garba *et al*., 2015)

2.2 Site Description: Kuala Terengganu Beach System

The study area is located on the east coast of Peninsular Malaysia and is divided into the northern and southern sectors; the boundary between these sectors is the Terengganu river mouth, which represents the sediment source. Furthermore, the two sectors taken together make up almost 30 km of the Kuala Terengganu coastline, extending from Kampung Batu Rakit to Marang (Figure 2.2). This area consist of a Quaternary coastal plain along most of its length. The study area lies in the humid tropical zone, where high rainfall is recorded during the northeast monsoon season. The northeast monsoon prevails between October and March, while the southwest monsoon tends to occur from May to September and the rest of the year corresponds to the monsoon transition. The mean annual temperature lies in the range of 25.6–33.8°C. The prevailing winds are northeasterly and southwesterly. Winds stronger than 20 km/h are mainly from the Northeast, accounting for about 70% of the frequency of winds coming from the sea (Rosnan and Mohd Lokman, 2005).

Raj (1982) states that there are two overall directions of present-day beach sediment transport by longshore drift along the coastline of Terengganu state; north-westerly in the sector north-west of Kuala Terengganu, but turning southerly farther south. The beach profile in the sector northwest of Terengganu River is relatively steep, compared to the gentle profile southeast of the river. Terengganu River is one of the major sources of river sand. Beach erosion represents the other major source providing significant volumes of sediment to the long shore transport system (Rosnan and Mohd Lokman, 2005).

The coastline is relatively straight and follows an orientation of about 135-315°. Sultan Mahmud Kuala Terengganu International Airport is located along the coast, 5 km north of Sungai Terengganu. A 1-km tarmac runway extension was constructed in 2010 (Figure 2.2). This construction has interrupted the longshore drift circulation and has led to marked variations in beach width. Apart from the runway extension, there are various other constructions along the coast, including university buildings, stadium, schools, houses and recreational areas. The main city of Kuala Terengganu is located along this coastline to the southeast of Terengganu River. Various construction developments are situated along this coast, including hotels, schools, houses, a recreational area and the Sultan's palace (Wong, 1990).

The study area is divided into three zones, namely: Zones A (North) and B (North-Central), with the latter being separated from Zone C (South) by the Terengganu River (Fig. 1). Zones A and B are characterized by many anthropic activities and developments as well as a high population density. By contrast, Zone C (from Kuala Ibai to Marang beach) is more of a natural beach compared to Zones A and B (Table 1 and Fig. 2), and is also much less densely populated. Furthermore, the longshore current direction also different in this area.

The division into zones represents an approach similar to the cell concept adopted by Aouiche *et al*. (2016), who based their study on alongshore wave gradients and longshore drift. Furthermore, the cell concept is commonly used in a purely sedimentary budget framework, in which processes may be disregarded, and where the emphasis is placed on (1) the definition of each coastal cell, (2) the net gains and losses of sediment within each cell, (3) the associated transport pathways, and (4) the way these pathways are linked to the net time-averaged shoreline variations (Anfuso *et al*., 2007; Patsch and Griggs, 2008; van Rijn, 2011).

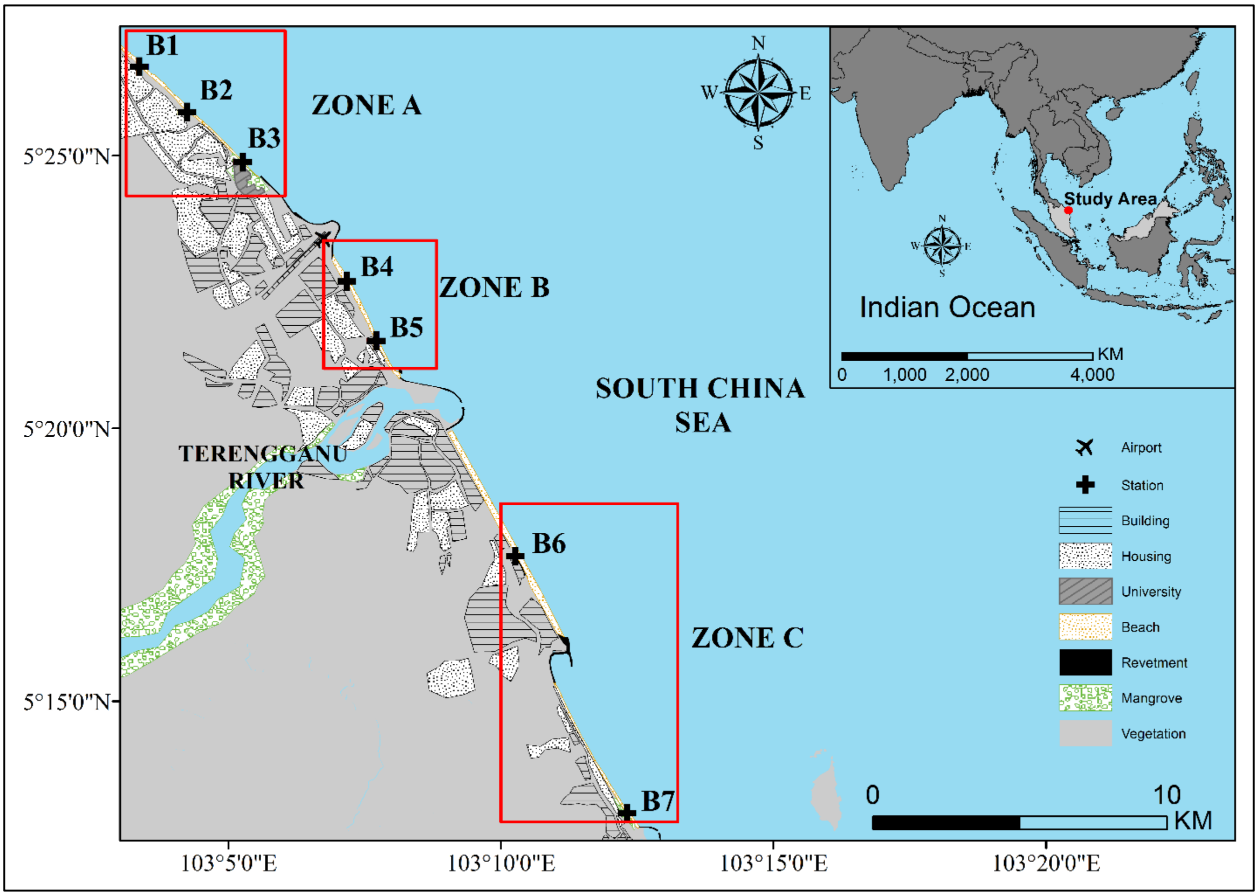

Figure 2.2: Study area on Kuala Terengganu coastline, with division into three zones.

2.3 History of Anthropogenic Influences on Kuala Terengganu Coastline

In recent years, coastal areas have been steadily in retreat due to human activities such as transportation, industry, tourism and recreation. A significant and growing proportion of the world's population lives near the sea. According to the Intergovernmental Panel on Climate Change (IPCC), two-thirds of the world's population lives within a distance of two hundred kilometres from the coast (Requejo *et al*., 2008). At the same time, development of these areas has commonly given rise to problems such as severe beach erosion and flooding. Consequently, coastal communities are becoming more and more vulnerable to these coastal hazards.

Human activities in the coastal zone play an important key role and are often supported by a physical infrastructure, which, in the case of an incorrect understanding of the coastal system, can have a dramatic effect on the coastline (Tilmans, 1991). Tourism is one of the significant factors that increases coastal development. The demand from mass tourism has led to the worldwide development of beach resorts, including the east coast of Peninsular Malaysia (Wong, 1990). A poor understanding of the coastal environment has led to the use of elaborate and expensive structures to control erosion on beaches.

Many coastal areas are currently at risk from multiple hazards created by natural processes or anthropic activities (Thomas *et al*., 2015). Carter (2002) defined the risks as being of two kinds: (i) short-term (e.g. hours, days or months), linked to natural hazards created by geological or meteorological disturbances, for example due to storms or earthquakes (tsunamis), and (ii) long-term (e.g. years or decades), created by human interference (anthropogenic) having a continuous effect on erosion. The short- and long-term risks presented in this study are created by northeast monsoon storms and anthropic activities.

Muslim *et al*. (2011) studied the shoreline evolution by the analysis of remote sensing data with GIS. The results show that the erosion and accretion trends from 1992 to 2010 can be divided into three zones (A, B and C). From 2000 to 2002, the shoreline in Zone A showed an accretion of 35 m. However, in 2008, work started on the extension to the Kuala Terengganu airport which affected the shoreline in this zone; in April and September 2009, an erosion of -37 and -43 m was recorded. The trend continued with a total erosion of -70 m in 2010. This process is also facilitated by the northeast monsoon which blows between October and March each year (Rosnan *et al*., 2003).

In 2002, an average erosion of -16 m occurred within Zone B. However, accretion took place during April 2009 and 2010, with shoreline movements of +71 m and +131 m, respectively. The main reason for this accretion could be the interruption of northward sediment transport (Rosnan and Mohd Lokman, 2005). Furthermore, Zone C underwent erosion from 2002 to 2010, with movements of -30 m to -29 m. This was because there was less sediment supply from Terengganu River to the coastline (Rosnan and Mohd Lokman, 2005). Table 2.1 presents the overall shoreline evolution in this area, based on the finding that erosion dominated to the north and accretion to the south of Sultan Mahmud Airport, while, erosion continued in the sector north of Terengganu River (Figure 2.3).

Table 2.1: Summary of shoreline evolution by zone (Zone A: stations 1 and 2; and Zone B: stations 7 to 11). The minus '-' values indicate the volume of sand eroded and plus '+' values indicate the volume of sand deposited (see Figure 2.3 for aerial photograph).

Site	Shoreline evolution (m)				
	July 2000	August 2002	April 2009	September 2009	March 2010
Zone A	44	35	-37	-43	-70
Zone B	7	-16	86	71	131
Zone C	-30	-44	-49	-2	-29

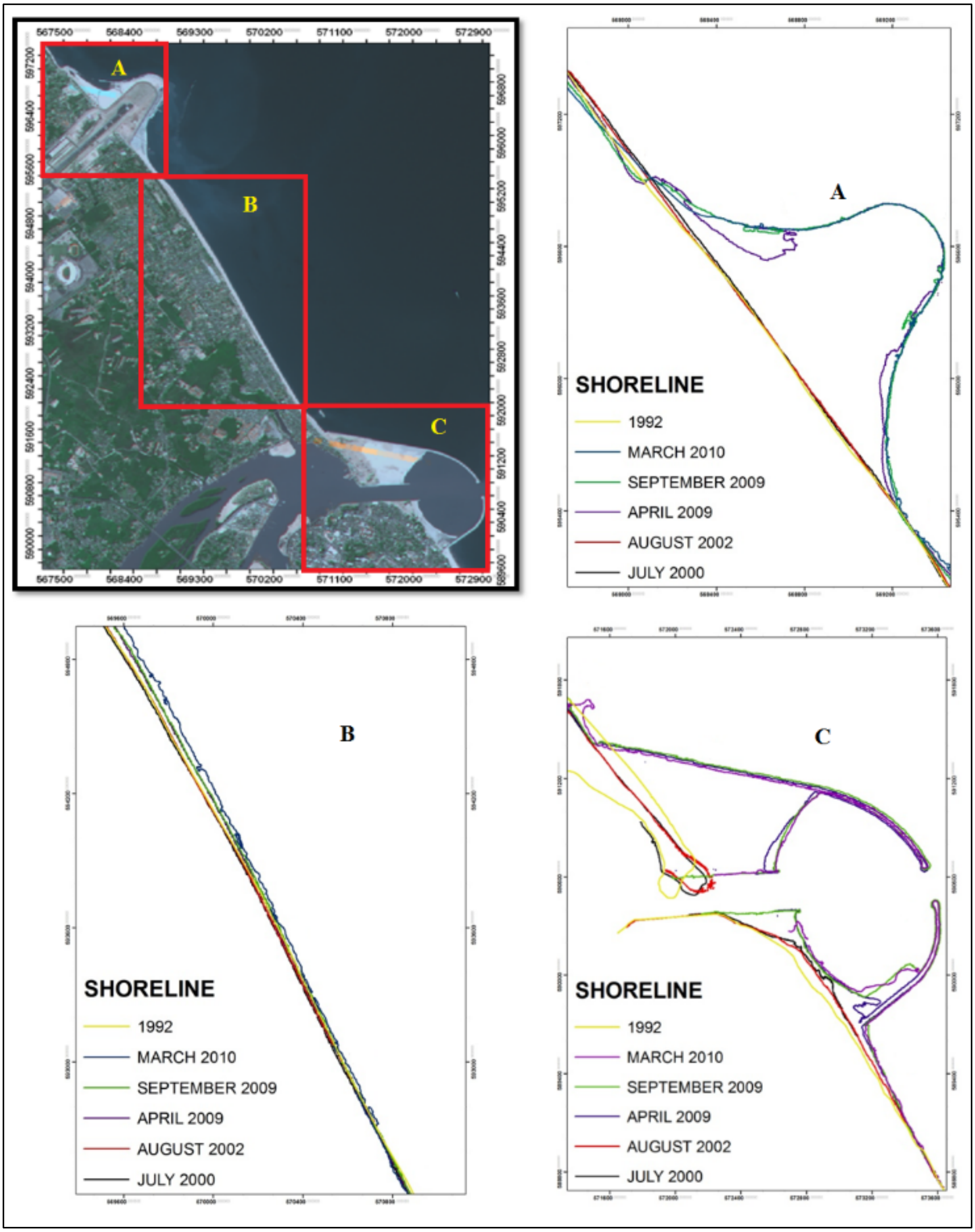

Figure 2.3: Shoreline evolution between 1992 and 2010. (Sources: Muslim *et al*., 2011)

Since construction of the airport tarmac runway extension in 2010, serious erosion has occurred north of the airport. Hence, the beach in the north is relatively steep compared to the gradual profile in the sector south of the airport. For the purpose of mitigation, the government took steps to construct coastal defences, but erosion persisted in the nearby areas. Table 2.2 and Figure 2.4 shows the history of construction along the Kuala Terengganu coast, as well as the coastline conditions since 2006 to 2016 based on field observations.

Table 2.2: History of construction of artificial structures on the Kuala Terengganu coastline from 2006 to 2016.

Year	Zone	Station Points (Marking Points)	Structure	Coastline Conditions
2006	B	B5 (i)	Breakwater	Erosion
	C	B6 (j)	Riprap	Erosion
	C	B6 (k)	Harbour	-
	C	B7 (l)	Breakwater	Accretion
2010	A	B3 (f-g)	Airport Tarmac Extension	Erosion
	B	B4 (g-h)	Airport Tarmac Extension	Accretion
2012	A	B3 (e-f)	Revetment	Erosion
2013	A	B3 (c)	Riprap	Erosion
2015	A	B3 (b)	Groyne	Erosion
	A	B3 (e)	Groyne	-
2016	A	B3 (a)	Riprap	Erosion
		B3 (d)	Tombolo Breakwater	Erosion
		B3 (e)	Tombolo Breakwater	-

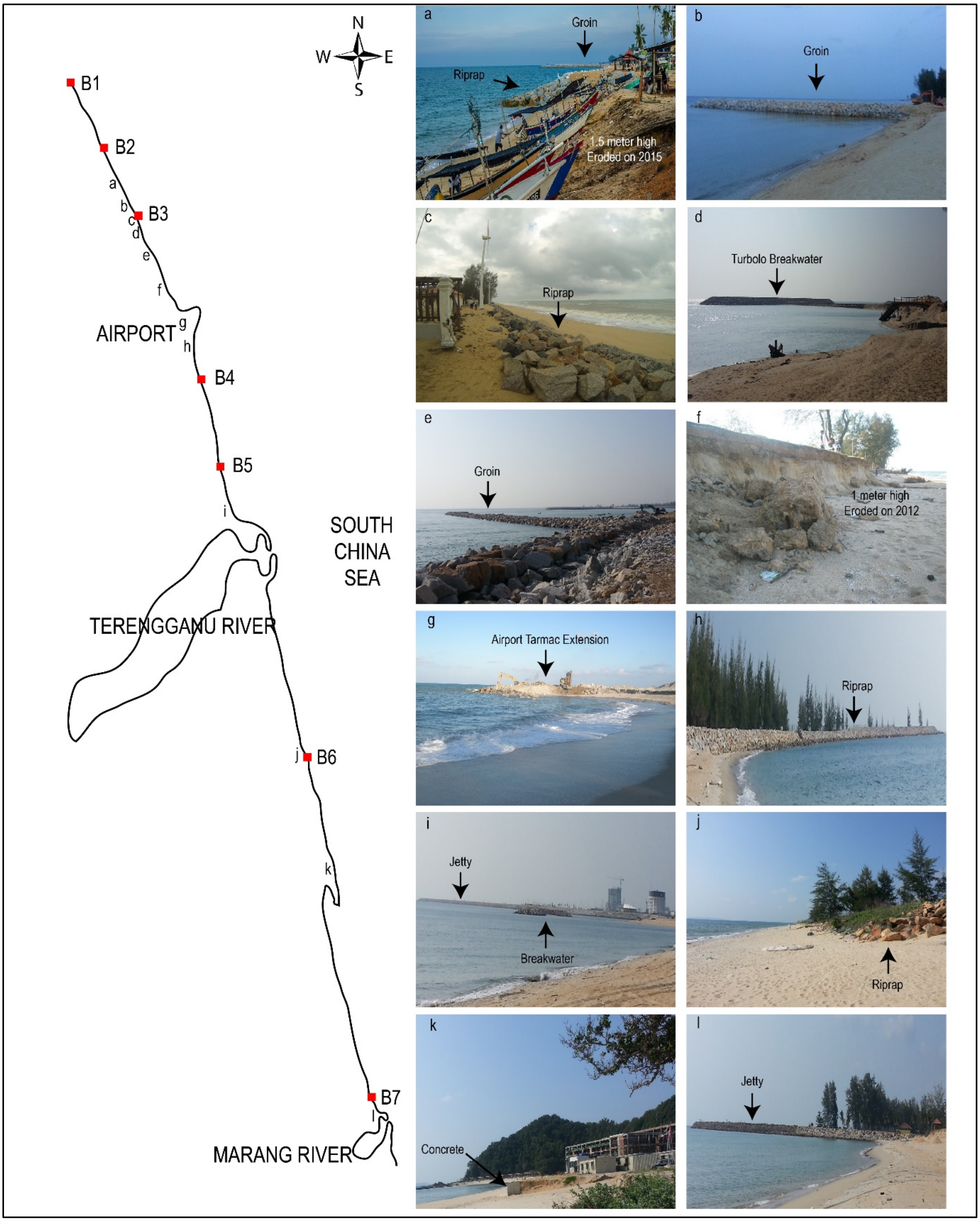

Figure 2.4: Artificial structures built along the Kuala Terengganu coastline from 2006 to 2016.
Note: B points refer to beach station points in Figure 2.2.

2.4 Sediment Transport

The sediment load is channelled by rivers towards coastal waters. In Peninsular Malaysia, there are two major rivers on the East Coast, the Pahang (in the south, with a length of 420 km) and the Kelantan (in the north, with a length of 280 km), both of which drain into the South China Sea. The Terengganu River (middle of the East Coast) also flows into the South China Sea, with a length of approximately 120 km from Kenyir Lake in the west, serving as the main channel draining the five major tributaries of the river and its estuary (Kawar Sultan and Noor Azhar, 2010) (Figure 2.5).

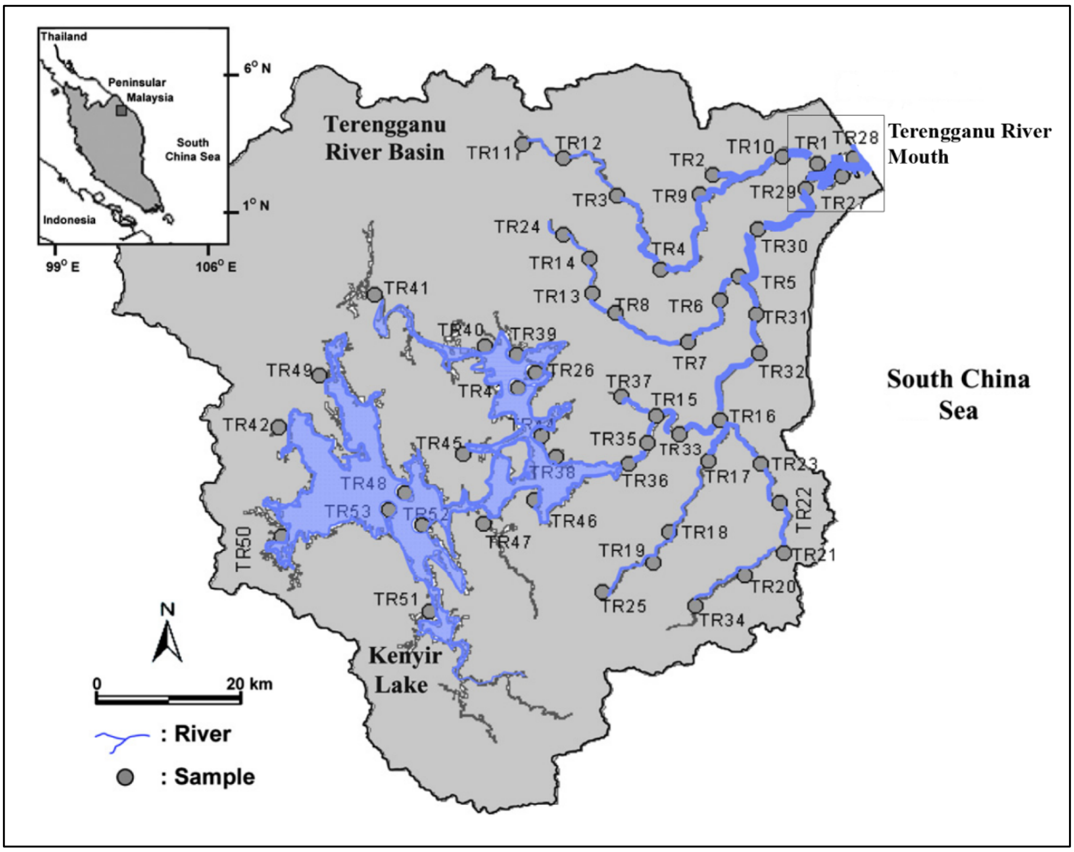

Figure 2.5: Terengganu River catchment area. (Source: Khawar Sultan *et al.*, 2011)

The Terengganu River is a main source of sediment supply from the river to the coastal area (Rosnan and Mohd Lokman, 2005). Studies of sediment grain-size distribution by Rosnan *et al*. (1995) indicate that, north-west of the Terengganu River mouth, sediment is moving to the northwest, while south-east of the river mouth, it is moving to the southeast. The average sediment transport rate on the Terengganu coast is about 250 cm/day (Phillips, 1985).

2.5 Atmospheric and Ocean Influences

Coasts are not isolated from the environments supplying inputs of energy and material, since these inputs are processed and can be subsequently lost from the system as an output. The physical processes or events combining these inputs, outputs and interactions can be determined in a system that acts together in shaping the morphology of the coast. Variations in inputs cause changes in the physical environment: for example, an increase in wave energy may enhance coastal erosion, or a decrease in nutrients may limit biological productivity, thus demonstrating that all natural coastal processes are interlinked in some way or another.

2.5.1 Monsoons

As mentioned above, coastal processes in Malaysia are greatly influenced by the monsoons. The monsoon brings about a greater intensity of the related physical phenomena, commonly associated with waves, current velocities, winds and a high frequency of rainfall. Many studies have been carried out showing that the monsoon period depends on rainfall distribution (e.g.: Bagyaraj *et al*, 2015; Chang, *et al*., 2005) (Figure 2.6). There are two monsoon conditions on the East Coast of Peninsular Malaysia, namely the northeast monsoon and the southwest monsoon. During the northeast monsoon, from October to March (Akhir and Chuen, 2011), the coast is exposed to strong wave action which leads to beach erosion.

The waves are higher than normal during this season due to the strong onshore winds, and thus can cause comparatively more damage (Mohd Lokman *et al*., 1995). Overwash deposits are thrown to a higher elevation and further inland than the backshore. During the southwest monsoon from May to September (Kok *et al*., 2015), the beaches build up or recover (Wong, 1990).

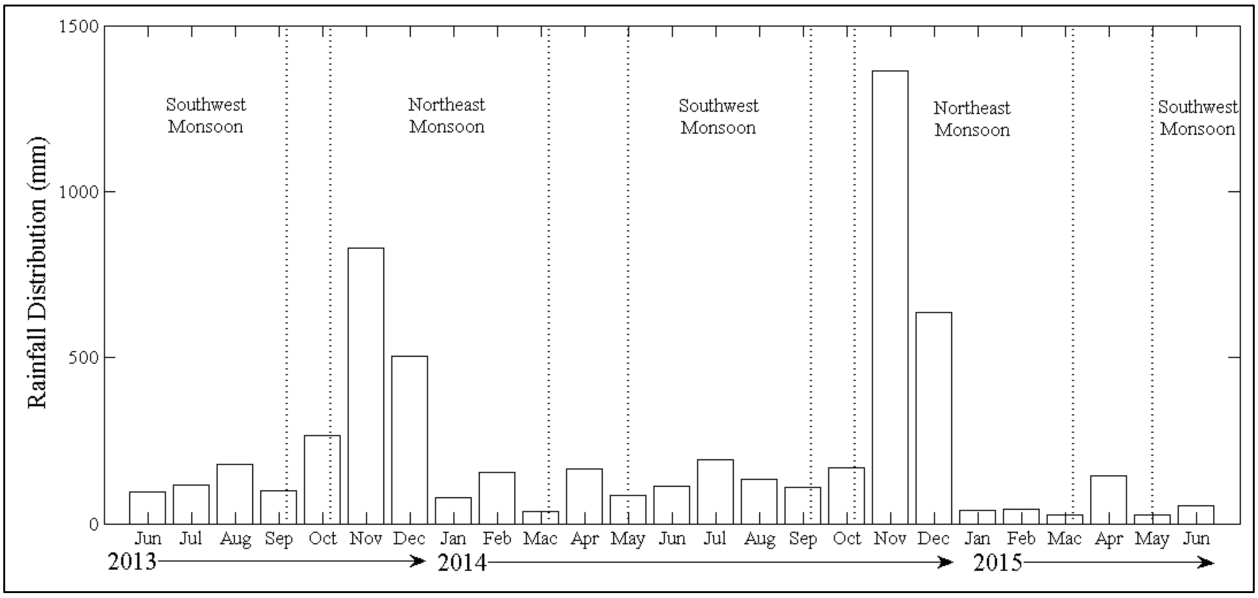

Figure 2.6: Rainfall distribution at Malaysia Meteorological Department station located at Sultan Mahmud Airport, Kuala Terengganu.

In the selection of potential sites, it is important to know that long-term erosion and deposition trends can be masked temporarily by the monsoons, and that the character of the beach varies with the monsoon season, e.g. a well-developed beach is apparent during the southwest monsoon and eroded during the northeast monsoon (Muslim *et al*., 2011; Rosnan *et al*., 2003). Although the northeast monsoon is generally regarded as an overriding climatic influence, its severity varies annually and spatially. Its effects can be mild and almost absent in certain years (Wong, 1981, 1990).

Meanwhile, during the transition period between monsoon seasons, the conditions are generally calmer compared to the energetic monsoons (northeast and southwest). Saadon and Marghany (1996) reported that the wind is generally weak and variable during transition periods, so the current circulation pattern not well defined. The above authors (*op. cit.*) conducted their study in April, when the circular current structure usually indicates the presence of an eddy. However, eddies are usually generated by the horizontal shear of the mean flow. In addition, Camerlengo and Somchit (2000) found that the rainfall variability recorded during the transition period was lower than during the monsoonal periods.

2.5.2 Wind Pattern

Wind can be defined as the horizontal movement of air caused by pressure gradients between adjacent areas. Pressure variations are generally the result of temperature differences due to inhomogeneous insolation of adjacent zones receiving solar radiation (e.g. between landmasses and oceans) (Benassai, 2006). Hydrodynamics is strongly influenced by wind action, which is responsible for wave generation, wind setup, surge and surface currents. Wind forces directly modify coastal morphology through the transport and deposition of sediments on beaches, dunes and also the berms. Periodic water level oscillations called seiches are caused by rapid changes in atmospheric pressure and directional shifts or strong winds on small seas and confined water bodies.

Chiang *et al*., (2003a) conducted a study around the coastline of Peninsular Malaysia facing the South China Sea, which involved the analysis of annual vector mean wind speed and direction according to two distinct seasons i.e. the northeast monsoon and the southwest monsoon. The wind direction was found to be north-eastward during the northeast monsoon (with higher vector mean wind speed) and south-eastward during the southwest monsoon

(Table 2.3). Generally, the mean vector wind speed on the coasts of Terengganu and Pahang is higher during the northeast monsoon season (2.06 m/s). Furthermore, the wind regime in Kelantan is influenced by the Gulf of Thailand, with a higher wind speed pattern (Akhir and Chuen, 2011; Kok *et al*., 2015).

Table 2.3: Mean vector wind direction and speed.

	Annual Mean Vector Wind		Northeast monsoon Mean Vector Wind		Southwest Monsoon Mean Vector Wind	
	Direction (º)	Speed (m/s)	Direction (º)	Speed (m/s)	Direction (º)	Speed (m/s)
Kelantan	89	2.06	76	2.57	227	0.51
Terengganu	113	1.03	71	2.06	221	1.54
Pahang	64	1.03	27	2.06	186	1.54

(Data compiled from: Chiang *et. al*., 2003a)

According to Kok *et al*. (2015), the dynamics of wind stress systems has an important influence on the physical characteristics of the sea. Furthermore, the cited authors used wind stress curl to examine the potential mechanism responsible for the formation of the thermal front during both monsoon seasons. Positive (negative) values of wind stress curl imply cyclonic (anti-cyclonic) motion in the Northern Hemisphere. The cyclonic (anti-cyclonic) winds cause a divergence (convergence) in the surface layer, which in turn causes cooler (warmer) water from deeper layers to rise (sink) and replace the diverging (converging) water, leading to upwelling (downwelling) (Knauss, 1997).

Figure 2.7 shows the wind stress curl over the period of one year, including the northeast monsoon, post-northeast monsoon, southwest monsoon and pre-northeast monsoon. During the northeast monsoon, which occurs in November, a slightly weaker or negative wind stress curl is observed, followed by a gradual increase in its intensity up to a maximum in January, especially between latitudes 2 and 5°N. Furthermore, the intensity of the negative wind stress curl decreases gradually from January until March at latitudes 2-5°N (see Figure 2.7c, d, e). During the post-northeast monsoon (Figure 2.7f), the negative wind stress curl changes to positive, but the intensity is weak and becomes located off the south-eastern coast of Thailand between latitudes 6 and 7°N.

On the other hand, between latitudes 5 and 7°N, a positive wind stress curl is observed in November and the intensity increases gradually until it reaches a maximum in January and February (Figure 2.7c;d), then decreasing gradually during the post-northeast monsoon in April (Figure 2.7f).

The wind stress curl during the southwest monsoon is the reverse of the northeast monsoon, showing positive values which reflect upwelling conditions between latitudes 1 and 6°N. The area concerned is located between the southern tip and the East Coast of Peninsular Malaysia during the months from May to September (Figure 2.7h,i,j,k). The positive wind stress curl increases gradually from May to August before dissipating in September and becoming located near the south-eastern coast of Thailand (between latitudes 6 and 7°N). Subsequently, the negative wind stress is associated with increasing intensity during October between latitudes 5 and 8°N (Figure 2.7l).

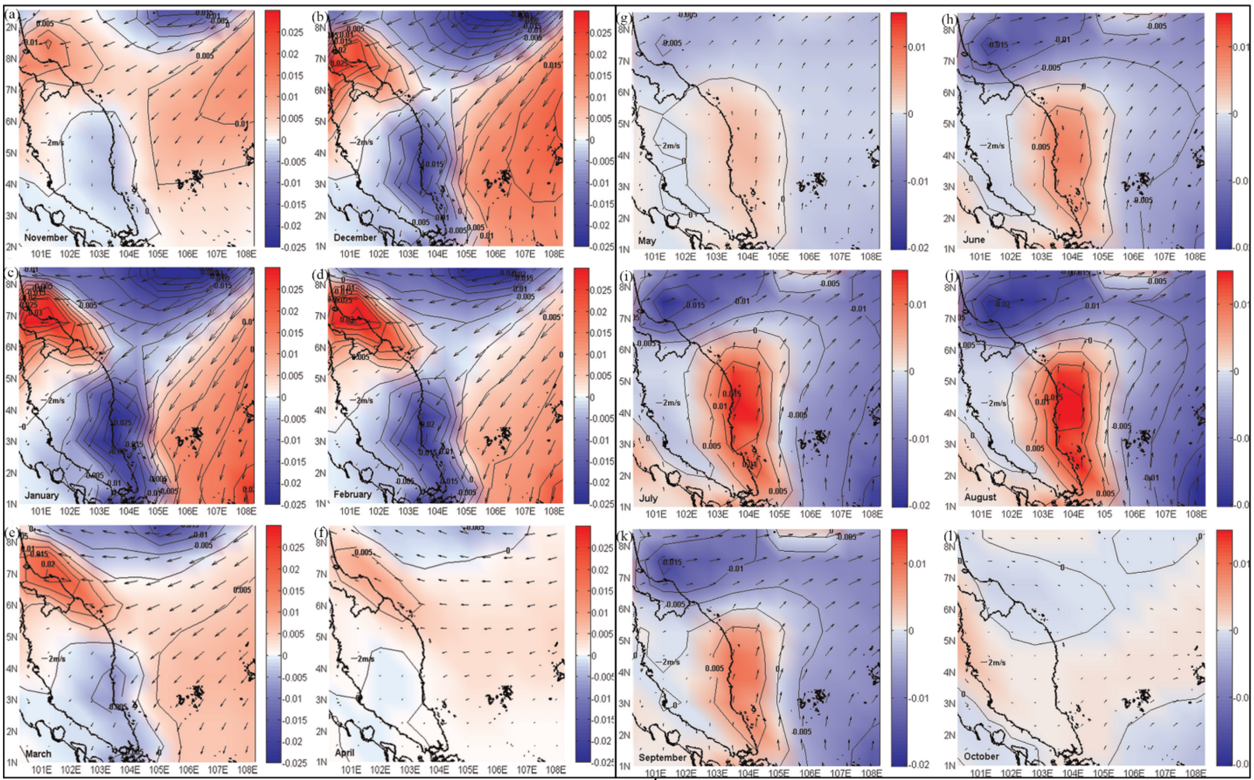

Figure 2.7: Monthly wind speed vectors (unit ms^{-1}) and wind stress curl in Peninsular Malaysia during the northeast monsoon: November to March (a to e); post-northeast monsoon: April (f); southwest monsoon: May to September (g to k); and pre-northeast monsoon: October (l). (Source: Kok *et al*., 2015).

2.5.3 Waves (Wind Waves)

Wave activity is one of the important factors that needs to be considered in discussing coastal processes. Waves are among the most fundamental and dynamic forces behind the shaping of coastlines. Waves form when the water surface is disturbed, for example by wind, earthquakes or planetary gravitational forces. During such disturbances, energy and momentum are transferred to the water mass and transmitted in the direction of the impelling force. In many cases, the undulations of waves moving on the sea surface result from the drag effect of the wind (Davis and Fitzgerald, 2004; Hill, 2004).

When the wind blows at a constant speed for a certain period, waves will increase in size to become Wind Waves as termed by Tolman (1991). Wind-generated waves are important energy transfer agents; waves first obtain their energy from winds, transferring it across the expanses of the ocean, and then delivering it to coastal areas where it can be the primary cause of erosion or can generate a variety of nearshore currents and sand transport patterns (Komar, 1985).

Furthermore, when a wave finally breaks, the energy is divided into swash and backwash. The swash and backwash motions breaking waves carry sediment across the foreshore, representing one of the most important mechanisms for sediment transport in the beach environment. There may be a significant difference between the amount of sediment carried up the beach and that carried off the beach depending upon the wave conditions, the slope of the beach and sediment permeability (Davis and Fitzgerald, 2004).

On the other hand, for general information on Peninsular Malaysia, we can refer to the study conducted by Chiang *et al*. (2003a) on wave power and direction associated with wind waves during northeast and southwest monsoons (Figure 2.8). On the Terengganu coast, the wave power from wind waves during the northeast monsoon is approximately 3.0 kW/m, while a value of 1.5 kW/m is obtained for wind waves during the southwest monsoon between latitudes 4-6°N. In another study, Chiang *et al*., (2003b) reported that wave conditions in Malaysia are greatly influenced by the northeast and southwest monsoon winds.

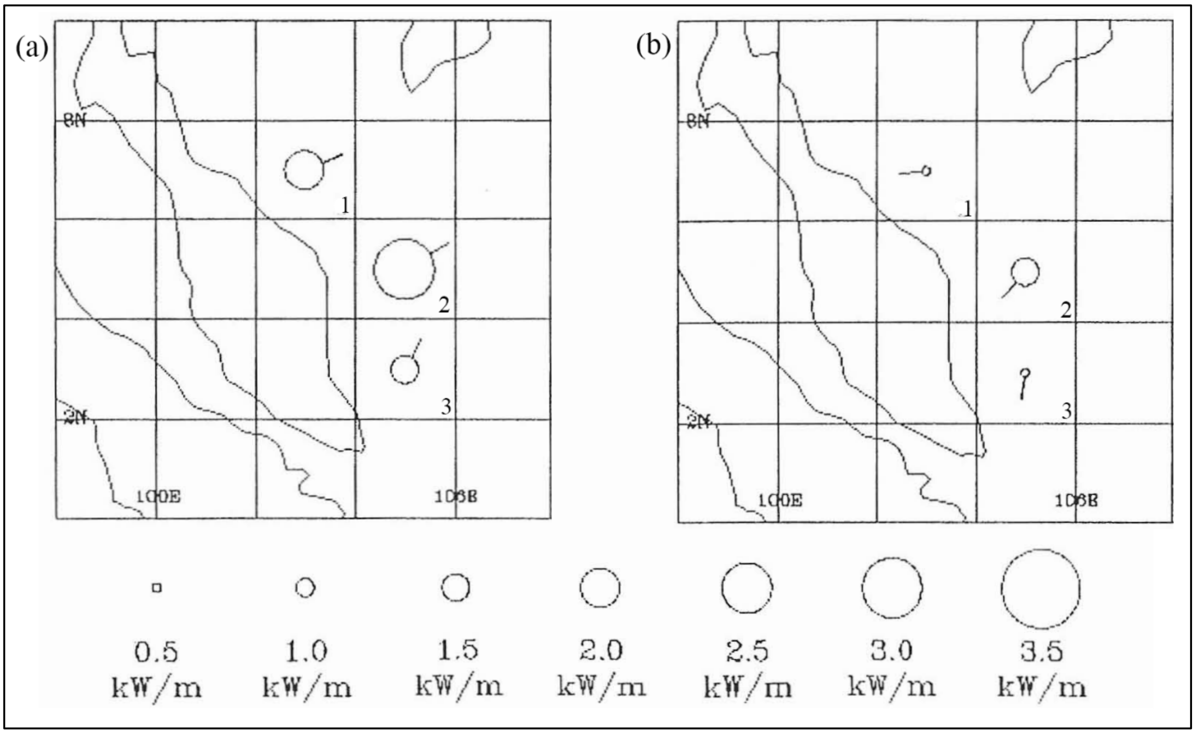

Figure 2.8: Wind wave power and direction in Peninsular Malaysia: (a) wind wave power during the northeast monsoon (b) wind wave power during the southwest monsoon. The different values of wave power are distinguished by grid numbers representing the states of (1) Kelantan, (2) Terengganu and (3) Pahang. (Source: Chiang *et al*., 2003a)

In specific studies on mean significant wave height and wave direction, Mirzaei *et al*. (2013) present the seasonal recordings of waves during the winter monsoon (northeast monsoon), spring (post-northeast monsoon), summer monsoon (southwest monsoon), and autumn (pre-northeast monsoon) from 1979 to 2009 (Figure 2.9). On the Terengganu coastline (between latitudes 4-6°N), the winter monsoon (DJF) yields the highest mean of significant wave height, ranging from 1.0 to 2.0 m. In comparison, the wave heights are less than 0.8 m during the summer monsoon (JJA).

These results are also supported by Young (1999), who studied the seasonal variability of the global wave climate (mean of significant wave height) in Terengganu during January (northeast monsoon) and July (southwest monsoon), obtaining values of 1.0 to 2.0 m and less than 1.0 m, respectively. There is very clear contrast in wave climate because of the higher intensity and variability of winds between the winter and summer monsoons. Furthermore, the transition seasons (MAM: Spring and SON: Autumn) show a similar pattern to that of the summer even though the winds are less intense.

On the other hand, mean wave direction is predominantly controlled by the monsoonal winds over this region, especially on the Terengganu coastline. The wind starts to blow around November during the northeast monsoon (DJF), when the Siberian High pushes the airflow around an anticyclone that carries air from Siberia across China and out over the South China Sea. The mean wave direction is predominantly north-easterly during DJF and MAM. Furthermore, at the beginning of JJA, the wind over the South China Sea becomes predominantly south-westerly. Finally, during the SON transition season, the mean wave direction gradually becomes westerly in the central South China Sea and turns southward along Peninsular Malaysia.

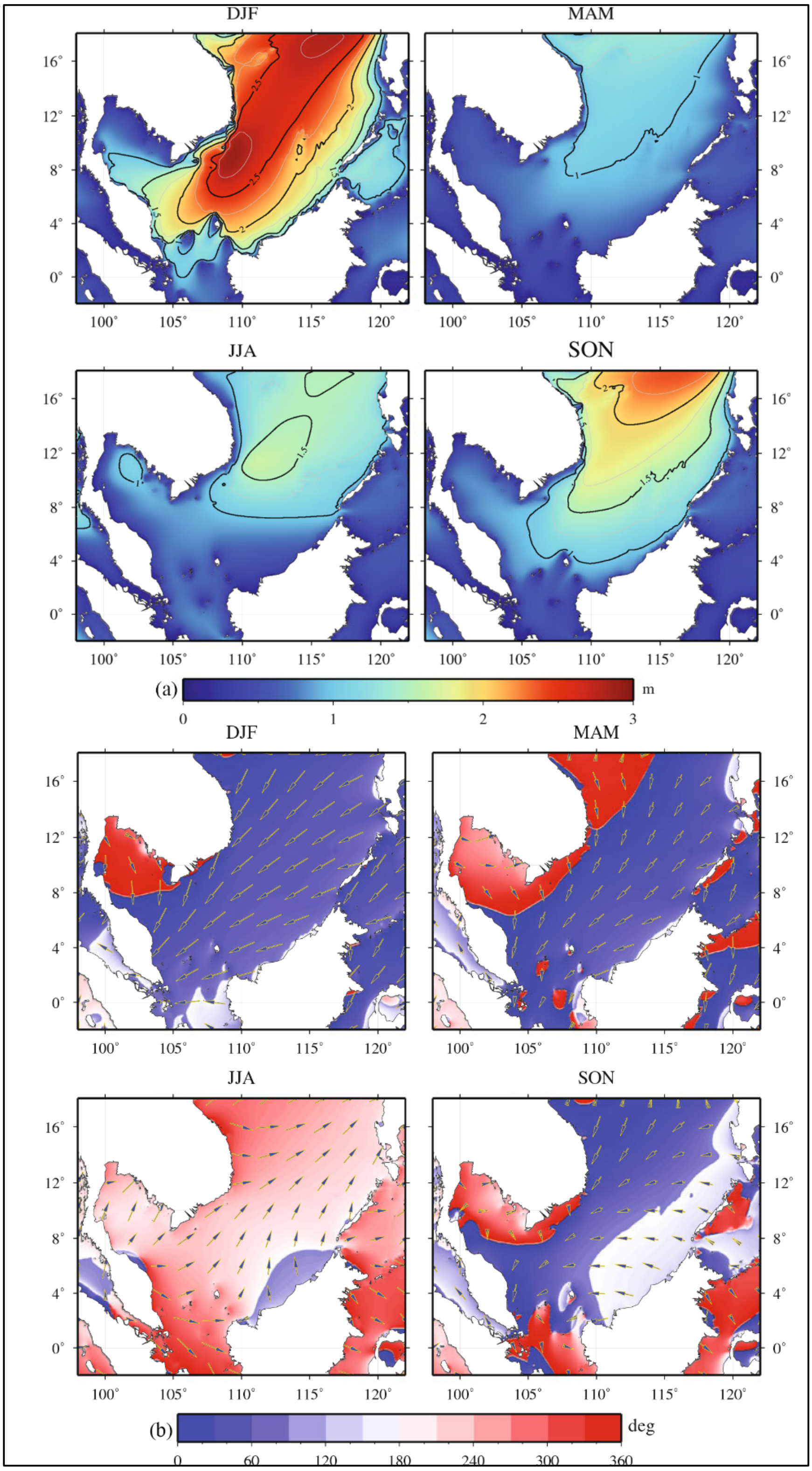

Figure 2.9: Seasonal mean of (a) significant wave height and (b) wave direction for the period 1979-2009 model hindcast. (DJF) December-January-February: Winter; (MAM) March-April-May: Spring; (JJA) June-July-August: Summer; and (SON) September-October-November: Autumn. (Source: Mirzaei *et al*., 2013).

2.5.4 Currents

Coastal currents include flows of water both parallel to and normal to the shore. Parallel flows within the surf zone are generally called longshore currents, which arise from continuity requirements of mass, momentum and energy near the coast. They are generated by a number of mechanisms, including oblique wave approach, differential water levels due to local variations in wave height, tidal streams, wave diffraction or direct wind shear. Understanding longshore current generation forms a link between waves, sediment movement and coastline evolution (Carter, 2002).

However, nearshore currents are mainly caused by surface waves breaking on a beach. In fact, when surface waves break on a beach, wave energy is lost to turbulence generated in the process of breaking, and the wave momentum transferred into the water column generate nearshore currents (Benassai, 2006). According to Davis and Fitzgerald (2004), there are three types of coastal currents that are produced by waves: (i) longshore currents, (ii) rip currents; and (iii) undertow. All three types of currents develop as the result of the shoreward progression of waves, and all three can play a role transporting sediment on the beach, especially in the surf zone.

However, the surface flow in the South China Sea during the northeast monsoon creates an anticlockwise circulation pattern. The wind pushes cooler coastal waters down through the Taiwan Straits to circulate west and southwards along the coast of China and Vietnam. These waters then either leave the South China Sea via the Karimata Straits or turn north-easterly and run along the coasts of Borneo and Palawan. This creates an anticlockwise gyre in the central area (Figure 2.10a). Meanwhile, under the influence of the southwest monsoon, current flow is reversed and water enters from the Java Sea via the Karimata Straits to sweep up into the central area and exit through the Taiwan Straits (Figure 2.10b) (Morton and Blackmore, 2001).

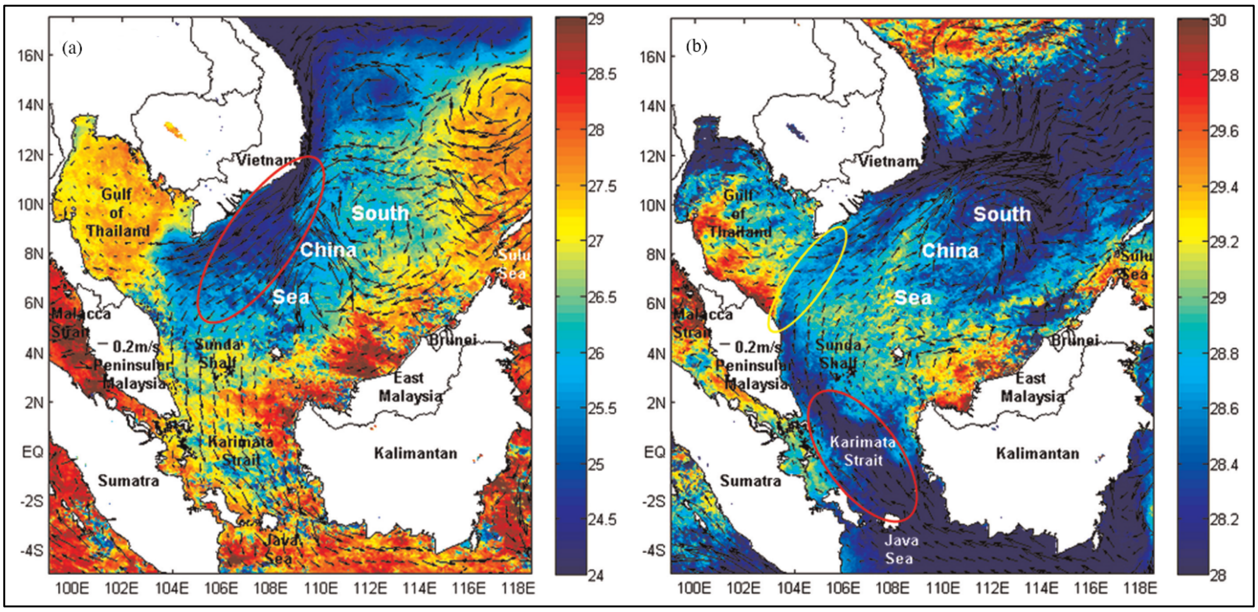

Figure 2.10: The surface currents of the South China Sea during (a) northeast monsoon and (b) southwest Monsoon. (Source: Kok *et al*., 2015).

On the east coast of Peninsular Malaysia, especially in the states of Kelantan, Terengganu and Pahang (between latitudes 3-6°N), the current circulation is greatly influenced by the monsoon winds. In Terengganu, coastal currents generally flow parallel to the coastline (Mohd Nasir and Meged, 1996; Rosnan and Mohd Lokman, 2005). The current flows southward during the northeast monsoon and northward during the southwest monsoons (Akhir and Chuen, 2011). Furthermore, the current is one of the factors acting on sediment transport and shoreline changes. According to Rosnan and Mohd Lokman (2005), fine sand particles are transported further by weak currents than coarser particles during strong currents. Rosnan and Mohd Zaini (2009) have established that the coastal sediments have an excess coarse fraction, and the area is under the influence of a strong current.

Furthermore, in Terengganu (Kuala Terengganu) the current flows north-west at an average speed of about 0.14 $m.s^{-1}$, which affects the volume and rate of longshore drift along the coastline (Mohd Lokman *et al*., 1998). However, the hydrodynamic regime has changed since the construction of the airport tarmac extension in 2010, especially as regards the current parameters. Hence, the effect on current velocities due to the interaction between an airport tarmac extension and hydrodynamic fields was examined in the laboratory by Mohd Radzi *et al*., (2014).

The results of the study show the impact of the airport tarmac extension leads to stronger current velocities on the north side (before the northeast monsoon storm), and tend to increase even further during the northeast monsoon storm. However, the currents on the south side are observed to be slower compared to the north side. The current velocity in the south tends to be even slower before the northeast monsoon storm, and then decreases slightly again during the storm.

On the other hand, the longshore current is an agent of coastline change (erosion or accretion). Figure 2.11 shows that the sector north of the airport extension underwent erosion, whereas accretion occurred on the southern side. According to Mohammad Fadhli *et al*. (2014), the longshore current during the southwest monsoon season is expected to be stronger than during the northeast monsoon, and the net longshore transport should be to the north. The longshore current is reduced by the new extension of the airport tarmac, while the sediment transport is blocked. Measurements obtained in the study area provide a general explanation and information on stations B3 (Universiti Malaysia Terengganu-North) and B4 (Teluk Ketapang-South).

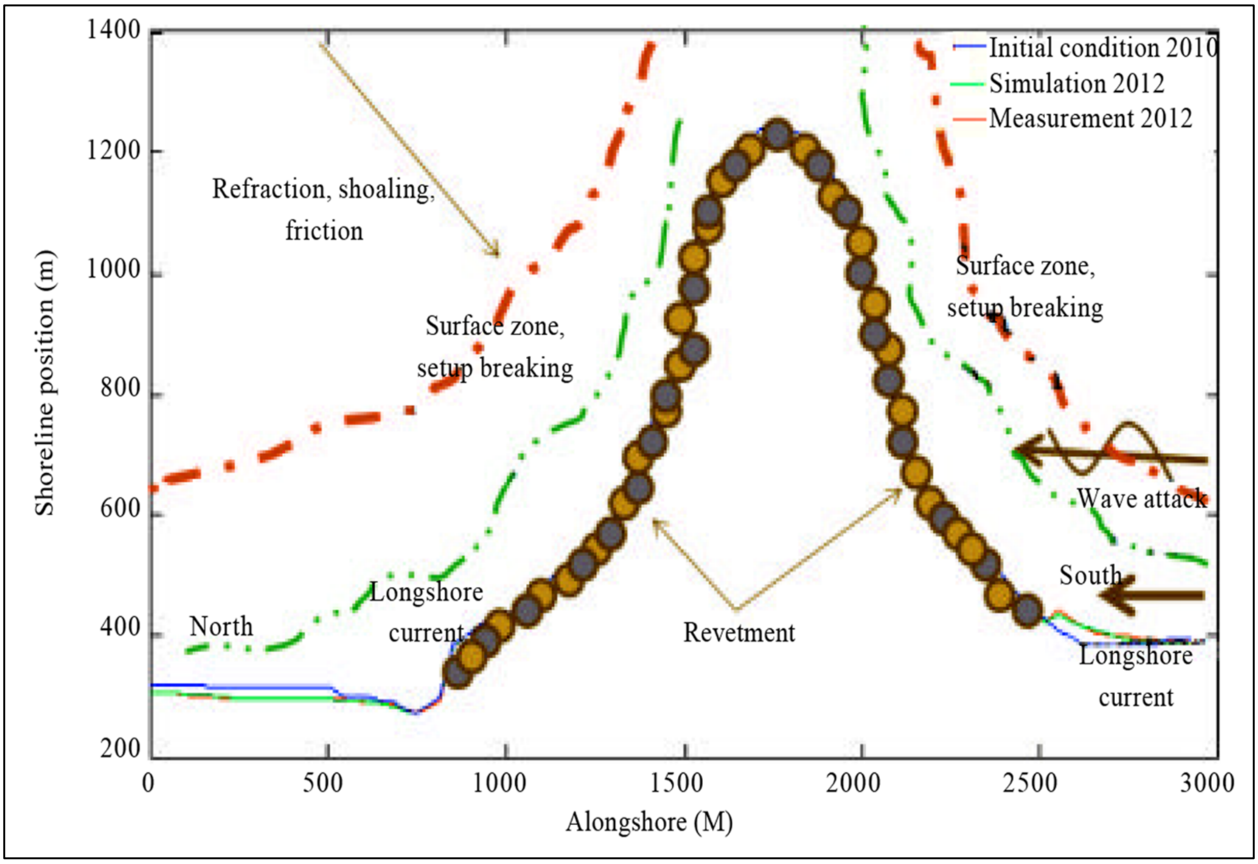

Figure 2.11: Longshore current in simulation and measurement shoreline on Sultan Mahmud Airport, Kuala Terengganu. (Source: Mohammad Fadhli *et al*., 2014).

2.5.5 Tides

Along with waves and currents, tides are among the major phenomena that control the interactions between sea and coast. The tides are best known as the rise and fall of the sea around the edges of the land. In some coastal areas, there is a regular pattern of one high tide and one low tide each day; this is called a diurnal tide. In other areas, there is a cyclic sequence of high water – low water that is repeated twice every day; this is called a semidiurnal tide (Duxbury *et al*., 2002). However, a mixed tide occurs when the high tides regularly reach different heights and the low tides drop regularly to different levels. Furthermore, tides are in fact waves with extremely long wavelengths (Haslett, 2000).

Rosnan *et al*. (1995) pointed out that the east coast of Peninsular Malaysia (Kuala Terengganu) is characterized by two types of tides; diurnal and semidiurnal. The diurnal component, giving one high water and one low water level every day, is dominant during most days. However, the semidiurnal component becomes more important during the equinoxes, resulting in two high and two low water levels a day. The successive high and low water levels, however, are unequal in height and time (Rosnan *et al*., 2003).

Table 2.4: Tidal levels at Standard Ports in Peninsular Malaysia, referred to DTGSM datum (West and East Coast).

Standard Port	MLWS	MLWN	MSL	MHWN	MHWS
	Unit in metres				
Penang (WC)	1.69	2.58	2.70	3.05	3.77
Klang (WC)	1.53	3.05	3.65	4.49	5.76
Tanjung Gelang (EC)	1.26	2.02	2.82	3.05	3.70
Chendering (EC)	1.12	1.72	2.22	2.71	3.28
Geting (EC)	1.72	2.09	2.31	2.59	2.77

*Note:

MLWS : Mean Low Water Spring WC: West Coast

MLWN : Mean Low Water Neap EC: East Coast

MSL : Mean Sea Level

MHWN : Mean High Water Neap

MHWS : Mean High Water Spring

However, in this study, the Peninsular Malaysia Geodetic Vertical Datum (DTGSM) is used as a reference for tide correction. Hence, the adjusted DTGSM datum is referred to the vertical datum of the Survey and Mapping Department Malaysia (2013) for analysis of the height discrepancy. Table 2.4 show the tidal levels on the west and east coasts of Peninsular

Malaysia at standard ports as referred to the DTGSM datum. However, in this study, the benchmark at Chendering Port is used as a reference for all beaches, which is a close approximation to the DTGSM datum in the study area.

Hence, the coast of Kuala Terengganu has a Mean Higher High Water (MHWS) and Mean High Water Neap (MHWN) tidal range of 3.28 m and 2.71 m, respectively. On the other hand, the tidal ranges at Mean Low Water Neap (MLWN) and Mean Low Water Spring (MLWS) are 1.72 m and 1.12 m, respectively. Furthermore, the Mean Sea Level (MSL) is 2.22 m. These tidal ranges exceeding 2 m are categorized as being of micro to meso-tidal (Ariffin *et al*., 2016) coastal type based on Short (1991).

CHAPTER THREE: METHODOLOGY

Contents:

3.1 Introduction

In this chapter, appropriate techniques and suitable methods are briefly discussed. Details are given of the procedures for data acquisition and interpretation, along with the sampling techniques and laboratory analyses carried out to meet the research objectives. This presentation includes observations of shoreline evolution, beach morphology (morphodynamic) measurements, sediment collection and grain-size analysis, as well as the determination of related physical parameters using the Mike hydrodynamic module.

3.2 Hypotheses

Several hypotheses are proposed and investigated as part of this study:

i. Changes in beach morphology are based on the alternation mechanism. The rotational process of sediment transport (erosion and deposition) creates a variability of beach profile and produces a cyclic motion.

ii. It is possible to estimate the cycle period of particular beach state based on its profile variance in relation to seasonal monsoons.

Testing the validity of these hypotheses yields some important information on the usefulness of investigating beach formation based on morphological profiles. Therefore, the analytical techniques for identifying beach modifications in different environments can be used to highlight the variety of beach dynamic conditions.

3.3 Materials and Methods

In order to test the hypotheses, data acquisition and sampling procedures were carried out that involved fieldwork, laboratory analyses and data interpretation. Fieldwork operations involved beach profile measurements and sediment sample collection, as well as Acoustic Wave and Current Profiler (AWAC) measurements (validation for wave modelling). These operations were conducted concurrently during the day of sampling. Stations were selected in areas affected by anthropic activities, which is the case for UMT (B3), Teluk Ketapang (B4), Seberang Takir (B5), Kuala Ibai (B6) and Marang (B7) (see Table 2.2). Two stations, situated at Batu Rakit (B1) and Pengakalan Maras (B2), are located far from human influence and show a more stable beach morphology. The data collection was carried out bi-monthly from July 2013 to June 2015 over a period of two years (24 months).

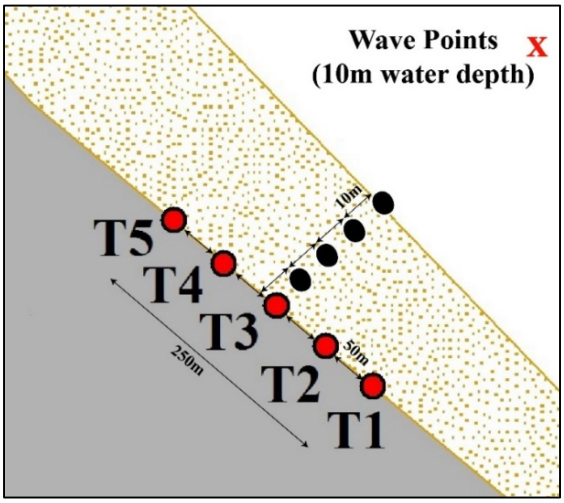

Figure 3.1: Map showing transects in location of station points.

As presented and illustrated in Chapter 2 (Figure 2.2), the study area is divided into three zones covering seven beaches (station points) along the Kuala Terengganu coastline. Each studied beach area comprises five transects with a spacing of 50 m between transect lines and covers a beach length of 250 m. The sediment sampling points were taken in the middle of the transects (Transect 3 - T3), placed at intervals of 10 m starting from the dune/vegetated zone and extending down to the low tide mark. The data used for modelling were extracted from each wave parameter station point within a 10 m water depth (Figure 3.1).

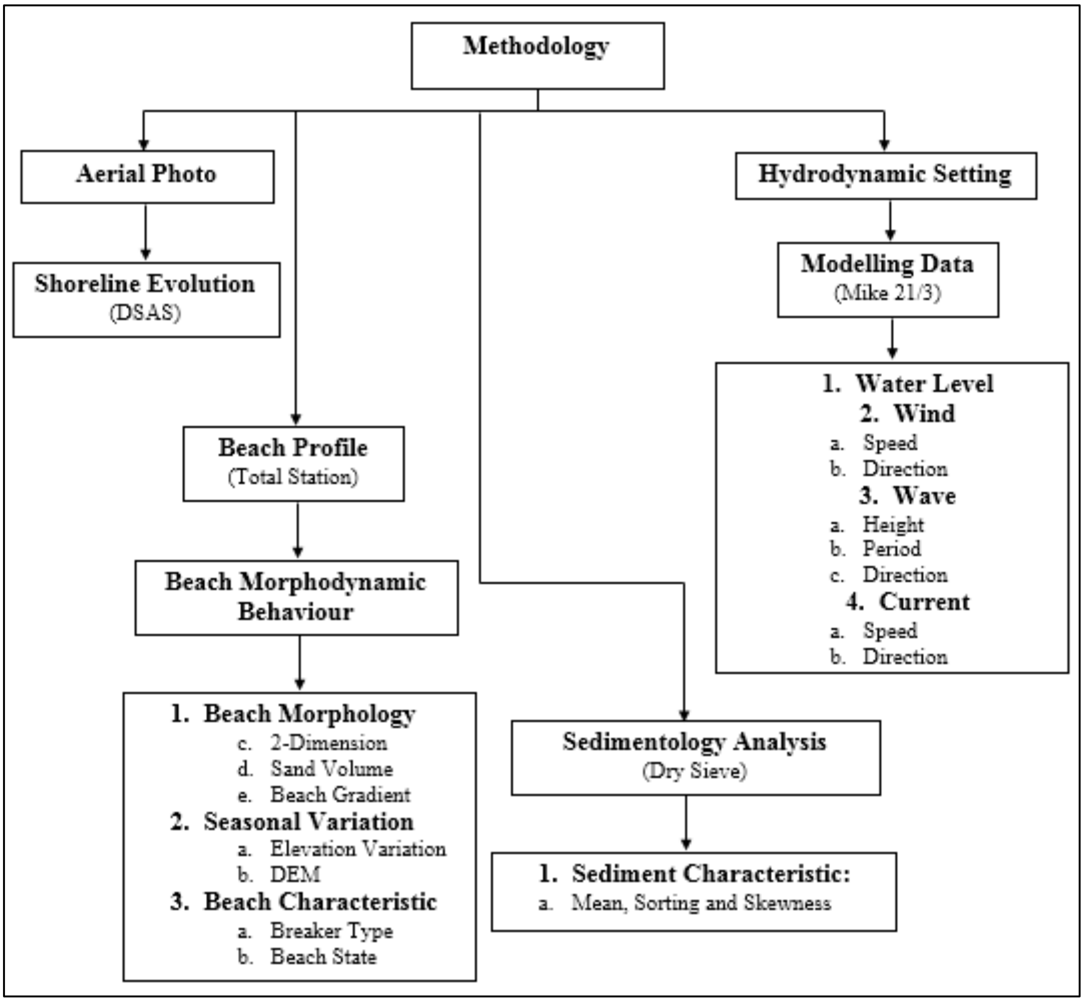

Figure 3.2: Schematic diagram of methodology used in the study.

Figure 3.2 presents a simplified flow chart of the methodology applied in this study. Details of the materials and methods are presented below in 3.3.1) shoreline evolution; 3.3.2) beach morphodynamic behaviour; 3.3.3) sedimentology analysis and; 3.3.4), hydrodynamic setting in modelling module.

3.3.1 Shoreline Evolution

The evolution of the Kuala Terengganu shoreline was determined using the Digital Shoreline Analysis System (DSAS). Shoreline changes were observed between 2006 and 2014 using aerial photographs. The images were then processed by geometric correction using UTM-WGS 1984 projection. A large number of studies have employed DSAS to determine shoreline evolution, associated with the application of various sub-methods (Aouiche *et al*., 2016; Hapke *et al*., 2013; Kaliraj *et al*., 2013; Sudha Rani *et al*., 2015; To and Thao, 2008). The present study, however, only incorporates the End Point Rate method. The End Point Rate (EPR) is calculated by dividing the distance of the shoreline movement by the time elapsed between the earliest and latest measurements (i.e., the oldest and the most recent shoreline).

The major advantage of using the EPR is its ease of computation and minimal shoreline requirements (two shorelines). However, the major disadvantage is that, when more than two shorelines are available, the information about shoreline behaviour provided by these additional shorelines is not taken into account. Thus, changes in the sign or magnitude of the shoreline movement trends, or the cyclicity of behaviour, may be overlooked. Hence, we present two separate comparative studies which analyse the shoreline evolution from 2006 to 2012 and from 2012 to 2014. This procedure is used to determine and compare the rates of shoreline change at different periods.

Based on the report of Thieler *et al*. (2009), DSAS was developed using Avenue to build an ArcView extension to the ArcGIS software, with the purpose of extending its normal functionality to include historical shoreline change analysis. This software extension was designed to guide the user efficiently through all the major steps of change analysis in a clearly organized and attractive user interface. This extension to ArcView contains three main components: a) to help the user define a landward baseline, b) to generate orthogonal transects with a user-defined separation, and c) to calculate rates of change.

To carry out the calculation of shoreline changes, 246 transects at 100 m (Kaliraj *et al*., 2013; To and Thao, 2008) transect intervals were automatically established as seen in Figure 3.2 There are 139 transects in Zones A and B, and 107 in Zone C. With reference to the baseline, each transect position representing accretion is considered as a positive value, whereas landward shifts are considered as negative and represent erosion. The rate of statistical change on each transect is expressed in metres. However, this method is only applied in Chapter 4 to calculate the shoreline evolution from 2006 to 2014.

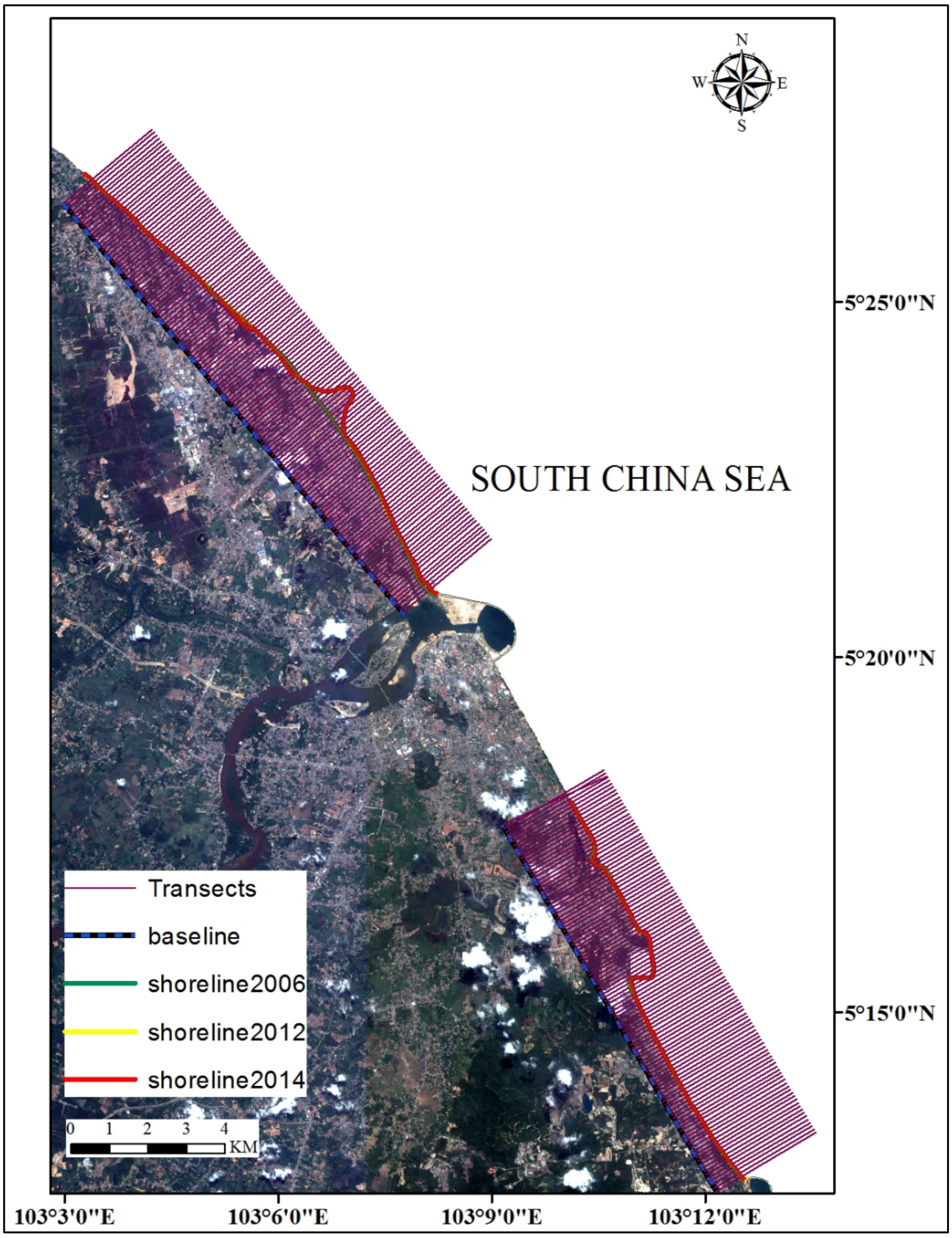

Figure 3.3: Methodology for calculating rate of shoreline change using DSAS software.

3.3.2 Beach Morphodynamic Behaviour

Beach profile studies (topographic surveys) were carried out at seven station points located in three selected zones of the Kuala Terengganu coast (Figure 2.2) every month over two years using a Topcon (GPT-3000) Total Station (Figure 3.4), with an accuracy of ±1 cm. Benchmarks located on the backshore (berm/vegetated zone) of the survey sites were adjusted to the DTGSM datum (see Table 2.4). In detail, the surveys covered the berm/vegetated areas and extend seaward over an average beach width/profile length of 40-80 m down to a water depth of 0.5 m. Furthermore, the beach profile, volumetric and slope variations are calculated from the Profiler 3.0XL-Excel program.

(a) (b)

Figure 3.4: (a) elevation survey (b) beach profile measurements using Total Station.

However, to determine the beach morphodynamics, different parameters are used to predict the beach characteristics (e.g. breaker type and beach state). Two classic morphodynamic parameters, based on wave height, period and beach slope, are employed here to characterize the studied beaches (Taaouati *et al*., 2011). This study depends on two types of method describing the Breaker Type and Beach State, to classify the beaches according to their morphodynamic characteristics. However, to apply these methods, the deep water wave height (H_0) is used to estimate the breaking wave height (H_{ob}), which itself depends on the morphology of the subtidal zone and its alongshore variation (Larson and Kraus, 1994).

Since the subtidal zone exhibits a broadly constant slope on the shoreface of Kuala Terengganu, the breaking wave height is calculated using the approximation proposed by Komar and Gauhan (1972), as expressed in Equation 3.1:

$$H_b = 0.39 g^{0.2} (T H_0^2)^{0.4}$$ Equation (3.1)

where:

H_b is the breaking wave height

g is the acceleration due to gravity

T is the wave period, and

H_0 is the wave height in deep water.

In addition, the breaker type is calculated by the surf similarity index (Battjes, 1974; Galvin, 1968), which differentiates between spilling, plunging and surging breakers. This index is estimated in Equation 3.2 as follows:

$$\xi_b = \frac{\tan\beta}{(H_b/L_0)^{0.5}}$$ Equation (3.2)

where:

$\tan\beta$ is the beach slope, and

L_0 is the wave length

However, to calculate L_0, we use Equation 3.3 as follows:

$$L_0 = gT^2/2\pi$$ Equation (3.3)

where:

g is the acceleration due to gravity (9.81 m/s^2),

T is the offshore wave period, and

π is taken as 3.142.

On a uniformly sloping beach, breaker type is estimated as spilling ($\xi_b<0.4$), plunging ($0.4<\xi_b<2$) or surging ($\xi_b>2$).

Additionally, Wright and Short (1984) provide a criterion for predicting beach state based on breaking wave height and sediment grain size using the dimensionless fall velocity (Ω) proposed by Dean (1973) and Gourlay (1968), expressed in Equation 3.4 as:

$$\Omega = \frac{H_b}{w_s T} \qquad \text{Equation (3.4)}$$

where:

H_b is the breaking wave height

w_s is the sediment fall velocity, and

T is the offshore wave period.

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

3.3.3 Sedimentology Analysis

Samples were collected only from Transect 3 at each station, along a beach profile from dune to low-tide mark (Figure 3.1). Hence, the coordinates of the sediment sampling points and their elevations were measured by Total station to identify eventual correlations between elevation and sediment characteristics (Kim *et al.*, 2016). The samples were taken (monthly survey) from a 1-7 cm-thick surface layer, placed in plastic bags and labelled for laboratory analysis. In the laboratory, carbonate fragments such as shells and other debris including pieces of wood, roots and leaves were removed carefully from the sample. Then, the samples were dried in an oven at a temperature of 60 – 70 °C for about 48 hours.

Sediments were dried and split to obtain sub-samples of around 100 g, which were sieved for 15 minutes with 4 to -2 Φ sieve sizes (0.063 to 2 mm) to obtain fractions ranging from fine to coarse sand (Folk, 1980). Then, grain-size analyses were conducted to determine the statistical parameters such as mean size, sorting and skewness, which were calculated using the GRADISTAT program (Blott and Pye, 2001). In statistical parameter calculations, phi (Φ) units are commonly used rather than the normal metric units. This is because fine particles are usually predominant in sediments compared with the coarser fractions, thus yielding a skewed distribution. The Φ scale transforms the sediment grain-sizes into an approximately log-normal distribution (Buller and McManus, 1979; McBride, 1971). The Φ scale values are calculated by Equation (3.5):

$$\Phi = -\log_2 d \qquad \text{Equation (3.5)}$$

Where:

d is diameter of the grains in millimetres

However, a brief explanation is given here of the equations used to calculate statistical parameters such as mean size, sorting and skewness. Mean grain size (*x*Φ) is controlled by the magnitude of forces applied by water or wind, which are responsible for moving the grains; it is computed by Equation 3.6:

$$(x\Phi) = \frac{\Sigma fm}{n} \qquad \text{Equation (3.6)}$$

where:

f is the weight percentage of each particle-size grade

m is the median particle size in Φ units, and

n is the total number of grains in sample, in 100s

The standard deviation of the sorting index reflects the range of forces which determine the sediment grain-size distribution. *Sd*Φ is determined using Equation 3.7:

$$(Sd\Phi) = \sqrt{\frac{\Sigma f(m-x)^2}{100}} \qquad \text{Equation (3.7)}$$

where:

f is weight percentage of each particle-size grade

m is the midpoint of each size class, and

x is the mean grain size

Skewness indicates how the sample was formed. The equation for skewness is given in Equation 3.8:

$$(Sk\Phi) = \frac{\Sigma f(m-x)^3}{100\sigma\Phi^3} \qquad \text{Equation (3.8)}$$

where:

f is frequency in percent of each size class

m is midpoint of each size class

x is mean size, and

$\sigma\Phi$ is the standard deviation of Phi

In Kim *et al.* (2016), the grain-size trend analysis (GSTA) proposed by Gao and Collins (1992) was applied to particle-size data to estimate net sediment transport patterns on beaches. According to Gao and Collins (1992) and McLaren and Bowles (1985), two spatial trends are considered to represent sediment pathways. The first trend represents finer grained, better sorted and more negatively skewed distributions, while the second represents coarser grained, better sorted and more positively skewed distributions.

3.3.4 Hydrodynamic Setting

A hydrodynamic model was simulated using a flexible mesh to determine wave parameters and current circulation patterns in Kuala Terengganu coastal waters. The modelling was performed using MIKE 21/3 (Spectral Wave and Flow Model) modules, developed by the Danish Hydraulic Institute (DHI, 2011). The model was simulated for two years, and the monthly results obtained are the subject of detailed discussion. The model is constrained with three major forcings: wind, tides and density. Six-hourly wind data were extracted from the ECMWF database. However, the tidal data used at the boundary was obtained from the nearest tide gauge (Figure 2.2).

As a prior step, model validation is performed using field measurement data to check the simulation output. The root mean square error (RMSE) is calculated using the significant wave height field (AWAC data, see Figure 2.2 for location) as well as the modelled data. The results of the models are validated with four months of AWAC wave height data recorded nearshore at Kuala Terengganu (12 m water depth). The AWAC measurements are available in six hourly intervals covering the period from November 2013 to February 2014. Figure 3.5 shows the computed statistics for the entire data set, including the root mean square error (RMSE). Generally, based on the scatter plots, the model performs reasonably well in simulating the wave and current parameters. For these simulation runs, the RMSE is 0.29 m, which is acceptable for model validation since it close to the value obtained by Fatimah and Nuramalina (2012) and Mirzaei *et al*. (2013). The equation used to calculate RMSE is show in Equation 3.9 as follows:

$$\text{RMSE}=\sqrt{\sum \frac{(H_{s\,InSitu} - H_{s\,Model})^2}{N}} \qquad \text{Equation (3.9)}$$

where:

Hs is the significant wave height, and

N is the number of significant wave height readings (H_s).

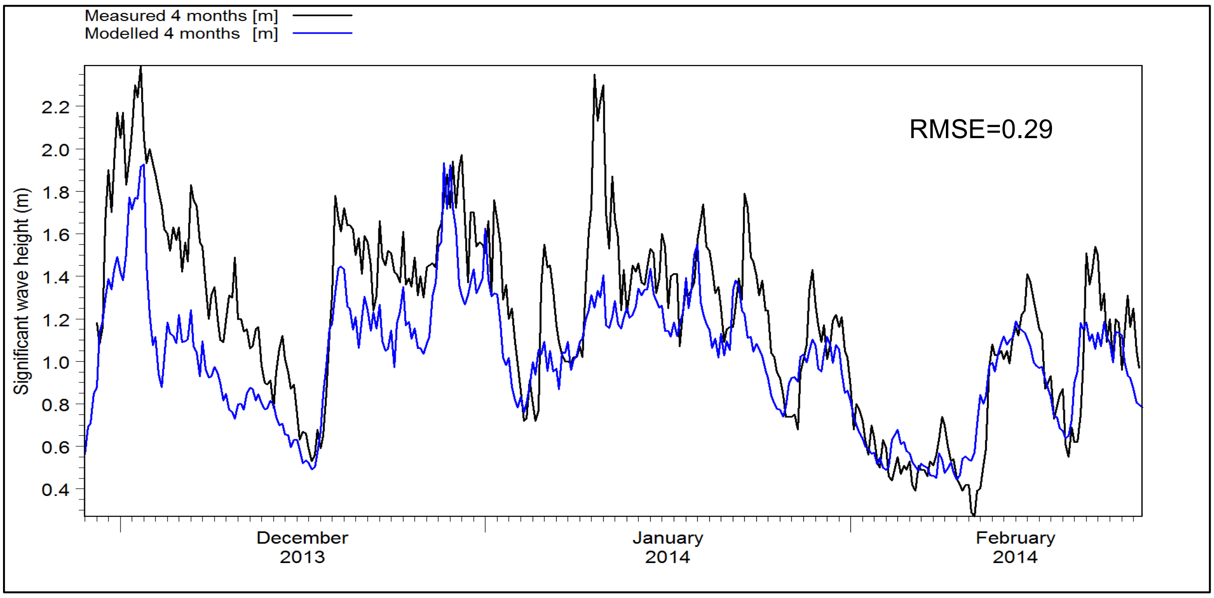

Figure 3.5: Comparison between measured and modelled significant wave height at AWAC measurement points in 12 m water depth (see Figure 2.2 for location).

At certain times, the model underestimates the wave height; in such cases, a higher resolution of wind forcing is required to simulate forcing at the boundary. Moreover, the wave height could be influenced by strong wind forcing, especially during the monsoon season (Camerlengo and Demmler, 1997).

Model calibration is carried out to find the best tuning for the model setup. Five coefficients are considered in the calibration process, i) bottom dissipation given in terms of the Nikuradse roughness, ii) wave breaking coefficient, iii) wave current interaction, iv) water surface elevation and v) wind wave growth formulation. These coefficients are used as variable parameters in the basic equations of the hydrodynamic model.

Model calibration is executed by replacing the selected coefficients with a recommended value. The initial calibration is based on the default value recommended by the model developers using values of 0.002 mm for Nikuradse roughness and 0.8 for the Gamma coefficient (DHI, 2011). The calibration using these values produces good results (Table 3.1).

Table 3.1: Key model settings applied in calibration and data production in SW flexible mesh.

Parameters		Description
Bottom dissipation	Model	Nikuradse roughness, KN
	Nikuradse roughness data	Constant: 0.002 mm
	Current friction	0
Wave breaking	Model	Wave breaking
	Type of Gamma	Constant: 1
	Gamma data	Constant: 0.8
	Alpha	Constant: 1
Wave current interaction		No current effect
Water surface elevation		Constant: 0
Wind wave growth formulation		SPM73/HBH

CHAPTER FOUR: ASSESSMENT OF THE IMPACT FROM ARTIFICIAL COASTAL STRUCTURES ON THE SHORELINE EVOLUTION OF MONSOON DOMINATED COASTS IN KUALA TERENGGANU, MALAYSIA

Effi Helmy Ariffin, Mouncef Sedrati, Mohd Fadzil Akhir, Nurul Rabitah Daud, Rosnan Yaacob and Mohd Lokman Husain, XXXX. The Shoreline evolution of monsoon-dominated coasts through integrated management in Kuala Terengganu Malaysia. *Journal of Ocean and Coastal Management* (Submitted).

Contents:

4.1 Introduction

The erosion of coastal areas is indeed a topic of great concern worldwide, since at least 70% of sandy beaches across the globe are currently being eroded (Bird, 1985). In the context of this global problem, coastal areas of the United States of America, for example, have been undergoing all types of erosion over the past 100 years (Zhang *et al*., 2004) with well documented widespread erosion being observed, especially in California (Moore *et al*., 1999). China, on the other hand, regards coastal erosion as a major concern for the future socio-economic development of its coastal cities (Cai *et al*., 2009). India, however, has had to come to terms with coastlines that have been relentlessly modified as a result of mounting development activities that have not been properly managed and, at times, this has led to severe coastal erosion problems (Rajawat *et al*., 2015). Another example is provided by Australia, where 85% of the population lives within 50 km of the coastline, which will eventually lead to risks of coastal erosion at some stage (Watson *et al*., 1996).

In the case of South East Asia, the coasts of southern Thailand are subject to erosion that is damaging many infrastructures and threatening the livelihoods of coastal communities in the region (Saengsupavanich *et al*., 2009). As a major research effort in this global context, Malaysia has conducted its own National Coastal Erosion Study, concluding that nearly 30% of its coastal areas are threatened by erosion in some way, thus attracting the attention of the relevant Government bodies since the 1980s (Nor Hisham, 2007).

The main causes of erosion worldwide are clearly related to natural as well as anthropogenic factors. Natural phenomena such as storms (monsoonal storms) with their associated strong winds, waves and currents, are among the obvious factors that contribute to erosion along the coasts of many countries. Another important factor leading to erosion arises from various anthropogenic modifications and structures along a coast. Although most of these structures (e.g. revetments, ripraps, seawalls, groynes and breakwaters) are designed to control erosion, it is interesting to note that they can actually cause erosion in many cases.

Breakwaters were constructed in Agadir Bay, Morocco, to address erosion problems after the establishment of Agadir Port in 1978 (Aouiche *et al.*, 2016). Furthermore, in the case of Gopalpur Harbour, India (which was built in 1987), similar problems necessitated the construction of a groyne. This structure juts out into the sea and is designed to trap longshore sediments for the conservation of a busy protected beach. In this way, the groyne serves to reduce erosion as well as prevent longshore drift from reaching downdrift areas in nearby ports or inlets (Mohanty *et al.*, 2012).

Groynes are able to modify the longshore transport of sediment, resulting in the accumulation of sand mostly on the updrift side, as well as erosion of sand on the downdrift side (Aouiche *et al.*, 2016; Mohanty *et al.*, 2012). In another study, the opposite is observed, with modifications in longshore sand transport caused by groynes leading to erosion on the updrift side and accretion on the downdrift side (Hsu *et al.*, 2007; Muslim *et al.*, 2011). The above examples show that hard structures, whether on the updrift or downdrift side of a shoreline, are able to mitigate the impact of erosion and accretion, which remain at stable levels depending on the rates at which the sediment is supplied to or removed from the foreshore (Türker and Kabdaşli, 2007).

The effects of groynes on shoreline changes have been studied using physical and other numerical models (Elmoustapha *et al.*, 2007; Elsayed and Mahmoud, 2007; Pattiaratchi *et al.*, 2009). According to Pattiaratchi *et al.* (2009), groynes are often used along coastlines to protect beaches against coastal erosion. A substantial number of studies have been carried out to determine the impact of groynes on coastlines. However, fewer studies have examined the interaction between groynes and hydrodynamic characteristics (Castelle *et al.*, 2015; Escudero *et al.*, 2014; Nair *et al.*, 2015).

The circulation (or eddy) patterns of the hydrodynamic field around groynes can affect local sediment transport rates. The interaction between these groynes and the hydrodynamic field creates currents with flow separation which produce eddies around the groyne (Pattiaratchi *et al*., 2009). A similar situation is also reported by Silva *et al*. (2010) near a headland (coastal landform). While the headland is similar in form to a groyne (jutting out into the sea), the downslope area is nevertheless affected by erosion due the currents and waves being oriented perpendicular to the shore (Frihy and Lotfy, 1997).

According to Silvester (1961) (as cited in Masselink and Pattiaratchi, 2001), currents generated by north-westerly storms in winter result in the southward movement of sand. Hence, the currents are strongest during a storm and can move sediments to other areas. According to Pattiaratchi *et al*. (2009), currents are produced from diffraction and refraction of the waves. The wave direction angle also provides energy to the current velocity; an increasing angle tends to produce higher current velocities compared to lower angles which are associated with a much lower velocity.

Kurian *et al*. (2009) reported that the wave direction angle changes from 226° during a pre-monsoon period to 246° during a monsoon. It then turns back to 204° during the post-monsoon. This clearly shows that the wave direction angle increases during the monsoon and decreases during the post-monsoon. The wave direction is predominantly influenced by the change in direction of monsoonal winds. For example, during the northeast monsoon along east coast of Peninsular Malaysia, the wind is north-easterly, whereas during the southwest monsoon, it becomes south-westerly (Mirzaei *et al*., 2013).

In the present study, the Kuala Terengganu coastline is analysed using aerial photographic surveys carried out from August 2006 to August 2014, by comparing observations prior to and after the construction of the tarmac extension (into the sea) of Kuala

Terengganu airport. In addition, a beach profile survey was carried out during September 2013 to August 2014 to characterize the beach morphology viewing. However, in view of the objective of this study, the hydrodynamic results allow a comparison of the impact of shoreline modifications which take into account the presence or absence of the airport tarmac extension (into the sea). Furthermore, this study also acts as a preliminary guide to the introduction of appropriate measures for the reduction of erosion in future offshore and coastal construction projects (by maintaining safety and economics of design).

4.2 Summary of Study Area

The study area was divided into three zones; namely Zone A and Zone B which comprised of the areas in the north of Kuala Terengganu, and Zone C comprising areas in the south of Kuala Terengganu being separated by the Terengganu River. In this study, the wave parameter station points (M station points) in every zone are selected based on particular coastline problems in Zone A (from M1 to M4), Zone B (M5 to M7) and Zone C (M8 to M10). However, every zone has one beach profile survey (B station points) to examine the changes during the peak of northeast and southwest monsoon. However, only Zone C has two beach profiles survey due to the big distance between two station points. The beach profile of the station points in Zone A and Zone B are B3 and B6 respectively. Zone C's beach profile is B8 and B10 (Figure 4.1). Furthermore, in detail of study area description is discussed in Chapter 2.

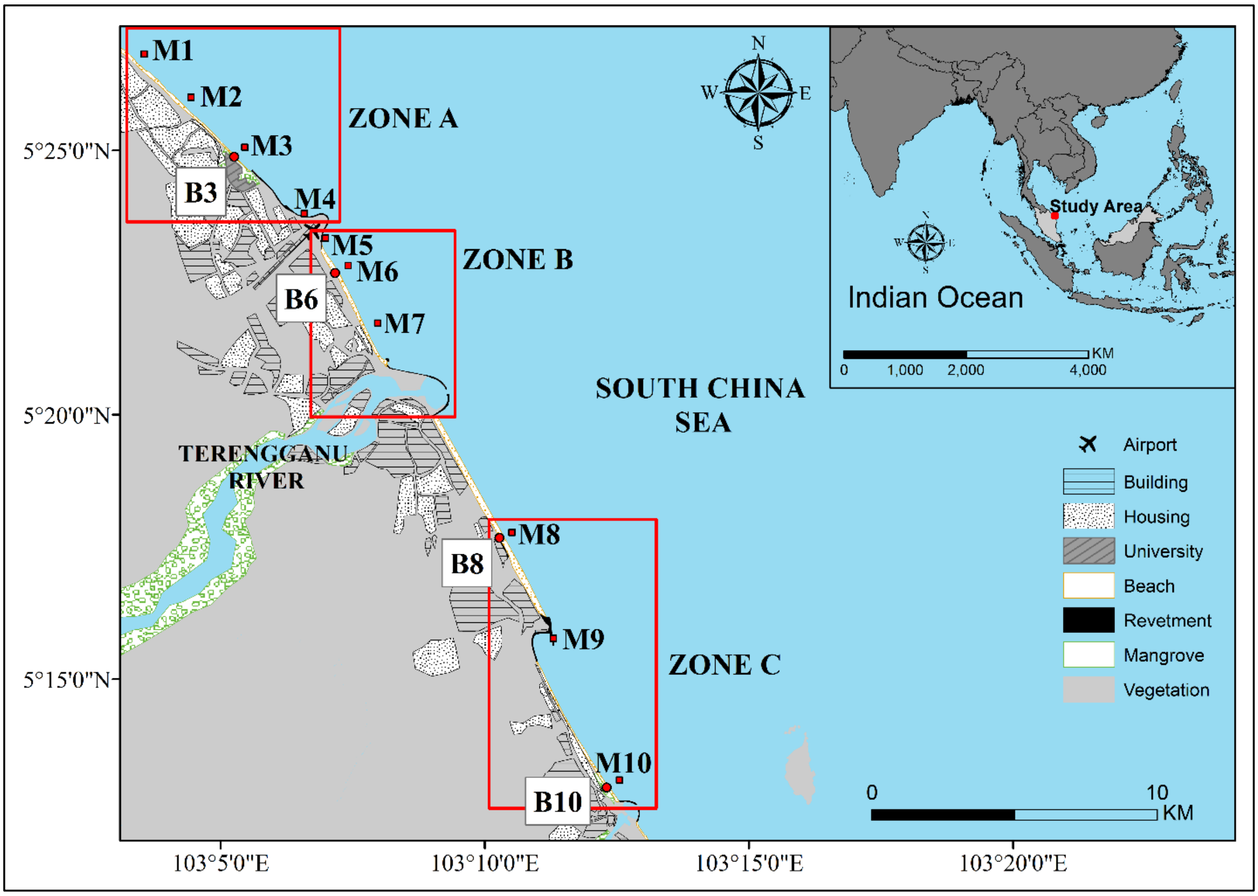

Figure 4.1: Kuala Terengganu on the Terengganu coast; where the beach profile (B points) and wave (M points) station are in circle and square symbols respectively.

4.3 Summary of Methodology

In this chapter, shoreline evolution is briefly discussed with the Digital Shoreline Analysis System (DSAS) software, which was used in observing historic shoreline positions. For a clearer perspective of the historical shoreline evolution, a comparison of the shoreline was determined based on aerial photograph between 2006 - 2012 and 2012 - 2014. On the other hand, the construction of the new airport tarmac extension began in 2007 and was completed in 2010. In addition to that, the beach profile survey was taken after the construction of new airport tarmac extension whereas on September 2013, December 2013 and August 2014 respectively. Four beach profiles (Figure 4.1) were selected for a one-year data analysis period based on seasonal monsoons i.e. in September 2013 and August 2014 (in between the peak of the southwest monsoon). The peak of the northeast monsoon however was found to be in December 2014. However, to know the impact of airport tarmac extension, the comparison of hydrodynamic model by without and with the airport tarmac extension was used. It should be noted that the hydrodynamic setting analysis used Mike 21-SW for wave and Mike 3-FM for current parameter measurements respectively. This model was observed during 2006 to 2014. However, in detail of methodology is discussed in Chapter 3.

4.4 Results

This chapter presents the shoreline evolution before and after construction of the airport tarmac extension in relation to seasonal monsoons. The rates of erosion and accretion along each sector are calculated for the periods 2006 - 2012 and 2012 - 2014. However, additional information is included here regarding the beach profile. The seasonal monsoon is discussed in more detail in terms of its hydrodynamics (waves and currents), based on a study carried out in 2005 - 2006 (before construction of the airport tarmac extension), as well as in 2011 - 2012 and in 2013 - 2014 (after the airport tarmac extension was completed).

4.4.1 Historic Rates of Shoreline Change

4.4.1.1 Shoreline Evolution between 2006 and 2012

From 2006 to 2012, as illustrated in Figure 4.2, Zone A was a sector of erosion located on the updrift side of the airport tarmac extension. The maximum erosion obtained shows a shoreline position change of -15.84 m near the airport tarmac extension, with an average value of -11.38 m. However, the accretion readings reach an average of +0.85 m, which is observed just outside the maximum erosion area. Zone B represents a sector of accretion located on the downdrift side of the airport tarmac extension. Two patterns of accretion are observed in this area, with a maximum recorded change of +21.32 m and an average value of +6.81 m. However, intense accretion is observed to the north of Terengganu River. Zone C represents a sector of accretion, with a change of +15.76 m observed between 2006 and 2012. In detail, an accretion of 18.32 m is recorded in Zone C at the mouth of Kuala Ibai River. On the other hand, accretion to the south of Chendering Port corresponds to an average shoreline evolution of +1.00 m. However, an accretion of +2.74 m is recorded to the north of Marang River.

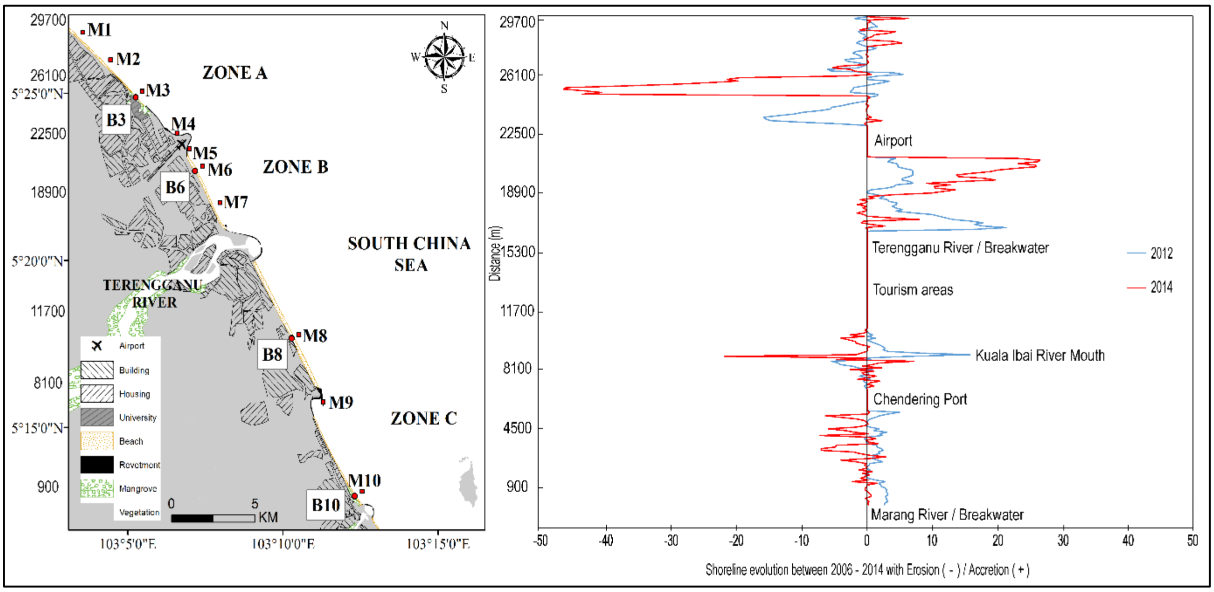

Figure 4.2: The shoreline evolution during 2006 to 2014.

4.4.1.2 *Shoreline Evolution between 2012 and 2014*

Figure 4.2 shows the shoreline evolution in these three zones between 2012 and 2014. In Zone A, a coastline defence structure (2.5 km revetment) was constructed after the erosion problem was observed in 2012 (see Table 2.2 in Chapter 2). In 2014, however, the erosion moved to an area just beyond the revetment, with the most intense erosion being observed at a maximum value of -46.50 m and an average of -17.82 m. The same situation is observed in

2006 - 2012, when accretion is observed with a reading of +1.28 m on the updrift side (in an area just outside the zone affected by erosion). In Zone B, the same pattern is observed in 2006 – 2012, with two patterns of accretion. However, intense accretion is also observed in Zone B near the airport tarmac extension. This accretion corresponds to a maximum change of +26.48 m, with an average value of +9.03 m. In Zone C, an erosion of -21.83 m is recorded at Kuala Ibai River mouth. An average rate of erosion of -1.45 m is observed to the south of Chendering Port. By contrast, a lesser degree of accretion (+0.02 m) is observed to the north of Marang River compared with 2006 - 2012.

4.4.2 Beach Profile and Volume Changes

Figure 4.3 summarizes the shoreline evolution information obtained from the four beach profiles carried out in September 2013, December 2013 and August 2014, while Table 4.1 reports the beach volume data. The profile B3 (in Zone A) is located on a beach at the Universiti Malaysia Terengganu (UMT), situated about 3 km along the coast from the northern part of Kuala Terengganu airport. The foreshore at profile B3 did not undergo any changes up to December 2013 since the riprap was still in place at this site. However, the backshore zone received an input of sediments represented by an increase of 4.48 m^3 in sand volume. By contrast, half of the area of B3 beach became eroded by August 2014, resulting from a collapse of riprap that occurred in April 2014 (during pre-southwest Monsoon). The beach volume at this site corresponds to an erosion of -1.78 m^3 in the period up to August 2014. The second beach profile is located at Teluk Ketapang (B6-Zone B), south of Kuala Terengganu Airport and north of the Terengganu River. The beach profile B6 surveyed in December 2013 shows that accretion is occurring over the interval from 25 to 65 m, corresponding to an increase in sand volume of 23.27 m^3, which was then reworked to yield +2.10 m^3 of sand volume on the foreshore in August 2014.

The third beach profile (B8) in Zone C is located on Kuala Ibai beach, in a sector with revetment on the backshore. This pattern of change at B8 beach is the same as the natural beach cycle on the Kuala Terengganu coastline, depending on the northeast monsoon which tends to enhance erosion and the southwest monsoon which leads to recovery and/or accretion. The B8 beach profile shows that, prior to December 2013, the beach profile was subject to erosion with a loss of 10.92 m^3 of sand volume. Up to August 2014, the beach tends to undergo accretion compared to the profile in September 2013, with a sand volume increase of 11.82 m^3. Lastly, the Marang Beach (B10-Zone C), located north of the Marang River, undergoes some erosion up to December 2013, with a loss of 5.68 m^3 of sand volume. At this site, only the foreshore shows some recovery between September 2013 and August 2014, corresponding to an increase of 1.17 m^3 in sand volume.

Table 4.1: The beach volume sequence at four beaches along Kuala Terengganu coast with comparison profile of seasons. The minus '-' value indicates the volume of sand eroded; plus '+' value indicates the volume of sand deposited (refer to Figure 4.3 for the 2-D graph).

Station Points	Sep-13	Dec-13	Aug-14	A	B
	Volume in cubic meters				
B3	50.13	54.61	52.83	+4.48	-1.78
B6	133.35	156.62	158.71	+23.27	+2.1
B8	49.77	38.85	50.67	-10.92	+11.82
B10	90.95	85.27	86.44	-5.68	+1.17

**A: Northeast monsoon (comparison between September 2013 and December 2013); B: Southwest monsoon (comparison between December 2013 and August 2014).*

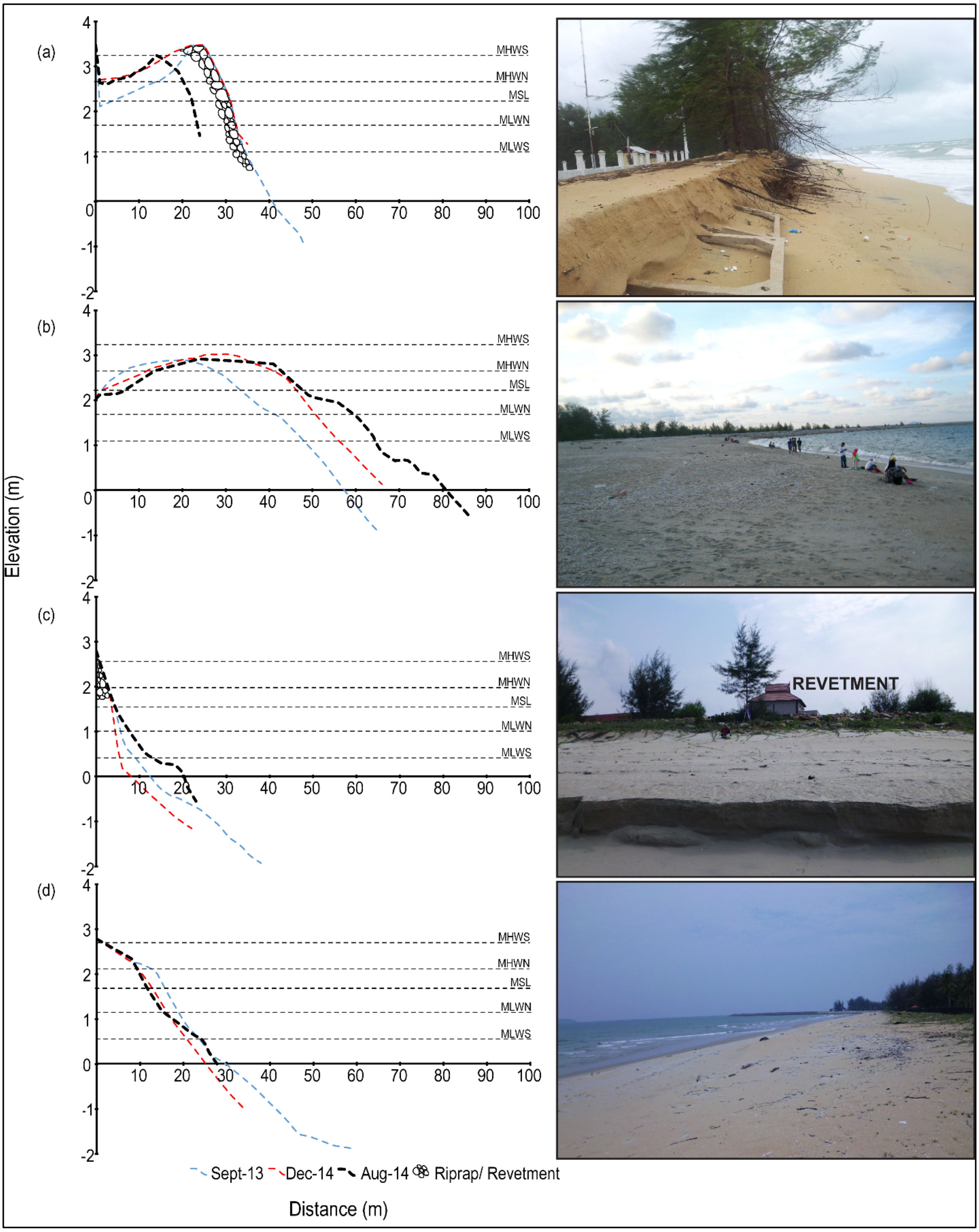

Figure 4.3: Beach profile sequences for the one year surveyed beaches along Kuala Terengganu coast between September 2013 to August 2014 (elevation are relative to DTGSM datum): (a) Universiti Malaysia Terengganu (UMT-B3) beach; (b) Teluk Ketapang beach (B6); Kuala Ibai beach (B8); and (c) Marang beach (B10).

4.4.3 Seasonal Variation of Hydrodynamic

The wave parameters are different in each of the three zones during the seasons studied here (2005 - 2006, 2011 - 2012 and 2013 - 2014). Table 4.2 presents the maximum, minimum and average values (x) of the wave parameters. However, the current distribution is represented separately for the Northeast (i.e. 2005 - 2006, 2011 - 2012 and 2013 - 2014) and southwest monsoon (i.e. 2006, 2012 and 2014).

Table 4.2: The wave parameter in three zones with the comparison of seasonal monsoon.

Monsoon	Zone	H_s (m)			T_p (s)			Wave Direction (°)		
		Max	Min	$\bar{x}$	Max	Min	$\bar{x}$	Max	Min	$\bar{x}$
NE 2005/06	A	2.90	0.35	1.07	9.33	4.28	6.33	356.86	1.54	58.40
	B	2.93	0.35	1.08	9.35	4.28	6.36	358.99	2.35	57.13
	C	2.89	0.33	1.04	9.36	4.29	6.37	363.89	1.95	49.74
SW 2006	A	0.58	0.04	0.20	6.47	2.52	4.51	343.24	2.59	154.98
	B	0.45	0.04	0.19	6.48	2.40	4.50	356.87	5.28	146.46
	C	0.44	0.05	0.22	6.46	2.08	4.48	358.13	4.30	141.31
NE 2011/12	A	2.66	0.31	1.10	10.70	4.04	6.44	357.62	2.30	61.92
	B	2.73	0.19	1.10	10.77	4.04	6.46	357.03	0.37	60.51
	C	2.69	0.21	1.08	10.78	4.04	6.46	357.67	1.28	58.09
SW 2012	A	0.68	0.01	0.16	6.96	1.85	4.52	355.47	68.63	170.35
	B	0.63	0.01	0.17	7.03	2.28	4.46	359.33	0.08	148.63
	C	0.62	0.02	0.20	7.06	2.45	4.45	359.70	1.84	157.98
NE 2013/14	A	2.34	0.35	1.09	8.32	3.93	6.15	72.89	34.90	53.92
	B	2.39	0.37	1.10	8.34	3.94	6.16	74.73	39.90	54.55
	C	2.34	0.34	1.08	8.34	3.94	6.16	68.13	39.17	51.35
SW 2014	A	0.75	0.02	0.14	5.94	2.23	4.30	337.47	82.24	154.26
	B	0.45	0.03	0.16	6.13	2.10	4.25	356.68	1.51	140.93
	C	0.50	0.01	0.18	6.10	2.35	4.24	356.97	0.97	146.69

*Note: NE: Northeast Monsoon; SW: Southwest Monsoon.

4.4.3.1 2005 - 2006 seasons (without the airport tarmac extension structure)

The wind speed during the 2005 – 2006 northeast monsoon reached a maximum reading of 13.00 m/s, which produced high-energy conditions contributing to the significant wave height in all zones (Figure 4.4). The percentage exceedance for wave heights (H_s)

greater than 1 m is at a maximum in Zone B (with 54.20%), while Zones A and C yield values of 44.00% and 43.10%, respectively. The wave direction does not show any marked changes, especially in Zones A and B. However, during the southwest monsoon, low-energy conditions affected the significant wave height distribution in all zones, with a percent exceedance of 0% for H_s > 0.5. A similar pattern is also observed in the wave direction, without any large changes in any of the zones.

On the other hand, the current speeds in Zones A, B and C show similar readings ranging from 0.32 to 0.01 m/s, 0.32 to 0.01 m/s and 0.33 to 0.01 m/s, respectively, during the northeast monsoon, while the current direction was southward (as in Figure 4.5). By contrast, during the southwest monsoon, the current direction flowed northwards with speeds of 0.32 to 0.01 m/s in Zones A and B. The current speed in Zone C ranges from 0.25 to 0.01 m/s (as shown in Figure 4.6).

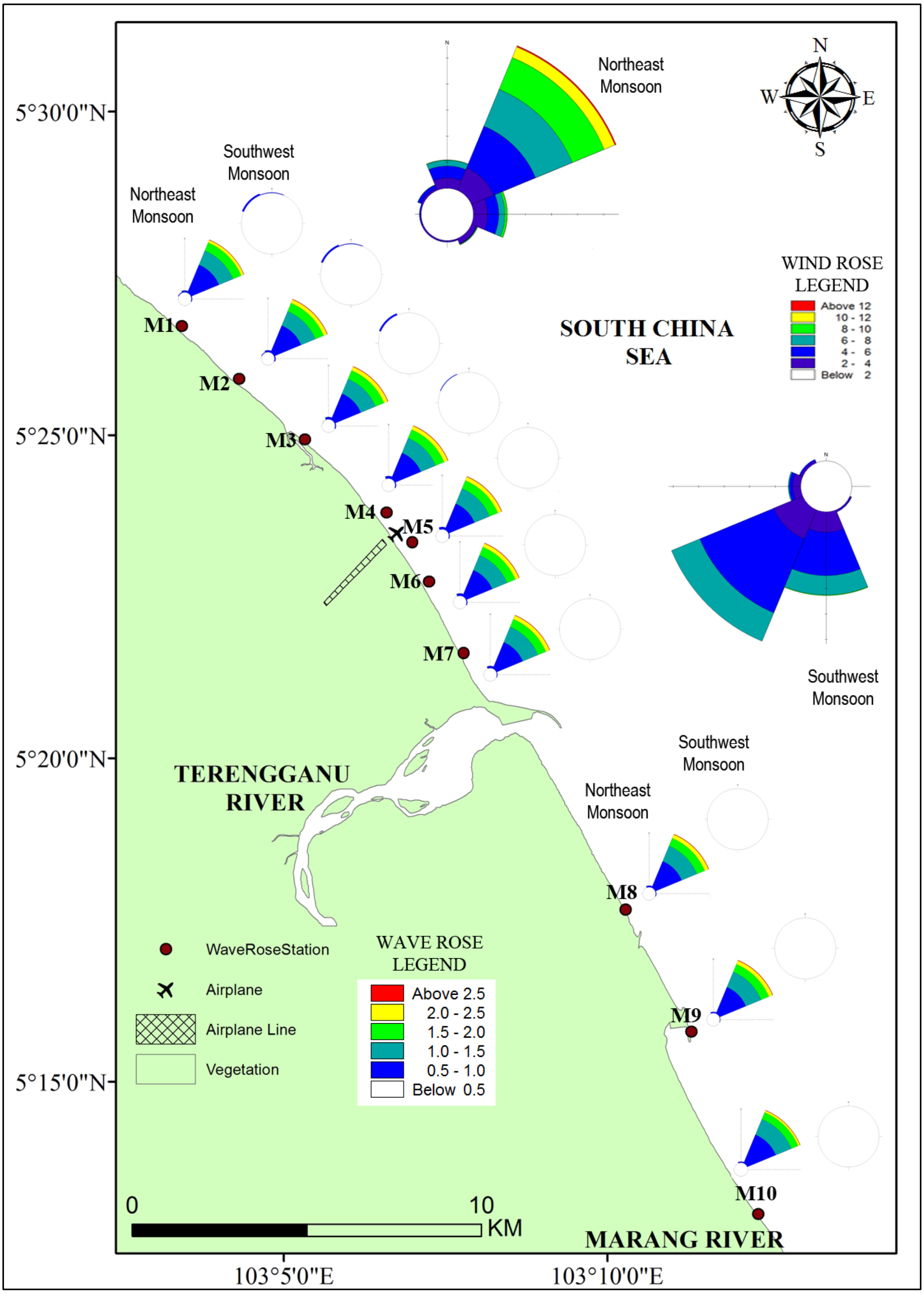

Figure 4.4: Wind and wave rose during northeast and southwest monsoon along coastlines (2005 – 2006) without airport tarmac extension; which station points in Zone A (M1 to M4), Zone B (M5 to M7) and Zone C (M8 to M10).

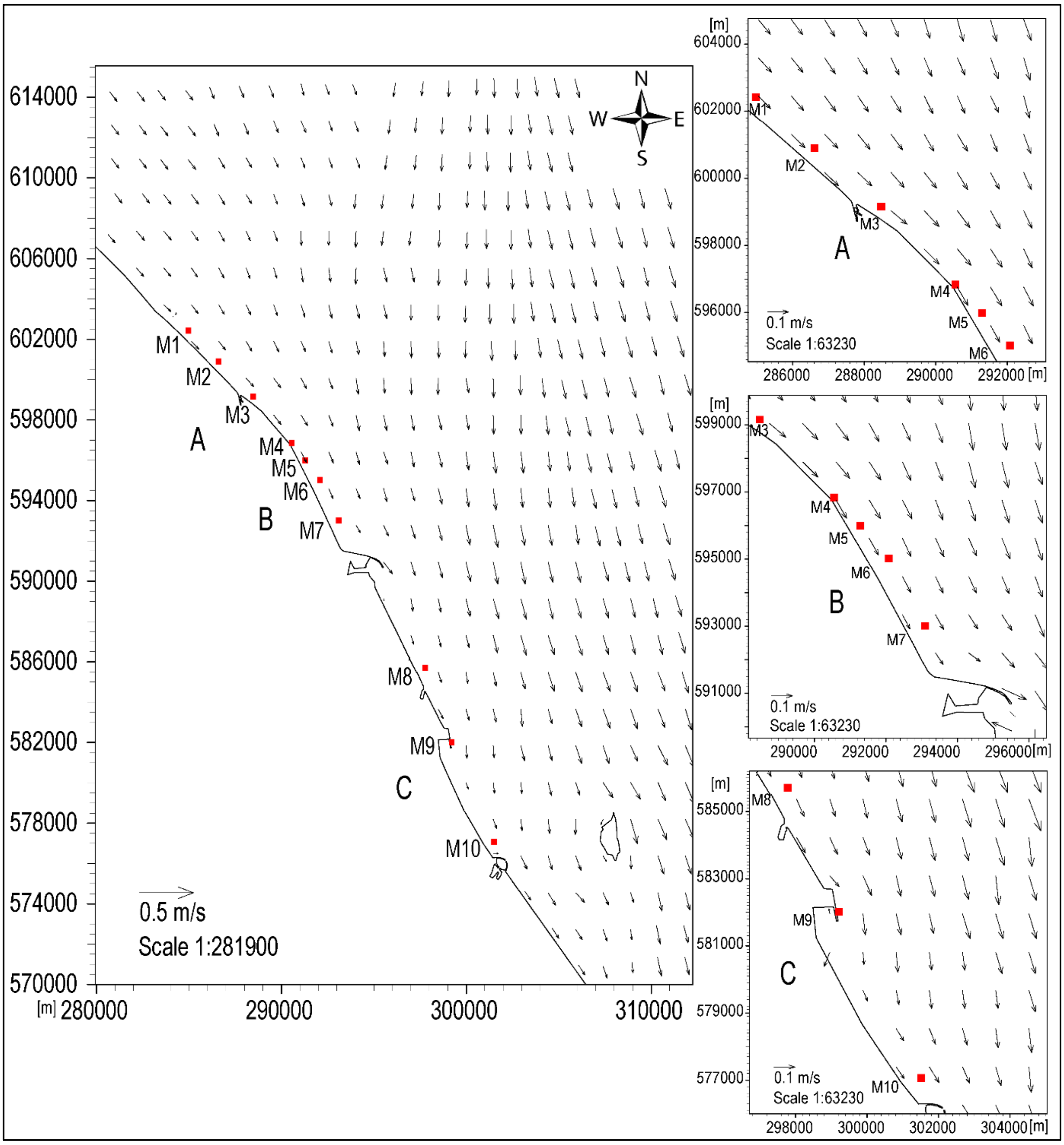

Figure 4.5: Current distribution during northeast monsoon along coastlines (2005 - 2006) without airport tarmac extension; which station points in Zone A (M1 to M4), Zone B (M5 to M7) and Zone C (M8 to M10).

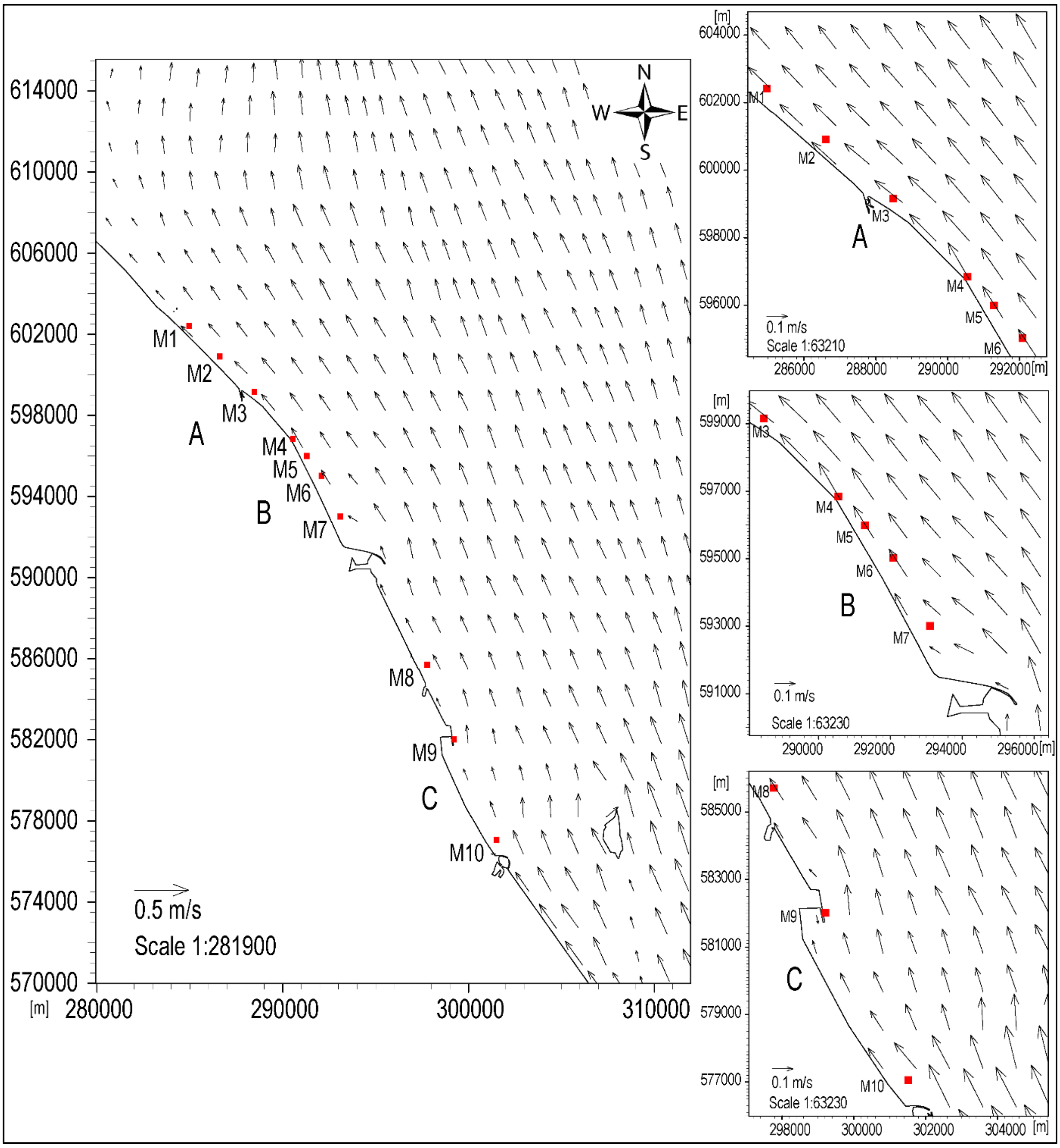

Figure 4.6: Current distribution during southwest monsoon along coastlines (2006) without airport tarmac extension; which station points in Zone A (M1 to M4), Zone B (M5 to M7) and Zone C (M8 to M10).

4.4.3.2 2011 - 2012 seasons (with the airport tarmac extension structure)

Figure 4.7 shows that during the 2011 – 2012 northeast monsoon seasons; the wind speed was lower compared to the 2005 – 2006 northeast monsoon, with a maximum reading of only 11.71 m/s. However, this monsoon still produced high-energy conditions contributing to the significant wave height in all zones especially in Zone B. The percentage exceedance of the wave distribution (H_s > 1 m) is highest in Zone B (at 56.07%), while Zones A and C show values of 54.84% and 54.03% respectively. The wave direction does not display any large changes, notably in Zones A and C. However, Zone B shows a change in wave direction from 357.03° – 0.37°.

During the southwest monsoon, on the other hand, low energy levels are associated with the wave distribution observed in Zones B and C, with a percent exceedance of significant wave height (H_s > 0.5 m) of 1.84% and 1.91%, respectively. However, the airport tarmac extension (into the sea) actually generated a significant increase in wave height in Zone A, which is also due to high wind speeds. However, the higher energy hydrodynamics (leading to this increase in wave heights) corresponds to 5.12% exceedance of the wave distribution in Zone A (H_s > 0.5 m). The wave simulation also shows that the wave direction in Zone A is different (ranging from 355.47° to 68.63°) compared to Zones B and C (which show similar patterns).

After the airport tarmac extension was constructed in 2010, it is interesting to note that the current speeds recorded during the northeast monsoon in Zone A (Figure 4.8A), ranging from 0.34 to 0.01 m/s, are higher than in Zone B (Figure 4.8B), which range from 0.22 to 0.01 m/s. However, the southward flowing current in Zone C became more stable, with speeds in the range of 0.30 m/s to 0.01 (Figure 4.8C).

By contrast, the current direction during the southwest monsoon (as in Figure 4.9) was different since it flowed northwards. A similar pattern is also observed with the northeast monsoon, with Zone A showing higher current speeds (0.30 – 0.01 m/s) compared to Zone B (0.26 – 0.01 m/s). However, while the current speed was slightly lower in Zone A during the southwest monsoon compared to the northeast monsoon, it increased in Zone B. On the other hand, Zone C shows much lower readings in contrast to the northeast monsoon period, with values in the range 0.25 to 0.01 m/s.

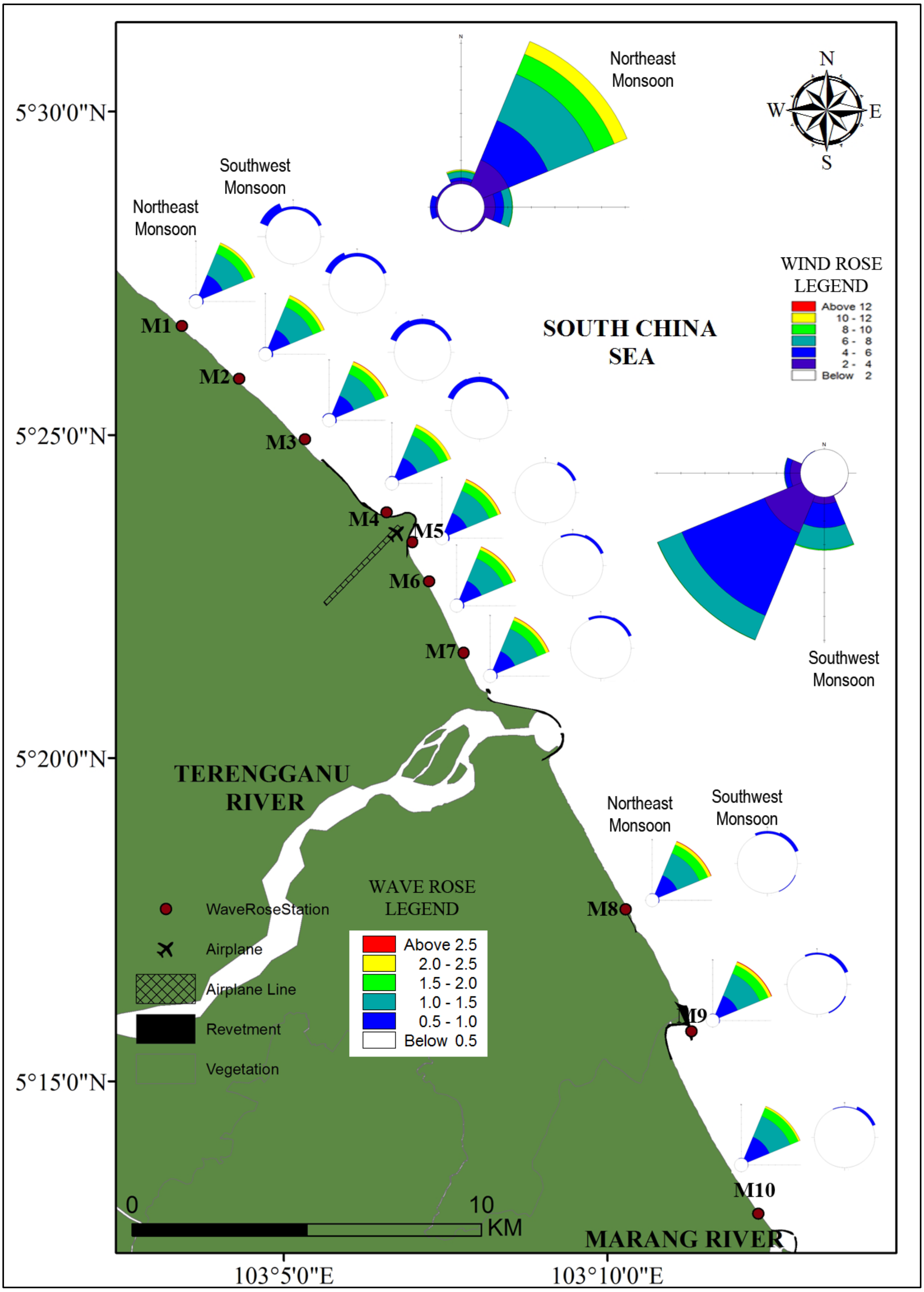

Figure 4.7: Wind and wave rose during northeast and southwest monsoon along coastlines (2011 – 2012) with airport tarmac extension; which station points in Zone A (M1 to M4), Zone B (M5 to M7) and Zone C (M8 to M10).

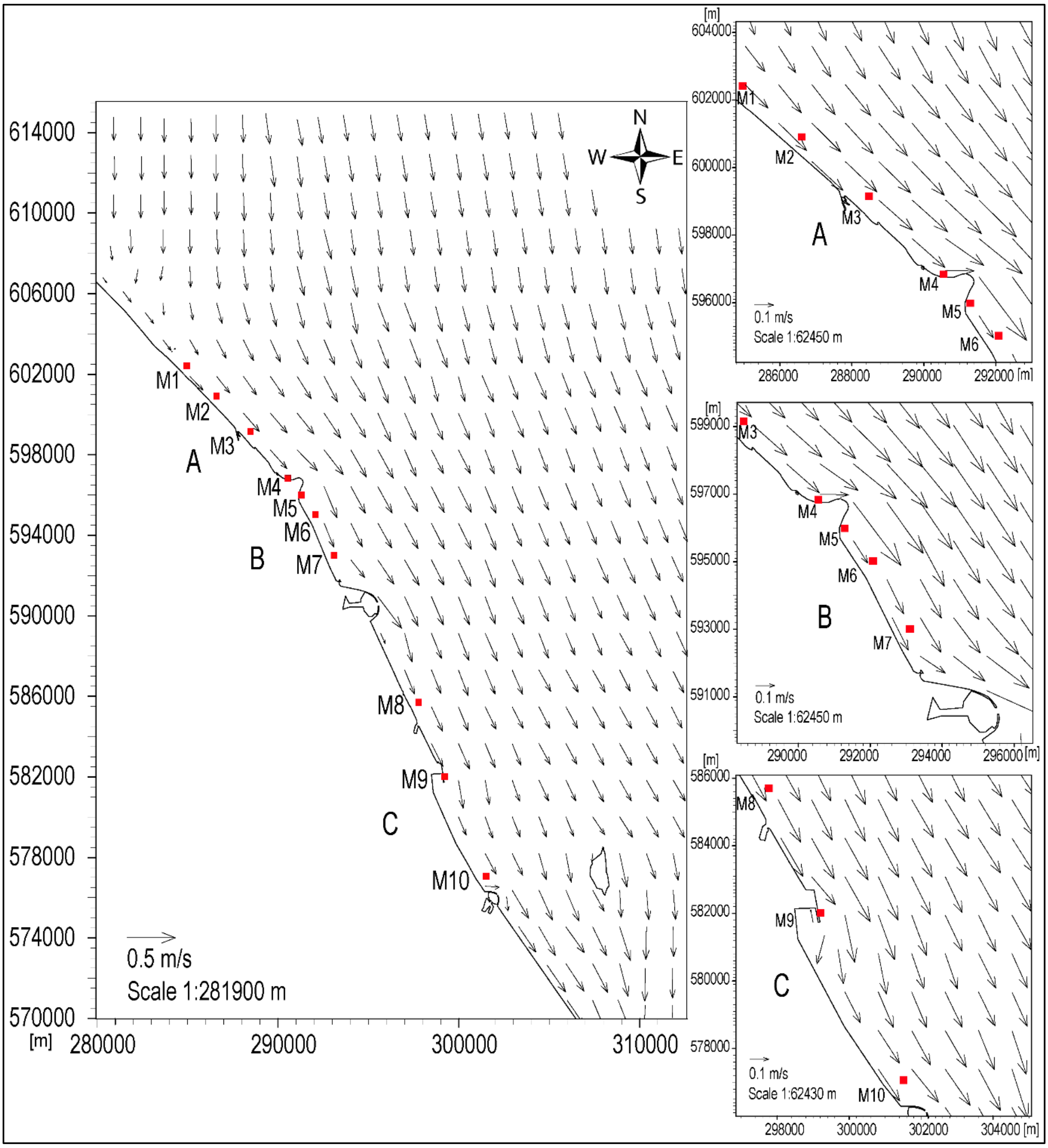

Figure 4.8: Current distribution during northeast monsoon along coastlines (2011 - 2012) with airport tarmac extension; which station points in Zone A (M1 to M4), Zone B (M5 to M7) and Zone C (M8 to M10).

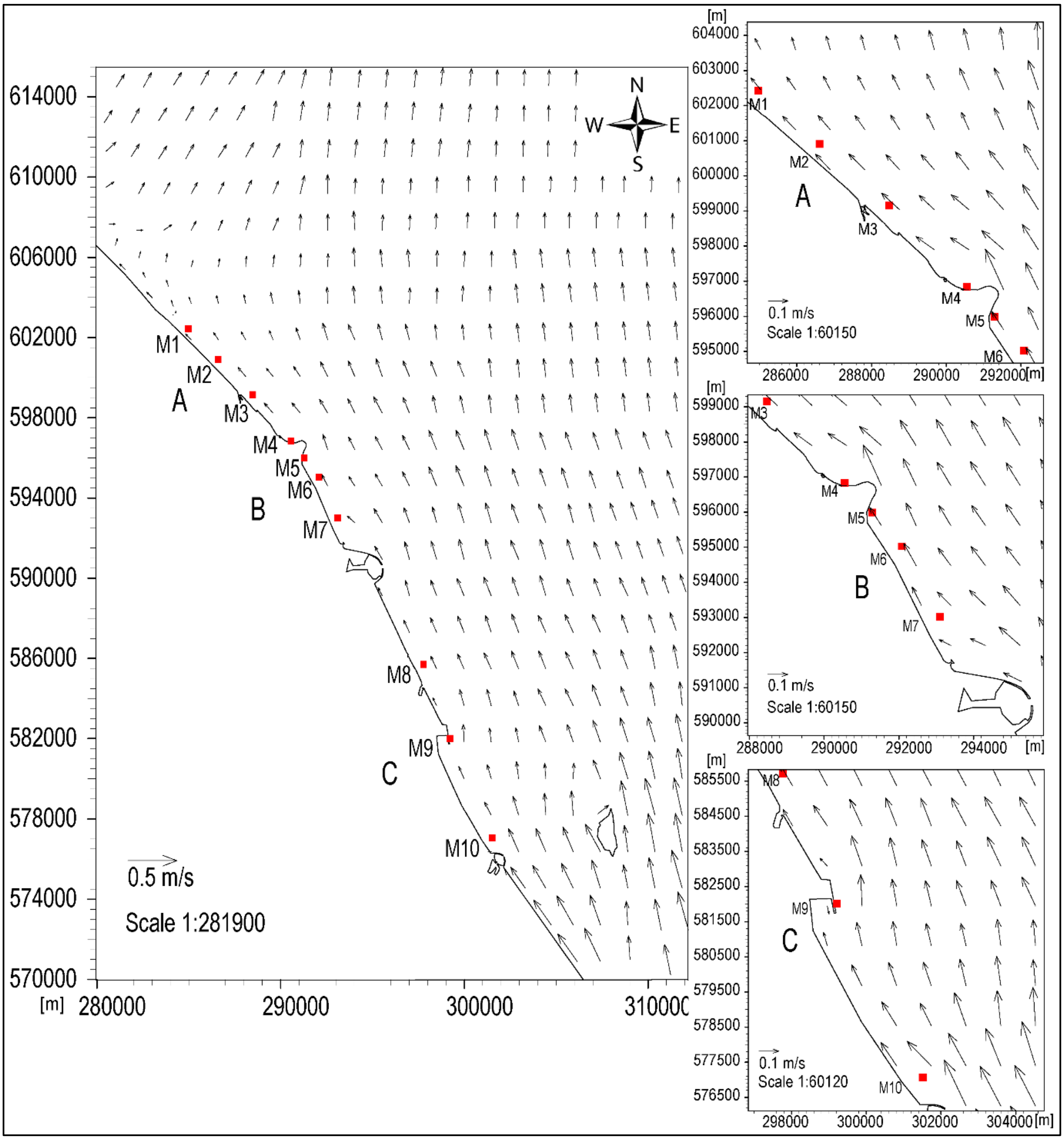

Figure 4.9: Current distribution during southwest monsoon along coastlines (2012) with airport tarmac extension; which station points in Zone A (M1 to M4), Zone B (M5 to M7) and Zone C (M8 to M10).

4.4.3.3 2013 - 2014 seasons (with the airport tarmac extension structure)

During the 2013 - 2014 northeast monsoon, the wind speed was much less compared to previous years, with a maximum reading of only 11.55 m/s (as shown in Figure 4.10). However, it still produced high energy conditions contributing to the significant wave height of all zones. The percentage exceedance of the wave distribution (H_s > 1 m) attains a maximum in Zone B (at 51.43%), whereas Zones A and C show values of 50.21% and 49.72%, respectively. The wave direction pattern does not show any significant changes across the different zones.

On the other hand, the southwest monsoon shows low-energy conditions contributing to the significant wave heights of Zone B and C, with a percentage exceedance of the wave distribution (H_s > 0.5 m) at 0%. However, the airport tarmac extension (into the sea) definitely generated a major increase in wave heights in Zone A, although the wind speeds were notably lower during this season compared to the previous year's observations. However, the higher energy hydrodynamics (leading to this increase in wave heights) corresponds to 2.61% exceedance of the wave distribution in Zone A (H_s > 0.5). The wave simulation also shows that Zone A exhibits a different wave direction pattern compared to Zones B and C (which are more similar), ranging from 337.47° to 82.24° (Zone A).

The current speed during the northeast monsoon shows a different pattern of direction compared to the 2011 – 2012 season. During the 2013-2014 northeast monsoon, the current flowed simultaneously to the north and south in Zone A, with separation taking place at the M3 station point (with stronger currents to the north compared to the south - see Figure 11A). During this northeast monsoon, the higher current speeds ranged from 0.33 to 0.01 m/s in Zone A compared to Zone B with readings of 0.20 to 0.01 m/s. However, the current speed in Zone C was in the range 0.27 to 0.01 m/s associated with a southward flow (see Figure 11C).

During the southwest monsoon season, Zone A recorded stronger currents flowing northwards, with speeds ranging from 0.29 to 0.01 m/s (Figure 12A). The current speed in Zone B was lower (Figure 12B) compared to Zone A, with northward flow ranging from 0.23

to 0.01 m/s. The current in Zone C also flowed northwards, with slightly lower speeds ranging from 0.22 to 0.01 m/s (see Figure 12C).

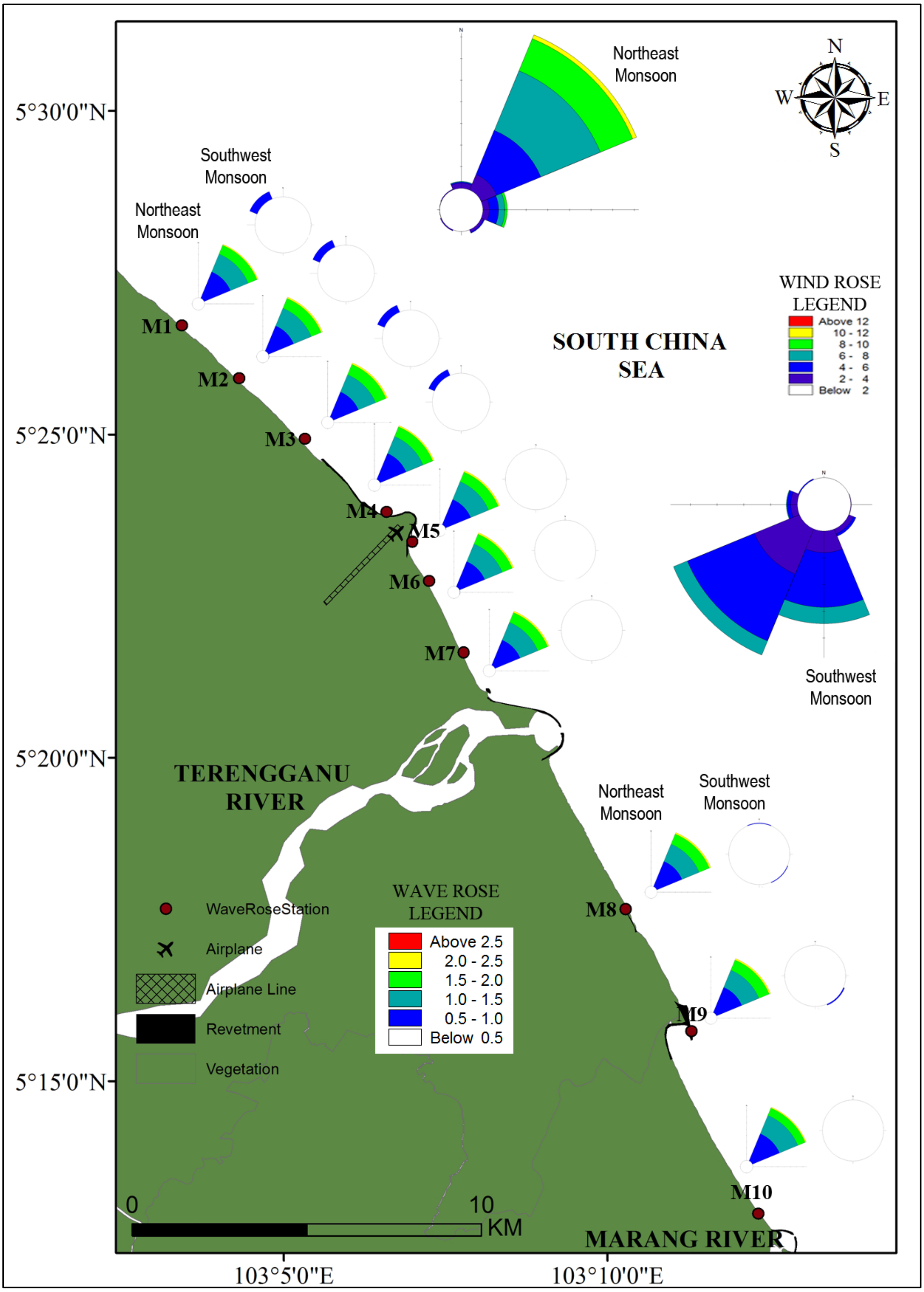

Figure 4.10: Wind and wave rose during northeast and southwest monsoon along coastlines (2013 – 2014) with airport tarmac extension; which station points in Zone A (M1 to M4), Zone B (M5 to M7) and Zone C (M8 to M10).

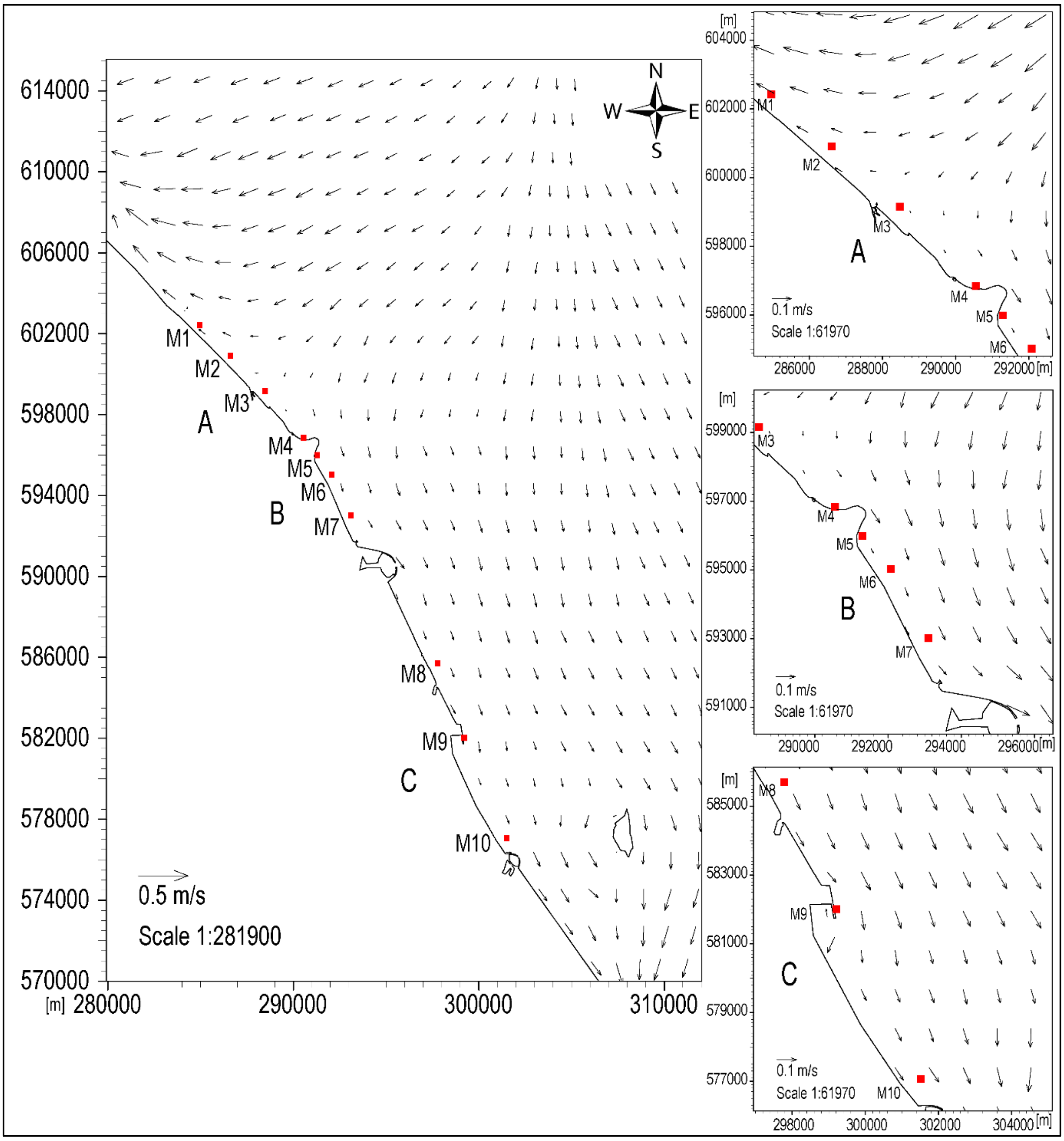

Figure 4.11: Current distribution during northeast monsoon along coastlines (2013 - 2014) with airport tarmac extension; which station points in Zone A (M1 to M4), Zone B (M5 to M7) and Zone C (M8 to M10).

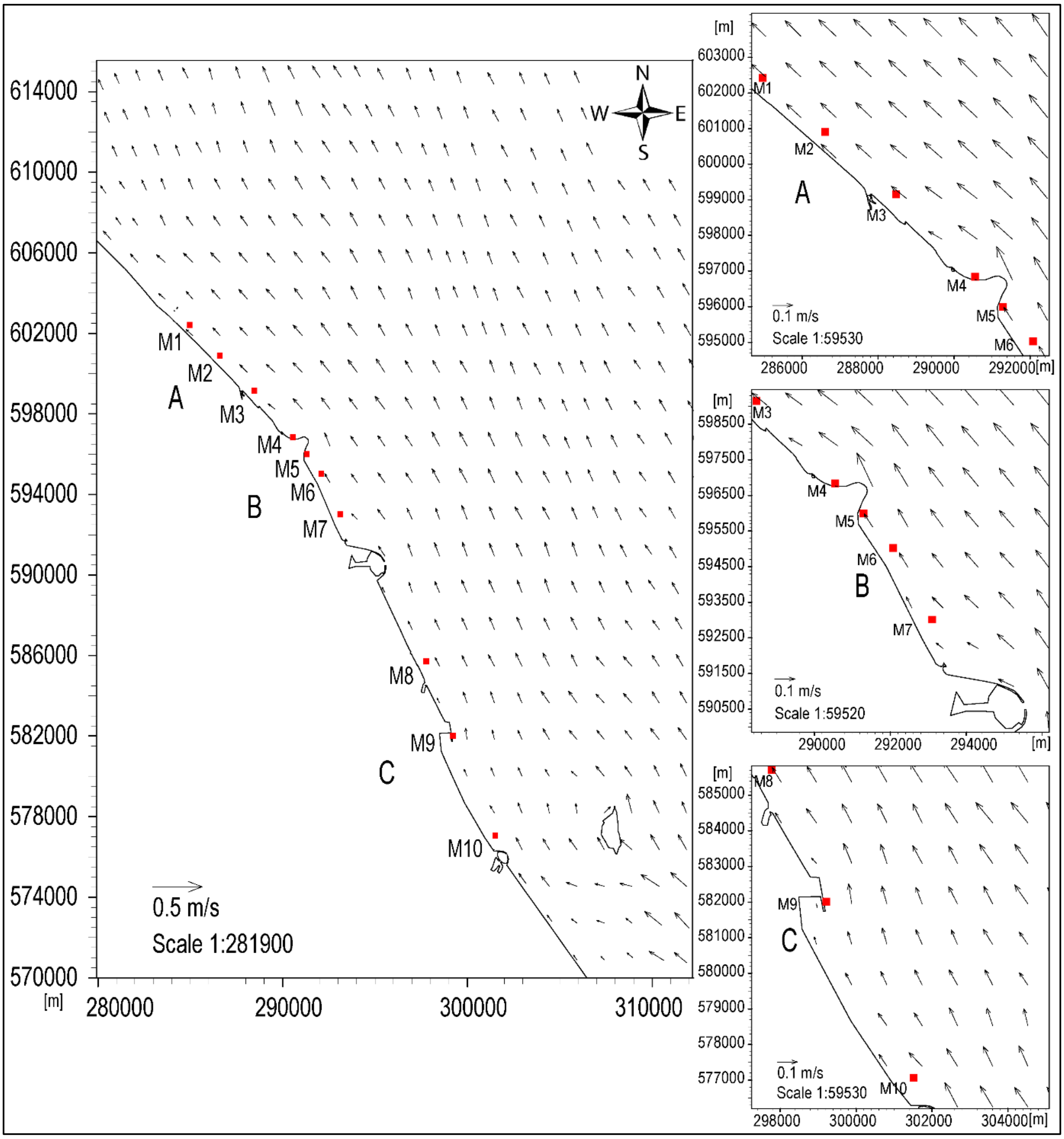

Figure 4.12: Current distribution during southwest monsoon along coastlines (2014) with airport tarmac extension; which station points in Zone A (M1 to M4), Zone B (M5 to M7) and Zone C (M8 to M10).

4.5 Discussions

In general, studies assessing particular shoreline changes aim to systematically document and monitor the process of coastal changes that may be occurring. As a result, evaluations of the rate of change related to the natural and human-induced factors will have an influence on the assessment of coastal behaviour. The Kuala Terengganu region is one of the most populated coastal regions on the East Coast of Peninsular Malaysia. Before 2008, this region also contained a number of natural coastal areas that were not developed. During the 2005 – 2006 monsoonal seasons, the hydrodynamic parameters of the area showed a similar pattern across all the coastal zones, which were then only influenced by natural monsoonal factors. Figure 4.4 shows a wave rose that clearly indicates the impact of monsoons along the coastline unaffected by anthropogenic modifications, with all zones showing a strong increase in significant wave height during the northeast monsoon and calmer conditions during the southwest monsoon.

However, this region underwent major development after Kuala Terengganu was officially proclaimed a City by the Federal Government in 2008. This new City status certainly became a catalyst for unprecedented growth and rapid large-scale development projects that transformed Kuala Terengganu into an economic powerhouse on the east coast. A certain number of the many ambitious infrastructure projects commissioned were designed to redefine the coastal areas as a world-class waterfront city. Figure 4.1 provides some perspective on the great variation between different zones within the Kuala Terengganu region, with Zones A and B undergoing rapid development after 2008 (monsoonal seasons of 2011 – 2012 and 2013 – 2014). In fact, Zones A and B of the Kuala Terengganu coastline are generally more urbanized compared to Zone C.

In general, the results of this study (after the year 2008) reveal that, along these coastlines, the rates of erosion (in Zone A) and accretion (in Zone B) are high as compared to Zone C, which is more stable (due to less development operations). Previous studies by Rosnan and Mohd Lokman (2005) have shown that the beach to the north (Zones A and B) of

Terengganu River is relatively steep compared to the gradual slope of dissipative beaches farther to the south (Zone C). The new reality is that the coastlines and hydrodynamic parameters of the Kuala Terengganu region have been abruptly modified by the rapid development taking place since 2008 (after being granted City status).

Under natural conditions, the Kuala Terengganu shoreline is exposed to the open beach and the wave climate is influenced directly by the monsoonal winds (Chiang *et al*., 2003). The strong winds can generate large waves (Lin *et al*., 2015), which tend to be higher during the northeast monsoon and normal (lower) during the southwest monsoon (Akhir *et al*., 2011; Ariffin *et al*., 2016; Rosnan and Mohd Zaini, 2009).

Human-induced factors certainly influence coastal behaviour, as observed during the 2011 – 2012 seasonal period with very strong winds that, in turn, generate very strong (higher) waves during both monsoons (especially in Zone A), a pattern quite different compared to natural factors. However, during the 2013 – 2014 seasons, even though the winds were much lighter, the waves were still strong (especially in Zone A). These strong waves are definitely related to anthropogenic factors and have caused significant changes of the Kuala Terengganu coastline.

A more detailed explanation can be obtained by dividing the studied coastline into zones. Firstly, Zone A is undergoing high negative rates of shoreline change. The dynamics of this coastal system is due to the open exposure to wave energy, which results in a landward migration of the shoreline. This erosion is also favoured by the lack of sediment supply via longshore drift from the Terengganu River to Zone A, due to the blocking of sediment in Zone B by the newly constructed airport tarmac extension into the sea (Mohammad Fadhli *et al*., 2014). According to Rosnan and Mohd Lokman (2005) the longshore drift in the north sector of the Kuala Terengganu coastline moves the sediment from southeast to northwest.

As further evidence, after construction of a revetment in 2012 (see Figure 2.4 and Table 2.2) near the north of the airport's new tarmac extension, the erosion became quite intense and shifted to include other areas compared to the previous year, despite the higher wave energy observed at the revetment site. The erosion was actually concentrated around the northern part of the airport's new tarmac extension, with degradation of the structure due to strong currents (Mohd Radzi *et al*., 2014). According to Van Rijn (2011), the sedimentation will decrease in the sediment trap between the groyne (airport tarmac extension) as the wave angle increases. In this study, the wave angle increased in 2011 - 2012 and 2013 - 2014 seasons, tending to cause more erosion in Zone A (sediment trap in Zone B) compared to the 2005 – 2006 seasons before construction of the airport tarmac extension into the sea. Furthermore, according to Yang *et al*. (2007) and Kaliraj *et al*. (2013), sediment transport was induced by the wave direction and the seasonal changes of littoral currents which further elucidate the processes leading to erosion.

By contrast, the high positive rates of shoreline change in Zone B can be attributed to the relative degree of protection from wave energy; the coastline here is often protected by the airport's tarmac extension since this structure jutting out into the sea acts like a groyne with a large amount of sediment deposition in this area. The waves coming onshore here dissipate their energy after breaking on the new runway/tarmac of extension and then distribute sediments into adjacent areas (Hsu *et al*., 2007; Kaliraj *et al*., 2013; Lin *et al*., 2015). This process serves to show that accretion (sediment trap) is enhanced on the coast near the airport after the construction of the new runway/tarmac of extension in 2010. This accretion is also increased due to the sediment supply coming from the Terengganu River and transported by the longshore drift (Rosnan and Mohd Lokman, 2005) towards the airport tarmac extension (Ariffin *et al*., 2016). The current becomes weaker in the approaches to the airport tarmac extension, and eventually transports the sediments towards the north, leading to the trapping of sediments on the downdrift side of the groynes (Aouiche *et al*., 2016; Cuadrado *et al*., 2005; Kaliraj *et al*., 2013).

Finally, Zone C does not correspond to a naturally formed beach, despite the influence of some anthropogenic activities. This area has sustained less impact from human activities and the beach is wider. Although erosion and accretion can still be observed, as illustrated by the results, shoreline changes are less marked compared to Zones A and B in the north of Kuala Terengganu. Hence, this southern area generates less wave energy (Rosnan and Mohd Lokman, 2005). Furthermore, the current is observed to be smooth in this zone along the coastline unaffected by any human interference (such as reclamation from the sea, etc.).

In assessing the coastlines of the three zones, the beach profiles reveal that Zone A is subject to erosion during both monsoons. On the contrary, Zone B is prone to accretion during both monsoons. Zone C, however, shows a tendency to natural erosion during the Northeast monsoon, while the southwest monsoon is associated with higher accretion levels. As a result of natural phenomena (classic of monsoonal morphodynamic model), the beach dynamics of Kuala Terengganu tend to show erosion during the northeast monsoon and recovery/accretion during the southwest monsoon (Ariffin *et al*., 2016; Mohd Lokman *et al*., 1998; Rosnan and Mohd Lokman, 2005; Rosnan and Mohd Zaini, 2009).

The difference in current behaviour observed in Zones A and B (north of Kuala Terengganu) compared with Zone C (south of Kuala Terengganu) is likely related to anthropogenic factors. The main beaches in the north of Kuala Terengganu are more heavily developed, and structures such as ripraps or revetments are extensive in some areas. These structures inhibit the natural response of a beach to storms and exacerbate erosion due to scouring, passive erosion and the disruption of coastal sediment transport (Coco *et al*., 2014;

Houser *et al*., 2015; Prasad *et al*., 2009; Yu *et al*., 2013). The artificial fixing of the back-beach environment mimics a setting similar to a rocky coast environment. The lack of accommodation space able to respond to storms likely results in increased rates of erosion (Hapke *et al*., 2013).

This explanation in terms of different zones is supported by a diagram that shows a correlation between wind speed and significant wave heights during the Northeast (Figure 4.13) and southwest monsoons (Figure 4.14). A good correlation can be seen for all the northeast monsoon seasons considered here. However, during the northeast monsoon of 2011 – 2012, the correlation observed in Zones B and C is less well marked, while conditions are calmer compared to Zone A. This provides evidence that human activities create and add to erosion problems. Moreover, during the northeast monsoon of 2013 – 2014, the erosion not only appears to result from anthropogenic structures, but is also due to natural monsoons.

In addition, during the southwest monsoon of 2012, higher waves are observed mostly in Zone A, in an area which also tends to show erosion. However, during the southwest monsoon of 2014, predominantly higher waves are restricted to Zone A and are associated with erosion of the coastline. Normally, beach recovery takes place during the southwest monsoon, but the correlation diagram shows that the increased wave energy is a hindrance to recovery in certain parts of Zone A. However, during the southwest monsoons of the 2012 and 2014 seasons, the significant wave heights show calm energy conditions at M4 (wave station point), at a site where the wave energy is blocked by the new airport tarmac extension, thus increasing the wave energy to the north.

Many studies have examined the various effects of development and associated human activities on coastal change, especially the impact of engineering structures (e.g. see Anfuso *et al*. 2007). Human activities can possibly affect the rates of shoreline movement due to either erosion or accretion. It is well substantiated by Elmoustapha *et al*. (2007) and Patsch and Griggs (2008) that structures such as groynes and harbour/jetties can result in either erosion or accretion on the updrift side of the structure, and accretion/erosion on the downdrift side depending on the longshore drift and sediment supply.

As the sediment supply increases, some parts of the coastal area are subject to accretion, while other areas undergo erosion associated with decreasing sediment supply (Kaliraj *et al*., 2013). The prevailing conditions of accretion in Zone A are linked to the high rates of sediment supply which control the rate of coastal erosion. Hence, the relatively permanent structure will have an impact that may persist for a short period of time because of the effect of monsoonal storms (Mohanty *et al*., 2012).

As observed in the present study, the airport tarmac extension interferes with the wave directions and longshore drift currents, which are the main causes of seasonal variations in shoreline changes throughout the year. The coastal environment is strongly influenced by natural and human activities which control the stability of coastal landforms and sedimentation. Moreover, any natural signal is likely to be masked by activities associated with anthropogenic pressures in most areas, except in environments with sparse levels of development.

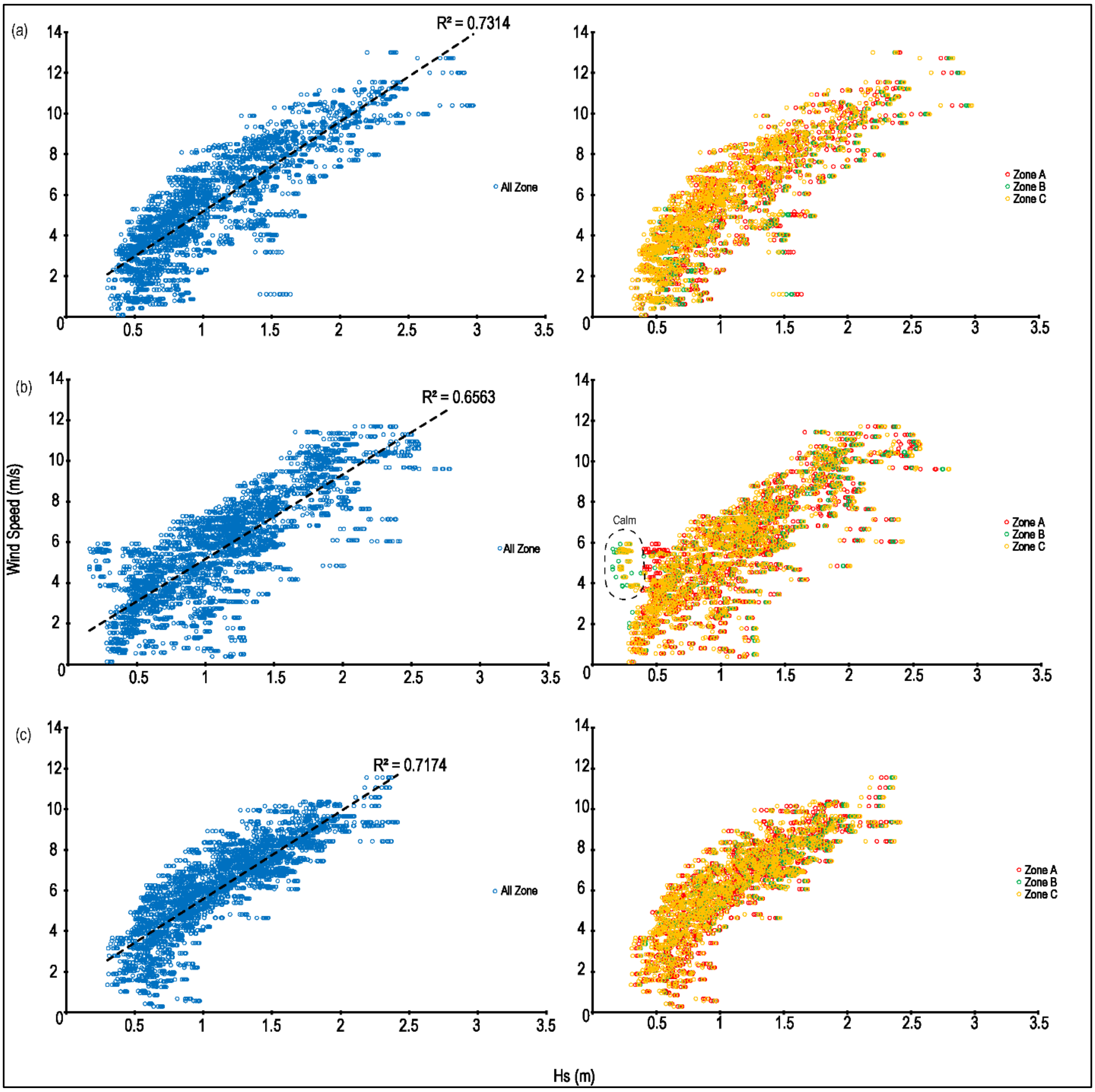

Figure 4.13: Correlation between wind speed and significant wave height (H_s) during northeast monsoon seasons whereas; (a) 2005 – 2006; (b) 2011 – 2012; and (c) 2013-2014. The station points show in Zone A (M1 to M4), Zone B (M5 to M7) and Zone C (M8 to M10).

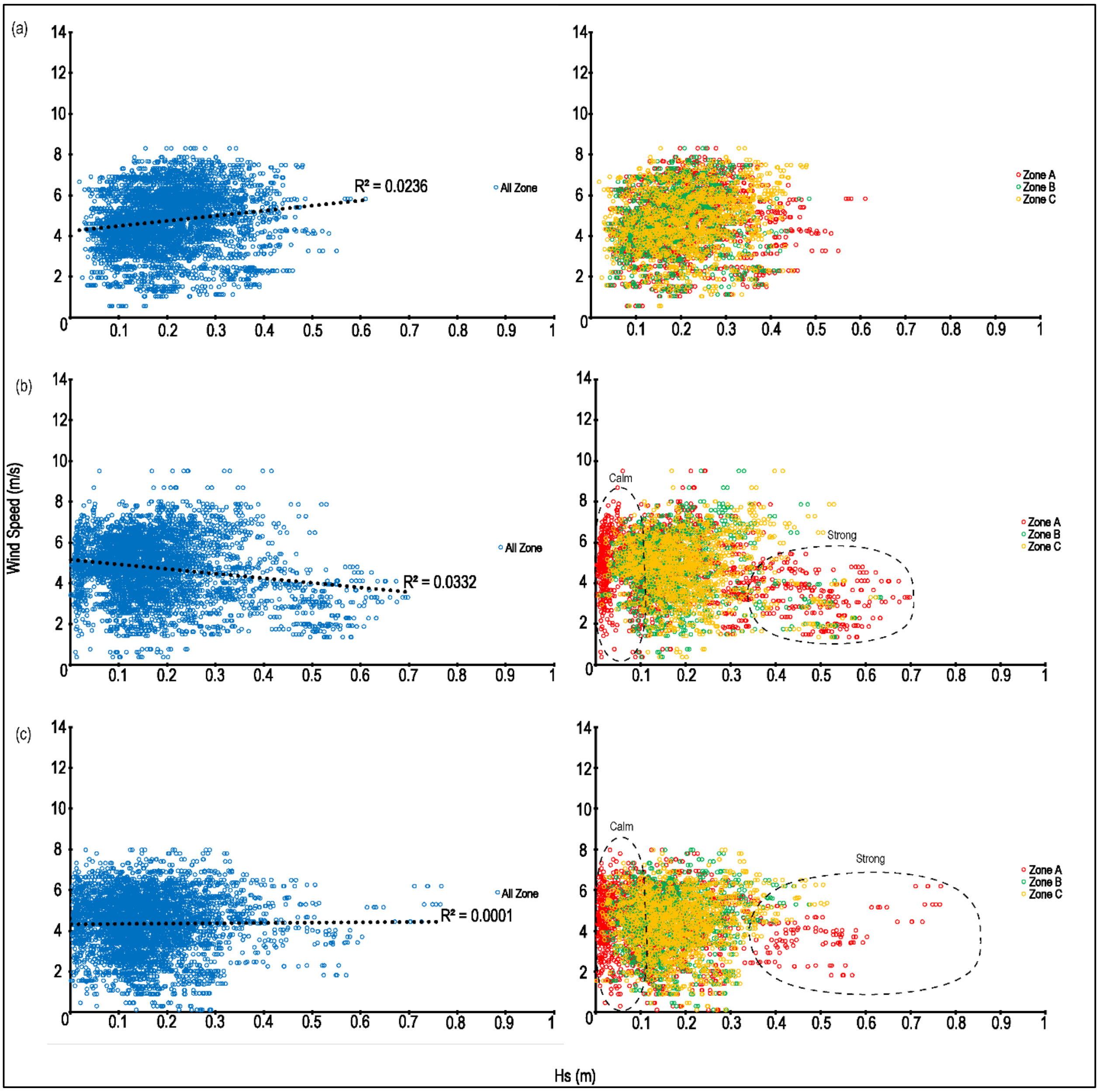

Figure 4.14: Correlation between wind speed and significant wave height (H_s) during southwest monsoon seasons whereas; (a) 2006; (b) 2012; and (c) 2014. The station points show in Zone A (M1 to M4), Zone B (M5 to M7) and Zone C (M8 to M10).

4.6 Summary

The assessment of shoreline change based on an analysis of aerial photographs reveals that the study area has been subject to high rates of erosion (Zone A) and accretion (Zone B) on the northern part of the Kuala Terengganu coastline over the period 2006 – 2014, while stable conditions rates are observed in the southern part (Zone C). The rate of shoreline change reflects the characteristics of coastal dynamics. The new airport tarmac structure mainly disturbs the shoaling, refraction and diffraction of waves, leading to erosion on the updrift side and accretion on the downdrift side of the coastline. The basic question addressed here is whether the impact of human activities has caused erosion on the Kuala Terengganu coastline.

Our main objective is to raise awareness of the important environmental factors affecting coastal changes. Building groynes, harbours and detached breakwaters along an eroding coast may block the longshore transport of sediment or even remove it entirely from the system. In this way, artificial structures may interrupt the natural hydrodynamic system involving waves, currents and the movement of the shoreline. Since the 2010s, the Terengganu authorities have undertaken several strategies to prevent further erosion, to rebuild and protect the eroded beaches of Terengganu and to restore acceptable beach width. A number of projects have been implemented which involve the construction of a series of ripraps/revetments, groynes and breakwaters. After a few years, it now appears that these structures are ineffective in reducing erosion.

Coastal erosion has been a serious problem in Kuala Terengganu, and it has become difficult to use public funding for any new requirements of coastal protection other than repairing the damaged units. It is evident that engineering structures designed to stabilize the shoreline can inadvertently cause rapid erosion. However, we need to have a better understanding of the physical nature of the problem before considering any possible solutions. It may be possible to establish a natural bypassing of sediment, resulting in a more continuous shoreline and the prevention of large-scale erosion beyond the area of the airport tarmac extension.

CHAPTER FIVE: THE SIGNIFICANCE OF MORPHODYNAMIC CHANGES IN RELATION TO SEASONAL MONSOONS

Effi Helmy Ariffin, Mouncef Sedrati, Mohd Fadzil Akhir, Rosnan Yaacob and Mohd Lokman Husain, 2017. Open sandy beach morphology and morphodynamic as response to seasonal monsoon in Kuala Terengganu, Malaysia. *Journal of Coastal Research.* Special Issue, No. 75, pp. 1032-1036.

Contents:

5.1 Introduction

Currently, there is a worldwide increase in the demand for recreational use and urban development of beaches, and this has resulted in a rise in the number of studies on the morphodynamic processes that affect the coastline. Such studies are useful for appropriate coastal erosion management, and for designing structures suitable for recreational beaches (Anfuso, *et al*., 2001). The geomorphological setting of the coastline is a key factor in coastal morphodynamics, along with the influence of local environmental factors such as monsoons. The monsoonal factor determines whether beaches are exposed, sheltered or transitional.

However, the variation of coastal morphodynamics, as expressed in coastal morphology and sedimentation, mainly depends on the local environmental conditions such as the tide, wind, waves and currents (Kaliraj et al., 2013). These environmental conditions characterize the differentiation of monsoons that normally is an influential factor in the South Asia region (Clift and Plumb, 2008).

In the South Asia region, the effects of the seasonal monsoon are modified according to the wave characteristics conditioned by the monsoon winds (Phantuwongraj *et al*., 2013; Saravanan and Chandrasekar, 2010). Hence, the monsoon storm tends to strongly influence the coastal wave characteristics and geomorphology, and *vice versa* (Akhir and Chuen, 2011; Clift and Plumb, 2008; Kok *et al*., 2015; Pham *et al*., 2010). However, the monsoon storm causes a decrease in the mean grain size of the sediments (Mohanty *et al*., 2012).

Some regions are subject to different conditions during the annual monsoon season, such as in India, where the southwest monsoon tends to create more storms, and the northeast monsoon is associated with a calmer regime (Kurian *et al*., 2009; Mishra *et al*., 2011; Saravanan and Chandrasekar, 2015; Wilson *et al*., 2014). However, Pham *et al*., (2010) and Tamura *et al*., (2010) point out that, in Vietnam, the winter monsoon tends to cause stronger monsoon storms compared to the summer monsoon with calmer conditions. A similar pattern is encountered in the Gulf of Thailand (east of Thailand) (Sojisuporn, *et al*., 2010).

The shoreline of Peninsular Malaysia can be divided into the west and the east coasts. The west coast of Peninsular Malaysia has a similar monsoon pattern as developed by the southwest and northwest monsoons of India. On the other hand, the east coast of Peninsular Malaysia experiences a similar environment as Vietnam and the east of Thailand. In this region, the northeast monsoon is stormier compared to the southwest monsoon (Ariffin *et al*., 2016; Camerlengo and Somchit, 2000; Rosnan and Mohd Zaini, 2009).

However, anthropic activities often conflict with natural factors (i.e. geomorphological setting) because of the interests of various stakeholders that influence the evolution of these coasts by modifying the hydrodynamic, morphological and sedimentary behaviours (El Mrini, *et al*., 2012). An example of human activities is the construction of hard structures on the beach, such as groynes, riprap/revetment or breakwaters, which influence the coastal defence system. The shoreline is eroded, accreted or remains stable depending on the rate at which sediment is supplied or removed from the shore. This impact is also reflected in the action of coastal processes (Türker and Kabdaşli, 2007).

On the other hand, sediment grain size also indicates the erosional or accretion processes that prevail in the environment of a specific area and reflects the beach stability. Accretion is marked by an increase in mean grain size while erosion causes a decrease (Hegde *et al*., 2009; Noraisyah *et al.*,, 2015; Rosnan and Mohd Zaini, 2009). For example, in coastal engineering projects such as ports and harbours, the sediment properties have important consequences on dredging operations, the types of dredges used, beach nourishment and protection against scouring, as well as on sediment transport, all of which need to be considered to understand the implications (Gujar *et al*., 2011).

Another example is given by coastal defence projects with structures jutting out into the sea that can modify the longshore sand transport. As a result, the accumulation of sand mostly on the updrift side and erosion on the downdrift side depends on the direction of the longshore drift (Türker and Kabdaşli, 2007). According to Benavente *et al*. (2002), and as discussed in El Mrini (2012), artificial structures must adapt to the natural state of beaches to achieve the goal of beach stability.

However, the morphodynamics of coastal areas, specifically on beaches, can be described in terms of beach morphology and sediment variation. For example, studying the morphodynamics of coastal areas leads us to classify beaches as dissipative, intermediate or reflective (Wright and Short, 1984). Moreover, the classification of beaches into different groups or types can provide a convenient framework for beach morphodynamics and morphological changes. Normally, sandy beaches can be classified according to their overall slope, either steep or gentle. These two types represent two fundamentally different morphodynamic process regimes.

Firstly, on a steeply sloping beach, the surf zone generally has no incidence on wave breaking. Rather, the waves surge directly or plunge onto the beachface. A significant part of the incoming wave energy is reflected back from the shoreline. Hence, these beaches can be referred to as reflective beaches. Secondly, on gently sloping beaches, the surf zone is wider with multiple lines of spilling breakers. Most of the incoming wave energy is dissipated during the wave breaking process, hence these beaches are known as dissipative beaches (Masselink and Hughes, 2003). On the other hand, Klein, *et al*. (2005) observed that the grain size of sediments is coarser on reflective beaches, in contrast to dissipative beaches that show finer grains. Imhansoloeva *et al*. (2011) observed that high wave energy and strong currents are responsible for the grain-size distribution on beaches.

Several studies of morphodynamic changes have been carried out along Australian beaches regarding the volume variations, equilibrium beach profiles, shoreface profiles and beach classification, and also seasonal modifications (Harley *et al*., 2015; Masselink and Pattiaratchi, 2001; Masselink and Short, 1993; Wright and Short, 1983, 1984). Some other studies mainly carried out on the Indian coasts are related to the hydrodynamic processes and heavy mineral budget (Black *et al*., 2008; Saravanan and Chandrasekar, 2010; Saravanan *et al*., 2011; Wilson *et al*., 2014).

However, in Malaysia, many studies have involved classic observations of morphodynamics based on volumetric variations and shoreface profiles. For example, Rosnan and Ariffin (2010), Rosnan and Mohd Lokman *et al*. (1995) and Rosnan *et al*. (2003) presented a comparison of volumetric variations and shoreface profiles as a function of seasonal monsoons.

This chapter also highlights the relationship between coastal erosion, hydrodynamics and the influence of monsoons on the east coast of Peninsular Malaysia with example at Kuala Terengganu. It also discusses in detail the seasonal morphodynamic changes that led to the beach classification. In addition, this chapter not only describes the conflicting natural and anthropogenic factors that directly cause erosion, but also presents some approaches to alleviate the problem. To achieve this objective, the changes in beach morphology are investigated using a 2D topographic monitoring program over a period of two years. The data obtained are very useful for describing beach morphodynamic behaviour at the seasonal time scale.

5.2 Summary of Study Area

The study area is divided into three zones: Zones A and B, which comprise beach areas in the northern part of Kuala Terengganu, and Zone C lying to the south of Terengganu River (Figure 5.1). Specifically, seven beaches along the Kuala Terengganu coastline are located in Zone A, represented by station points B1 to B3, while Zone B is represented by station points B4 and B5. Farther along the coast, station points B6 and B7 lie within Zone C. Furthermore, each beach area (station point) includes five transects, with intervals of 50 m between each transect, covering a beach length of 250 m. Moreover, the sediment samples were collected at points from the middle of the transects (Transect 3 - T3) at intervals of 10 m starting from the berm/vegetated zone and extending down to the low tide mark. Meanwhile, wave parameters were recorded at each station point within 10 m water depth. A detailed description of the study area is given in Chapter 2.

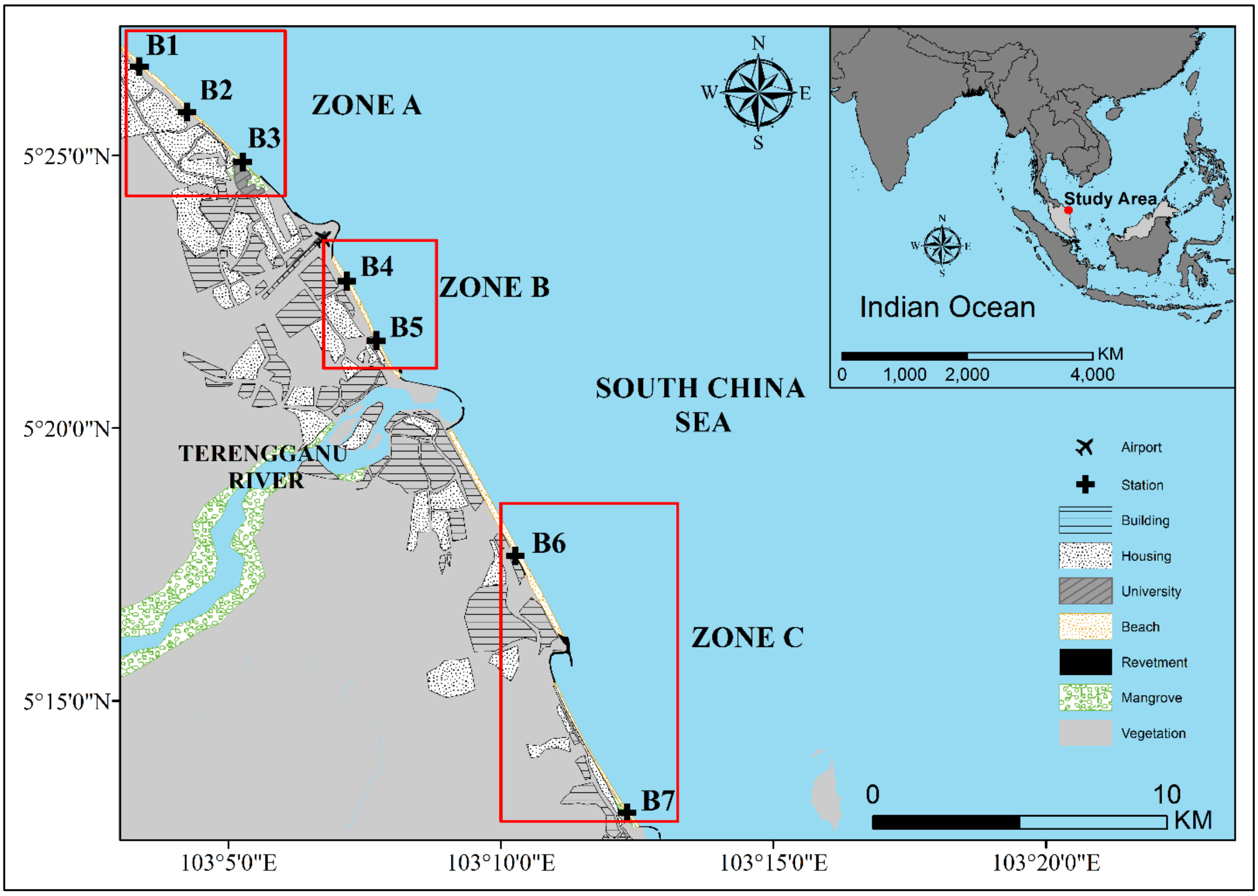

Figure 5.1: Kuala Terengganu coastline divided into three zones.

5.3 Summary of Methodology

In this chapter, the beach morphodynamic behaviour and sedimentological changes are briefly discussed in relation to hydrodynamic changes. To achieve the objective of this study, beach morphodynamic, sedimentological and hydrodynamic parameters are compared between July 2013 and June 2015 (2-year monthly data). The detailed methodology is discussed in Chapter 3.

5.4 Results

The main findings of this chapter are presented in three sections, i) beach morphodynamic behaviour, ii) sediment characteristics, and iii) modelling data. The results of the first section concern the beach profile (morphology), variations of beach volume, beach slope, and seasonal variations of bed level and beach characteristics. The second section describes the sediment characteristics, giving details of the mean, sorting and skewness as well as the intercorrelations among these parameters. Finally, the modelling data describes the wind, wave and current parameters. The results from these three sections can be correlated among themselves to understand the evolution of beaches, which can then be linked to the impact of monsoons or/and human interference. However, for a clearer understanding, each of the subtopics summarizes the results presented by zone (Zones A, B and C), and broken down according to each station point.

5.4.1 Beach Morphodynamic Behaviour

Figure 5.2 presents the beach profiles at seven stations surveyed from July 2013 to June 2015 (2 years of monthly surveys). The beach profiles B1, B2 and B3 are located in Zone A, while B4 and B5 are in Zone B, and B6 and B7 are in Zone C. The data selected from the beach profile surveys are estimated by comparison between monsoon seasons: July 2013 (as a baseline profile), July 2014 and June 2015 represent the southwest monsoon, while December 2013 and December 2014 represent the northeast monsoon.

The beach volume variations, i.e. giving a record of accretion and erosion, are estimated with reference to the July 2013 profile, which is taken as a baseline (presented in Figure 5.3). Meanwhile, the observed beach slope is compared across different monsoonal seasons, and the results are presented in Figure 5.4. These parameters (beach profile, beach volume and beach slope) are discussed briefly under the beach morphology subtopic in the section on beach morphodynamic behaviour.

A detailed description of beach morphodynamic evolution is given in the subtopic dealing with bed level variations (Figure 5.5 and 5.6), while the beach characteristics are presented by breaker type (Table 5.4) with a classification in terms of beach state (Figure 5.7).

i) Beach Morphology

Batu Rakit beach (B1)

B1 is located in Zone A, as shown in Figure 5.2i, on a beach where all the transects show accretion (sediment draping/accumulating onto the backshore) in December 2013. This month corresponds to the northeast monsoon period (stormy conditions). In July 2014 (southwest monsoon period), all the transects exhibit an increase in accretion. Similarly, the data for December 2013 and December 2014 (northeast monsoon-storm conditions) show that almost all transects tend to undergo accretion. However, erosion is recorded on Transect 1 (Figure 5.2i-a) and Transect 4 (Figure 5.2i-d) in the backshore at a distance of 0-30 m from the dune.

During December 2014 (very heavy rainfall), this area was flooded and a change of the beach morphology was observed. The same pattern was seen during June 2015 (southwest monsoon period). Further scrutiny reveals an increase in the amount of sediments that underwent accretion. Hence, B1 can be represented as a semi-arcuate beach since its profile showed recovery over a duration of two years.

Otherwise, the variations of beach volume show that almost all transects have a tendency to accretion (Figure 5.3). For example, the beach profile at Transects 1 and 4 needs more time to build up or recover due to the effects of flooding. Meanwhile, the beach profile at Transect 3 shows an increase of slope during the northeast monsoon and a decrease during the southwest monsoon (Figure 5.4).

Pengkalan Maras beach (B2)

As presented in Figure 5.2ii, B2 is located in Zone A. In December 2013, almost all transects at B2 underwent erosion, which occurred during the northeast monsoon (stormy conditions). However, Transect 2 (Figure 5.2ii-b) and Transect 3 (Figure 5.2ii-c) were subject to accretion, while the foreshore (30 - 60 m distance) showed sediment accumulation/draping. In July 2014 (during the southwest monsoon), almost all transects underwent accretion except Transect 4 (Figure 5.2ii-d), whereas Transect 5 (Figure 5.2ii-e) showed erosion on the foreshore (30-60 m distance).

In December 2014 (northeast monsoon-storm conditions), almost all transects tended to erosion, except for Transect 1 (Figure 5.2ii-a) and Transect 2 (Figure 5.2ii-b), which were subject to accretion on the foreshore (30-60 m distance). Furthermore, all transects displayed an increase in erosion in June 2015 (the southwest monsoon) except for Transect 2 (Figure 5.2ii-b) which underwent less accretion. Hence, B2 can be represented as a semi-arcuate beach since its profile displayed almost complete recovery over a duration of two years (except Transect 4 and 5).

In the meantime, the variation of beach volume shows that all transects have a tendency to be eroded except for Transect 2 (Figure 5.3), and Transect 3, which showed an increase of beach slope during the northeast and southwest monsoons (Figure 5.4).

UMT beach (B3)

As shown in Figure 5.2iii, B3 is located in Zone A, on a beach where almost all transects underwent erosion in December 2013. This month corresponds to the northeast monsoon (stormy conditions). However, Transect 1 (Figure 5.2iii-a) and Transect 2 (Figure 5.2iii-b) tended to undergo accretion (maintained) since the beach was already covered by a riprap in September 2013. Subsequently, this riprap collapsed in April 2014 during the pre-southwest monsoon period.

Consequently, erosion increased in July 2014 as there was no longer any adequate protection from coastal defences on the beach. The vast majority of the studied beaches then recorded an enhanced level of erosion up to August 2014 (at the end of the survey period, followed by collapse of the beach in September 2014). B3 cannot be represented as an arcuate-type beach because its profile did not recover to any extent for two years.

However, the variation of beach volume shows that all transects have a tendency to be eroded (Figure 5.3). On Figure 5.4, the beach (Transect 3) shows an increase of slope up until October 2013 (riprap constructed in September 2013), and maintained a similar slope until March 2014. In April 2014, after the riprap collapsed, the beach slope continued to increase from month to month.

Teluk Ketapang (B4)

B4 is located in Zone B, as presented on Figure 5.2iv, in a beach area where almost all transects are found to have undergone accretion in December 2013 during the northeast monsoon (storm conditions). However, Transects 1 and 2 tended to erosion in this beach area far from the airport tarmac extension. In July 2014 (during the southwest monsoon), almost all transects underwent erosion except Transects 1 and 2 (Figure 5.2iv-d,e) which show accretion.

In contrast with December 2013, the data for December 2014 (northeast monsoon-storm conditions) show that all transects tended to accretion. Furthermore, all transects were subject to accretion in June 2015 (the southwest monsoon period). B4 can be represented as a semi-arcuate type beach because there was recovery of the profile over a period of two years.

However, the variation of beach volume shows that all transects display a tendency to go through a phase of accretion (Figure 5.3). The beach slope of Transect 3 decreased month by month, with a similar pattern during the northeast and southwest Monsoon periods (Figure 5.4).

Seberang Takir (B5)

B5 is located in Zone B, as presented in Figure 5.2v, in an area where almost all transects underwent erosion except Transect 2 (Figure 5.2v-b) and Transect 4 (Figure 5.2v-d) which showed sediment draping on the backshore during December 2013. This month represents the northeast monsoon period (storm conditions). In July 2014 (southwest monsoon), all transects showed accretion.

In December 2014 (northeast monsoon-storm conditions), all transects tended to erosion. However, in June 2015 (southwest monsoon period) the beach profiles show a similar pattern (erosion) compared with December 2014. However, there was an increase in the sedimentation due to decreasing erosion. Moreover, B5 can be represented as a semi-arcuate beach because the profile shows almost complete recovery over a period of two years.

The variation of beach volume shows that almost all transect had a tendency to erode less (Figure 5.3). However, the beach slope on Transect 3 showed an increase during the northeast monsoon and decreased during the southwest monsoon (Figure 5.4).

Kuala Ibai (B6)

B6 is located in Zone C, as presented in Figure 5.2vi, in an area where almost all transects underwent erosion except at Transect 4 (Figure 5.2vi-d) and Transect 5 (Figure 5.2vi-e) which showed sediment draping on the beach in December 2013. These transects were not covered with revetment on the berm and the sediment drape was supplied from another transect. However, this month represented the northeast monsoon period (storm conditions). Furthermore, in July 2014 (the southwest monsoon period), all transects indicate accretion.

Similarly, in December 2014 (northeast monsoon-storm conditions) almost all transects tended to erode except Transect 4 and Transect 5, which underwent accretion. However, in June 2015 (the southwest monsoon period), almost all transects indicated accretion except for Transect 4 and Transect 5 that underwent erosion. Moreover, B6 can be represented as semi-arcuate natural beach because the profile almost completely recovered over a period of two years. However, the situation was different at Transect 4 and Transect 5, which did not show total recovery because of the effect of revetment on Transects 1 to 3.

The variation of beach volume shows that almost all transects have a tendency to accrete except for Transect 4 and Transect 5 which underwent erosion (Figure 5.3). However, the beach slope of Transect 3 showed an increase during the northeast monsoon and decreased during the southwest monsoon (Figure 5.4).

Marang (B7)

B7 is located in Zone C, as presented in Figure 5.2vii, in an area where all transects recorded erosion in December 2013 during the northeast monsoon (storm conditions). Furthermore, in July 2014 (during the southwest monsoon), almost all transects showed accretion except for Transect 4 (Figure 5.2vii-d) and Transect 5 (Figure 5.2vii-e) which tended to accrete due to the distance from the breakwater.

In December 2014 (northeast monsoon - storm conditions) almost all transects tended to erode except for Transect 4 and Transect 5 that tended to accrete. However, in June 2015 (the southwest monsoon period), all transects had underwent erosion. Moreover, B7 cannot be represented as a natural beach because the profile did not recover over a period of two years.

The variation of beach volume indicates that all transects have a tendency to erode (Figure 5.3). However, the beach slope on Transect 3 shows an increase during the northeast monsoon and decreases during the southwest monsoon (Figure 5.4).

Beach morphology by zone

The beach morphology by zone is estimated by averaging the transects in each beach area. Hence, the evolution of beach morphology on the Kuala Terengganu coastline follows two patterns, from Zone B in the south to Zone A in the north, and from Zone B in the north to Zone C in the south). It can be observed that Zones A and C have a more reflective type of beach profile compared to Zone B. In Zone A, a nearly straight beach is observed at B1 (compared to B2 and B3) and tends to be more arcuate in shape (natural beach - full beach recovery) because this area is far from the airport tarmac extension. However, in Zone B, particularly at B4, the beach has undergone intense accretion (beach recovery). Lastly, in Zone C, the beach cannot be represented as a natural beach because was no recovery of the profile over a period of two years

Table 5.1 summarizes the accumulation (accretion process) and erosional trends during monsoonal seasons, with the southwest monsoon of 2013 (July 2013) being presented as a baseline profile. During the northeast monsoon, natural beach process on the Kuala Terengganu coastline tend to cause erosion, while, during the southwest monsoon, the tendency is to accretion (recovery). Comparing these two years of beach morphology surveys, the net volume changes due to beach processes is different between the northeast (NE) monsoon and southwest (SW) monsoon during the periods 2013-2014 and 2014-2015.

For the period 2013-2014, the cumulative result of beach processes in Zone A during NE-SW monsoons led to a maintenance of erosion. However, in Zone B the cumulative result of beach processes over the same period changed from accretion to erosion, in contrast to Zone C which changed from erosion to accretion. Meanwhile, during the NE-SW monsoons of 2014-2015 in Zone A (erosion to erosion), we observe the same pattern as in 2013-2014. This contrasts with Zone B and Zone C during the NE-SW monsoons of 2014-2015, which show maintenance of accretion and erosion, respectively.

Table 5.1: Summary of beach morphology evolution in relation to monsoonal seasons.

Monsoon	Zone A	Zone B	Zone C
Southwest 2013	as a base profile	as a base profile	as a base profile
Northeast 2013-2014	Erosion	Accretion	Erosion
Southwest 2014	Erosion	Erosion	Accretion
Northeast 2014-2015	Erosion	Accretion	Erosion
Southwest 2015	Erosion	Accretion	Erosion

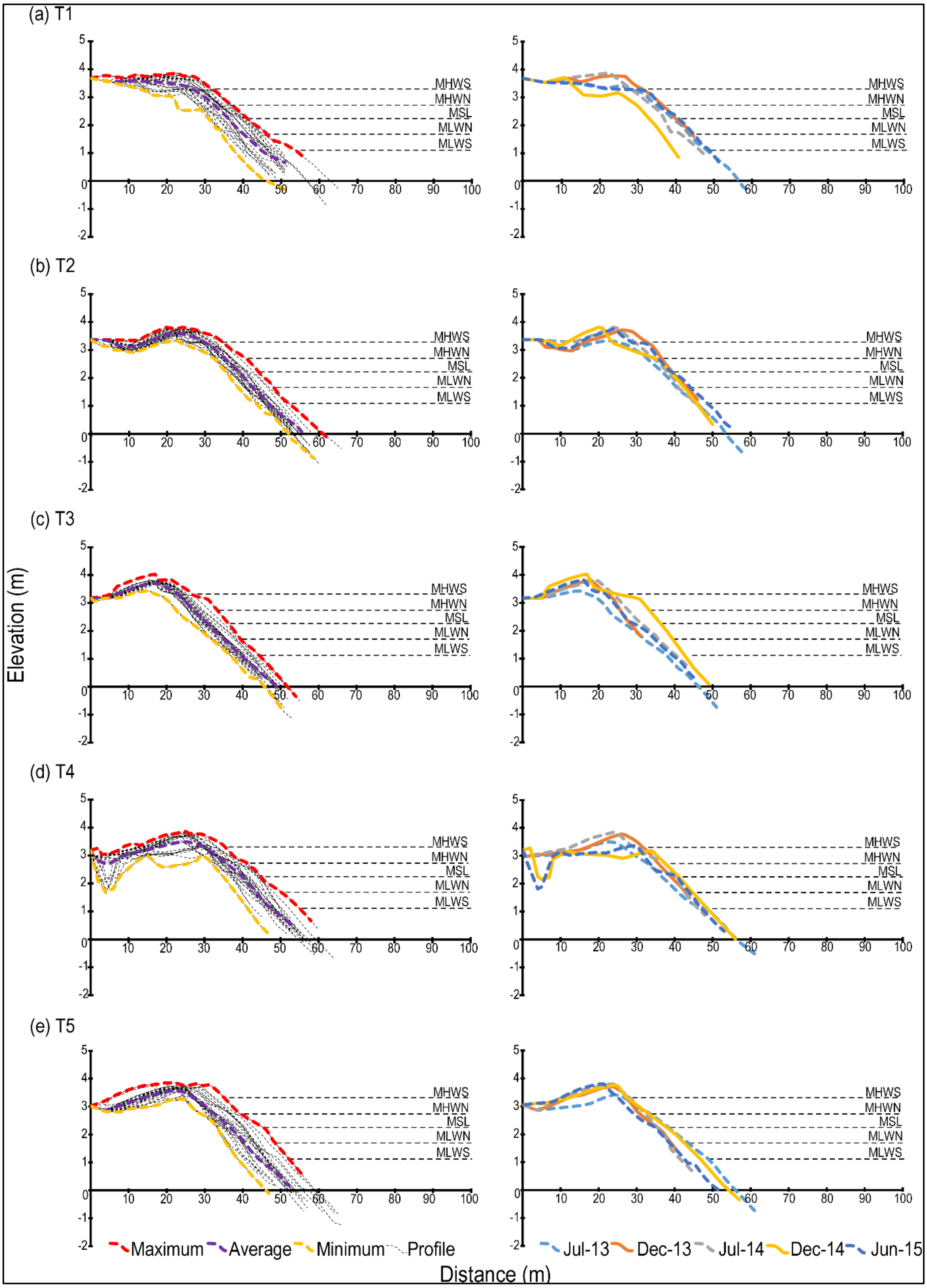

Figure 5.2i: Batu Rakit (B1) beach profile surveyed from July 2013 until June 2015; transects on left and right show profiles over two years and during monsoonal seasons, respectively; (a) Transect 1, (b) Transect 2, (c) Transect 3, (d) Transect 4, and (e) Transect 5.

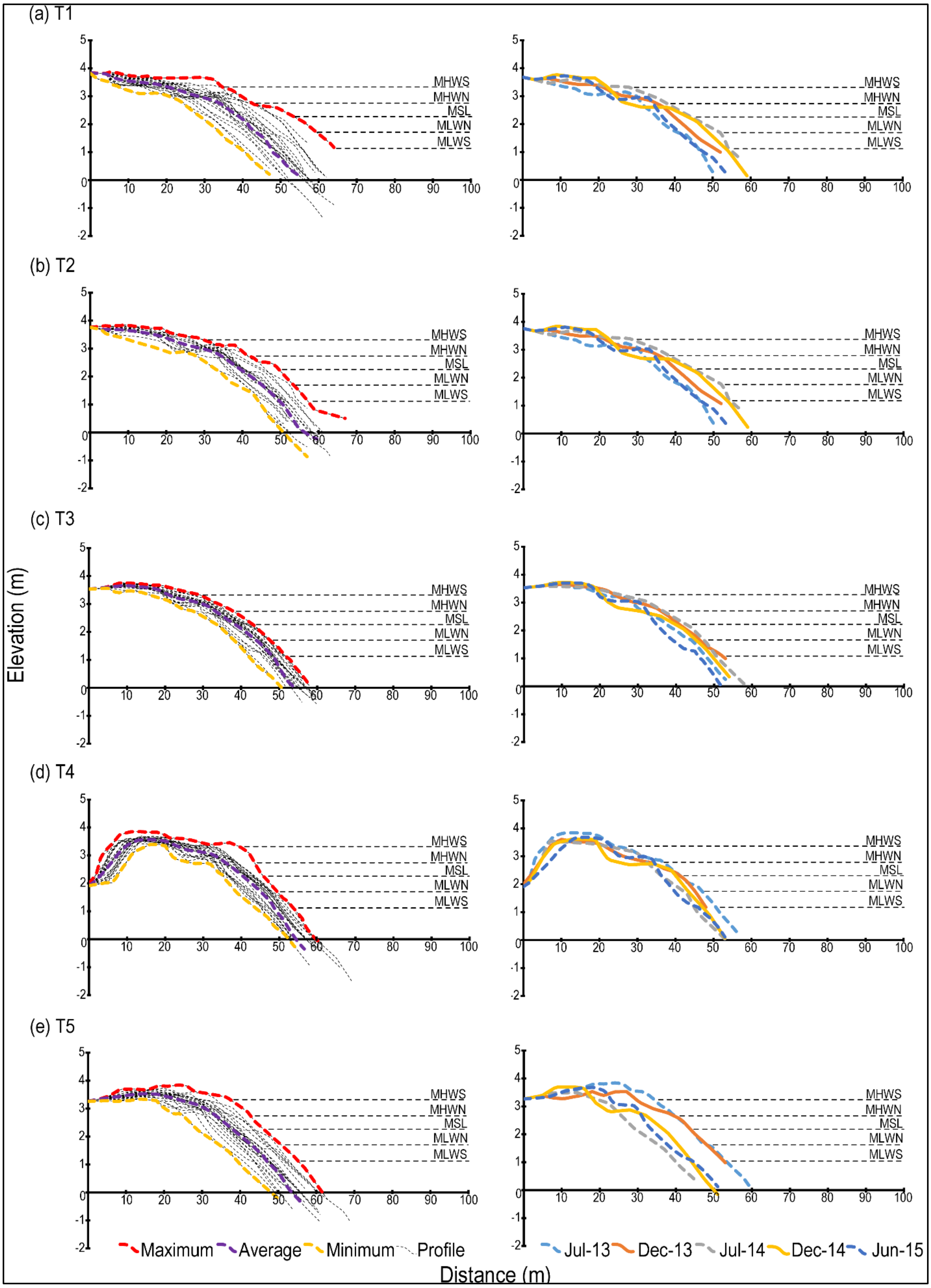

Figure 5.2ii: Pengkalan Maras (B2) beach profile surveyed from July 2013 until June 2015; transects on left and right show profiles over two years and during monsoonal seasons, respectively; (a) Transect 1, (b) Transect 2, (c) Transect 3, (d) Transect 4, and (e) Transect 5.

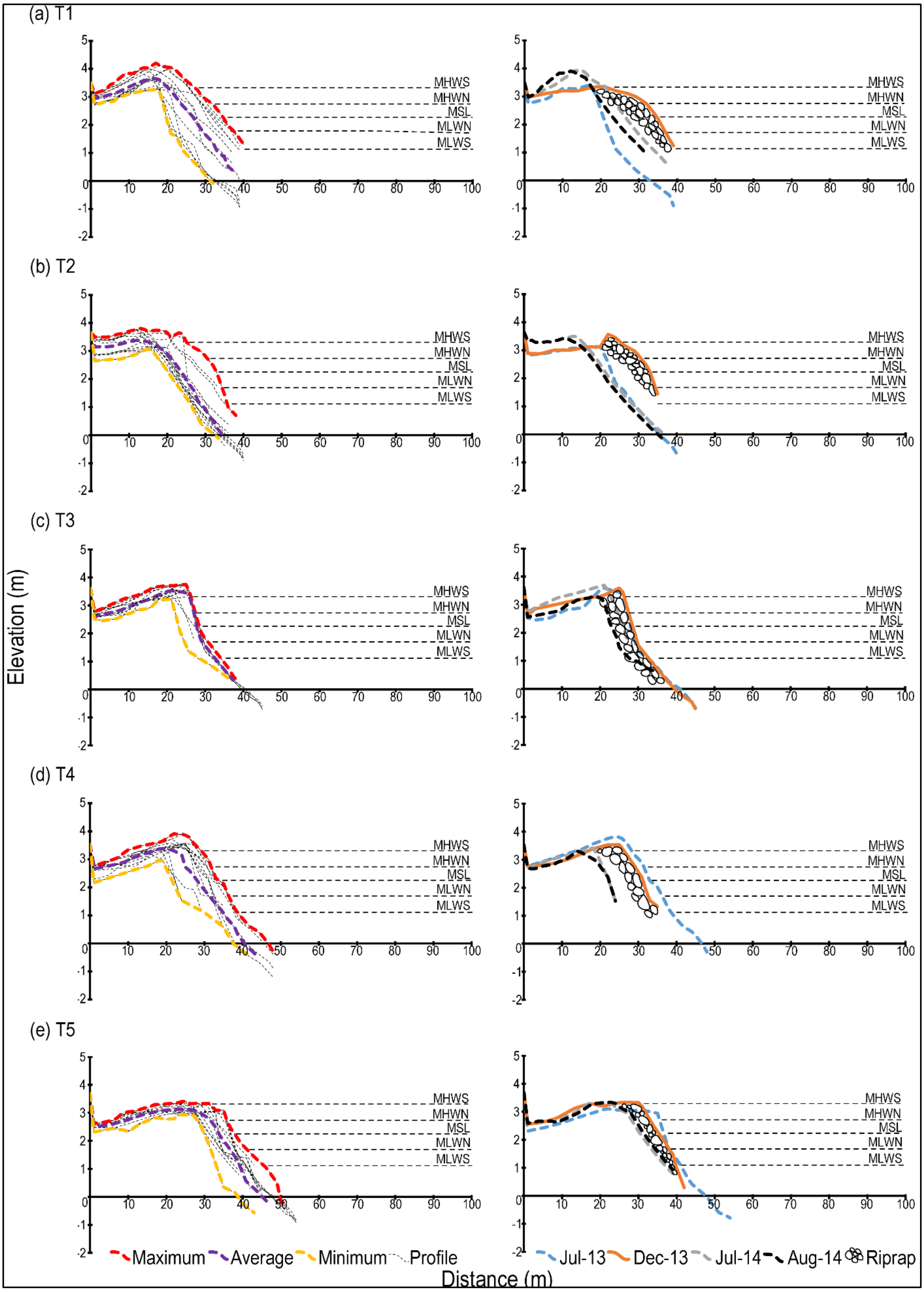

Figure 5.2iii: UMT (B3) beach profile surveyed from July 2013 until August 2014; transects on left and right show profiles over two years and during monsoonal seasons, respectively; (a) Transect 1, (b) Transect 2, (c) Transect 3, (d) Transect 4, and (e) Transect 5.

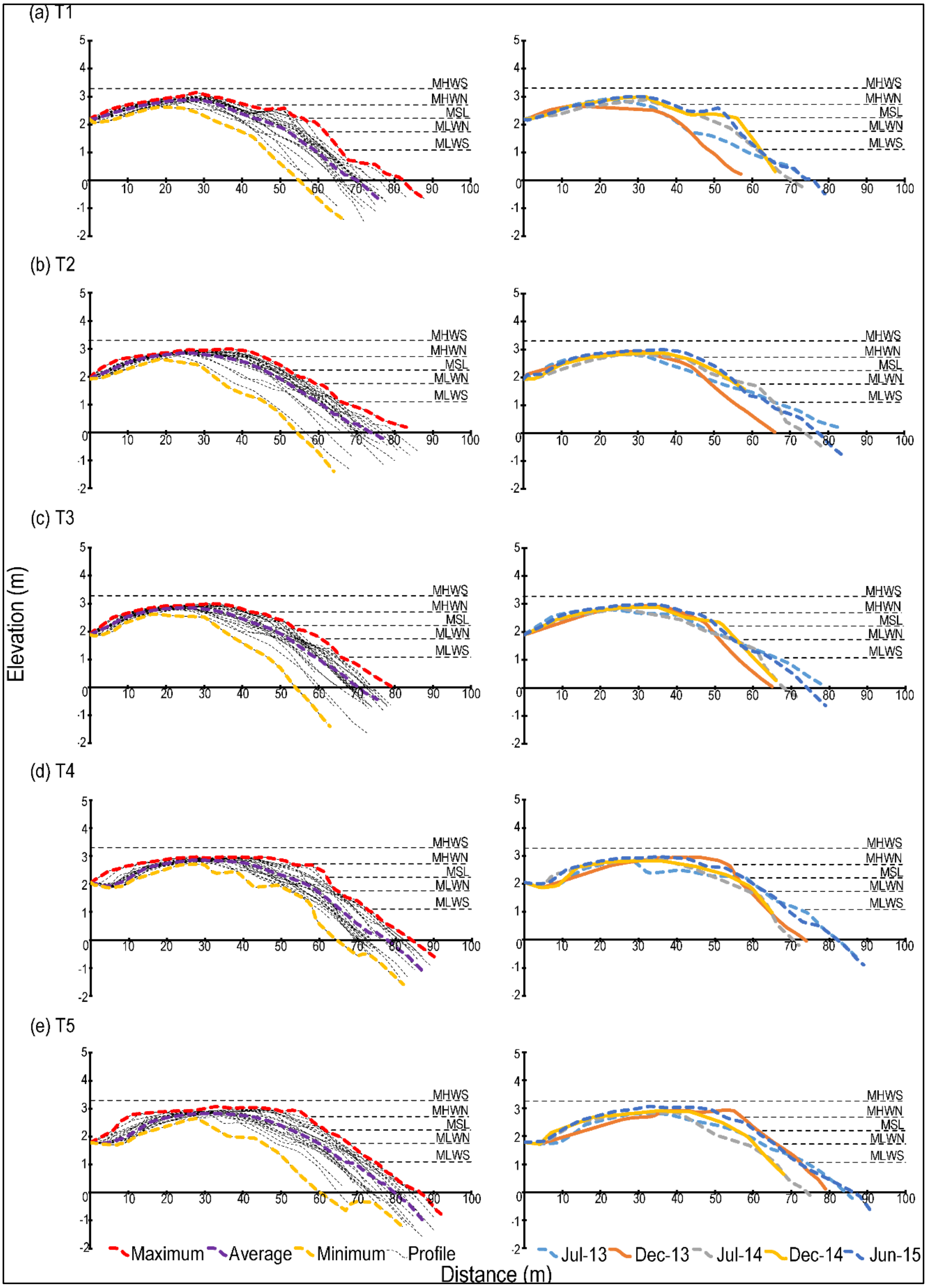

Figure 5.2iv: Teluk Ketapang (B4) beach profile surveyed from July 2013 until June 2015; transects on left and right show profiles over two years and during monsoonal seasons, respectively; (a) Transect 1, (b) Transect 2, (c) Transect 3, (d) Transect 4, and (e) Transect 5.

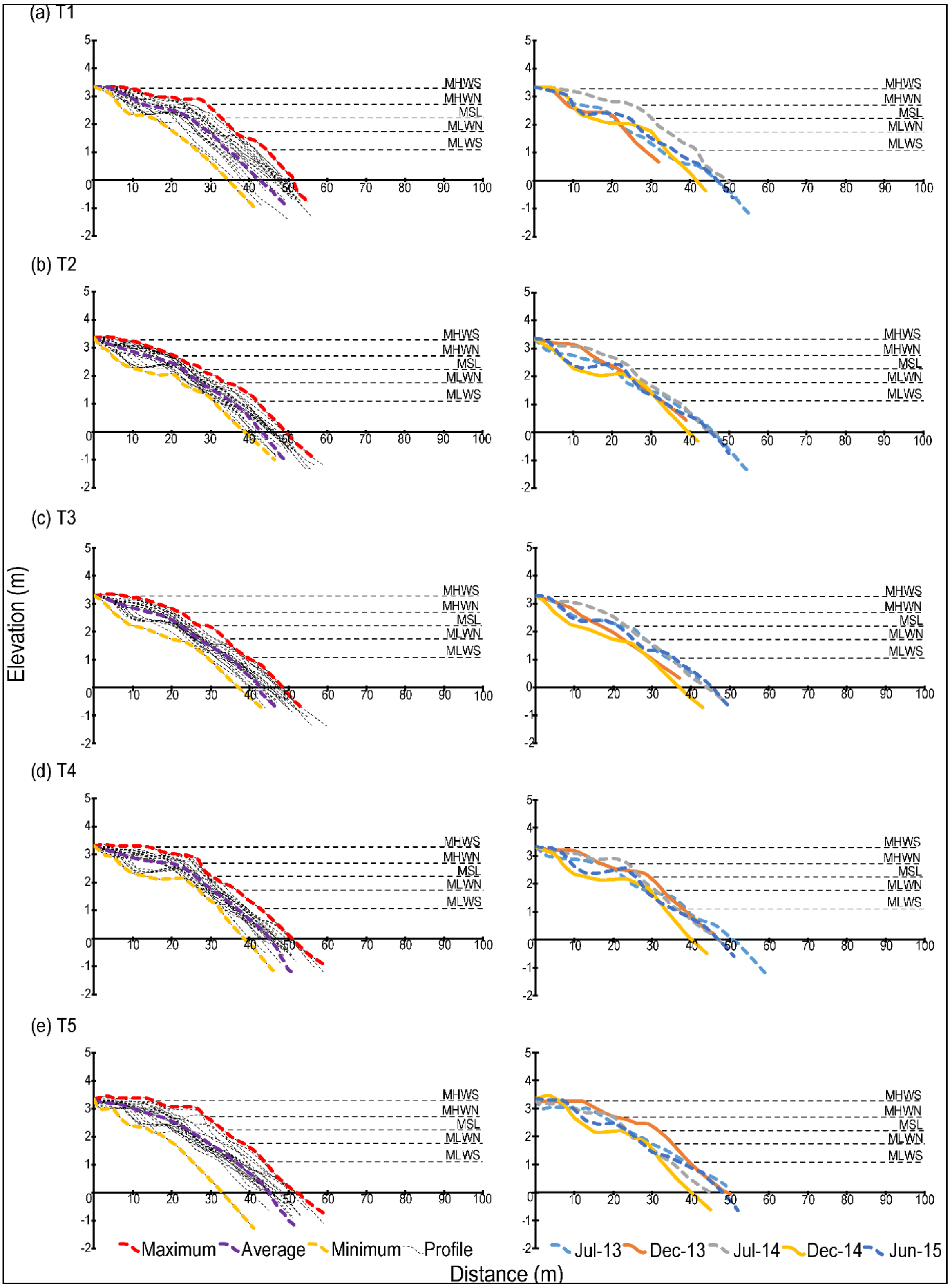

Figure 5.2v: Seberang Takir (B5) beach profile surveyed from July 2013 until June 2015; transects on left and right show profiles over two years and during monsoonal seasons, respectively; (a) Transect 1, (b) Transect 2, (c) Transect 3, (d) Transect 4, and (e) Transect 5.

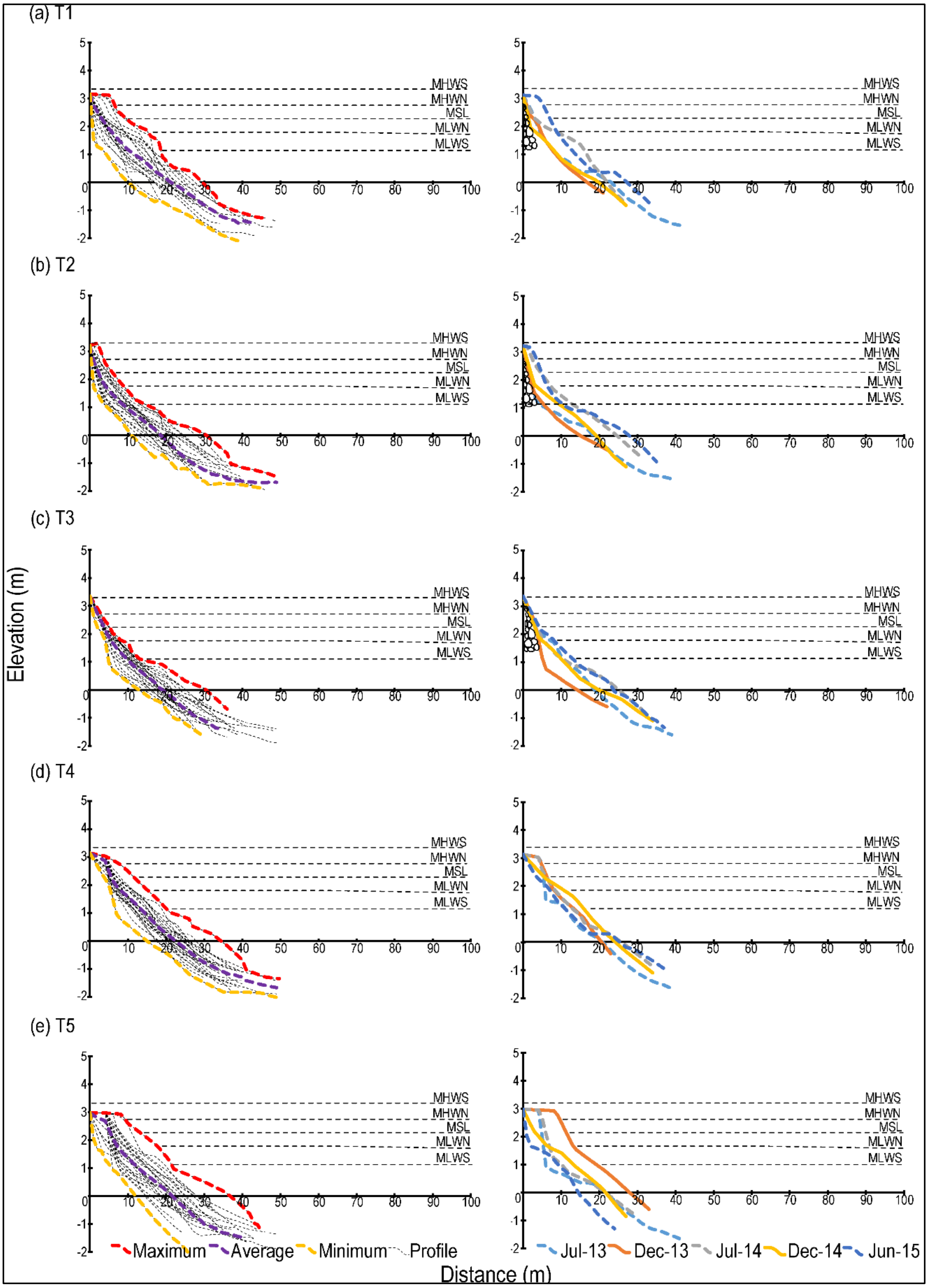

Figure 5.2vi: Kuala Ibai (B6) beach profile surveyed from July 2013 until June 2015; transects on left and right show profiles over two years and during monsoonal seasons, respectively; (a) Transect 1, (b) Transect 2, (c) Transect 3, (d) Transect 4, and (e) Transect 5.

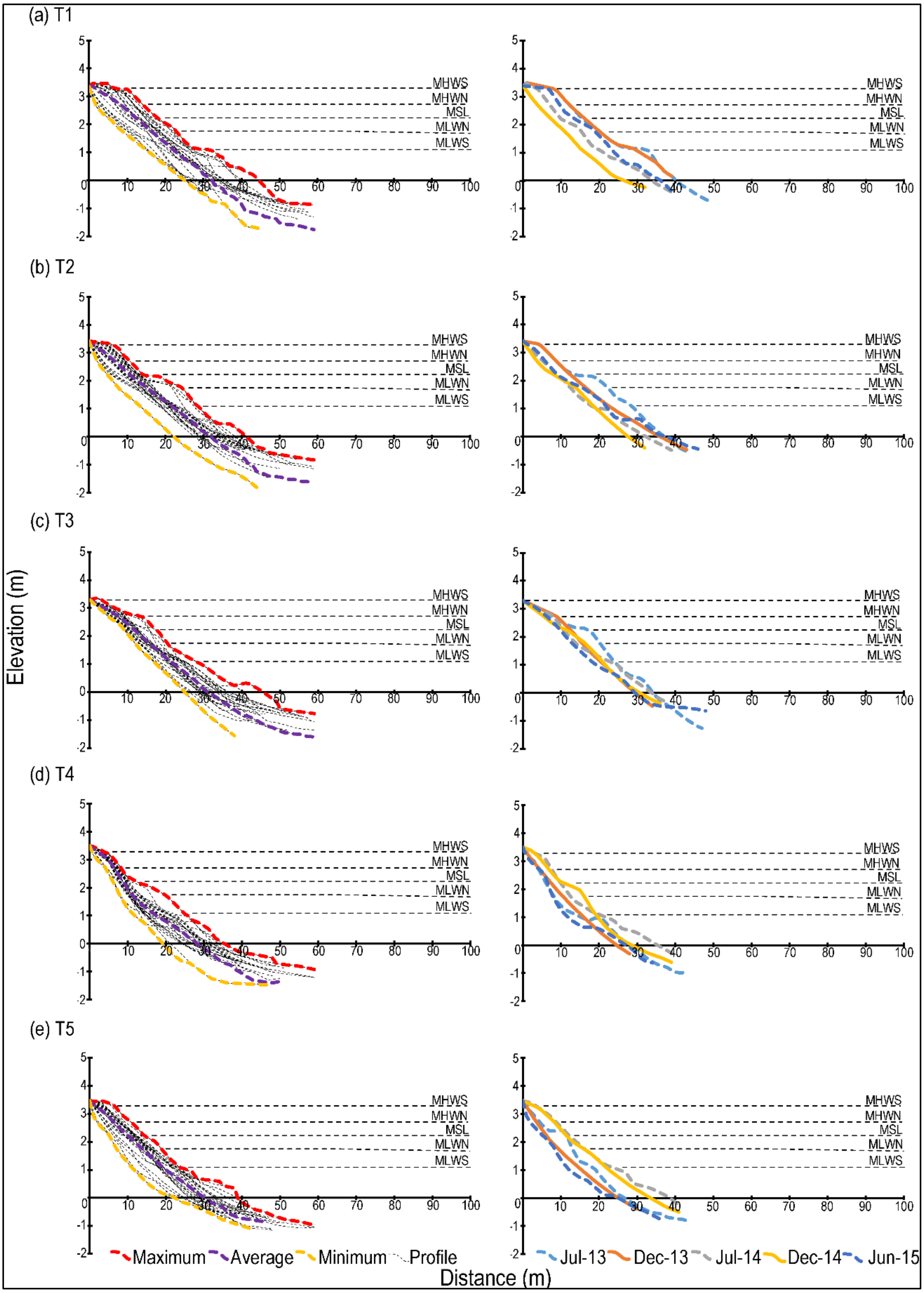

Figure 5.2vii: Marang (B7) beach profile started from July 2013 until June 2015; transects on left and right show profiles over two years and during monsoonal seasons, respectively; (a) Transect 1, (b) Transect 2, (c) Transect 3, (d) Transect 4, and (e) Transect 5.

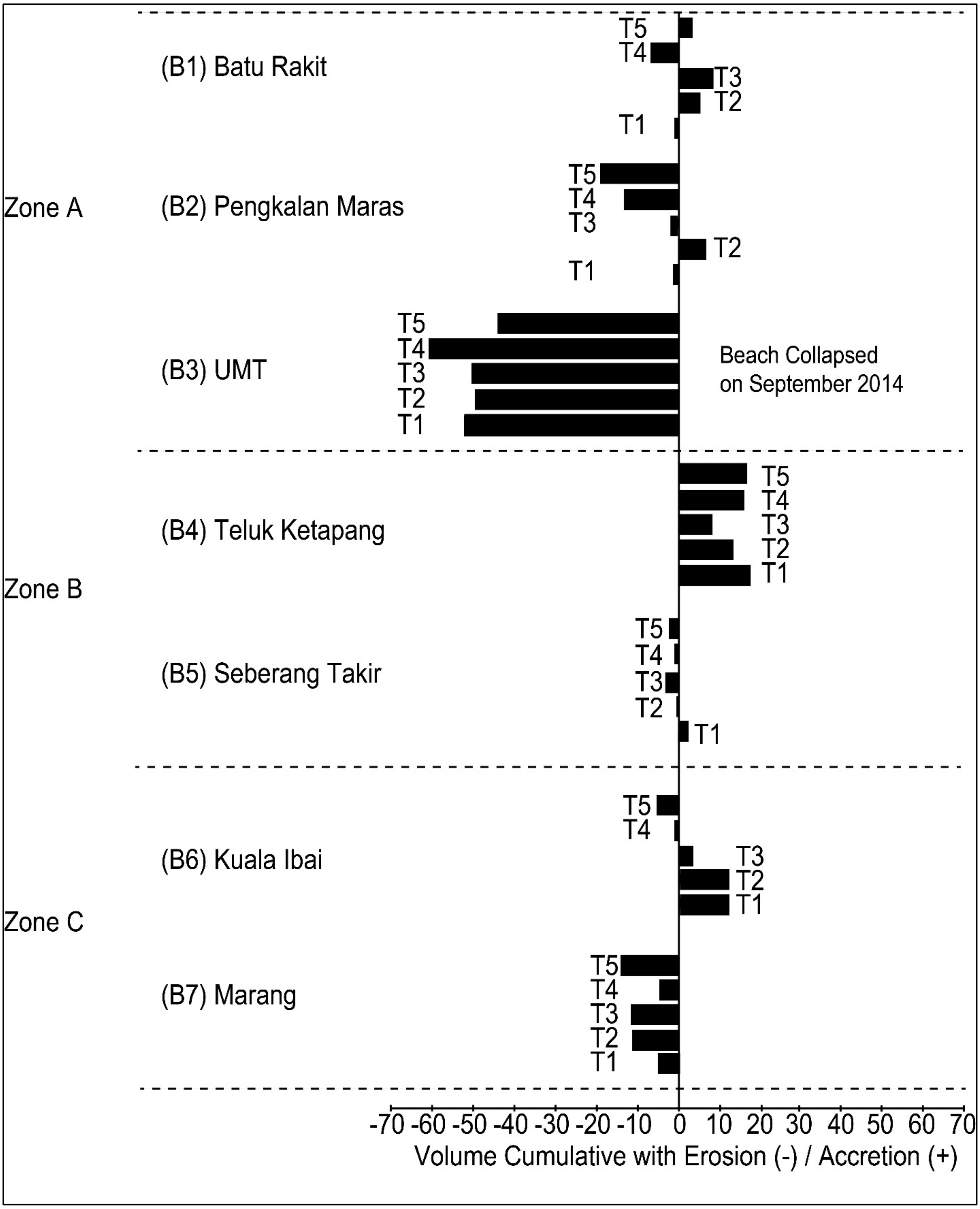

Figure 5.3: Variation of beach volume in the three zones for the two-year data series.

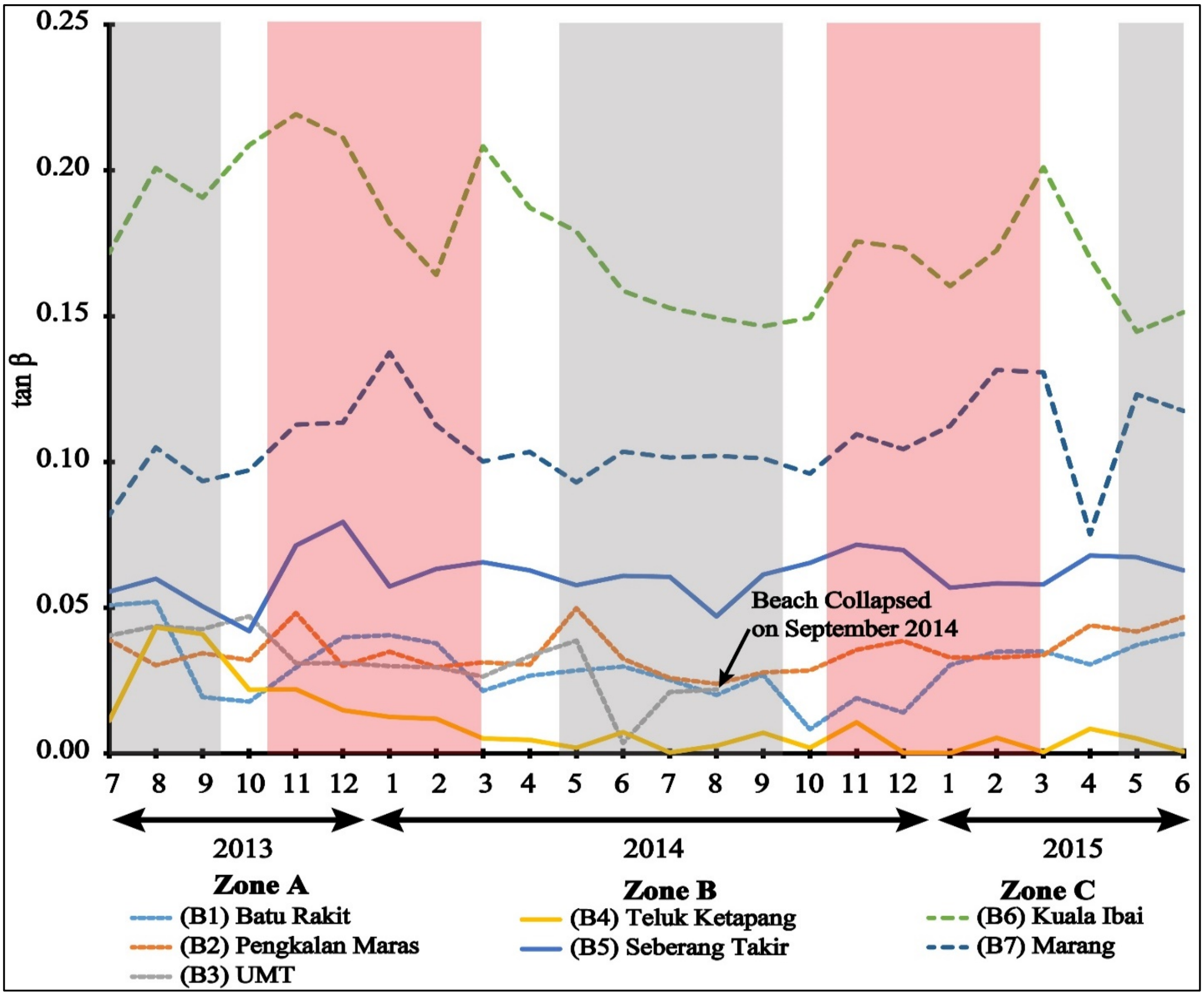

Figure 5.4: Beach slope for the two-year data series; grey and red boxes represent the southwest monsoon and the northeast monsoons, respectively.

ii) Seasonal Variation of Bed Level

Batu Rakit beach (B1)

As shown in Figure 5.5i, there is a seasonal variation in the beach morphodynamics which leads to a bed level change at B1 (Zone A). Firstly, a slip-face bar was observed in July 2013, that is, during the 2013 southwest monsoon season. However, at the end of the southwest monsoon in 2013 (August – September 2013), the slip-face bar was reduced due to infilling of troughs. Furthermore, the beach started to be eroded at the onset of the northeast monsoon of 2013 – 2014 (September 2013 to October 2013). Hence, the formation of a slip-face bar was observed associated with storm activity during the northeast monsoon of 2013 – 2014. However, the rest of this monsoonal season is associated with the occurrence of erosion and occasionally accretion, especially at a distance of 20 – 60 m along the profile, between the mean low and high water spring water levels. The accretion of sand and infilling of troughs started at the end of the northeast monsoon of 2013 – 2014 (February – March 2014).

On the other hand, during the start of the southwest monsoon of 2014, the infilling of beach sand continued with occasional erosion activity at a distance of 0 – 20 m along the profile (berm/dune area), and accretion at a distance of 20 – 60 m (tidal beach area). However, opposite changes in erosion and accretion sometimes occurred on this beach. Hence, the bar (beach sand) was almost completely refilled during the end of the southwest monsoon of 2014 (August – September 2014). Furthermore, at the onset of the northeast monsoon of 2014 – 2015 (September – October 2014), some erosion was seen at a distance of 0 – 20 m (berm/dune area) and heavy accretion at a distance of 20 – 60 m (tidal beach area). In this situation, the prominence of the slip-face bar morphology is reduced because of the full refilling of beach sand. However, erosional activity started late in this northeast monsoon season (onset in October – November 2014 compared to the previous northeast monsoon of 2013 – 2014.

Furthermore, heavy accretion occurred in November – December 2014, and heavy erosion during December 2014 – January 2015 (the slip-face bar started to be observed). However, at the end of the 2014 – 2015 northeast monsoon, the slip-face bar and erosion was still observed in February – March 2015. The same situation occurred during the start of the 2015 southwest monsoon, since the slip-face bar was still observed, but the beach was subject to infilling. Lastly, the cumulative elevation variation over the period from July 2013 to June

2015 shows that the beach fully recovered at the same time as accretion was being observed. In this situation, B1 can be classified as a natural beach.

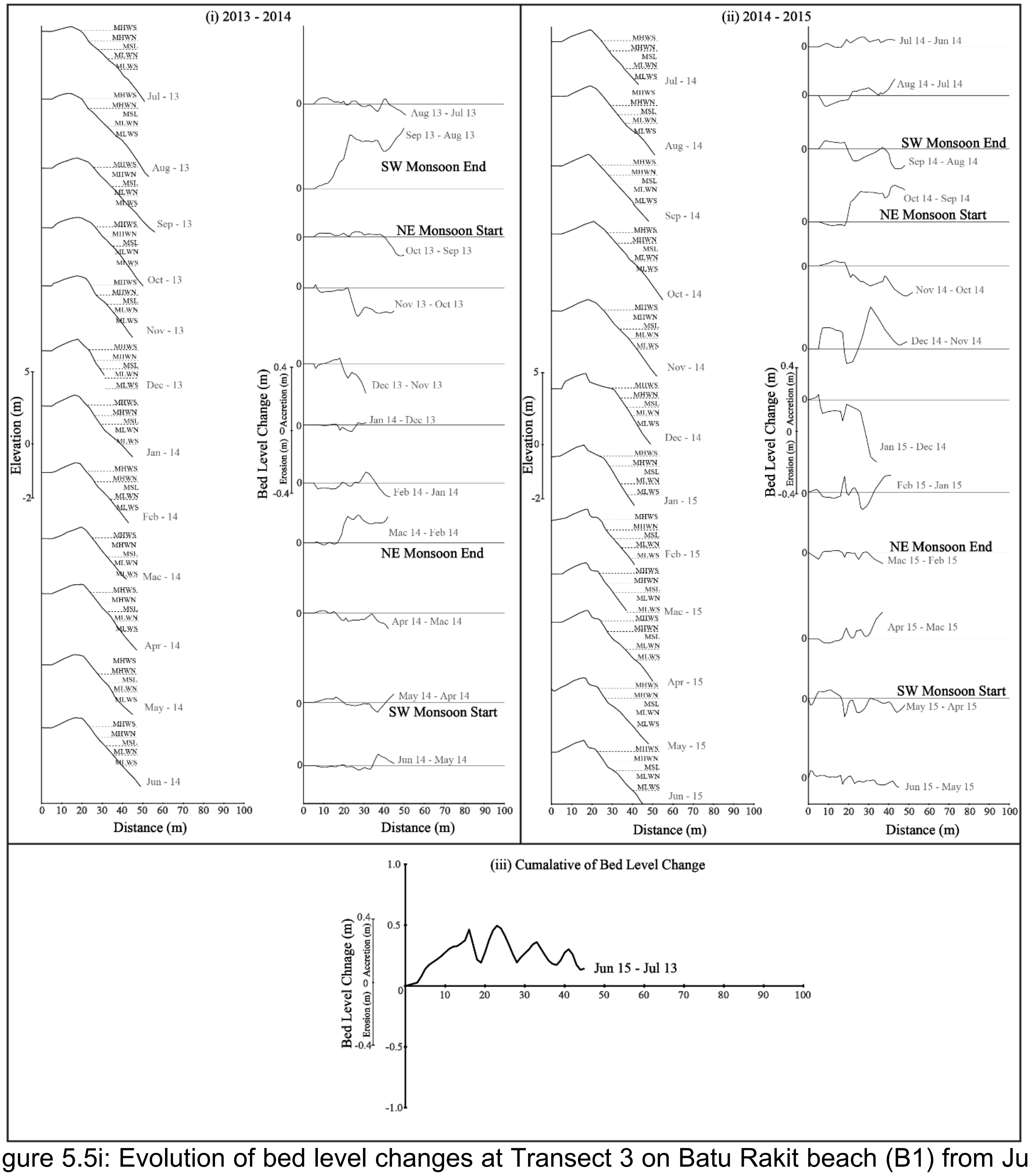

Figure 5.5i: Evolution of bed level changes at Transect 3 on Batu Rakit beach (B1) from July 2013 until June 2015; left and right are beach profiles and bed level changes, respectively; (i) July 2013 – June 2014, (ii) July 2014 – June 2015, and (iii) cumulative bed level change.

Pengkalan Maras beach (B2)

As shown in Figure 5.5ii, the bed level changes at B2 (Zone A) indicate a seasonal variation in the beach morphodynamics. Firstly, similar to the situation at B1, a slip-face bar was observed in July 2013 (during the 2013 southwest monsoon). However, at the end of the 2013 southwest monsoon (i.e. August – September 2013) the slip-face bar increased in volume. Furthermore, the bar was reduced and infilling was observed especially at a distance of 40 – 60 m during the start of the 2013 – 2014 northeast monsoon (September 2013 – October 2013). Hence, the slip-face bar still can be observed in this monsoonal season. In contrast to B1, the erosion started late (i.e., in October – November 2014 due to the formation of slip-face bar. However, the rest of this monsoonal season shows erosion and occasional accretion. The erosion continued until the end of the 2013 – 2014 northeast monsoon (February – March 2014). However, there was less erosion compared to the start of the northeast monsoon.

On the other hand, during the start of the 2014 southwest monsoon (April – May 2014), heavy erosion was observed. Before the heavy erosion became established, heavy accretion was observed for May – June 2014. Accretion continued for the rest of the southwest monsoon and led to complete recovery of the beach sand. Toward the end of the 2014 southwest monsoon (August – September 2014), the beach exhibited some erosion.

Furthermore, during the start of the 2014 – 2015 northeast monsoon (September 2014 – October 2014), the beach morphology showed accretion at a distance of 0 – 40 m and erosion at a distance of 40 – 60 m. A slip-face bar was observed again during October – November similar to the situation during the previous northeast monsoon (late starting of erosion). The rest of the monsoonal season showed erosion and accretion. However, in this monsoon, the slip-face bar was more clearly observed. At the end of the 2014 – 2015 northeast monsoon (February – March 2015), the slip-face bar formed a ridge near the low tide area.

Lastly, during the start of the 2015 southwest monsoon (i.e., April –May 2015) the beach profile showed accretion. However, erosion still continued along with the infilling of sand. Hence, the cumulative bed level change (from July 2013 to June 2015) indicates recovery of the beach. However, the process took longer because the cumulative bed level variations are the result of accretion followed by erosion, and then accretion changing to erosion once again (mostly erosion).

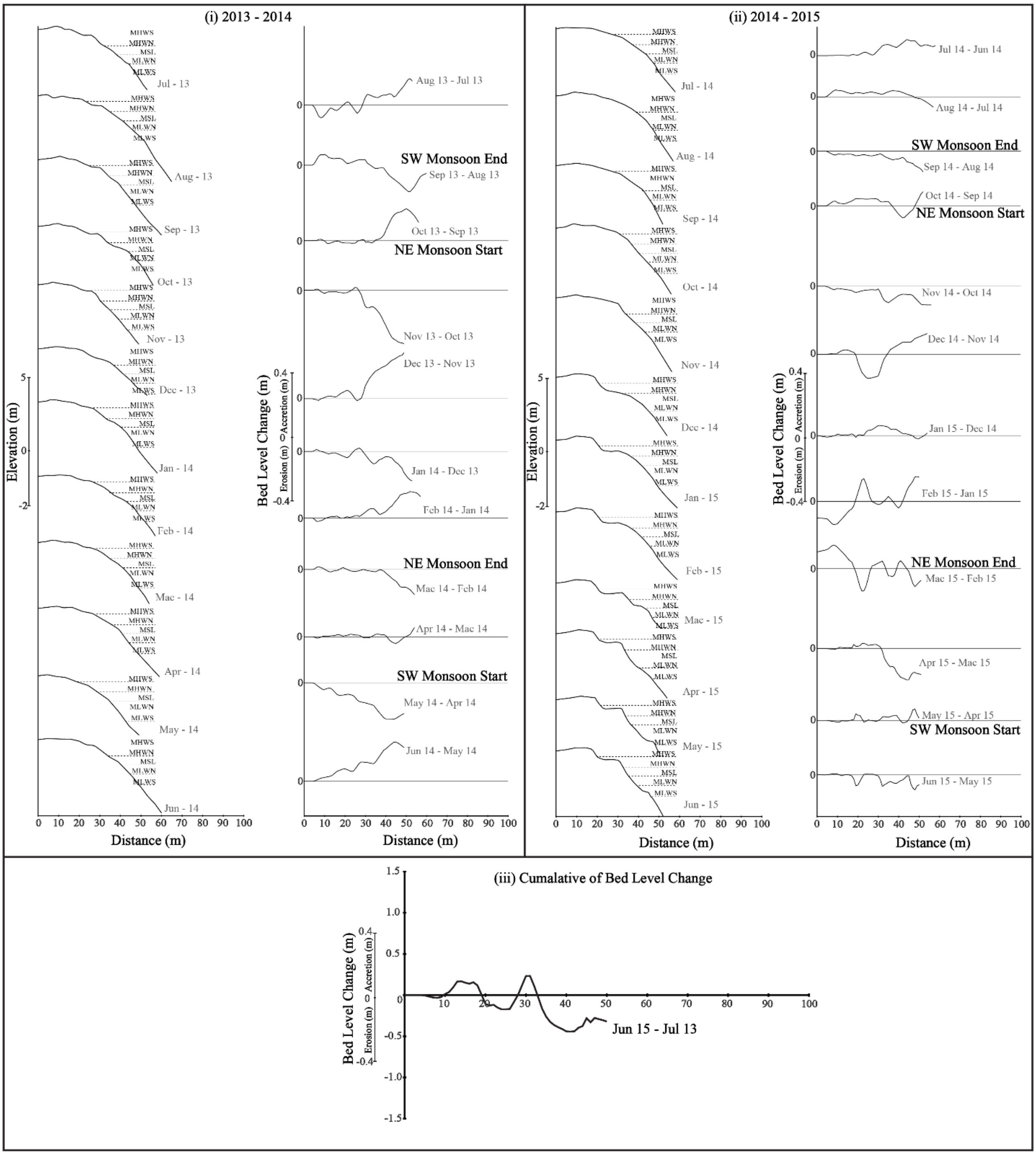

Figure 5.5ii: Evolution of bed level changes at Transect 3 on Pengkalan Maras beach (B2) from July 2013 until June 2015; beach profiles and bed level changes are shown on the left and right, respectively; (i) July 2013 – June 2014, (ii) July 2014 – June 2015, and (iii) cumulative bed level change.

UMT beach (B3)

As shown in Figure 5.5iii, there is a seasonal variation in the beach morphodynamics which leads to a bed level change at B3 (Zone A). Firstly, similar to the situation at B1 and B2, the slip-face bar was observed in July 2013 (during the 2013 southwest monsoon season) and the beach experienced erosion during the period from July to August. However, at the end of the 2013 southwest monsoon, that is, in August – September 2013, the slip-face bar increased and showed heavy erosion.

Hence, the riprap was constructed at the end of September 2013 (after the sampling period of September 2013) to protect the beach. During the start of the northeast monsoon (September – October 2013), accretion was observed behind the riprap, and erosion occurred in front of the riprap. However, similar to the situation in September – October 2013, bed level changes during the rest of the monsoonal season showed full accretion. While, erosion was observed toward the end of the 2013 – 2014 northeast monsoon (February – March 2015).

On the other hand, during the onset of the 2014 southwest monsoon (May – April 2014) after the riprap collapsed, the beach exhibited accretion as scattered rocks still protected the beach. In May – June2014, accretion was observed at a distance of 0 – 20 m and heavy erosion beyond a distance of 20 m, while the beach lost 10 m of width. The erosion continued during June and July 2014, and the beach lost another 10 m (a total of 20 m) of width. Moreover, during July August – July 2014 the beach still showed erosion and the beach lost another 5 m of width (leading to a total of 25 m).

Lastly, at the end of the southwest monsoon 2014, that is, during July and August 2014, the beach collapsed. Overall, the cumulative bed level change (between July 2013 and August 2014) indicates that the beach had suffered heavy erosion and collapsed in one year, while there was an approximately 50 m loss of beach width.

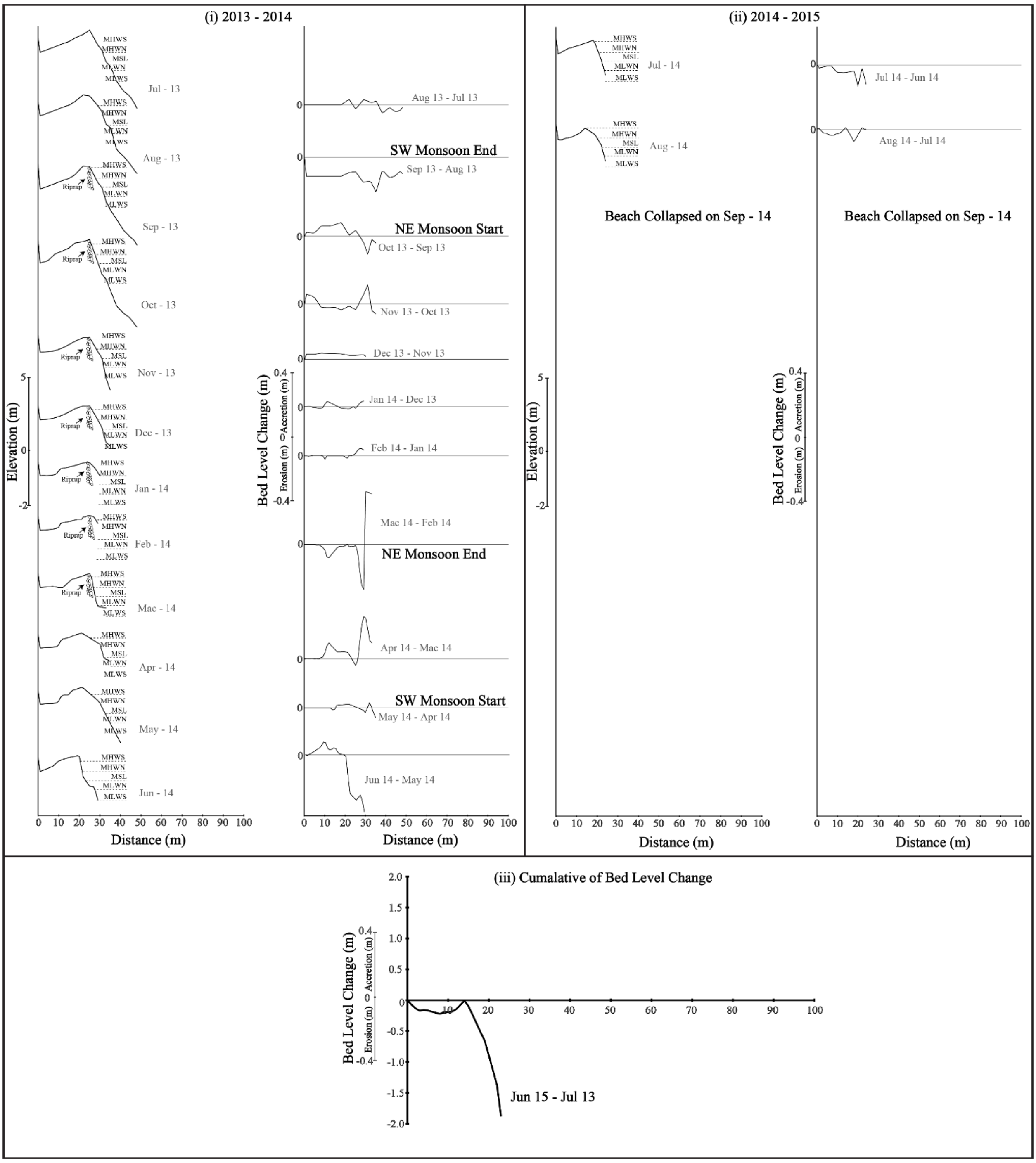

Figure 5.5iii: Evolution of bed level change at Transect 3 on UMT (B3) from July 2013 until June 2015; beach profiles and bed level changes are shown on the left and right, respectively ; (i) July 2013 – June 2014, (ii) July 2014 – June 2015, and (iii) cumulative bed level change.

Teluk Ketapang beach (B4)

As shown in Figure 5.5iv, there is a bed level change of seasonal variation of the beach morphodynamic at B4 (Zone B). Firstly, similar to the situation in Zone A, the slip-face bar was observed in July 2013 (during the southwest monsoon 2013 season). However, the morphodynamic pattern is different. In July – August 2013, the beach eroded heavily and the slip-face bar was more clearly seen. At the onset of the 2013 – 2014 northeast monsoon, the slip-face bar was reduced due to infilling of the trough and continued to occur in the consequent months. At the end of the 2013 – 2014 northeast monsoon, the beach still showed accretion and was able to fully recover.

On the other hand, during the onset of the 2014 southwest monsoon (May – April 2014), the slip-face bar was observed again due to erosion on the beach, and was partly subject to accretion. Furthermore, this situation was similar to that in the previous months, and the slip-face bar was more clearly seen. As observed in the previous month, the slip-face bar was in process of being infilled at the end of the 2014 southwest monsoon (August – September 2014).

The slip-face bar was reduced due to the infilling of troughs associated with accretion and erosion during the onset of the 2014 – 2015 northeast monsoon. In December 2014 and January 2015, the beach has fully recovered. However, this was a different situation compared with the previous end of the northeast monsoon (2013 – 2014), since the slip-face bar was observed during the 2014 – 2015 northeast monsoon.

Finally, the slip-face bar was observed as in the previous month, with the beach tending to accrete due to reduction of the bar during the onset of the 2015 southwest monsoon in May – April 2015. The cumulative bed level change (July 2013 – June 2015) indicates that the beach was subject to heavy accretion and the berm was built up over a distance of 35 – 65 m. On the other hand, the beach was eroded over a distance of 65 to 90 m from the berm.

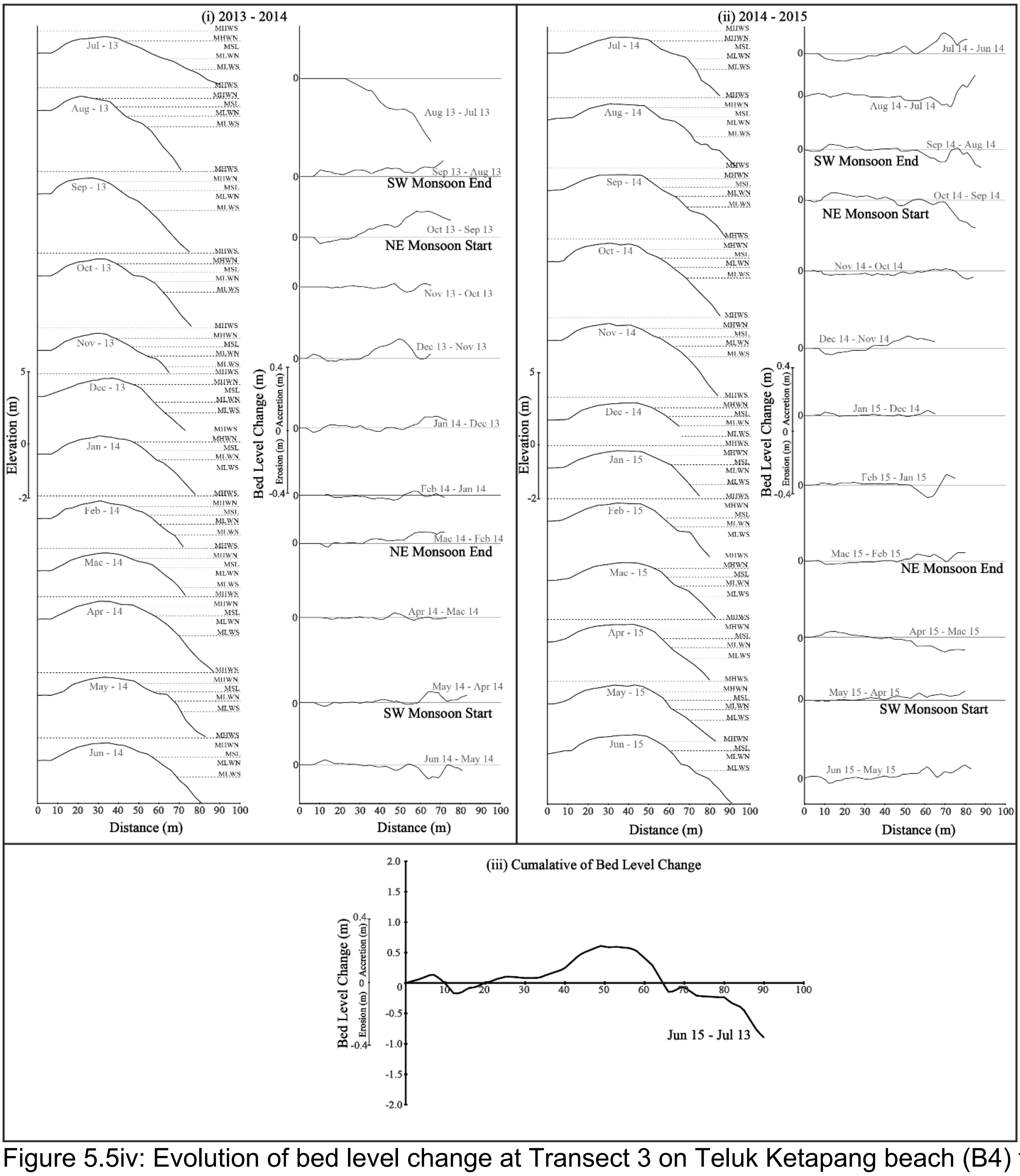

Figure 5.5iv: Evolution of bed level change at Transect 3 on Teluk Ketapang beach (B4) from July 2013 until June 2015; beach profiles and bed level changes are shown on the left and

right, respectively (i) July 2013 – June 2014, (ii) July 2014 – June 2015, and (iii) cumulative of bed level change.

Seberang Takir beach (B5)

As shown in Figure 5.5v, the bed level changes at B5 (Zone B) show there is a seasonal variation of the beach morphodynamics. Firstly, similar to the situation at B4, a slip-face bar was observed in July 2013 (during southwest monsoon of 2013 season). However, the pattern of morphodynamics was different. Meanwhile, at the end of the southwest monsoon of 2013 the slip-face bar was reduced due to infilling of the sand. During the onset of the 2013 – 2014 northeast monsoon, the bar was almost fully recovered with erosion on the dune and accretion on the foreshore. However, heavy erosion occurred during the period from October to November 2014 and the foreshore clearly showed a slip-face bar. Furthermore, the rest of the monsoonal season showed occasional erosion and accretion. Meanwhile, at the end of the 2013 – 2014 northeast monsoon (February – March 2014), this beach again showed heavy erosion.

On the other hand, during the onset of the 2014 southwest monsoon (March – April 2014) the beach started to recover with occasional accretion and erosion. However, due to the heavy accretion during the previous months (July – August 2014), the heavy erosion exhibited in August – September 2014 led to infilling of the slip-face bar. Furthermore, during the onset of the 2014 – 2015 northeast monsoon (September – October 2014) the beach underwent erosion which continued until the next month. In the period from December 2014 to January 2015, the beach showed accretion and almost completely recovered. However, from February 2015 onwards, the slip-face bar was observed and continued to the end of the 2014 – 2015 northeast monsoon (March 2015).

Lastly, the beach showed erosion during the onset of the 2015 southwest monsoon and did not recover compared to the previous southwest monsoon (2014). The cumulative bed level change (between July 2013 and June 2015) showed erosion on the dune, with accretion on the foreshore. In this situation, the beach was mostly eroded at the dune at the same level by higher tides.

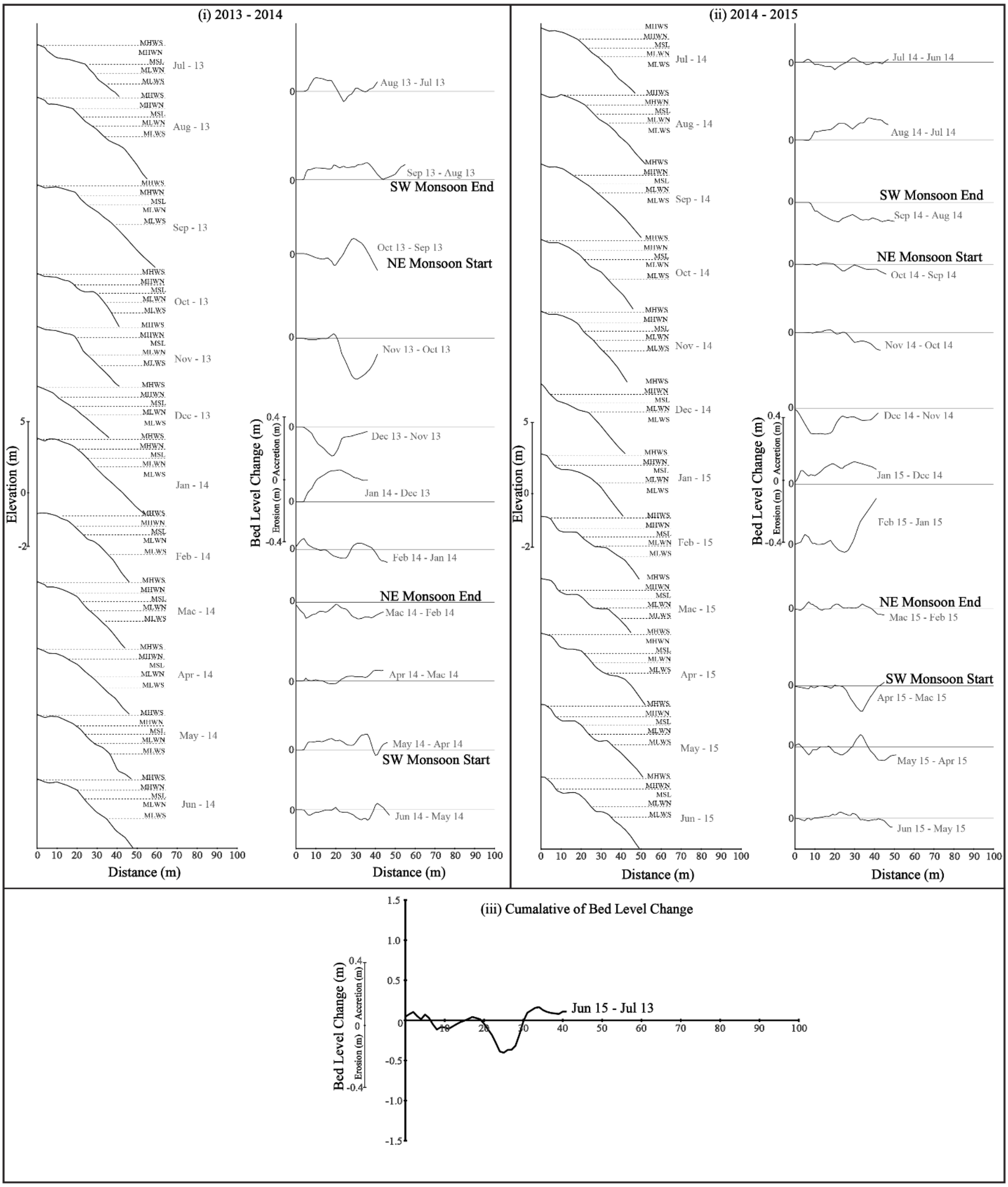

Figure 5.5v: Evolution of bed level changes at Transect 3 on Seberang Takir beach (B5) from July 2013 until June 2015; beach profiles and bed level changes are shown on the left and right, respectively; (i) July 2013 – June 2014, (ii) July 2014 – June 2015, and (iii) cumulative bed level change.

Kuala Ibai beach (B6)

As shown in Figure 5.5vi, the bed level changes at B6 (Zone C) shows there is a seasonal variation of the beach morphodynamics. Firstly, similar to the situation in Zones and B, the slip-face bar was observed in July 2013 (during the 2013 southwest monsoon season). However, the pattern of morphodynamic was the same as in B5. Hence, heavy erosion was observed and slip-face bar was clearly shown during August – July 2013. At the end of the southwest monsoon 2013 (August – September 2013), accretion was observed and the slip-face bar was reduced due to infilling of the trough. Meanwhile, accretion was observed in front the riprap and erosion occurred at the foreshore during the onset of the 2013 – 2014 northeast monsoon. The erosion continued in October and November 2013, and the rest of the monsoonal season showed accretion. However, at the end of the 2013 – 2014 northeast monsoon (February – March 2015), erosion was observed again and the slip-face bar was still present.

On the other hand, during the onset of the southwest monsoon (May – April 2014), accretion was observed and continued in the subsequent months. Similarly, at the end of the 2014 southwest monsoon (August – September 2014), there was also some accretion and the slip-face bar was reduced. However, during the onset of the 2014 – 2015 northeast monsoon (September – October2014), heavy erosion was observed and continued in the subsequent months (except December 2014 and January 2015, which showed accretion). In this northeast monsoon, the slip-face bar was not clearly seen. Heavy erosion was also seen at the end of the 2014 – 2015 northeast monsoon.

Lastly, during the onset of the 2015 southwest monsoon, accretion started to cause recovery of the beach. The cumulative bed level change between July 2013 and June 2015 indicates that the beach exhibited accretion after the revetment recovered.

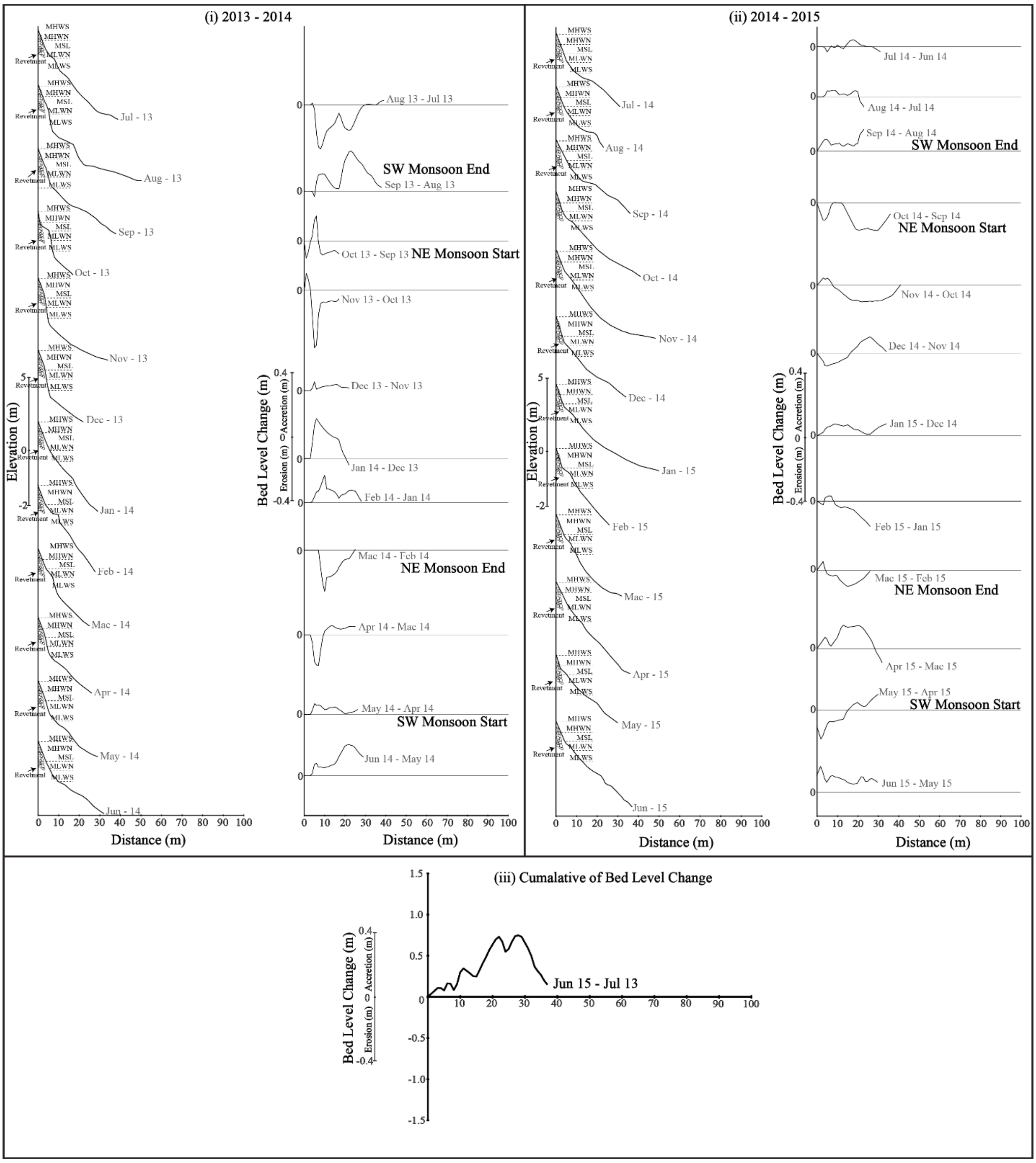

Figure 5.5vi: Evolution of bed level change at Transect 3 on Kuala Ibai (B6) between July 2013 until June 2015; beach profiles and bed level changes are shown on the left and right, respectively; (i) July 2013 – June 2014, (ii) July 2014 – June 2015, and (iii) cumulative bed level change.

Marang beach (B7)

As shown in Figure 5.5vii, the bed level changes at B7 (Zone C) indicate a seasonal variation of the beach morphodynamics. Firstly, similar to the situation at B6, a slip-face bar was observed in July 2013 (during the southwest monsoon 2013 season) and the morphodynamic pattern is also the same. Hence, heavy erosion occurred and a slip-face bar was clearly seen during the period from July to August 2013. At the end of the 2013 southwest monsoon (August – September 2013), accretion was observed and the slip-face bar was reduced due to infilling of the trough.

Accretion was observed at a distance of 0 – 25 m and erosion at a distance of 25 – 50 m during the onset of the 2013 – 2014 northeast monsoon. Erosion continued in November – October 2013, and accretion was seen for the rest of the monsoonal season. Heavy accretion was observed in January – February 2014. However, accretion was also seen at the end of the 2013 – 2014 northeast monsoon (February – March 2015).

On the other hand, during the onset of the southwest monsoon (May – April 2014), accretion was observed and continued during the subsequent months. However, at the end of the 2014 southwest monsoon (August – September 2014) erosion was observed. This situation is similar to that during the previous onset of the northeast monsoon (2013 – 2014), which showed accretion and erosion on the backshore and foreshore, respectively. The erosion continued in October – November 2014 and in the subsequent months except during November and December 2014, which showed accretion. Meanwhile, accretion was observed at the end of the 2014 – 2015 northeast monsoon.

Lastly, during the onset of the 2015 southwest monsoon, heavy erosion was observed and the slip-face bar became reduced in May – June 2015. However, the cumulative bed level change between July 2013 and June 2015 shows that the beach underwent erosion.

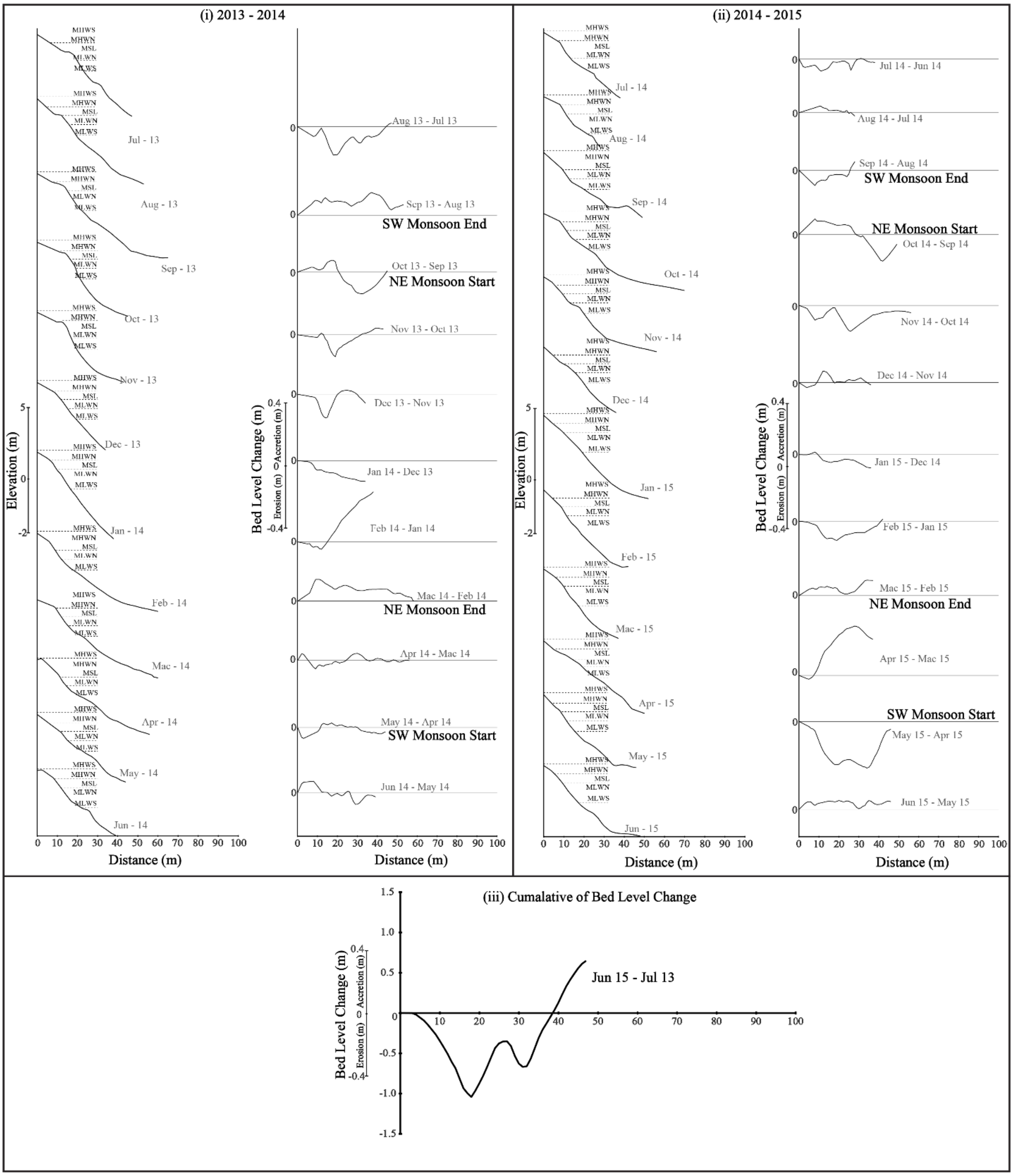

Figure 5.5vii: Evolution of bed level changes at Transect 3 on Marang beach (B7) from July 2013 until June 2015; beach profiles and bed level changes are shown on the left and right, respectively; (i) July 2013 – June 2014, (ii) July 2014 – June 2015, and (iii) cumulative bed level change.

Elevation variation by zone

Firstly, the slip-face bar was observed in July 2013 (during the 2013 southwest monsoon season) in all zones where recovery was in progress during this month. The beach morphodynamic evolution in Zone A is based on observations at stations B1, B2 and B3, while Zone B is represented by B4 and B5, and Zone C by B5 and B6 (Table 5.2).

Table 5.2: Summary of beach morphodynamic evolution (derived from bed level changes) during monsoonal seasons.

Monsoon	Zone A	Zone B	Zone C
Southwest 2013	Accretion	Erosion	Accretion
Northeast 2013-2014	Erosion	Accretion	Erosion
Southwest 2014	Accretion	Erosion	Accretion
Northeast 2014-2015	Erosion	Accretion	Erosion
Southwest 2015	Accretion	Erosion	Accretion

In summary, B2 and B3 in Zone A show a higher-energy morphodynamic state compared to B1, which is more typical of a natural beach. During the end of the 2013 southwest monsoon, that is, in August and September 2013, the slip-face bar was increased. On the other hand, the bar became reduced and infilling occurred especially on the foreshore during the onset of the 2013 – 2014 northeast monsoon (in September and October 2013), whereas the beach recovery process took place later. Hence, the slip-face bar can still be observed during this period (October 2013). However, erosion of the beach started late, that is, during October – November 201 due to the formation of slip-face bar. Meanwhile, the rest of the monsoonal season showed erosion and occasionally accretion. Furthermore, erosion continued up until the end of the 2013 – 2014 northeast monsoon (February – March 2014).

On the other hand, during the onset of the southwest monsoon 2014 (May – April 2014), heavy erosion was observed. At the end of the 2014 southwest monsoon (August – September 2014), the beach exhibited some erosion, and it should be noted that B3 collapsed during this period. Furthermore, during the onset of the 2014 – 2015 northeast monsoon (September – October 2014), the beach morphology showed accretion and erosion (not just erosion).

Hence, the slip-face bar was observed again in October and November 2014, which is the same situation as observed during the previous northeast monsoon (late starting of erosion). Furthermore, the rest of the monsoonal season showed erosion as well as accretion. However, during this monsoonal period, the slip-face bar was more clearly observed. At the end of the 2014 – 2015 northeast monsoon (February – March 2015), the slip-face bar was ridged/banked up against the low tide area.

Lastly, accretion was observed during the onset of the southwest monsoon in May – April 2015. However, erosion persisted and also the infilling of sand was observed. Hence, the cumulative bed level change (July 2013 –June 2015) indicates recovery of the beach except at B3 where it collapsed in September 2014.

However, to support this result, Figure 5.6i shows the DEM of the cumulative bed level change from July 2013 to June 2015 (for all transects at stations B1, B2 and B3). The results show that accretion is mostly observed in B1, except in the northwestern sector near the outlet system. Erosion was observed in B2 and B3, in areas located close to the airport tarmac extension.

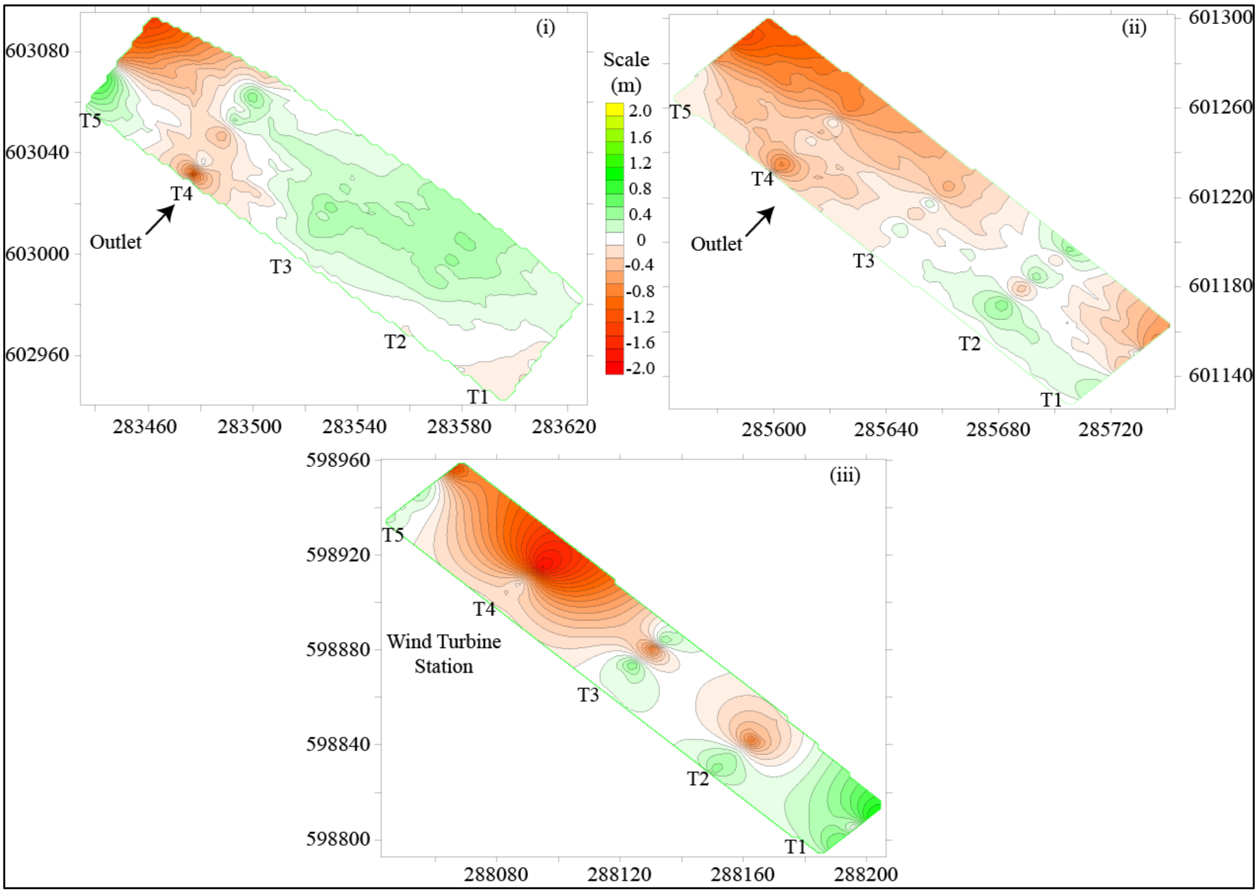

Figure 5.6i: DEM of cumulative bed level change between July 2013 and June 2015 in Zone A, covering: i) B1: Batu Rakit beach, ii) B2: Pengkalan Maras beach, and iii) B3: UMT beach.

However, the beach morphodynamic pattern in Zone B is different, since B4 (close to the southern side of the airport tarmac extension) exhibits accretion almost throughout the monsoonal season. Meanwhile, B5 (close to the northern breakwater of the Terengganu River) shows a similar beach morphodynamic pattern as in Zone C. Hence, station B4 was chosen to study the impact of the tarmac extension, which could be a contributing factor to the beach morphodynamics in Zone B.

In July – August 2013, the beach tended to become heavily eroded and the slip-face bar was more clearly seen. However, during the onset of the 2013 – 2014 northeast monsoon, the slip-face bar was reduced due to the starting of infilling of the trough, which continued in the subsequent months. Hence, the beach was fully recovered at the end of the 2013 – 2014 northeast monsoon.

On the other hand, during the onset of the 2014 southwest monsoon (May – April 2014), the slip-face bar was observed again. However, the slip-face bar was in the process of infilling during the end of the 2014 southwest monsoon of (August – September 2014). The slip-face bar was reduced during the onset of the 2014 – 2015 northeast monsoon. However, the situation in this 2014 – 2015 northeast monsoon was different compared with the end of the previous northeast monsoon (2013 – 2014) because the slip-face bar was observed.

Lastly, the beach exhibited accretion due to the reduced volume of the bar during the onset of the southwest monsoon in May – April 2015. Meanwhile, the cumulative bed level change (July 2013 to June 2015) indicates that the beach was subject to heavy accretion and the berm was built up. However, the beach was eroded in the low tide area.

On the other hand, the DEM in Zone B for the period between July 2013 and June 2015 can be used to support the beach morphodynamic pattern shown in Figure 5.6ii (for all transects at stations B4 and B5). The results also demonstrate that mostly accretion occurred at B4, except in low tide areas, while the outlet system areas also showed some erosion. On the other hand, mostly erosion was seen at B5, since this area is located close to the Terengganu River breakwater. However, less erosion was observed compared to the beach areas in Zone A.

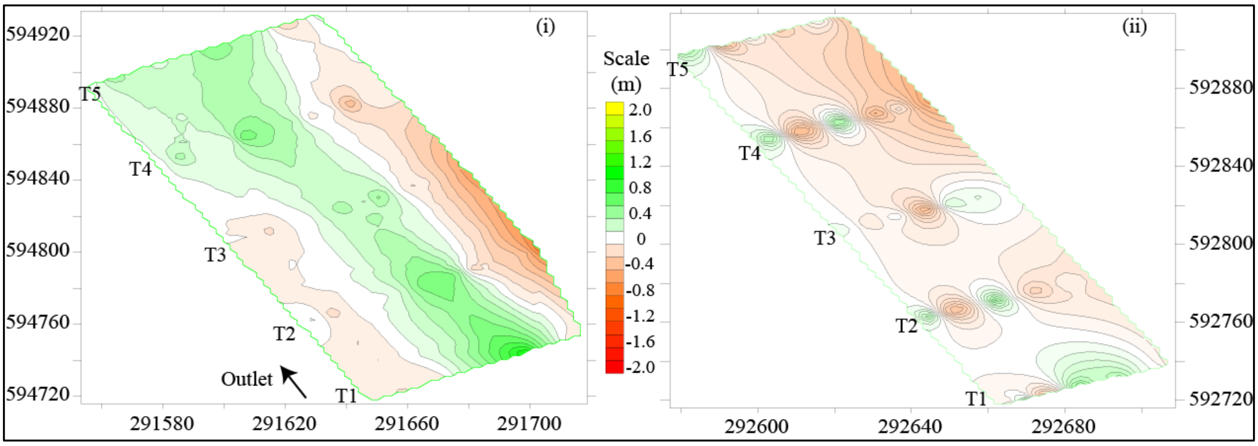

Figure 5.6ii: DEM of the cumulative bed level change between July 2013 and June 2015 in Zone A, covering: i) B4: Teluk Ketapang beach, and ii) B6: Seberang Takir beach.

In summary, Zone C (B6 and B7) shows contrasting beach morphodynamics compared with Zone A and Zone B (each comprises just one selected station). Furthermore, heavy erosion was observed and the slip-face bar was clearly seen from July to August 2013, starting to be reduced at the end of the 2013 southwest monsoon of (August – September 2013). The accretion and erosion during the onset of the 2013 – 2014 northeast monsoon was similar to that in Zone B, whereas full erosion started later in October – November 2013. Meanwhile, erosion was observed at the end of the 2013 – 2014 northeast monsoon (February – March 2015), when B6 showed accretion.

On the other hand, during the onset of the southwest monsoon (May – April 2014) accretion was observed and continued in subsequent months. However, at the end of the southwest monsoon 2014 (August – September 2014) accretion was seen (B7 showed erosion). However, the slip-face bar was still observed. It is the same situation as at the onset of the previous northeast monsoon (2013 – 2014), when accretion and erosion were observed on the backshore and foreshore respectively. The erosion continued in October – November 2014 and subsequent months (occasionally showing accretion). Meanwhile, erosion was observed during the end of the 2014 – 2015 northeast monsoon (B7 showed accretion). Lastly, during the onset of the southwest monsoon of 2015, heavy erosion was observed and the slip-face bar was reduced in May – June 2015.

However, the cumulative bed level change in June 2015 – July 2013 shows that the beach exhibited accretion in B6, in contrast with B7 that underwent erosion. Furthermore, similarly to Zone A and Zone B, the DEM for the period July 2013 – June 2015 can be used to support the beach morphodynamic pattern, which is shown in Figure 5.6iii (for all transects at stations B6 and B7). The results demonstrate that B6 mostly showed accretion except in the northwest sector, since these areas were located after/upslope from the revetment (on the berm). Meanwhile, B7 underwent erosion as this area is located close to the Marang River breakwater. However, the erosion was less marked compared to the Zone A beach areas.

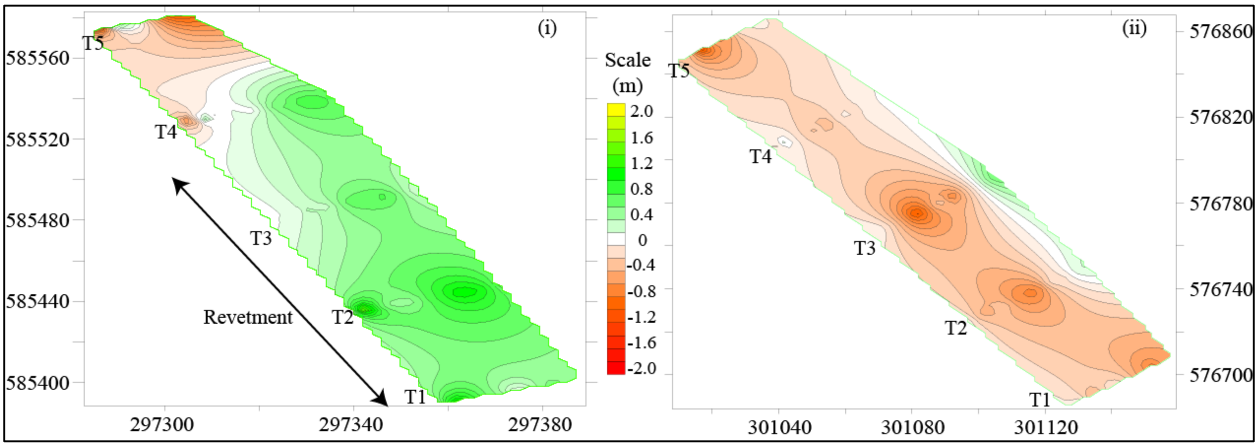

Figure 5.6iii: DEM of the cumulative bed level change between July 2013–June 2015 in Zone A, covering: i) B6: Kuala Ibai beach, and ii) B7: Marang beach.

iii) Beach characteristic

Table 5.4 shows that the values of H_b (wave breaking height) are closely similar on all beaches. The H_b on the Kuala Terengganu coastline is lowest during the southwest monsoon and increases during the northeast monsoon. In fact, H_b is an influential factor in the evolution of beach characteristics. However, the beach characteristics represented here by breaker type (ξ_b) and beach state (Ω) are different on all beaches, especially when making comparisons by zone.

Batu Rakit beach (B1)

B1 is located in Zone A, showing relatively constant ξ_b values as a result of spilling breakers at all monsoonal seasons. However, the ξ_b value is higher during the southwest monsoon compared to the northeast monsoon. On the other hand, the beach state (Ω) decreases in value for the southwest monsoon and increases during the northeast monsoon (Figure 5.7a). In May 2014, during the southwest monsoon, the beach state can be represented as a dissipative beach. However, on average, B1 can be classified as an intermediate beach (Ω = 3.39). B1 can also be considered as a natural beach because it shows two patterns at different monsoonal seasons.

Pengkalan Maras beach (B2)

B2 is located in Zone A, and shows relatively constant ξ_b values as a result of spilling breakers at all monsoonal seasons. However, displaying a similar pattern to B1, the ξ_b value is higher during the southwest monsoon than during the northeast monsoon. On the other hand, the beach state (Ω) decreases in value during the southwest monsoon and increases during the northeast monsoon (Figure 5.7b). However, on average, B2 can classified as an intermediate beach (Ω = 2.73). B2 can also be considered as a semi-natural beach because it shows two patterns: lower Ω values during the southwest monsoon and almost always higher values during the northeast monsoon (except in February 2014, December 2014 and January 2015).

UMT beach (B3)

B3 is located in Zone A, showing relatively constant ξ_b values as a result of spilling breakers at all monsoonal seasons. A similar pattern is seen to that observed in B1 and B2 during the southwest monsoon, with higher ξ_b values compared to the northeast monsoon. On the other hand, the beach state (Ω) reached its lowest value during the 2013 southwest monsoon and increased during the 2013-2014 northeast monsoon (Figure 5.7c). Furthermore, after the riprap collapsed in April 2014, there was a slight monthly decrease in the Ω value until the beach collapsed in September 2014 and became a reflective beach. Nevertheless, B3 can be classified on average as an intermediate beach with a Ω value of 2.30.

Teluk Ketapang beach (B4)

B4 is located in Zone B, which shows relatively stable/constant ξ_b values as a result of spilling breakers at all monsoonal seasons. However, a different pattern compared to Zone A is observed at B4 during the southwest monsoon, with ξ_b values being lower compared to the northeast monsoon. On the other hand, the beach state (Ω) decreases in value during the southwest monsoon and increases during the northeast monsoon (Figure 5.7d). In September 2014, during the southwest monsoon, the beach state corresponds to a reflective beach. On average, B4 can be classified as an intermediate beach (Ω = 2.57). B4 can also be considered as a natural beach because it shows two patterns: a lower Ω value for the southeast monsoon and a higher Ω value during the northeast monsoon.

Seberang Takir beach (B5)

Although B5 is located in Zone B, this beach does not show a constant ξ_b value associated with spilling-plunging breakers at all monsoonal seasons. Showing a similar pattern as observed at B4, the ξ_b value is lower during the southwest monsoon compared to the northeast monsoon. On the other hand, the beach state (Ω) undergoes a decrease in value during the southwest monsoon and increases during the northeast monsoon (Figure 5.7e). By contrast, a decrease in Ω value occurs in March 2015 (northeast monsoon), while an increase is observed in May 2015 (southwest monsoon). However, on average B5 can be classified as intermediate beach (Ω = 3.23). B5 can also be presented as semi-natural beach because it shows two patterns at different monsoonal seasons (except March and May 2015, which show different patterns).

Kuala Ibai beach (B6)

B6 is located in Zone C, where a revetment is present on the berm. The ξ_b value obtained here is a result of plunging breakers at all monsoonal seasons. During the southwest monsoon at B6, the ξ_b values are lower compared to the northeast monsoon. On the other hand, B6 shows different patterns compared to Zones A and B, whereas the beach state (Ω) increases during the southwest monsoon and decreases during the northeast monsoon. However, the beach state parameter is not constant, showing a pattern with Ω values that are higher during the southwest monsoon and lower during the northeast monsoon (Figure 5.7f).

The B6 beach can be considered as an intermediate-dissipative beach during the southwest monsoon. However, during the northeast monsoon, it can be classified as dissipative beach. Nevertheless, B6 can be classified on average as an intermediate beach (Ω = 4.04). Furthermore, B6 cannot be considered as a natural beach because it shows weak variations of patterns at different monsoonal seasons. This is due to the fact that the beach has been impacted by the presence of artificial structures (revetment on the berm).

Marang beach (B7)

B7 is located in Zone C, located close to the breakwater on Marang River. The ξ_b value obtained here is the result of spilling-plunging breakers at all monsoonal seasons. Furthermore, B7 yields the lowest ξ_b value during the southwest monsoon in comparison to the northeast monsoon. B7 also shows a pattern similar to that observed at B6, with the beach state (Ω) showing an increase during the southwest monsoon and a decrease during the northeast monsoon.

The 2013-2014 northeast monsoon and the 2014 southwest monsoon show a constant Ω value. However, the values are not stable during the 2014-2015 northeast monsoon and the 2015 southwest monsoon (Figure 5.7g). However, B7 can be classified on average as an intermediate beach (Ω = 4.21). B7 cannot also be considered as a natural beach because it shows a weak pattern of variation at different monsoonal seasons. In a similar way to B6, this beach is also impacted by the presence of artificial structures close to the breakwater.

The beach characteristics by zone

Table 5.3 shows the beach characteristic by zone obtained from the average values for each beach. According to breaker type (ξ_b), Zones A and B are characterized by spilling breaker waves while Zone C exhibits plunging breakers at all monsoonal seasons. Zone A shows an increase in ξ_b value during the southwest monsoon, but decreases during the northeast monsoon. In contrast, Zones B and C show a decrease in ξ_b value during the southwest monsoon and an increase during the northeast monsoon. The ξ_b value, however, depends on the beach slope.

The changes in beach state (Ω) along the Kuala Terengganu coastline are distributed according to two patterns, from Zone B in the south to Zone A in the north, and from Zone B in the north to Zone C in the south. This situation means that the Ω value in Zone B is higher compared to Zone A, while Zone B has a lower Ω value compared to Zone C. The average monthly values of Ω are 2.81 (Zone A), 2.90 (Zone B) and 4.13 (Zone C), which means they can be represented as intermediate beaches.

The distribution of beach states according to monsoonal seasons can be explained by comparing the southwest monsoon and the northeast monsoon (Table 4.5). In Zone A and Zone B, decreasing Ω values are observed during the southwest monsoon in contrast with the values during the northeast monsoon. However, there is an increase in Ω value in Zone C during the southwest monsoon and a decrease during the northeast monsoon.

Table 5.3: Summary of changes in beach morphology according to monsoons.

Monsoon	Zone A		Zone B		Zone C	
	ξ_b	Ω	ξ_b	Ω	ξ_b	Ω
Southwest 2013	0.26	2.57	0.30	1.77	0.97	4.19
Northeast 2013-2014	0.20	3.53	0.23	3.38	0.94	4.01
Southwest 2014	0.17	2.43	0.20	2.13	0.83	5.18
Northeast 2014-2015	0.17	3.09	0.20	3.47	0.84	3.61
Southwest 2015	0.26	1.52	0.21	2.94	0.81	3.86

Table 5.4: Evolution of beach characteristics during two-year data series: grey and red boxes represent southwest and northeast monsoons, respectively.

Month	Zone A						Zone B				Zone C			
	B1		B2		B3		B4		B5		B6		B7	
	Hb (m)	ξ_b	Hb (m)	ξ_b	Hb (m)	ξ_b	Hb (m)	ξ_b	Hb (m)	ξ_b	Hb (m)	ξ_b	Hb (m)	ξ_b
Jul-13	1.060	0.316	1.040	0.243	1.013	0.253	0.989	0.071	0.954	0.354	0.913	1.120	0.954	0.354
Aug-13	1.096	0.360	0.968	0.201	0.899	0.301	0.852	0.306	0.793	0.431	0.828	1.459	0.793	0.431
Sep-13	1.378	0.128	1.358	0.229	1.329	0.284	1.295	0.276	1.237	0.346	1.173	1.339	1.237	0.346
Oct-13	1.566	0.138	1.581	0.247	1.568	0.365	1.570	0.169	1.585	0.324	1.584	1.609	1.585	0.324
Nov-13	2.576	0.174	2.599	0.284	2.590	0.182	2.595	0.129	2.611	0.418	2.614	1.286	2.611	0.418
Dec-13	2.503	0.238	2.527	0.178	2.520	0.185	2.525	0.088	2.540	0.470	2.544	1.250	2.540	0.470
Jan-14	2.639	0.231	2.669	0.198	2.653	0.171	2.659	0.071	2.684	0.324	2.685	1.030	2.684	0.324
Feb-14	1.917	0.217	1.932	0.169	1.926	0.169	1.930	0.068	1.942	0.360	1.945	0.934	1.942	0.360
Mar-14	2.049	0.118	2.063	0.171	2.057	0.145	2.061	0.028	2.074	0.359	2.077	1.138	2.074	0.359
Apr-14	0.799	0.199	0.804	0.226	0.802	0.248	0.804	0.035	0.808	0.465	0.808	1.387	0.808	0.465
May-14	1.052	0.185	1.057	0.324	1.055	0.251	1.057	0.013	1.062	0.374	1.063	1.160	1.062	0.374
Jun-14	1.042	0.195	0.986	0.216	0.939	0.025	0.899	0.051	0.830	0.441	0.798	1.151	0.830	0.441
Jul-14	0.989	0.187	0.919	0.199	0.858	0.146	0.875	0.003	0.919	0.408	0.973	1.006	0.919	0.408
Aug-14	0.830	0.141	0.696	0.135	0.698	0.125	0.703	0.015	0.732	0.263	0.755	0.830	0.732	0.263
Sep-14	1.154	0.165	1.140	0.171			1.102	0.045	1.066	0.394	1.023	0.964	1.066	0.394
Oct-14	1.350	0.061	1.364	0.207			1.359	0.014	1.372	0.473	1.372	1.080	1.372	0.473
Nov-14	1.955	0.115	1.970	0.215			1.965	0.065	1.979	0.432	1.981	1.059	1.979	0.432
Dec-14	3.095	0.074	3.132	0.203			3.116	0.002	3.150	0.365	3.151	0.906	3.150	0.365
Jan-15	2.319	0.173	2.348	0.187			2.342	0.001	2.365	0.321	2.366	0.905	2.365	0.321
Feb-15	2.292	0.197	2.320	0.184			2.310	0.030	2.335	0.325	2.336	0.962	2.335	0.325
Mar-15	1.643	0.208	1.653	0.200			1.657	0.003	1.662	0.343	1.665	1.189	1.662	0.343
Apr-15	1.862	0.195	1.604	0.307			1.873	0.054	1.882	0.431	1.884	1.077	1.882	0.431
May-15	0.526	0.222	0.533	0.248			0.539	0.031	0.549	0.395	0.560	0.844	0.549	0.395
Jun-15	0.811	0.270	0.829	0.305			0.849	0.004	0.876	0.399	0.906	0.948	0.876	0.399
Average	**1.604**	**0.188**	**1.587**	**0.219**	**1.493**	**0.204**	**1.580**	**0.065**	**1.584**	**0.384**	**1.583**	**1.110**	**1.584**	**0.384**

Note: (B3) UMT beach collapsed on September 2014.

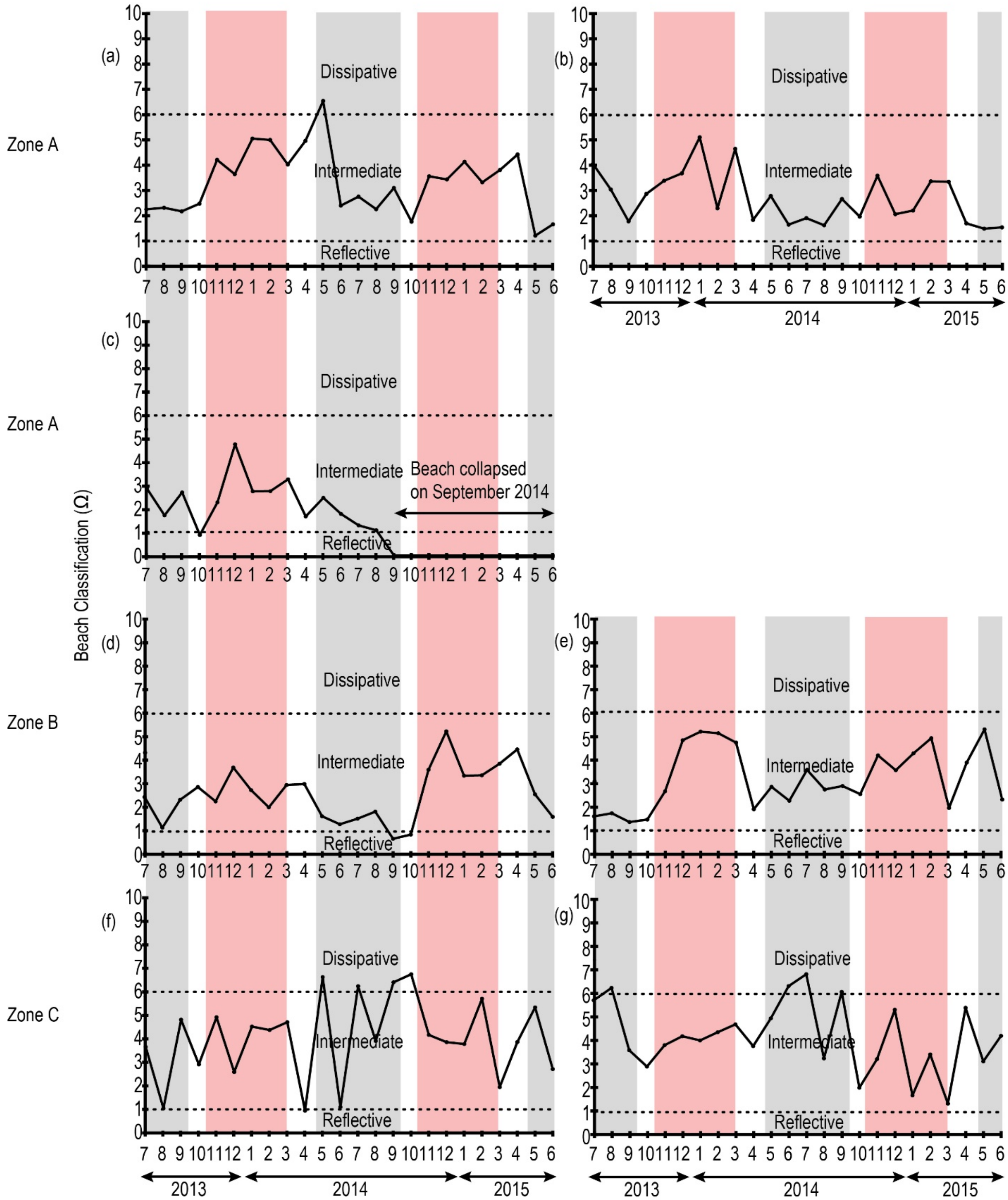

Figure 5.7: Beach state in two-year data series; grey boxes represent the southwest monsoon and red boxes represent the northeast monsoon.

5.4.2 Sediment Characteristics

Batu Rakit beach (B1)

Batu Rakit beach (B1) is located in Zone A, where the mean sediment grain-size is characterized by medium to coarse sand, along with some fine sand (southwest monsoon 2015) and very coarse sand (southwest monsoon 2013, southwest monsoon 2014 and northeast monsoon 2014-2015). B1 beach sediments can be characterized as moderately well-sorted to moderately sort. However, the skewness is characterized as symmetrical to coarse skewed.

Pengkalan Maras beach (B2)

Pengkalan Maras beach (B2) is located in Zone A, where the mean sediment grain-size is characterized by medium to coarse sand, along with some fine sand (southwest monsoon 2013 and southwest monsoon 2015) and very coarse sand (southwest monsoon 2013, southwest monsoon 2014 and northeast monsoon 2014-2015). B2 beach sediments can be characterized as moderately well-sorted to moderately sorted. However, the skewness is characterized as symmetrical to coarse skewed.

UMT beach (B3)

UMT beach (B3) is located in Zone A, where the mean sediment grain-size is characterized by medium to coarse sand along with some very coarse sand (southwest monsoon 2013 and southwest monsoon 2014). B3 beach sediments can be characterized as moderately well-sorted to moderately sorted. However, the skewness is characterized as fine skewed to coarse skewed.

Teluk Ketapang beach (B4)

Teluk Ketapang beach (B4) is located in Zone B, where the mean sediment grain-size is characterized by medium to coarse sand along with some fine sand (northeast monsoon 2014-2015 and southwest monsoon 2015) and very coarse sand (northeast monsoon 2013-2014 and northeast monsoon 2014-2015). B4 beach sediments can be characterized as moderately sorted to poorly sorted. However, the skewness is characterized as fine skewed to coarse skewed.

Seberang Takir beach (B5)

Seberang Takir beach (B5) is located in Zone B, where the mean sediment grain-size is characterized by medium to coarse sand along with some fine sand (southwest monsoon 2015) and very coarse sand (southwest monsoon 2013, northeast monsoon, 2013-2014, southwest monsoon 2014 and northeast monsoon 2014-2015). B5 beach sediments can be characterized as moderately well sorted to poorly sorted. However, the skewness is characterized as symmetrical to coarse skewed.

Kuala Ibai beach (B6)

Kuala Ibai beach (B6) is located in Zone C, where the mean sediment grain-size is characterized by fine to coarse sand along with fine sand (southwest monsoon 2013, southwest monsoon 2014 and southwest monsoon 2015) and very coarse sand (northeast monsoon, 2013-2014 and northeast monsoon 2014-2015). B6 beach sediments can be characterized as moderately well sorted to poorly sorted. However, the skewness is characterized as fine skewed to coarse skewed.

Marang beach (B7)

Marang beach (B7) is located in Zone C, where the mean sediment grain-size is characterized by fine to coarse sand along with a little fine sand (southwest monsoon 2013, northeast monsoon 2013-2014, southwest monsoon 2014 and southwest monsoon 2015) and very coarse sand (northeast monsoon, 2013-2014 and northeast monsoon 2014-2015). B7 beach sediments can be characterized as moderately well to poorly sorted. However, the skewness is characterized as very fine skewed to very coarse skewed.

Sediment characteristics by zone

The sediment characteristics by zone are obtained from the average of each beach. Hence, the changes in the sediment characteristics along the Kuala Terengganu coastline displays two patterns: from Zone B in the south to Zone A in the north, and from Zone B in the north to Zone C in the south. This situation means that the mean sand grain size is finer in Zone B compared to Zone A, while it is coarser in Zone B than in Zone C.

However, Zone B is poorly sorted compared to Zones A and C. The skewness in Zone B is coarser and less symmetrically skewed compared to Zone A, while Zone B distribution is fine (positive) skewed compared to Zone C. Table 5.5 summarizes the evolution of sediment during monsoons.

Furthermore, in Zone A, the mean grain size is characterized by medium to coarse sand along with some fine sand (southwest monsoon 2015) and very coarse sand (southwest 2013, southwest 2014 and northeast monsoon 2014-2015). However, Zone A beach sediments can be characterized as moderately well-sorted to moderately sorted. The skewness is characterized as symmetrical to coarse skewed. On the graphs showing the accumulated sediment characteristics, there is a good correlation between the mean size and sorting (Figure 5.8i), as well as between mean size and skewness (Figure 5.8ii). In B3, the data points are scattered because this beach area tends to undergo heavy erosion and also collapsed in September 2014.

Secondly, in Zone B, the mean grain size corresponds to medium to coarse sand along with some fine sand (southwest monsoon 2015) and very coarse sand (northeast monsoon 2013-2014 and northeast monsoon 2014-2015). Zone B sediments can be characterized as moderately sorted to poorly sorted, with symmetrical to coarse skewed grain-size distributions. Good correlations are observed between mean size and sorting (Figure 5.8i), as well as between mean size and skewness (Figure 5.8ii). However, there was less accumulation in Zone A than in Zone A.

Lastly, in Zone C, the mean sand grain size corresponds to medium to coarse sand along with some fine sand (southwest monsoon 2013, southwest monsoon 2014 and southwest monsoon 2015) and very coarse sand (northeast monsoon 2013-2014 and northeast monsoon 2014-2015). Zone C can be characterized as moderately well sorted to poorly sorted, with fine skewed to coarse skewed grain-size distributions. Weak correlations are observed between mean size and sorting (Figure 5.8i), as well as between mean size and skewness (Figure 5.8ii), associated with a scattering of data points on the graphs.

Table 5.5: Evolution of sediment characteristics during monsoons.

Monsoon	Zone A	Zone B	Zone C
Southwest 2013	Very Coarse Sand	Medium Sand	Fine Sand
Northeast 2013-2014	Coarse Sand	Very Coarse Sand	Very Coarse Sand
Southwest 2014	Very Coarse Sand	Medium Sand	Fine Sand
Northeast 2014-2015	Very Coarse Sand	Very Coarse Sand	Very Coarse Sand
Southwest 2015	Fine Sand	Fine Sand	Fine Sand

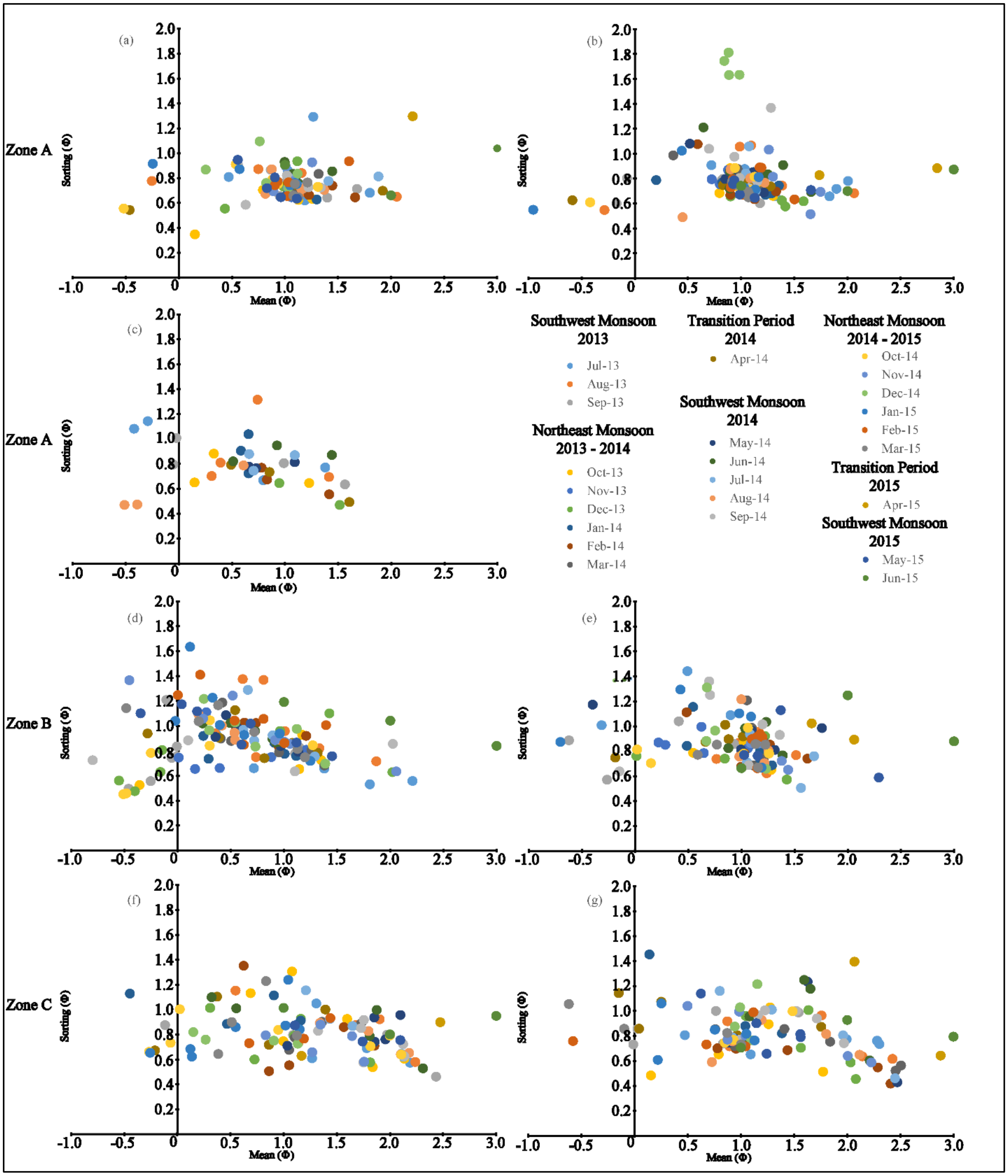

Figure 5.8i: Mean size versus Sorting.

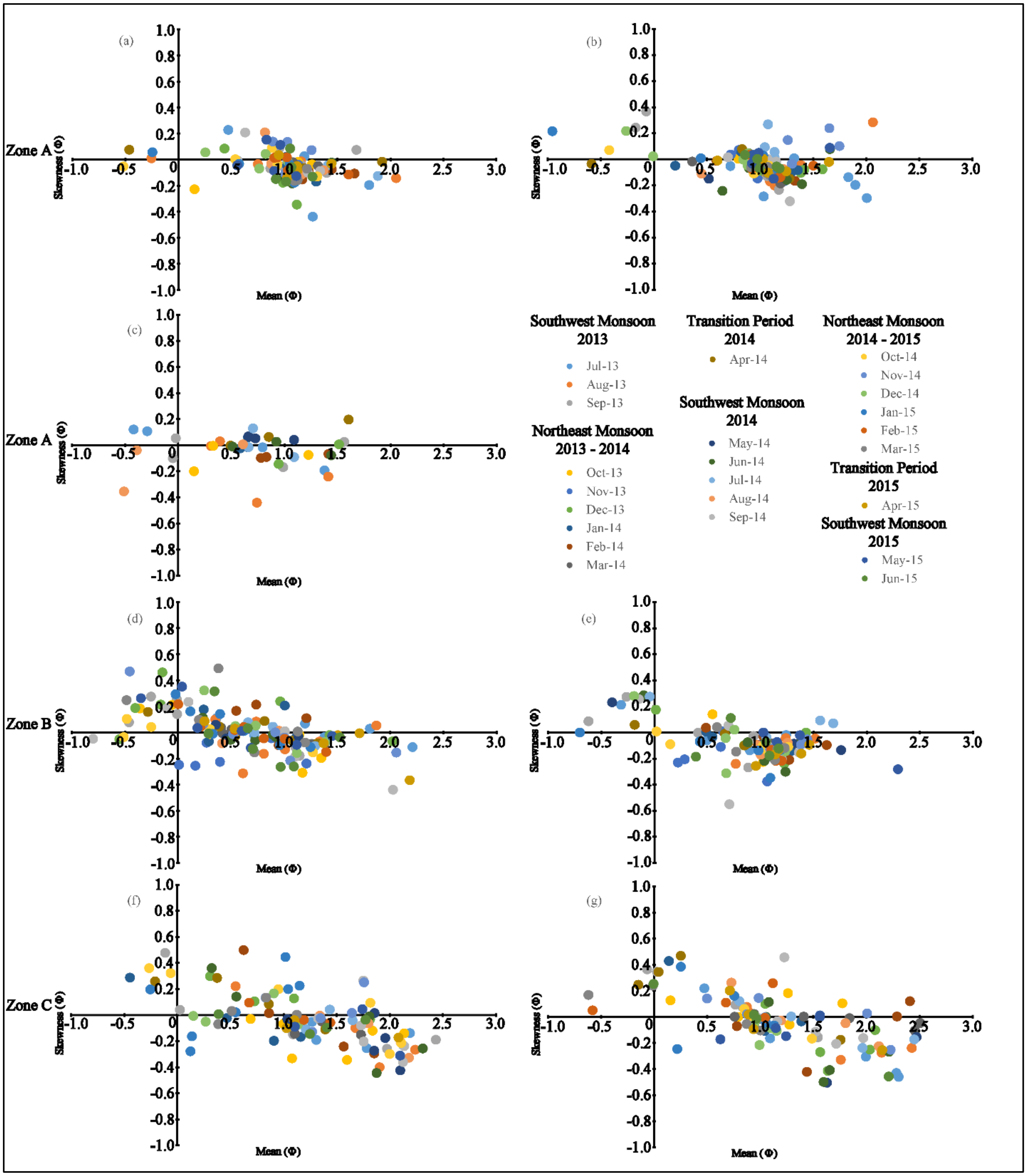

Figure 5.8ii: Mean size versus Skewness.

5.4.3 Modelling Data

i) Water level, wind speed and direction

Figure 5.9 shows the water level and wind parameters along the Kuala Terengganu coastline during the southwest and northeast monsoons. The water level on the Kuala Terengganu coastline varied from 0.94 to 3.60 m during the study period. The lowest water level was observed during the southwest monsoon and the highest during the northeast monsoon. On the other hand, the tides correspond to semi-diurnal and micro-meso regimes. During the study period, from July 2013 to June 2015, two patterns of wind speed and direction were seen along the Kuala Terengganu coastline.

These two patterns show the lowest values during the southwest monsoon and the highest values during the northeast monsoon. However, a maximum wind speed of 12.78 m/s (22 December 2014) was recorded during the northeast monsoon of 2014-2015, and 7.95 m/s (24 June 2015) during the southwest monsoon 2015. On the other hand, the predominant wind direction was southwesterly during the southwest monsoon and northeasterly during the northeast monsoon.

ii) Wave parameter

Figure 5.9 shows the wave and wind parameters in different zones along the Kuala Terengganu coastline. The wave parameters depend on the wind; the lowest values are recorded during the southwest monsoon and the highest values during the northeast monsoon. The lowest wind speed during the southwest monsoons of 2013 and 2014 corresponds to the highest value of significant wave height (H_s) in Zone A (compared to the other zones), associated with north-westerly winds (along the beach) and a predominantly southeast wave direction. Hence, the H_s is 0.71 m during the southwest monsoon 2013, and

0.76 m during the southwest monsoon 2014. The wave period (T_p) also increases as a function of H_s, rising from 5.02 s during the southwest monsoon of 2013 to 5.45 s during the southwest monsoon of 2014.

Zone B shows the lowest H_s readings, with northerly winds and predominantly southeast wave directions. Similarly, Zone C shows the lowest H_s reading, while the wave direction remains predominantly southeast. Moreover, during the southwest monsoon of 2015 a lower wind speed was recorded compared to the previous year; the lowest value of H_s (less than 0.35 m) and T_p (less than 4.78 s) are recorded in all zones dominated by the southeast wave direction.

Meanwhile, during the 2013-2014 northeast monsoon, the maximum H_s and T_p readings in all zones attain values of almost 2.39 m for H_s and 8.34 s for T_p. Hence, the wave direction reflects the dominance of north-easterly winds. However, due to the abrupt increase in wind speed during the 2014-2015 northeast monsoon, H_s rapidly attained its highest value of 2.49 m in December 2014, and the T_p was recorded as 9.18 s. Meanwhile, the wave direction reflects the dominance of north-easterly winds.

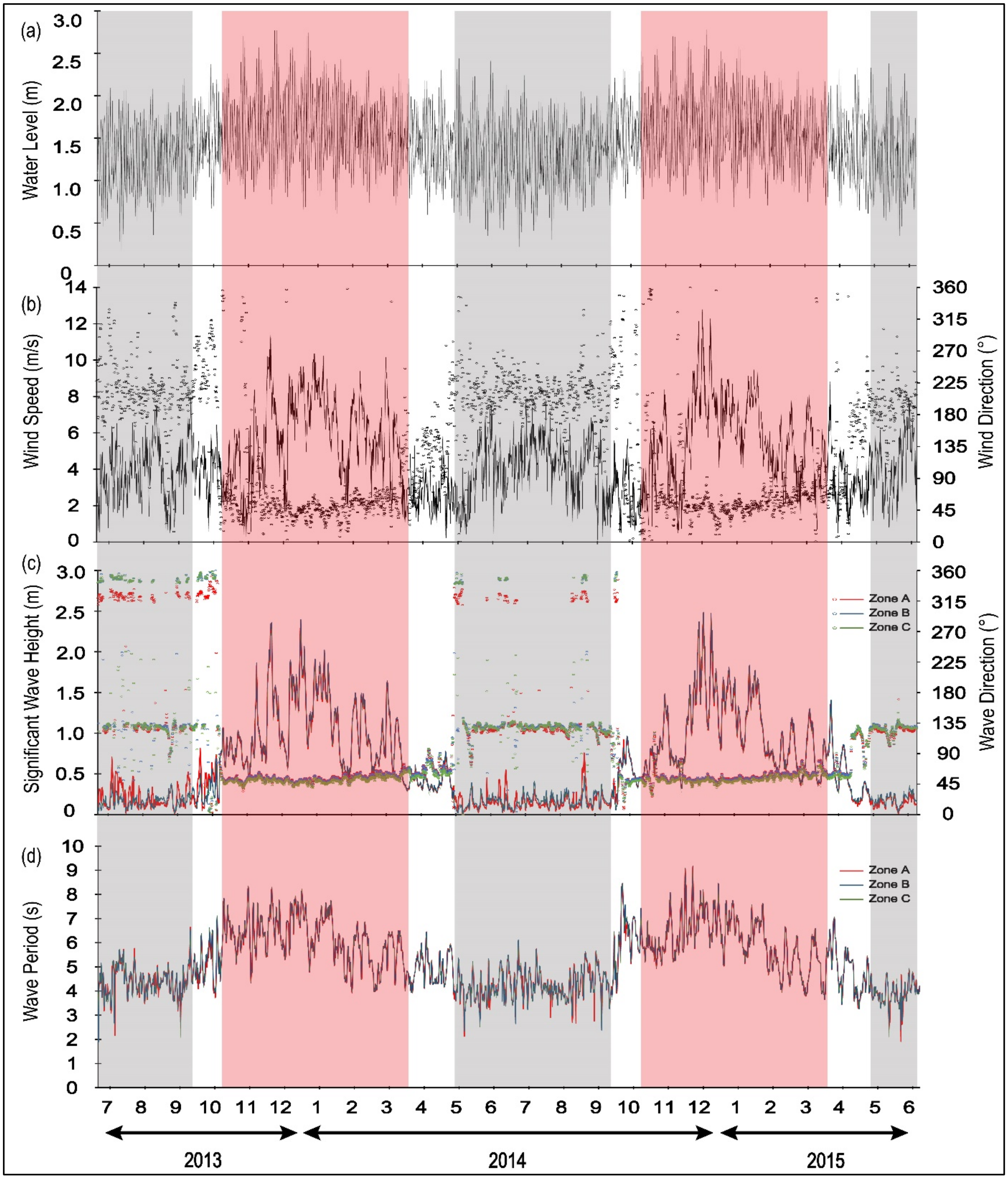

Figure 5.9: Modelling of physical data in the two-year study period; grey boxes represent the southwest monsoon and the red boxes represent the northeast monsoon.
Note: water level is measured *in-situ* by the tide gauge.

iii) Current Speed and Direction

2013 Southwest Monsoon

The current direction was northwards during the 2013 southwest monsoon (as shown in Figure 5.10i). Hence, Zone A (Figure 5.10iA) displays higher current speeds (0.01– 0.27 m/s) compared to Zone B (Figure 5.10iB), where the values are in the range 0.01– 0.18 m/s. However, Zone C show much lower readings in contrast to Zones A and B, which have values ranging from 0.01 to 0.17 m/s.

2013-2014 Northeast Monsoon

Current speeds during the 2013-2014 northeast monsoon show a different pattern, tending to move in two directions compared to the southwest monsoon 2013 season, which only has only one direction towards the north. Hence, in Zone A, the current flows simultaneously to the north and to the south, diverging at the M3 station point (with stronger currents to the north compared to the south - see Figure 5.10iiA). During this northeast monsoon, higher current speeds of 0.01– 0.33 m/s are observed in Zone A as compared to Zone B, with values of 0.01 – 0.20 m/s. However, Zone C shows current speeds of 0.01 – 0.27 m/s flowing southward (see Figure 5.10iiC).

2014 Southwest Monsoon

During the 2014 Southwest Monsoon season in Zone A, higher current speeds of 0.01 – 0.29 m/s are recorded flowing northwards (Figure 5.10iiiA). The current speed in Zone B is found to be slower (Figure 5.10iiiB) compared to Zone A, flowing northwards at 0.01 – 0.23 – m/s. The current speed in Zone C also flows northwards at a slightly slower current speed ranging from 0.01 to 0.22 m/s (see Figure 5.10iiiC).

2014-2015 Northeast Monsoon

The current during the 2014-2015 northeast monsoon shows a similar direction compared to the 2013-2014 northeast monsoon; however, the current speed is stronger. The current in Zone A flows simultaneously to the north and to the south, diverging at the B3 station point (with stronger currents to the north compared to the south - see Figure 5.10ivA). In detail, the current speed in Zone A (0.01 – 0.35 m/s) is higher compared to Zone B (0.01 – 0.24 m/s). However, the current in Zone C flows southwards at a speed 0.01 – 0.29 m/s (see Figure 5.10ivC).

2015 Southwest Monsoon

During the Southwest Monsoon of 2015 season the current speed slightly decreased compared to the previous Southwest Monsoon. Hence, Zone A recorded a higher current speed flowing northwards ranging from 0.23 – 0.01 m/s (Figure 5.10vA). The current speed in Zone B was observed to be slower (Figure 5.10vB) compared to Zone A and flowed northwards ranging from 0.13 – 0.01 m/s. The current speed in Zone C also flowed northwards with a slightly slower current speed ranging from 0.15 – 0.01 m/s (see Figure 5.10vC).

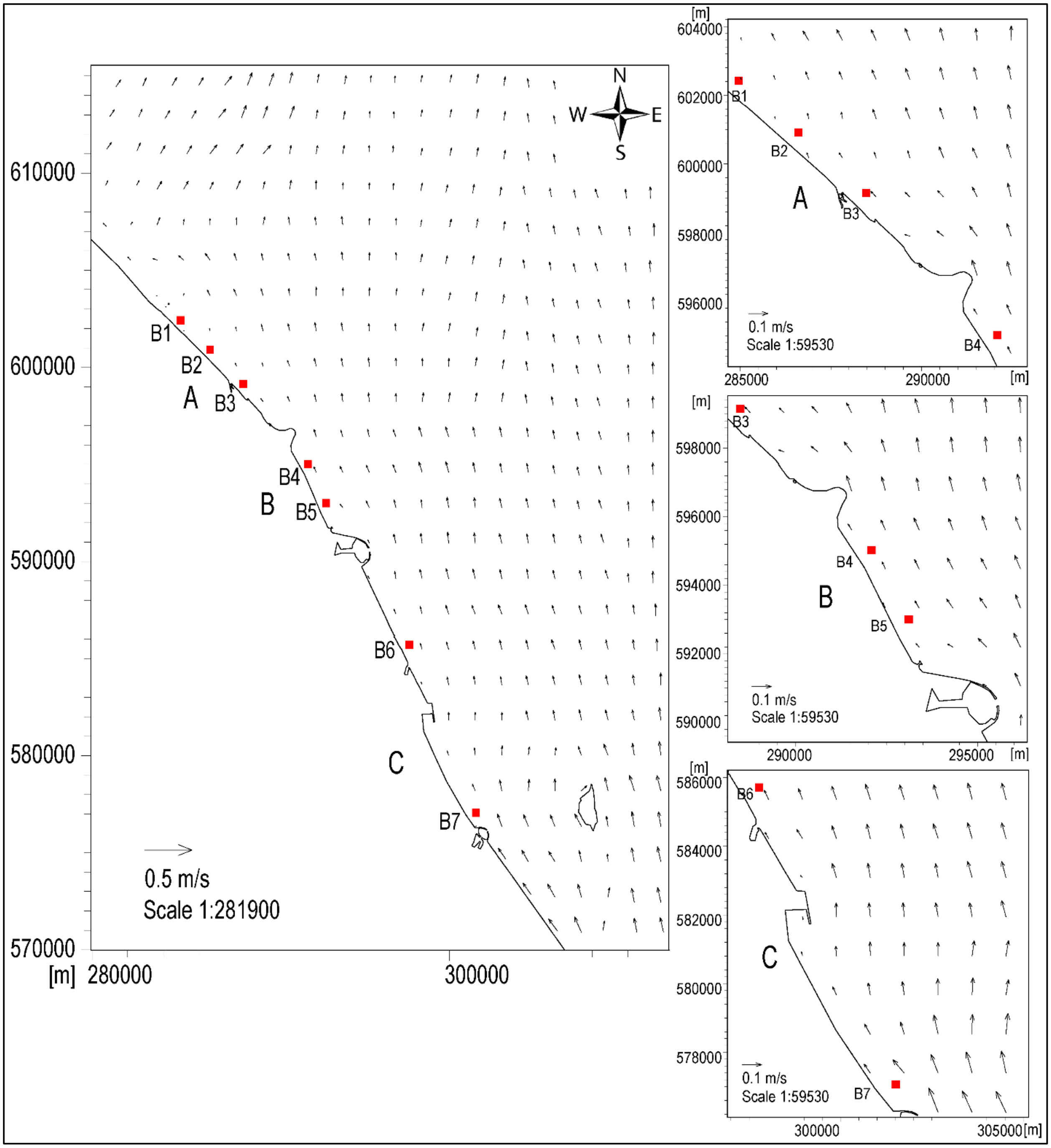

Figure 5.10i: Current distribution during the southwest monsoon along the coastline (2013); with station points in Zone A (B1 to B3), Zone B (B4 to B5), and Zone C (B6 to B7).

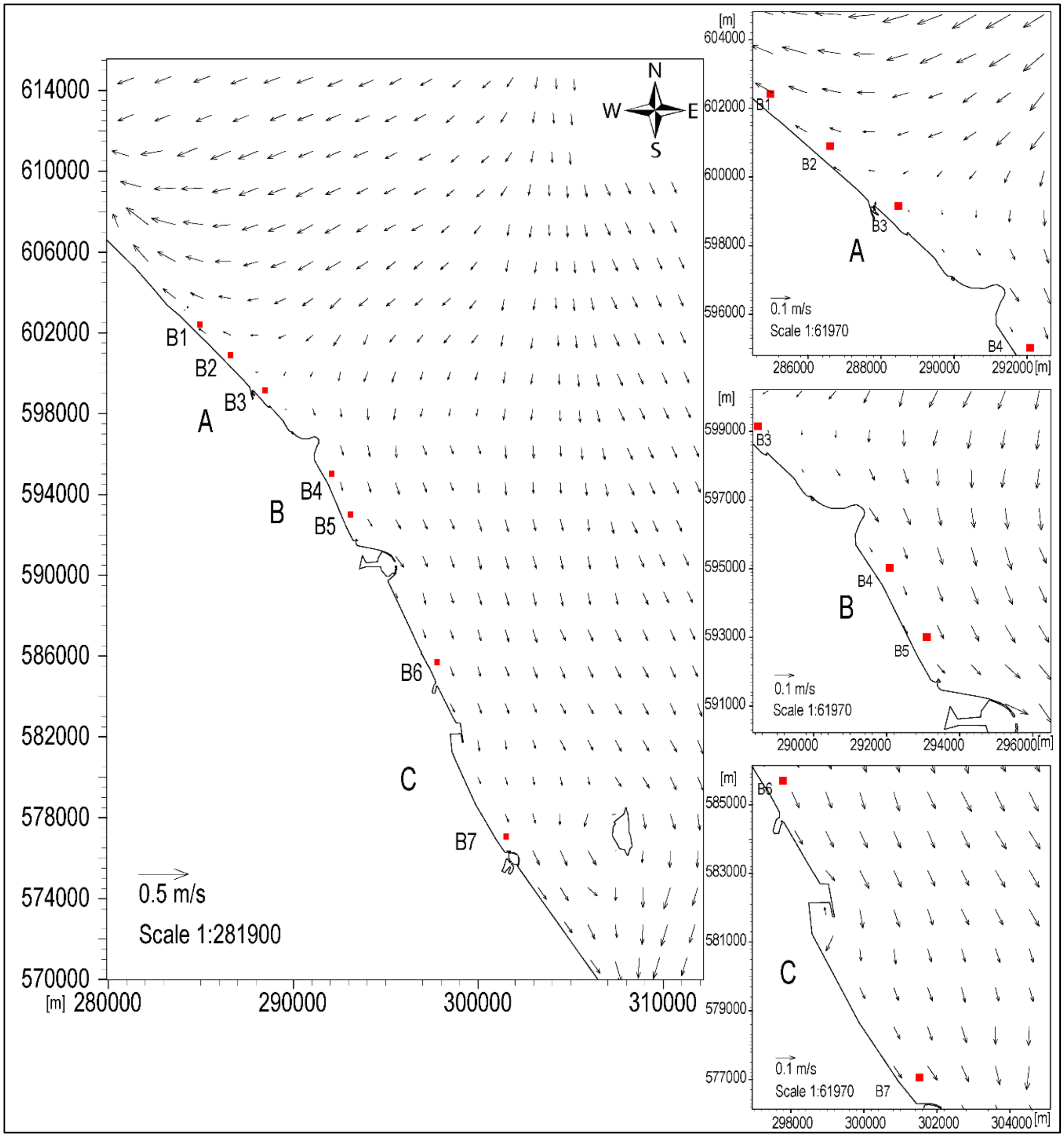

Figure 5.10ii: Current distribution during the northeast monsoon along the coastlines (2013 - 2014); with station points in Zone A (B1 to B3), Zone B (B4 to B5), and Zone C (B6 to B7).

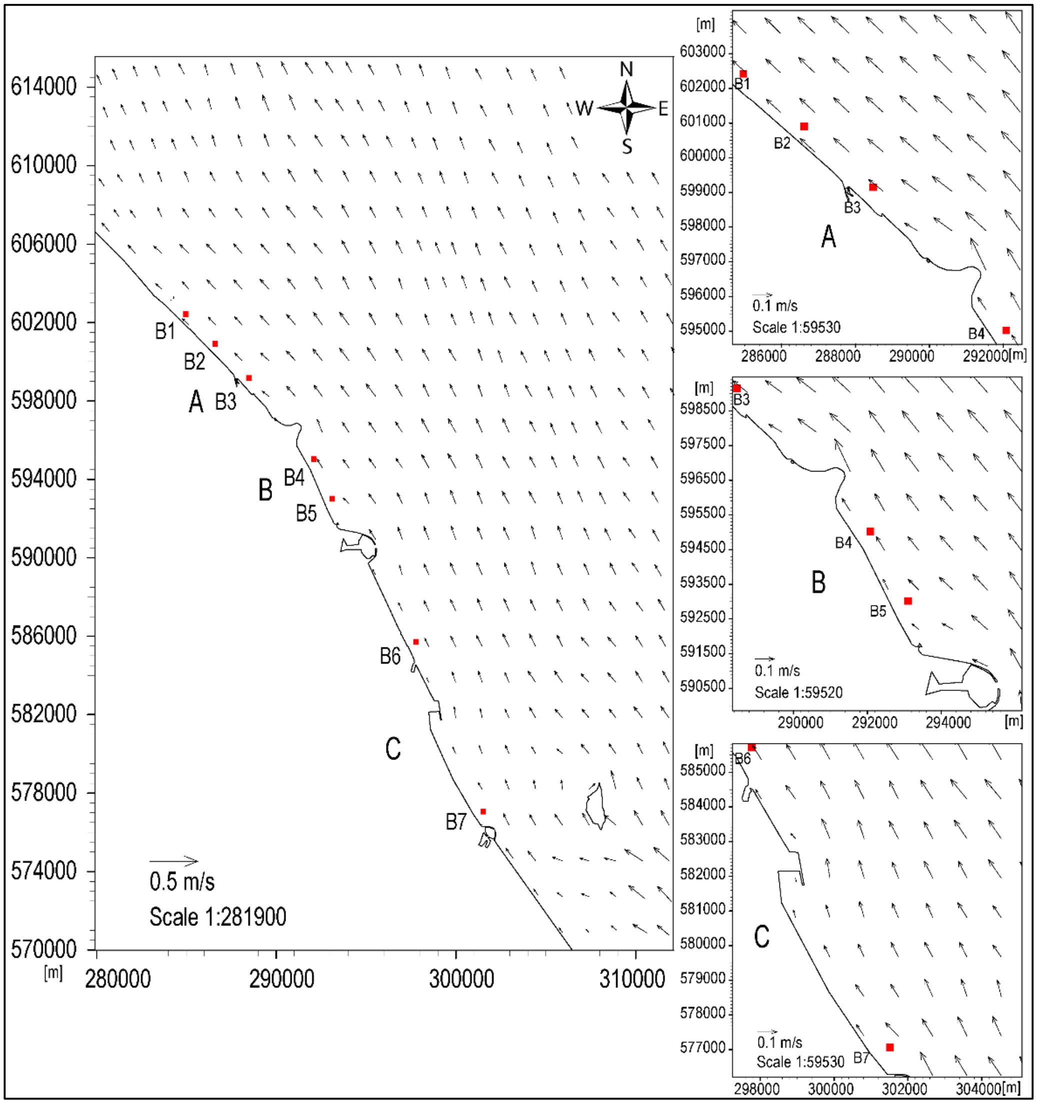

Figure 5.10iii: Current distribution during the southwest monsoon along the coastline (2014); with station points in Zone A (B1 to B3), Zone B (B4 to B5), and Zone C (B6 to B7).

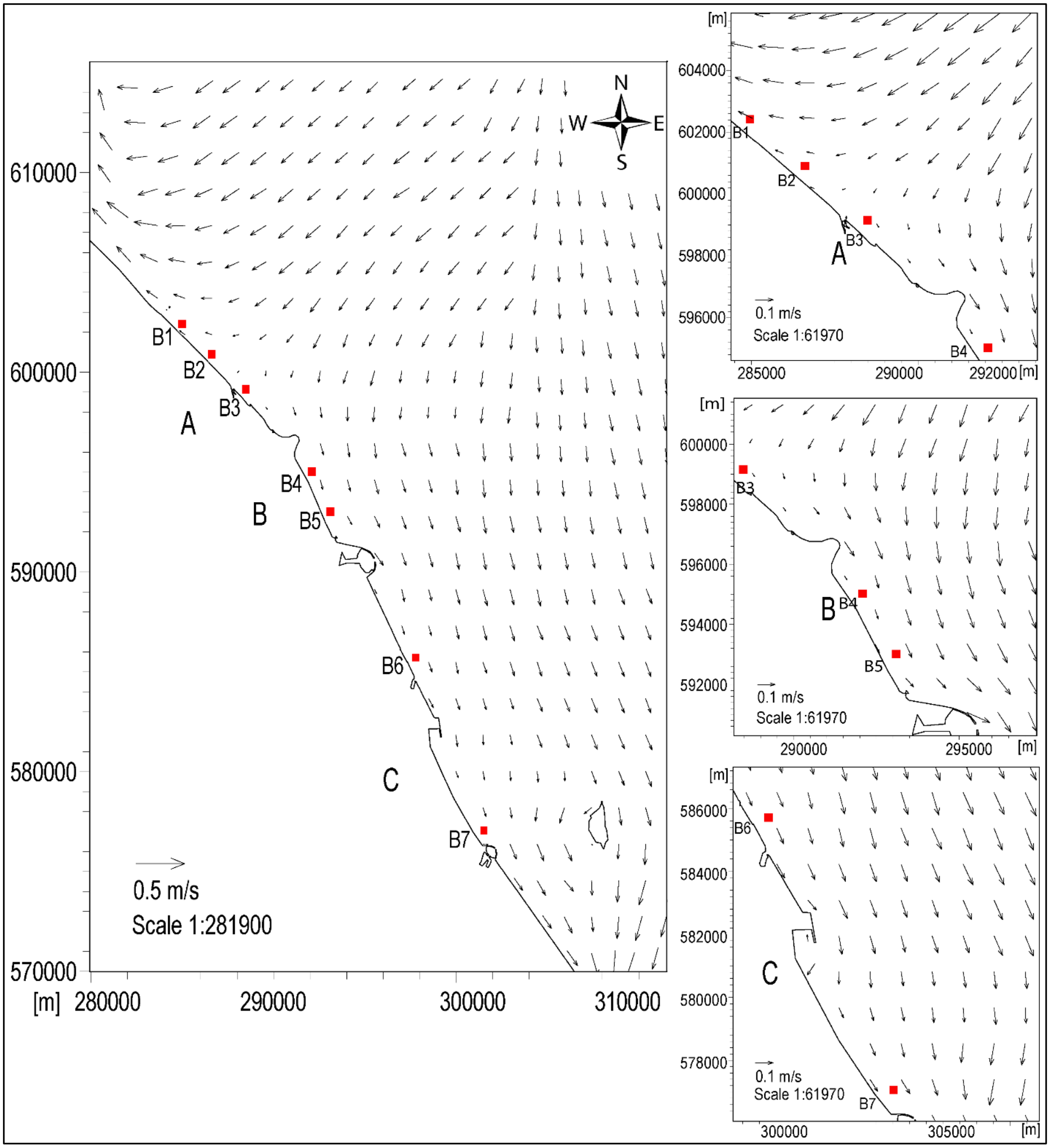

Figure 5.10iv: Current distribution during the northeast monsoon along the coastline (2014 - 2015); with station points in Zone A (B1 to B3), Zone B (B4 to B5), and Zone C (B6 to B7).

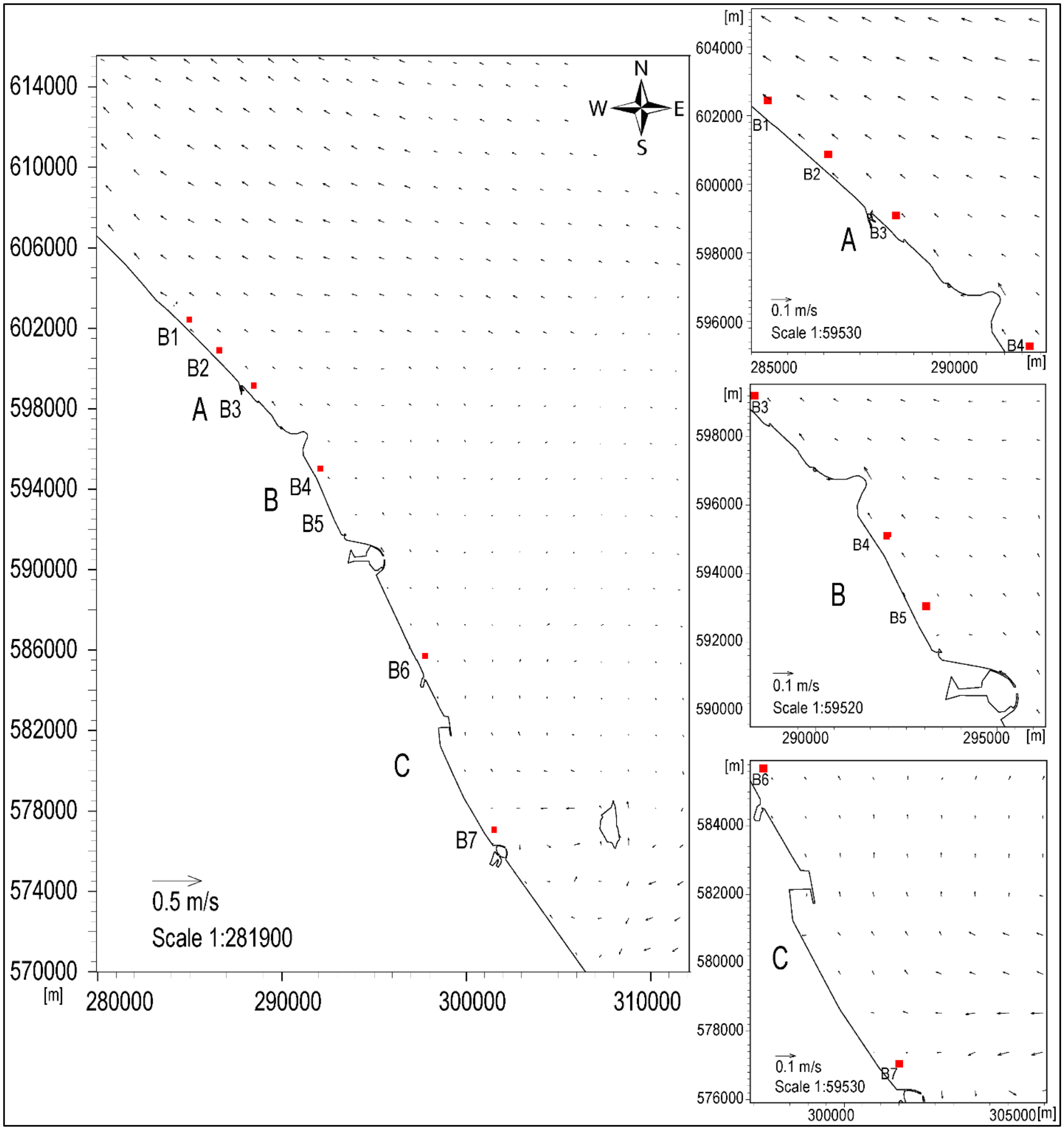

Figure 5.10v: Current distribution during the southwest monsoon along the coastlines (2015; with station points in Zone A (B1 to B3), Zone B (B4 to B5), and Zone C (B6 to B7).

5.5 Discussions

This chapter discusses the beach morphodynamics (beach elevation) in relation to changes in sediment characteristics for each station. This chapter also assesses the influence of hydrodynamics on beach morphology, in order to identify the recovery period of each selected site based on chronological changes. Apart from this aspect, the physical conditions affecting the variety and evolution of the coastal environment are considered among the influential factors that contribute to shaping and modifying the beaches.

5.5.1 Correlation between Beach Elevation and Sedimentology

Based on the results presented in this study, Zone A tends to show heavy erosion but with slight accretion (increase in sediment volume) in the north. This also supported by the observed beach elevation, which is related to a coarsening effect as shown in Figure 5.11 (all parameters). The sedimentological parameters (MS-CS, MSort-MWSort, and Symmetrical-CSkew) vary as a function of beach elevation, trending in the direction of lower elevation. However, B3 in Zone A shows heavy erosion because it is located closer to the airport tarmac extension (northern sector), and this trend is reflected by variations in CS, MSort-MWSort and Symmetrical-CSkew. The high elevation implies that coarse sand (CS) is abundant in this area (Kim *et al*., 2016).

However, the sediment volume changes in Zone B tends to indicate heavy accretion and slight erosion in the south. Zone B has two different trends of correlation between sediment and elevation (MS-CS, PSort-MWSort and FSkew-CSkew) i.e. at B4, these parameters are positively correlated with changes in elevation (i.e. trending in the direction of increasing elevation), but otherwise in B5. B4 is located quite close to the airport tarmac extension (on southern side) and tends to show heavy accretion associated with abundant coarse-grained sediment (some fine sand) at high beach elevation (Kim *et al*., 2016) compared to B5 station, where the data points are more scattered at low beach elevation.

On the other hand, the sediment volume in Zone C tends to undergo erosion and the elevation tends to be correlated with FS-CS, PSort-MWSort and VFSkew-VCSkew. Hence, the sediment trend is weakly correlated with beach elevation. There has been a change in sediment trend in this region since the 2005 time-series, because rapid development tends to lead to erosion phenomena (Rosnan and Mohd Lokman, 2005). Moreover, the decrease in new sediment supply from the Terengganu River has produced a trend similar to that previously observed.

According to Dora *et al*. (2011), the erosion of beaches is triggered by large wave heights, with finer grained sediments being washed away and the coarser sands being left on the beach. Furthermore, during periods of less wave activity (calm conditions-southwest monsoon), the beach volume increases and the sediment grain size decreases. According to Imhansoloeva *et al*. (2011), strong currents are also responsible for controlling the grain-size distribution, as seen the studied region (especially Zone A) where strong currents are recorded.

Furthermore, Hegde *et al*. (2007) observed better sorted sediments resulting from high waves during monsoons. However, this type of sediment sorting is exhibited on equilibrium beaches. Blackley and Heathershaw (1982) and Dora *et al*. (2011) also observed that high waves and tidal currents significantly affect the sorting of sediments on beaches with wide surf zones as developed in high-energy areas. However, Dora *et al*. (2011) also mentioned that beaches undergo erosion or non-deposition when the grain-size distribution is relatively more coarse skewed (CSkew) than fine skewed (FSkew).

On the other hand, Rosnan and Mohd Lokman (2005) noted that the mean sediment size in the northern sector of the Kuala Terengganu coast was finer, while the southern sector had coarser sediments. Their study was carried out before construction of many of the coastal structures along the Kuala Terengganu coastline, especially in the northern sector (rapid development in the southern sector). According to Bunicontro *et al*. (2015), based on studies of coasts without coastal structures or defences, the beach profile in environments such as foreshore and backshore is composed mainly of sediments with MS, MSort, and Symmetric to CSkew trends. After the installation of mounds, some of these parameters changed.

Currently, the B3 beach in Zone A tends to show heavy erosion because of the impact from coastal structures that have changed the original sediment trends (CS, MSort-MWSort and Symmetrical-CSkew). Hence, the northern beach areas (B1 and B2 stations) yield similar trends to those observed by Bunicontro *et al*. (2015), but without the effects of mound installation. Furthermore, accretion areas can be noted in Zone B where finer sediments are trapped by the slower currents near the airport tarmac extension. Lastly, in Zone C, the sediment trend has changed (erosion phenomena) since the 2005 time-series, and receives less sediment supply from the Terengganu River (Rosnan and Mohd Lokman, 2005).

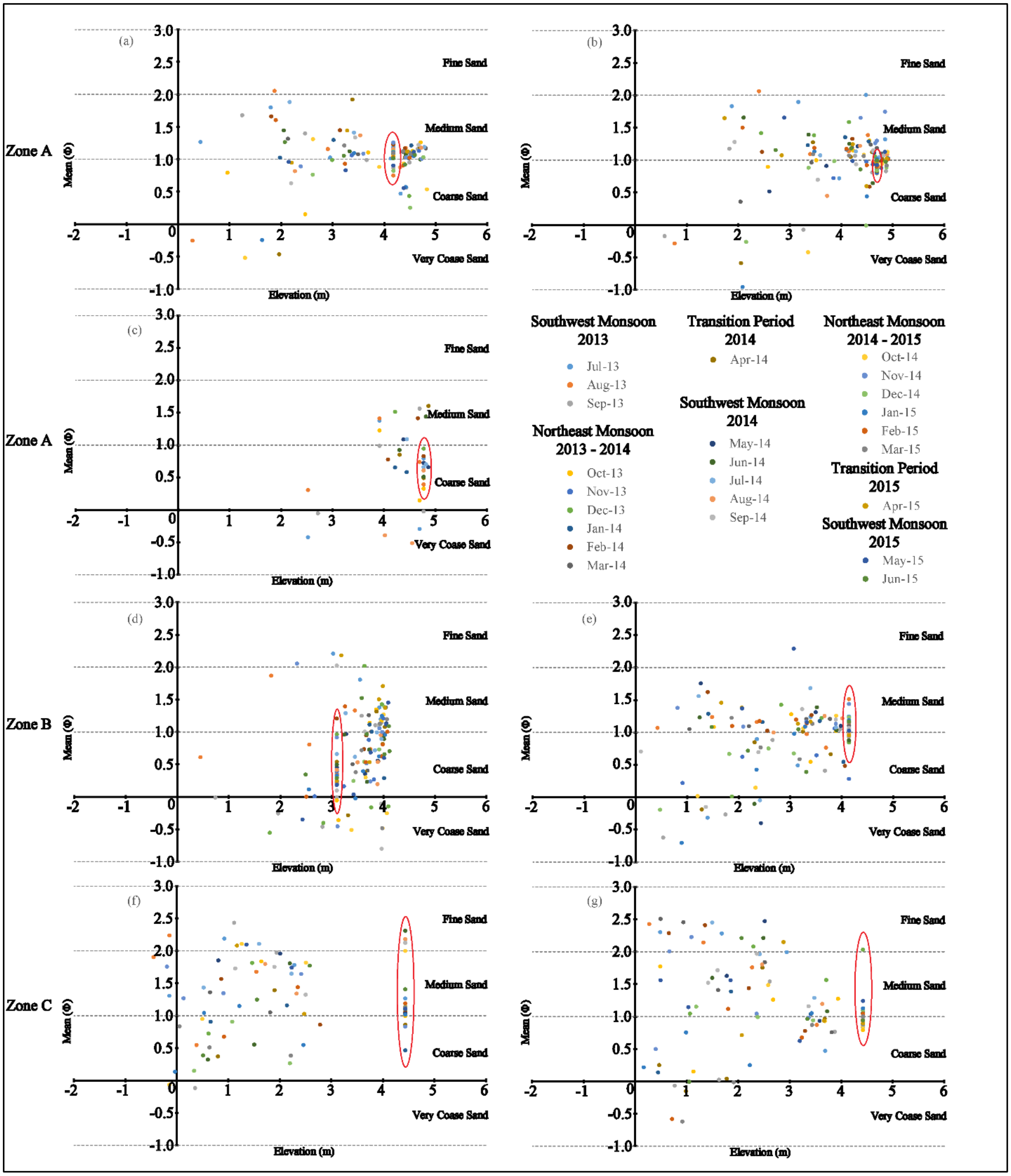

Figure 5.11i: Beach elevation versus mean size by zone for different station points. a) B1, b) B2 and c) B3 in Zone A; d) B4 and e) B5 in Zone B; and f) B6 and g) B7 in Zone C respectively.

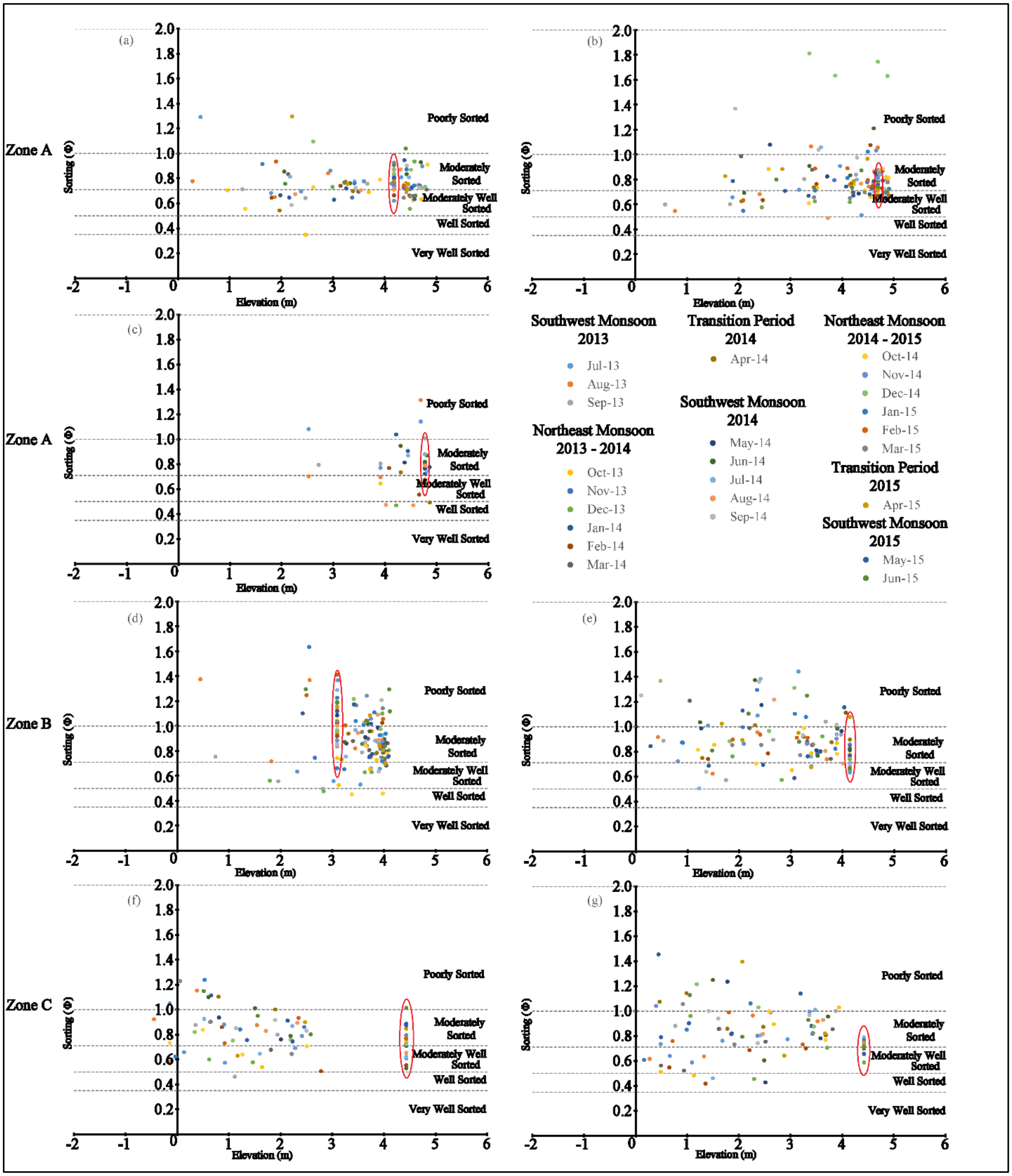

Figure 5.11ii: Beach elevation versus sorting by zone for different station points: a) B1, b) B2 and c) B3 in Zone A; d) B4 and e) B5 in Zone B; and f) B6 and g) B7 in Zone C respectively.

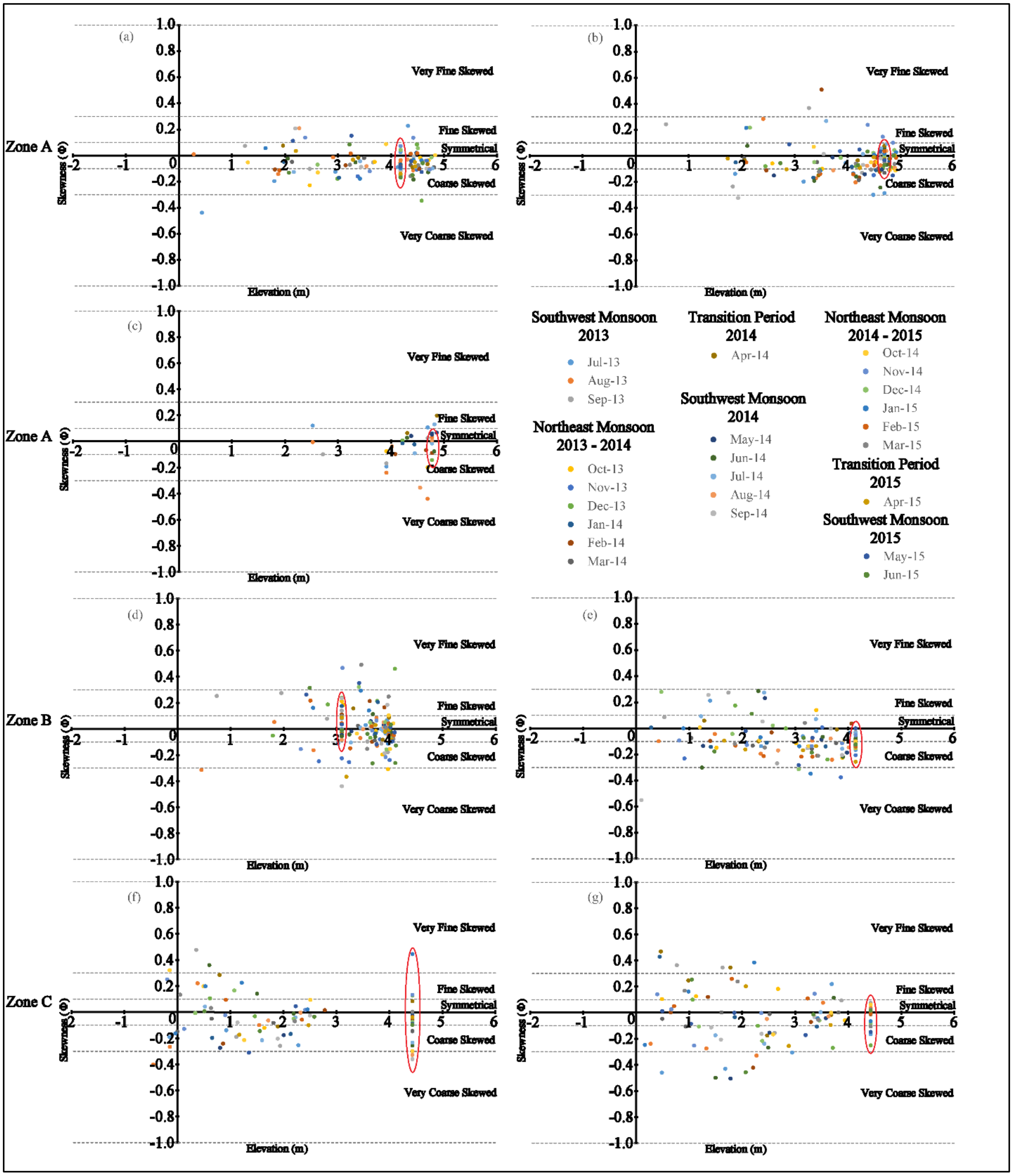

Figure 5.11iii: Beach elevation versus skewness by zone, for different station points: a) B1, b) B2, and c) B3 in Zone A; d) B4, and e) B5 in Zone B; and f) B6, and g) B7 in Zone C.

5.5.2 Hydrodynamic Influence on Erosion and Accretion

This study demonstrates that the morphological changes on most beaches along the Kuala Terengganu coast are triggered by variations in hydrodynamic influence. The hydrodynamic influence due to currents, waves, tidal regime and conditions related to seasonal changes that lead to variations in beach morphology (Masselink and Pattiaratchi, 2001; Mishra *et al.,* 2011; Rosnan and Mohd Lokman, 2005; and Wong, 1981). In fact, the seasonal changes on the Kuala Terengganu are related to the southwest monsoon (calm conditions) and the northeast monsoon (storm condition). Normally, the natural changes in beach morphology (seasonal erosion/accretion cycle) take place during the northeast monsoon that causes erosion, while the beach becomes accreted or recovers during the southwest monsoon (Rosnan and Ariffin, 2010; Rosnan and Mohd Lokman, 2005; Rosnan and Mohd Zaini, 2009).

The Kuala Terengganu coastline displays two patterns of beach morphological evolution, represented in Zones A and Zone C, which are characterized by accretion during the southwest monsoon and erosion during the northeast monsoon. However, Zone B shows erosion during the southwest monsoon and accretion during the northeast monsoon, in areas located close to the extension of the airport tarmac (e.g. B4 station). Normally, the Kuala Terengganu coast exhibits a relatively consistent/stable beach width, especially in the northern sector (Zones A and B separated Zone C by the Terengganu River) before the construction of the airport tarmac extension (Rosnan and Mohd Lokman, 2005; Rosnan *et al*., 2003). This seasonal erosion/accretion cycle changed following the rapid development along the Kuala Terengganu coastline since 2010, especially the construction of the airport tarmac extension (Mohammad Fadhli *et al*., 2014; Muslim *et al*., 2011).

Hence, according to Mohd Radzi *et al*., (2014), the physical conditions (longshore drift current) totally changed after the construction of the airport tarmac extension, especially in the surrounding area of the airport. Broadly speaking, the design of the airport tarmac extension is similar to a coastal structure such as a groyne where the reclaimed land extends seaward. The change in velocity of the longshore drift current causes deposition of suspended sand materials on the down-drift side of the airport tarmac extension (Hsu *et al*., 2007; Mohanty *et al*., 2012; Muslim *et al*., 2011). Hence, the current flows around the groyne, forming eddies which cause turbulence (Pattiaratchi *et al*., 2009), and this actually contributes to erosion on the up-drift side (Martin *et al*., 2005). However, Rosnan and Mohd Lokman (2005) pointed out that there are two net directions of sediment transport along the coastline in sectors separated by the Terengganu River; i) north-westward transport in the northern sector and ii) southward transport to the southern sector.

This airport tarmac extension structure acted as a groyne and was responsible for changing the sediment transport, while the sediment was trapped between the structures and there was less sediment supply from areas farther south. Normally, during the northeast monsoon, the beaches are eroded, and then recover during the southwest monsoon (classic monsoonal morphodynamic model). However, the present study reveals that developed beaches do not recover, especially in Zone A (except at B1, since recovery occurred there more naturally). Hill *et al.,* (2004) and Quartel *et al.,* (2008) also demonstrated that developed beaches did not recover from their post-storm conditions as quickly as undeveloped beaches. Developed beaches are unlikely to regain an equilibrium state compared to undeveloped beaches under natural conditions, and are hence more directly impacted by strong meteorological disturbances.

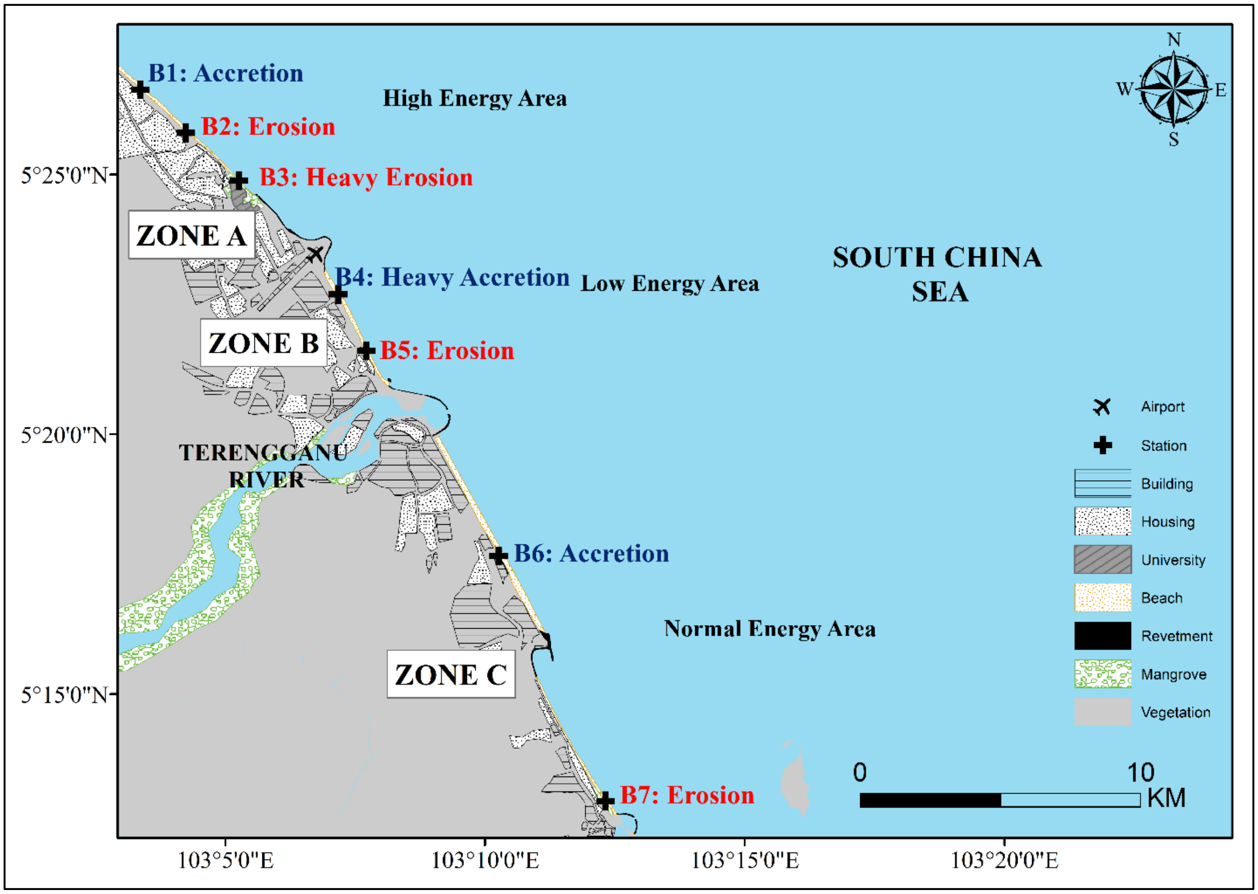

Figure 5.12: Beach morphological changes along the Kuala Terengganu coastline.

According to Mohd Lokman *et al*. (1998) and Rosnan *et al*. (1995), development on the coast involved less construction at Kuala Terengganu beach. Hence, during the period prior to 2010, the longshore current and wave conditions imparted less energy to the coast. Since 2010, numerous development projects have been implemented along the Kuala Terengganu coastline. Hence, the stronger currents and larger waves have produced multiple erosion on the coastline. Figure 5.12 represents the model for beach morphological evolution along the Kuala Terengganu coastline, showing the changes in sediment volume and cumulative bed level.

In this model, especially after the airport tarmac extension, Zone A shows a tendency to undergo a high rate of erosion (B3 station) and slightly higher rates toward the north (B1 station). In contrast, Zone B tends to undergo erosion at B5 (just north of the Terengganu River breakwater), while areas just south of the airport tarmac extension are becoming heavily accreted. Zone A is a high-energy area, and Zone B is a low energy area. This pattern is also supported by Mohd Radzi *et al*. (2014), who observed stronger currents after the airport construction (in the northern sector) compared to the southern sector.

Moreover, this case is similar to that in Zone C, especially at B7 station, where the Marang River breakwater in the south is causing erosion. At B6 station, showing compact coastal development, a revetment was constructed on the berm to protect the buildings, and the beach became accreted. By contrast, after the revetment, the beach areas with high energy produced high rates of erosion.

The currents tend to be stronger and, in the same situation, the waves would be expected to be larger (Lee *et al*., 2004; Yang *et al*., 2007). Under natural conditions, in Kuala Terengganu during the northeast monsoon (storm), there is tendency to have high waves which become slightly reduced in height during the southwest monsoon (Ariffin *et al*., 2016; Noraisyah *et al*., 2015; Rosnan and Ariffin, 2010; Rosnan and Mohd Lokman, 2005). Hence, almost all of the Kuala Terengganu beaches show erosion.

However, the situation is different during the southwest monsoon, since the high-energy environment in Zone A produces a strong current which generates high waves. In fact, during the southwest monsoon, the wave height is lower, but high waves are developed in Zone A as compared to Zones B and C because of the impact of the airport tarmac extension (Mohammad Fadhli *et al*., 2014; Mohd Radzi *et al*., 2014; Muslim *et al*., 2011). Furthermore, the design of the airport tarmac extension with the reclaimed area jutting out into the sea changed the wave direction on the coast.

The observations during the sampling period were carried out over two consecutive years (July 2013 – June 2015). Hence, in November and December 2014 during the 2014 – 2015 northeast monsoon season, heavy rainfall was observed and Kuala Terengganu was hit by floods that changed the beach morphodynamics, especially at B1 and B2 stations (flooded) (Pranzini *et al*., 2013). However, during the period of heavy rainfall, the strong winds produced higher waves and all the stations underwent heavy erosion (even though there was less erosion at B4 and the previous northeast monsoon had led to accretion) and a slip-face bar was clearly observed.

Subsequently, during the southwest monsoon of 2015, there was less rainfall associated with lower wind speed. Hence, with lower winds, the wave height was also reduced compared to the previous southwest monsoon, especially in Zone A. During this period, most of the beaches were built up or nourished by sand, as supported by many studies showing that, after the storm, beaches will recover with the return to calm condition (Coco *et al*., 2014; Corbella and Stretch, 2012; Houser *et al*., 2015; Kobayashi and Jung, 2012; Suanez *et al*., 2012; Yu *et al*., 2013).

5.6 Summary

The changes in beach morphodynamics described here show that the study area has undergone high rates of erosion in Zone A and accretion in Zone B. Meanwhile, erosion is observed in Zone C. The beach morphodynamic models show that Zone A can be represented as a high-energy area and Zone B as a low-energy area, while Zone C behaves as a normal-energy area. This pattern of energy dissipation has totally changed following the rapid anthropic development along the coast of Zone A since the 2010s.

However, over the last decade, the Terengganu authorities planned several strategies to prevent further erosion, aiming to rebuild and protect the eroded beaches of Kuala Terengganu and restore an acceptable beach width. These projects consisted of constructing a series of riprap/revetment structures, groynes and breakwaters, which have now been implemented. A few years later on, the installed structures have turned out to be ineffective in reducing erosion.

Subsequently, by observing the erosional systems, we note that the impact of anthropic activities associated with development are often concealed compared with natural signals. In fact, the coastal environment is strongly influenced by anthropic pressures which cause problems in terms of beach morphodynamics. Many studies can be used as examples to help in designing an approach to this problem.

For example, to address the problem of erosion, it is useful to consider profile changes in conjunction with the volumes of sand bypassing from Zone B to Zone A. Subsequently, the construction of hard coastal defence structures should be immediately halted because the hydrodynamic regime and erosional processes could be shifted to other locations. Furthermore, a management strategy needs to be implemented which can provide a better understanding and an integrated view of beaches.

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Open Sandy Beach Morphology and Morphodynamic as Response to Seasonal Monsoon in Kuala Terengganu, Malaysia

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ABSTRACT

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Understanding beach morphology and morphodynamic changes is important in regions where there is a large amount of recreation and development. Kuala Terengganu beaches has many anthropogenic infastructure such as an extension to an airport runway similar in design to a groin which affect morphology and morphodynamics in response to seasonal monsoon storms. Seasonal monsoon storms are one of the most important controls on the cycle of erosion and accretion on beaches. Beach profile data and wave modelling were used to determine the response of five beaches on the north of Kuala Terengganu to Northeast and Southwest seasonal monsoons. The beaches along the Kuala Terengganu state coast before the construction of the airport extension exhibited a classical morphodynamic response. This includes erosion during Northeast monsoon and accretion/recover during Southwest monsoon. The airport construction disturbed and changed normal coastal evolution. Two distinct sediment cells were generated, each having developed a proper morphodynamic response within the Northeast and Southwest monsoon wave regimes.

ADDITIONAL INDEX WORDS: *Beach Morphology and Morphodynamic; Northeast Monsoon Storm.*

INTRODUCTION

The open sandy beach is a natural sediment buffer for coastal systems. Erosion and accretion this buffer are correlated with high and low energy wave conditions. High energy waves erodes sand from the beach, while low energy waves supplies causes it to accrete. Stive *et al.* (2002) created a storm model which predicts rapid sediment erosion during storms and subsequent slower accretion in the post-storm period. This model may be applied to natural areas expressing a seasonal variable wave energy regime. However, anthropogenic impacts on coastal areas (eg Harbor jetties, groins and breakwaters) may affect sediment supply and transport. The coastal areas under both natural and anthropogenic impacts can suffer from severe erosion as the case of Taiwan and Sulawesi (Indonesia) coasts (Hsu *et al.*, 2007) and Umar *et al.*, 2015).

The coast of Peninsular Malaysia can be divided into two parts, West and East. The West Coast express a low wave energy regime because of the protection of Sumatera, whereas the East Coast faces the South China Sea is experiences high wave energy (Ghazali, 2006). Kuala Terengganu in the East Coast of Peninsular Malaysia territory is governed by two monsoonal wind and waves regimes.

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The Northeast Monsoon lasts from the end of October to middle of March and produces strong waves along the eastern coast of Peninsular Malaysia. However, during the Southwest Monsoon, which lasts from the middle of May till September, moderate waves are generated along the east coast of Peninsular Malaysia. The significant wave height during Northeast and Southwest Monsoon conditions on the east coast of Peninsular Malaysia varies from 2 m and 0.5 to 1 m respectively. The Sulawesi coast (Indonesia) is affected by the same two monsoonal regimes has a maximum significant wave height up to 3 meters and is affected by a severe erosion (Umar *et al.*, 2015). Furthermore, the strong waves can affect and modify erosion in coastal zone areas during a monsoon storm (Chempalayil *et al.*, 2014).

Considering the seasonal changes in wind-wave monsoon regimes and the net longshore drift from the southeast to northwest, two morphological annual stages which evolve erosional and depositional phases were defined in this coast (Rosnan *et al.,* 2003). Recently, the construction of Kuala Terengganu airport extension (similar to a groin) and several coastal protection structures along this coast perturbed the natural sediment balance equilibrium and the longshore sediment drift circulation under the variable monsoonal waves regimes.

Using a beach profile survey and wave modelling parameters, this paper investigates seasonal patterns of beach erosion and accretion along the Kuala Terengganu coast. Furthermore, we focused on the interpretation of longshore processes prevailing on this coast in term of natural versus human-induced perturbation of a natural/anthropogenic beach system.

Study Area

The study area comprises almost 15 km of the Kuala Terengganu coastline areas, extending from Kampung Batu Rakit to Kampung Seberang Takir (Figure 1). This coast is backed by a Quaternary coastal plain for most of its length. A 1km airport tarmac extension was constructed in 2010 (Figure 1). This construction interrupted the longshore drift circulation and resulted in marked variations in shoreline width. A number of rivers, the largest of which is Terengganu River occur on this coast (Figure 1).

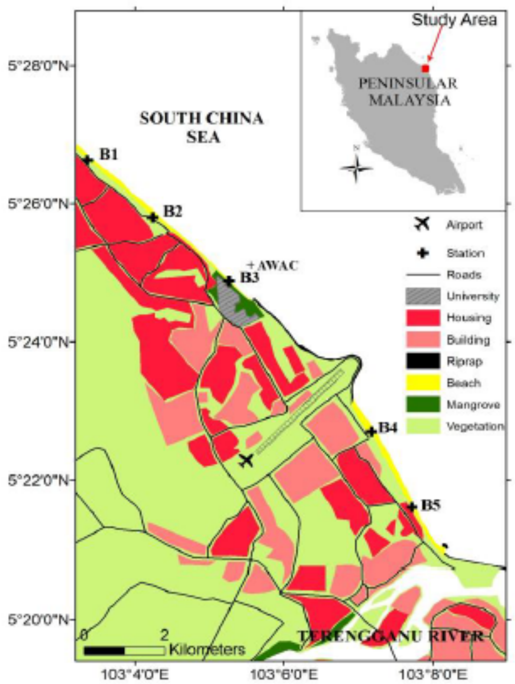

Figure 1. Study area with the location of the five surveyed beaches and the extended airport tarmac (form of a groin) constructed in 2010.

The coastal current at the Kuala Terengganu coastline flows more or less parallel to the coastline. Akhir and Chuen (2011) noted that during the Northeast Monsoon season, the surface current runs southward along the east coast of Peninsular Malaysia. However, during the Southwest Monsoon, the current moves to the north and the currents change with similar strength running to the south. Strong waves are prevalent during the Northeast Monsoon when the winds are onshore; during the southwest monsoon the winds are offshore and low energy (Rosnan *et al.,* 2003).

Tides are semi-diurnal and micro to meso-tidal. The Terengganu coast has a wet equatorial climate, which is which experiences high temperatures all year round and sporadic heavy rainfall, specifically during the Northeast Monsoon (Figure 2) when the average annual rainfall is 2987.9 mm/ year. The major weather systems, determining the wind speed in Sultan Mahmud Airport, Kuala Terengganu, during Northeast and Southwest Monsoon, are approximately 3.0 m/s and 1.7 m/s respectively.

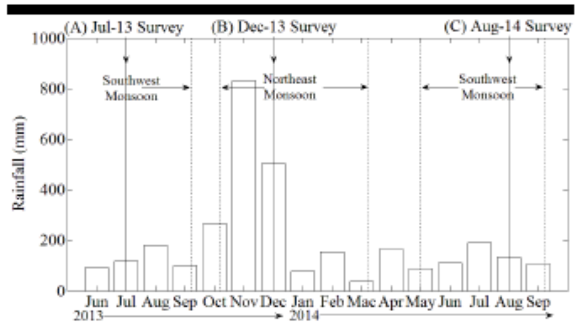

Figure 2. Monthly-average rainfall measured at the Sultan Mahmud Airport, Kuala Terengganu from June 2013 to September 2014 (refer to Figure 1 for location). Arrow line represents a profile survey: (A) July 2013; (B) December 2013; and (C) August 2014.

METHODS

Beach profile surveys were performed fourteen times (monthly) from July 2013 to August 2014 on the five studied beaches (B1 to B5, Figure 1). Beach profile surveys conducted at low tide using a theodolite, levels, and a Total Station (Topcon GPT-3100N). The profile started in the dunes (start vegetation) at a benchmark and ended in about 0.5 m water depth with the average of beaches width between 40-80 m. The benchmark elevations for each of the beaches were adjusted to the DTGSM datum.

The seasonal volume change of beach sand was initiated during the Southwest Monsoon in July 2013 (base profile), followed by profiling in Northeast Monsoon on December 2013. However, to quantify the cycle of seasonal change, profiling on August 2014 (Southwest Monsoon) was also undertaken. For each season, profiling was compared to the base profile of July 2013.

Wave measurements (*in-situ* data) were recorded with a current profiler and a wave directional system (AWAC) deployed in bottom-mounted frame at sub- tidal zone areas (10 m depth) from 28 November 2013 to 28 February 2014 in front of B3-UMT beach (Figure 1). Wind and wave modelling was generated by Mike-21 to estimate wave pattern during the survey period (June 2013 to September 2014).

The Spectral Wave Flexible Mesh (SW) was calibrated by testing the influence of bottom friction and its influence on wave breaking at the AWAC measurement location. It was shown that the combination of adjustable parameters leading to the best agreement between the measured and calculated data sets could adjusted by using a wave growth formula. Bottom dissipation gives no significant effect on the wave height and wave period since the AWAC measurement point is located in deep water. The significant wave height comparison shows close correlation between measured and modelled results; with the root mean squared value calculated is larger for significant wave height (RMSE=0.29).

RESULTS

The beach volume changes of the five surveyed beaches between July 2013 and August 2014 is summarised in Table 1 and the morphological changes of these beaches are shown in Figure 3. This study showed B1, B2 and B3 in the north (Zone A) part of the airport; while, B4 and B5 in the south (Zone B) part (Figure 4).

Batu Rakit (B1)

Batu Rakit is located on the north of Kuala Terengganu coastline (Figure 1). Figure 3 shows sediment deposition on backshore and foreshore with an increase of 10% in beach volume during Northeast Monsoon. During Southwest Monsoon deposition on the backshore and foreshore are shown; whereby this season still shows deposition with a decrease on percentage of beach volume (7.39 %).

Pengakalan Maras (B2)

Pengkalan Maras located on the north of Kuala Terengganu coastline and the extended Sultan Mahmud Airport (Figure 1). Backshore and foreshore on B2 show erosion during both Northeast Monsoon (-5.08 %) and Southwest Monsoon (-11.35 %) respectively (Figure 3).

UMT (B3)

B3 is Universiti Malaysia Terengganu beach located 3 km near the northern part Sultan Mahmud airport. Universiti Malaysia Terengganu (UMT) beach was resurfaced (on 20-30 m distance) on November 2013 after been victim of a major erosion from September to October 2013. However, we measured significant backshore accretion (6.33 %) during the Northeast Monsoon. In April 2014, the entire UMT beach was collapsed (Figure 3); while the beach eroded during the Southwest Monsoon by 2.65 % of the entire sand volume.

Teluk Ketapang (B4)

Teluk Ketapang is located south of the Kuala Terengganu coastline and the Sultan Mahmud Airport (Figure 1). Figure 3 shows the deposition and erosion on backshore and foreshore respectively, with a percentage of sand volume loss of 3.27 % during Northeast Monsoon. However, during the Southwest Monsoon deposition the accretion on backshore and foreshore reached 2.07% of the initial profile sand volume.

Seberang Takir (B5)

Seberang Takir is located along the south of Kuala Terengganu coastline and the extended Sultan Mahmud Airport (Figure 1). During the Northeast Monsoon, the profile loss of sediment reached up -10.69 % while during the Southwest Monsoon, 19.27 % of sediment gain was measured on backshore and foreshore areas of this profile.

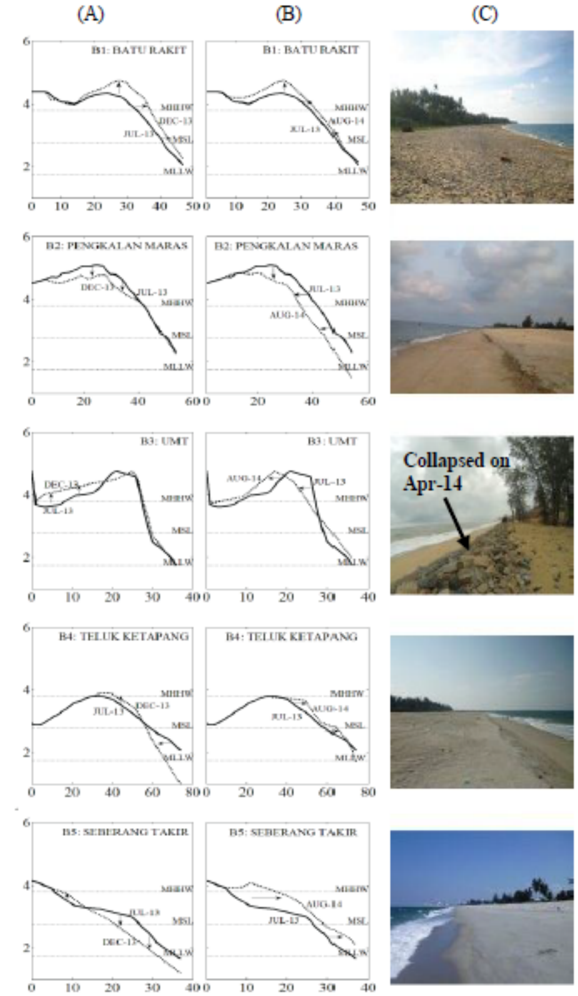

Figure 3. Beach profile sequences for the five surveyed beaches along Kuala Terengganu coast (elevation are relative to DTGSM datum) and July 2013 referred as base profile: (A) Northeast Monsoon-December 2013; (B) Southwest Monsoon-August 2014; and C) field observation on August 2013. The solid line represents the beach profile during July 2013 and the dashed line represents December 2013 and August 2014 profiles.

The volume sediment variation *i.e.* erosion and deposition, was referenced to July 2013 profile considered as a base profile; volume changes during seasons are compared and presented in Table 1 and Figure 4. The north (Zone A) of the study area shows B1 and B3 accretion during Northeast Monsoon and decrease in volume during Southwest Monsoon. However, B2 is moderately and highly erosional during the Northeast and Southwest Monsoon respectively. Lastly, B4 and B5 located in the south (Zone B) of the study area show erosion and deposition during Northeast and Southwest Monsoon respectively.

Table 1. *Beach volume sequence for five beaches along Kuala Terengganu coast with comparison profile of seasons. The minus '-' value indicates the volume of sand eroded; plus '+' value indicates the volume of sand deposited (refer to Figure 3 for the 2-D graph).*

Profile Name	Jul-13	Dec-13	Aug-14	A	B
	Volume in cubic meters				
B1	109.72	120.69	117.83	10.00	7.39
B2	179.95	170.81	159.53	-5.08	-11.35
B3	90.90	96.66	93.31	6.33	2.65
B4	236.10	228.39	240.98	-3.27	2.07
B5	76.31	68.15	91.02	-10.69	19.27

**A: Northeast Monsoon (from July 2013 to December 2013); B: Southwest Monsoon (from July 2013 to August 2014).*

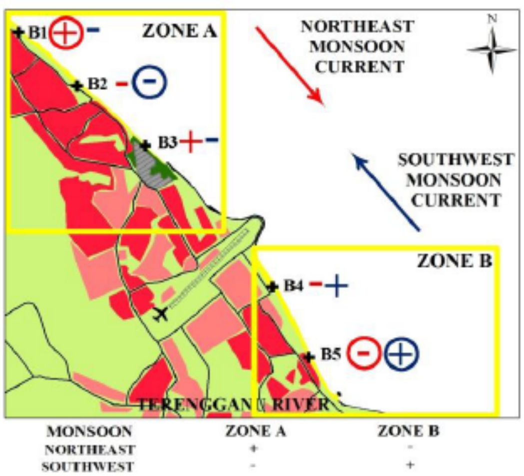

Figure 4. Volume changes during Northeast (Red) and Southwest (Blue) Monsoon. The minus '- and +' value indicates the volume of sand eroded and deposited respectively; and circle indicates heavy erosion or deposition.

Inshore Wind and Wave Conditions

Figure 5 represents the responses observed by the modelled wind and waves in this study. The wind speed shows an increase during the Northeast Monsoon (November 2013) and at the end of the post-Northeast Monsoon (March 2014). The storms started from November 2013 to March 2014 and three major storms took place during this season. The first and second storms were in December 2013 and the third occurred in January 2014. The highest Northeast Monsoon storm of January 2014 produced the largest significant wave height of 1.48 m, while another two storms during Northeast Monsoon reached 1.45 m wave height. Southwest Monsoon did not include any storms and the average of significant wave height was < 0.66 m

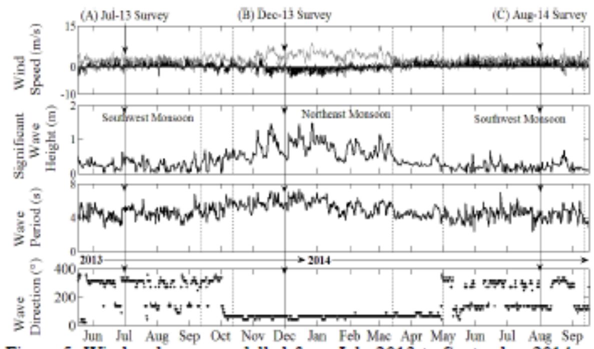

Figure 5. Wind and wave modelled from July 2013 to September 2014: (A) wind speed and direction; (B) significant wave height; (C) wave period; and (D) wave direction. Arrow line represents a profile survey: (A) July 2013; (B) December 2013; and (C) August 2014.

DISCUSSION

This study demonstrates that morphological changes (Northeast Monsoon effect) on the majority of the beaches along the Kuala Terengganu coasts are triggered by variations in wave energy and relate seasonal changes in the littoral drift direction; (Masselink and Pattiaratchi, 2001; Mishra *et al.,* 2011; Rosnan and Mohd Lokman, 2005; and Wong, 1981). Normally, during the Northeast Monsoon storms, the beaches on the north subsequently shows deposition when the long-shore sediment transport operates toward the south. Furthermore, the beaches located on south become narrower during the Northeast Monsoon and wider during the Southwest Monsoon. B1 and B3 beaches.

To the north of the study area (Zone A with B1 to B3 beaches), the Northeast monsoon is responsible for significant accretion along the zone (except B2) when the Southwest monsoon generates erosion of this area. The B2 beach remains the exception by having intensive erosion during this period. To the south of the study area (Zone B with B4 and B5 beaches), the Northeast monsoon storms cause erosion while the Southwest monsoon conditions lead to significant accretion. This zone highlights a contrasted morphological model compared to the northern zone which presents normal hydrodynamic and sedimentological processes under the Northeast and Southwest Monsoons impacts.

However, it is challenging to generalize a simple morphodynamic model for this coast (seasonal accretion/ erosion cycle) with a reversal in littoral drift under Northeast and Southwest monsoon's wave regime. Longshore wave energy gradients and littoral drift may undergo medium-term (order of several years) modifications in one of at least three ways, rarely in combination: (1) commonly cyclic changes in deep-wave approach directions due to climatic oscillations; (2) cyclic changes in nearshore bathymetry due to large-scale intrusion of longshore migrating sediment bodies into the wave field affecting bays; and (3) perturbation of the wave field by human constructions, notably port breakwater structures (Sedrati and Anthony, 2007). Type 3 modifications are perfectly exemplified by Terengganu Coast evolution (the extension of Terengganu airport tarmac in 2010).

Rosnan and Mohd Lokman (2005) states that there are two net directions of sediment transport by littoral drift along the Terengganu state coast; a north-westward transport and southward transport, to the north-west, and south of Kuala Terengganu respectively. Terengganu state coast exhibited a relatively consistent beach width before the extension of the Terengganu Airport tarmac. This construction acted like a groin and was responsible of the generation of two separately and distinguishes sediment cells. These multiple cells are suggested to explain longshore changes in beach morphology, and the marked spatio-temporal variability in morphology. Over shorter time scales, Mohd Radzi *et al.* (2014) revealed that on the beaches located between groins, variations in beach volume may arise as a result of a short-term reversal of longshore transport.

Normally, during Northeast Monsoon the beaches are eroded and recover on Southwest Monsoon (classic monsoonal morphodynamic model) however, this study represents developed beaches that did not recover. Hill *et al.,* (2004); and Quartel *et al.,* (2008) also demonstrated that the developed beaches did not recover from their post-storm conditions as quickly as the developed beaches. The developed beaches are unlikely to naturally regain an equilibrium state that the undeveloped beaches do, and are hence, more directly impacted by strong meteorological circumstances.

CONCLUSIONS

The main dynamic model of the evolution of Terengganu state coast was completely disturbed by human constructions. Since 2010s, several strategies to prevent further erosion or to rebuild and protect the eroded beaches of Terengganu coast and to restore acceptable beach widths have been realised by Terengganu authorities. These projects that consist in the construction of a series of groins or breakwaters have been implemented. Few years later, the installed structures turned out to be ineffective in reducing erosion. It's however clear there is a need of management strategy involving a good understanding and an integrated view of beaches and coastal dynamics, as well as defence strategies covering not only the beaches but also the dunes and the nearshore zone.

ACKNOWLEDGMENTS

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CHAPTER SIX: SHORT-TERM MORPHODYNAMIC CHANGES IN MONSOON COMPARISON

Effi Helmy Ariffin, Mouncef Sedrati, Mohd Fadzil Akhir, Mohamad Noradlan Mohd Norzilah, Rosnan Yaacob and Mohd Lokman Husain, XXXX. Short-term observation of beach morphodynamic during seasonal monsoons: two examples from Kuala Terengganu coast. *Journal of Coastal Conservation* (Submitted).

Contents:

6.1 Introduction

The beaches of Kuala Terengganu are characterized by sandy sediment (Rosnan and Ariffin, 2010), where the intertidal zone (foreshore) behaves as a dynamic zone affected by natural events (i.e. waves, tides and winds) as well as human activities (i.e. impact of coastal structures) (Kumar *et al*., 2012; Wright and Short, 1984). These sandy beaches act as natural sediment buffers for the coastal system, with erosion and accretion being correlated with high- and low- energy wave conditions, respectively (Ariffin *et al*., 2016). In particular, it is noteworthy that the wave regime is correlated with seasonal variations, with high-energy wave conditions occurring during storms and low-energy during periods of calm.

Additionally, the seasonal variations in beach erosion and/or accretion (beach changes) provide useful information for understanding coastal processes as well as for coastal management planning. However, changes in beach morphology take place seasonally over variable durations, with short-term changes occurring on an hourly (defined as short in the tidal cycle), daily or weekly time scale, and long-term changes implying monthly or yearly observations during the seasonal periods (Davis, 1985). According to Masselink *et al*. (2007), most short-term observations address the morphological changes of sandy beaches impacted by the action of waves and tides in microtidal or mesotidal settings.

It is of interest here that Stive *et al.* (2002) created a storm model based on seasonal observations which actually predicted the rapid erosion of sediments during storms and their subsequent slower accretion during post-storm periods. This model can also be applied to natural areas (on beaches) subject to a seasonally variable wave energy regime. However, beach morphodynamics may also be affected by anthropogenic impacts on coastal areas (such as harbours, riprap or revetments, groyne and breakwaters). Surveys and analyses carried out on modern beaches (associated with dense human habitation) serve as a benchmark to determine the morphodynamic state, as well as whether the beach is in a state of equilibrium or disequilibrium.

An interesting example is observed at Charf el Akab, a high wave energy beach on the north of the Moroccan Atlantic coast showing a unique correlation between the intensification of human activities (during the past few years) and the increasingly energetic events taking place during winter storms (Taaouati *et al*., 2011). Another example is given by Cherating beach on the East Coast of Peninsular Malaysia, which has undergone apparent coastal erosion associated with the formation of 1-2 m high scarps and a beach bar along the coast, clearly indicating that this beach is not in equilibrium. The development of scarps in this case has been influenced by the high energy of waves and tides on the modern beaches (Wong, 1990).

Many beach studies have adopted the model of a morphodynamic system evolving towards a state of dynamic equilibrium (under steady forcing conditions). These models describe the morphological beach form (Dean, 1973; Masselink and Short, 1993; Wright and Short, 1984), giving an estimation of the equilibrium state. Such models of beach systems are now commonly applied in many studies of coastal morphodynamics (Woodroffe, 2002), and are used to relate the three-dimensional morphology to a small number of environmental parameters.

Other studies have also attempted to examine morphological beach states using models based on direct visual observations (Wright and Short, 1984). 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.

Moreover, beach evolution can be linked to various processes such as wave properties (wave height and period), sediment characteristics, tidal variations and beach morphology (using an average beach slope). Given sufficient time (within one beach cycle), processes of formation, modification, destruction and/or migration of the beach lead to morphological changes which in turn create landforms such as beach bars, swash bars or nearshore bars (Masselink *et al*., 2007). Many attempts have been made to correlate beach morphology with environmental forcing. Moreover, the beach itself exhibits a distinct cyclic response to the seasons, individual storms, tidal cycles, and even to higher frequency forcing (Taaouati *et al*., 2011).

However, the aim of this study is to characterize the beach morphodynamics at two locations (in the north and south of Kuala Terengganu) for a comparison of equilibrium states. Moreover, this investigation represents a new study based on short-term observations during seasonal monsoons, since many previous studies on Kuala Terengganu beaches were only concerned with longer term assessments in relation to seasonal monsoons (i.e Ariffin *et al*., 2016; Rosnan and Ariffin, 2010; Rosnan and Mohd Lokman, 2005). 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).

6.2 Summary of Study Area

The study area is located on the coast of Kuala Terengganu (on the East Coast of Peninsular Malaysia) and is divided into two sectors, namely the northern and southern coasts, which are separated by the Terengganu River (refer in Figure 2.2). The coastline is NNW-SSE trending and is dominated by sandy beaches and only two beaches were selected from this study (7 beaches) i.e. Pengkalan Maras (B2) in the north and Kuala Ibai (B6) in the south (Figure 6.1). The growing pressure of human activities negatively impacts the evolution of beaches and changes the dynamics controlling their equilibrium state, causing increased erosion. B2 does not have any coastal defence structures on the beach, as compared to B6 where there is a 3-m wide revetment on the berm. Coastal defence structures are designed to address the problem of erosion. However, these structures had also led to significant changes in the morphodynamic characteristics (especially in the beach slope) of the area, which also includes changes in the wave and sediment transport system. However, in detail of study area description is discussed in Chapter 2.

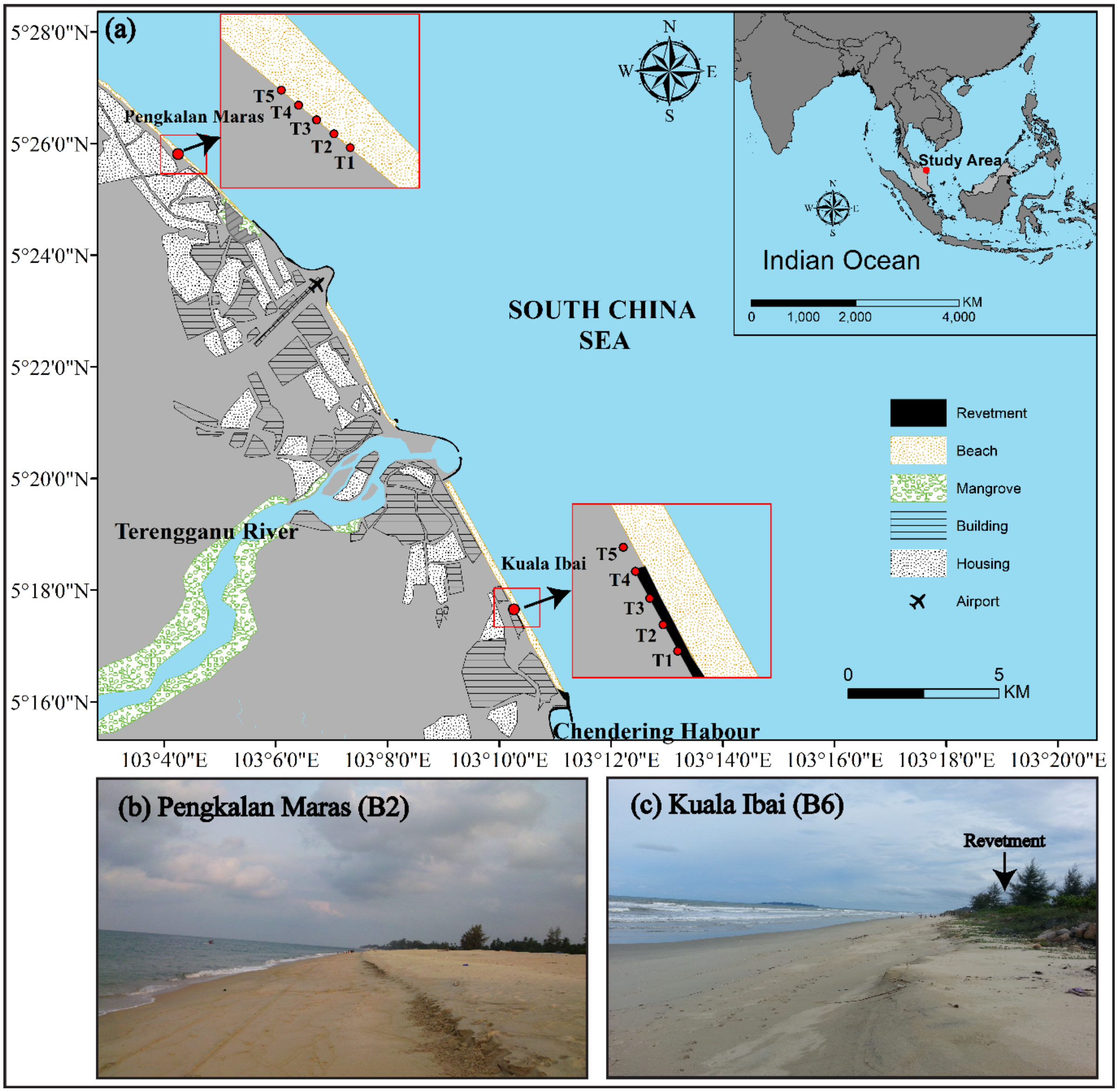

Figure 6.1: Study area showing a) two selected beaches on the Kuala Terengganu coast, namely; b) Pengkalan Maras (PM-B2) to the north and c) Kuala Ibai (KI-B6) to the south of the Terengganu River, respectively. Each beach comprises five transects (T1 to T5).

6.3 Summary of Methodology

The study was carried out during the two monsoon seasons on the Kuala Terengganu coast, namely the northeast monsoon (survey during late October 2014), and the southwest monsoon (survey during late May 2015). Hence, analyses of the wave parameters and beach profiles were conducted to determine the morphodynamic characteristics in the study areas. The wave parameters were determined using wave modelling modules (Mike-21 – Spectral Wave Flexible Mesh) applied to data collected in in October 2014 and May 2015 (DHI, 2011). This wave modelling 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 data (H_o) 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 3.1 (refer Chapter 3).

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 breaking wave heights, wave period and beach slope. The breaker type is usually estimated by the surf similarity index (ξ_b) (Battjes, 1974; Galvin, 1968), defined in Equation 3.2 (refer Chapter 3). Additionally, Wright and Short (1984) provide a criterion for predicting beach state based on breaking wave height and sediment grain size using the dimensionless fall velocity (Ω) proposed by Dean (1973) and Gourlay (1968) in Equation 3.4 refer Chapter 3).

On the other hand, the beach profile surveys were carried out over five days from 28th October to 1st November 2014, and over four days from 28th May to 31st May 2015. Each studied beach area was covered by five transects with a spacing of 50 m between transect lines (see Figure 6.1). However, it should be noted this chapter only shows bed level changes for Transect 3 since the sediment sample was collected from the middle of the beach (only on Transect 3). The mean grain size (D_{50}) of the sediment was determined using the GRADISTAT V4.0 program. 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). However, in detail of methodology is discussed in Chapter 3.

6.4 Results

The main findings of this study are presented under two sections, the first dealing with wave characteristics and second with beach morphodynamics. The results from the wave characteristics study include information on significant wave height and wave breaking type, which can be linked to beach morphodynamics. In particular, significant wave heights (H_s) during storms are generally around 2 m or more on the Terengganu coastline as observed us during the northeast monsoon (Ariffin *et al*., 2016; Mirzaei *et al*., 2013). As shown on Figure 6.2, neither of the monsoon periods mentioned above show any signs of such storms.

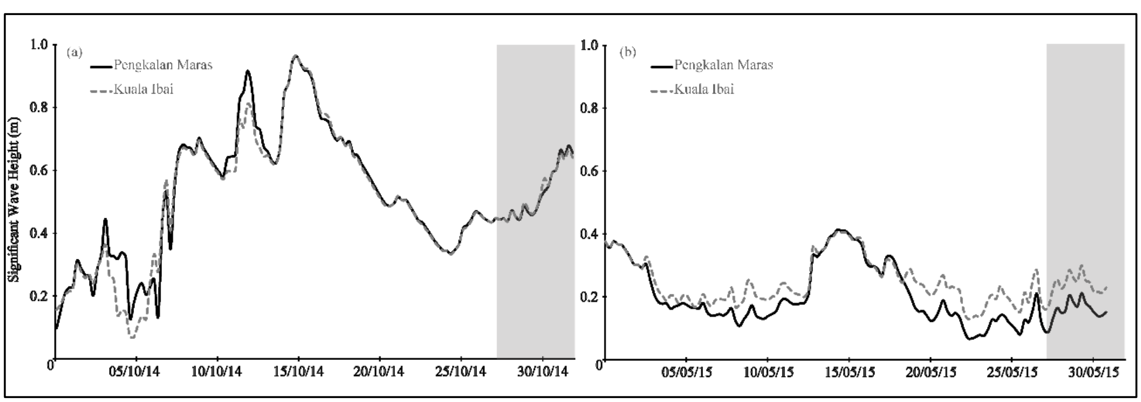

Figure 6.2: Significant wave height (a) in October 2014 and (b) in May 2015; grey boxes represent beach profile survey periods.

However, the study of beach morphodynamics and behaviour also involves the measurement of mean sediment grain size (D_{50}). This section also describes beach volumes, beach gradients, breaker types and beach states, as well as beach profile and bed level changes, which are analysed to understand the short-term impacts of beach morphodynamics on both studied beaches (B2-Pengkalan Maras and B6-Kuala Ibai) during typical seasonal monsoons.

6.4.1 Northeast Monsoon

i) Wave characteristics

Wave heights in the study areas generally show higher values in October 2014 than at the beginning of the northeast monsoon and indicates a normal pattern of significant wave heights (Figure 6.2). This is also supported by the data for H_b (breaking wave height), which show higher values during the northeast monsoon (Table 6.1). Furthermore, in October 2014, during the survey period at B2 beach, the average H_s reading is 0.52 m and the maximum 0.68 m. In B6 display a closely similar pattern to that observed on B2 in October 2014, with an average H_s reading of 0.52 m and a maximum of 0.66 m.

ii) Beach morphodynamics and behaviour

The beach volume in October 2014 (during the northeast monsoon) indicates accretion at B2 and erosion at B6 (Figure 6.3). However, in detail at B6 during October 2014, the beach volume shows only Transect 4 is subject to some accretion because this transect is covered by the end of the revetment (as shown in Figure 6.1). Hence, Transect 5 suffers the highest erosion because it is situated beyond the end of the revetment.

On the other hand, during the survey period on northeast monsoon (October 2014) and sign no storm hence, the beach gradient (tan β) undergoes only minor variations at B2 and B6 (see Table 6.1). However, with the beach gradient value, this study was defining the morphodynamic states with the surf similarity index (ξ_b) and the Dean number Ω are shown in Table 6.1. During the northeast monsoon period, the morphodynamic state of B2 is due to the spilling breakers and low slope values, as well as its intermediate beach state (low Ω readings). The opposite situation is observed for the surf similarity index (ξ_b) at B6, which is a result of the plunging breakers at this site in accordance with the higher slope values and intermediate-dissipative beach state (higher Ω readings).

On the other hand, the morphodynamic changes present the Transect 3 of the beach profile and bed level changes observed at B2 (see Fig. 6.4). The pattern of during October 2014 (northeast monsoon) indicates Accretion-Accretion-Erosion-Accretion on the second, third, fourth and fifth days of observation, respectively. In terms of detailed morphodynamic changes (Transect 3) at B6 beach is totally different compared to B2, with a different pattern of bed level change despite the same northeast monsoon conditions (Figure 6.5). The pattern of bed level change during October 2014 (northeast monsoon) indicate Erosion-Erosion-Accretion-Erosion on the second, third, fourth and fifth days of observation.

Lastly, the sediment size (D_{50}) shows coarse and fine sand being observed at B2 (beach in the north) and B6 (beach in the south) respectively (Table 6.1).

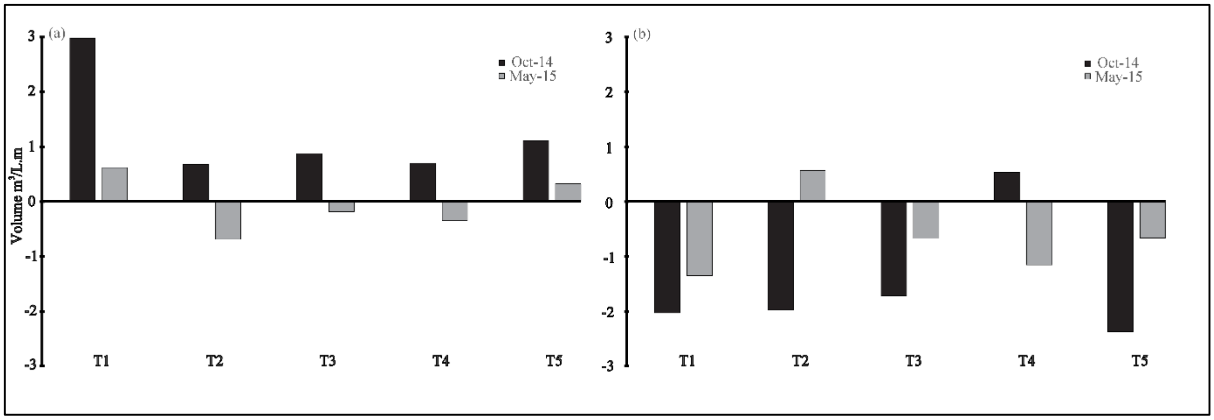

Figure 6.3: The cumulative beach volume at a) Pengkalan Maras beach and b) Kuala Ibai beach during October 2014 and May 2015.

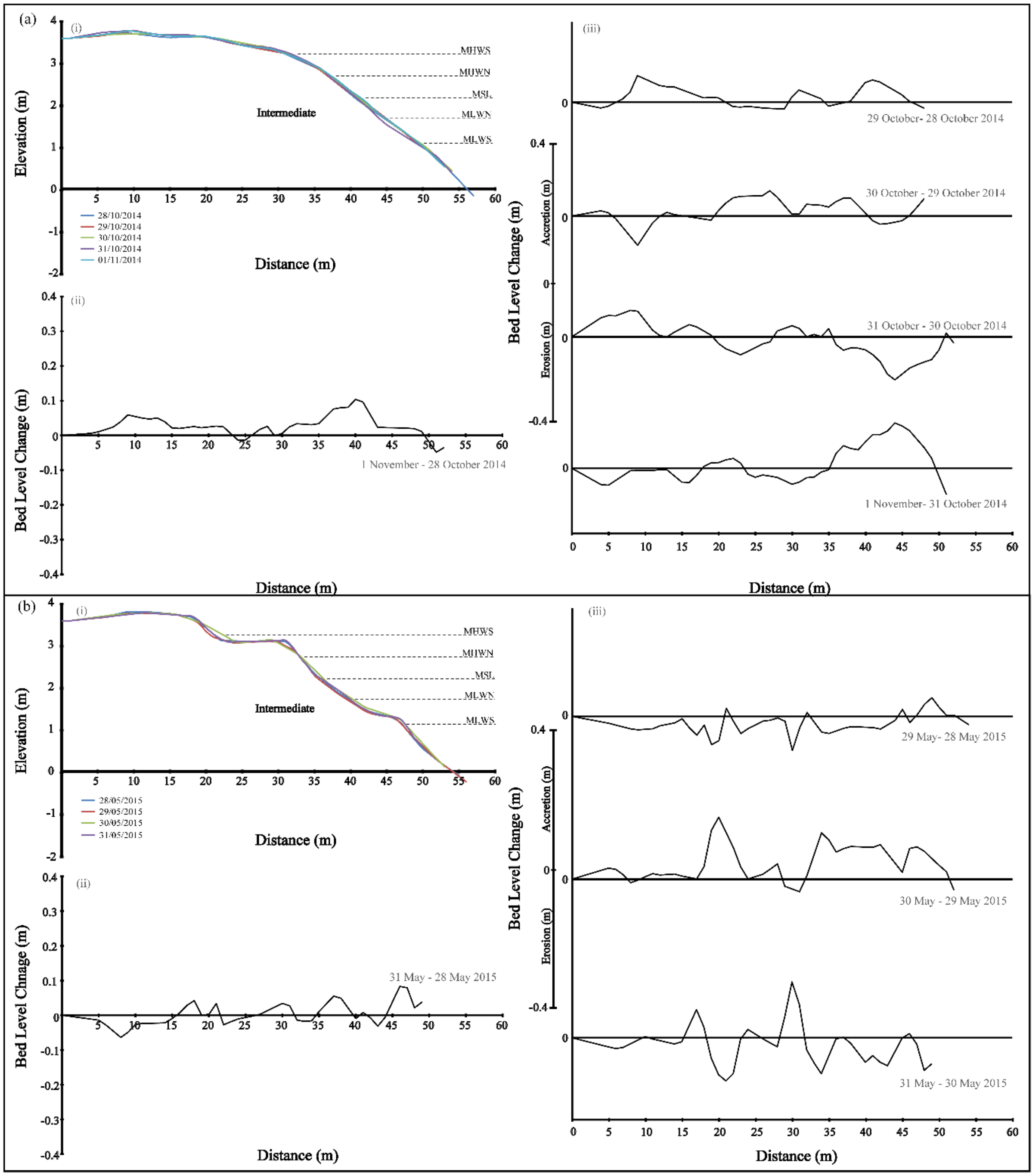

Figure 6.4: Levelling surveys along Transect 3 of beach profile at Pengkalan Maras, (a) during October 2014 and (b) during May 2015, showing (i) beach profile; (ii) bed level change between 28 October and 1 November 2014; and (iii) bed level change between respective daily observations.

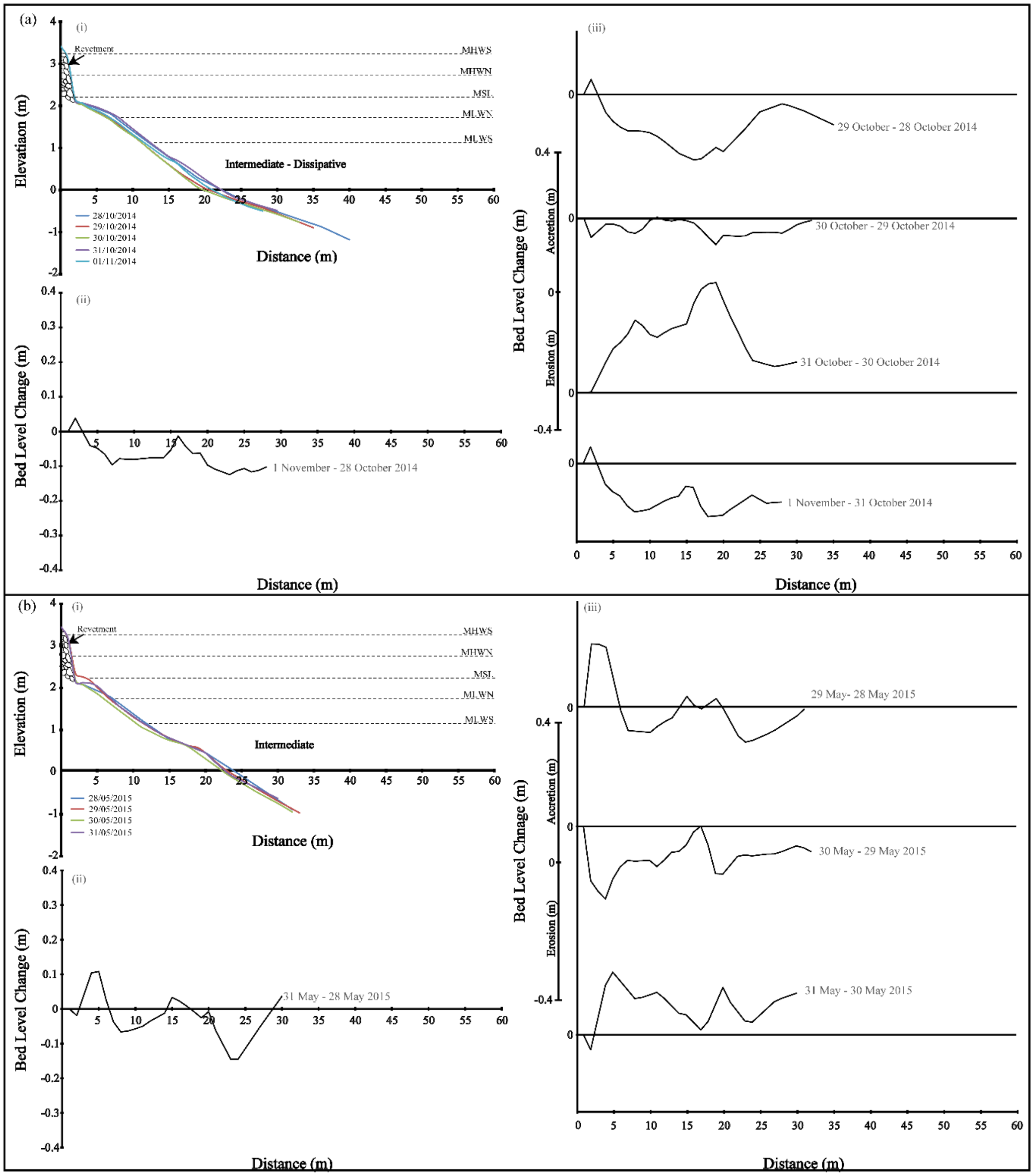

Figure 6.5: Levelling surveys along Transect 3 of beach profile at Kuala Ibai, (a) during October 2014 and (b) during May 2015, showing (i) beach profile; (ii) bed level change between 28 October and 1 November 2014 and; (iii) bed level change between respective daily observations.

Table 6.1: Beach morphodynamic parameters.

Month	D50 (mm)		H_b (m)		tan β		ξb		Ω	
	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

6.4.2 Southwest Monsoon

i) Wave characteristics

In contrast with lower values on significant wave height (H_s) (Figure 6.2) observed in May 2015 during the southwest monsoon and also supported by the data H_b (breaking wave height), which show lower values (Table 6.1). However, during May 2015, the average H_s is 0.16 m and the maximum 0.21 m in B2. On the contrary, the H_s pattern at B6 in May 2015 shows higher readings than those recorded at B2. Hence, the average H_s value for this latter beach in May 2015 is 0.23 m compared with a maximum of 0.30 m.

ii) Beach morphodynamics and behaviour

The beach volume in May 2015 (during the southwest monsoon) indicates erosion and slightly accretion at B2. However, the beach volume at B6 shows a variable and slight decrease in the level of erosion in May 2015 during the southwest monsoon (only Transect 2 shows accretion) (Figure 6.3).

On the other hand, during the survey period on southwest monsoon (May 2015) and sign no storm hence, the beach gradient (tan β) undergoes only minor variations at B2 and B6 (see Table 6.1). However, Table 6.1 was defining the morphodynamic states with the surf similarity index (ξ_b) and the Dean number Ω value. It is same (northeast monsoon) during the southwest monsoon period, the morphodynamic state of B2 is due to the spilling breakers and low slope values, as well as its intermediate beach state (low Ω readings). In contrast at B5 is observed for the surf similarity index (ξ_b), which is a result of the plunging breakers at this site in accordance with the higher slope values and intermediate-dissipative beach state (higher Ω readings).

On the other hand, the morphodynamic changes present the Transect 3 of the beach profile and bed level changes observed at B2 (see Fig. 6.4). By contrast (northeast monsoon), during May 2015 (southwest monsoon), only the fourth day of observation shows a pattern of Erosion-Accretion-Erosion. However, in terms of detailed morphodynamic changes (Transect 3) at B6 beach is totally different compared to B2, with a different pattern of bed level change despite the same southwest monsoon conditions (Figure 6.5). The pattern of bed level change during May 2015 (southwest monsoon) indicates a same pattern to previous northeast monsoon (October 2014) which presented as Erosion-Erosion-Accretion.

Lastly, the sediment size (D50) during May 2015 shows coarse sand being observed at B2 in the north. Furthermore, with fine sand being observed at B6 in the south (Table 6.1).

6.5 Discussions

6.5.1 Comparison between Northeast and Southwest Monsoon

As we know both of monsoon not sign any storm, however, the results show the northeast monsoon (October 2014) presented the highest in significant wave height (H_s) at both of study areas. According to Coco *et al*. (2014) the erosion still can occur also when large waves are not presented in the study area. Hence, it is also noteworthy that the highest energy wave patterns (lowest compare October 2014) are observed at B6 during May 2015, which also explains why this beach is in disequilibrium compared to B2 with a lower energy wave pattern.

This difference is due to the presence of a revetment on the berm which changes the hydrodynamics of the foreshore (Kaliraj, *et al*,, 2013; Masselink and Short, 1993), in agreement with the fact that the H_b (breaking wave) values are closely similar on both studied beaches (Table 6.1), while their H_s values are remarkably different. However, Masselink and Short (1993) stated that the artificial structures such as revetments or sea walls are causing shoreline changes with the removal of sedimentary material from the coast.

While, B6 is seen to have a steeper slope compared to B2 observed in both of monsoons. As an illustration, the B6 of beach slope is steeper because the revetment on the berm has changed the beach morphodynamics in the foreshore zone (Kaliraj, *et al*., 2013). However, most studies use environmental parameters to predict the beach morphodynamics (e.g. ξ_b and Ω) based on breaking wave heights (H_b), wave period and beach slope. (Battjes, 1974; Dora *et al*., 2014; Galvin, 1968; Jackson *et al*., 2005; Taaouati *et al*., 2011). According to Jackson *et al*. (2005), an increase in H_b also leads to a higher Dean number Ω. As result, H_b is higher during the northeast monsoon compared to the southwest monsoon, when this parameter (Ω) tends to decrease.

However, a comparison of two different monsoonal seasons shows that the ξ_b value is increasing at B2 while the Dean number Ω value is decreasing. In contrast at B6, a comparison of the monsoonal seasons reveals that the ξ_b value is decreasing. In relation to this point, B6 shows decreasing values of Dean number Ω, which is similar to the situation observed at B2. According to Taaouati *et al*. (2011), gently sloping beaches do not display major changes in their ξ_b and Ω values despite extremely high energy wave conditions. This is supported by the observations of Aagaard *et al* (2005) showing that gentle slopes do not change significantly during extreme wave conditions.

Furthermore, B6 beach yields higher Ω values in October 2014 compared to May 2015 (B2 is lower Ω value). This scenario is also supported by Masselink and Pattiaratchi (2001), who reported higher H_s and Ω readings during stormy conditions. During calm conditions, however, the H_s and Ω readings return to lower values. While the lower Ω value shows in B2 and the beach exhibited equilibrium beach.

On the other hand, based on the bed level change between 28 October and 1 November 2014 in B2, the active part of the beach profile corresponds to a plateau at a distance of 25 m. Conditions are more dynamic over the distance interval from 25 m to 50 m, since this zone lies between the Mean High Water Spring (MHWS) and Mean Low Water Spring (MLWS) tide levels. While, based on the bed level change between 28 October and 1 November 2014, the active part of the beach profile corresponds to a dynamic zone which begins at 15 m from the revetment (i.e. the Mean Low Water Spring (MLWS) tide level) and extends to a distance of 30 m farther down the profile. However, the more dynamic show during southwest monsoon whereas in this period the beach in going to recovery.

Lastly, the sediment size (D50) shows only minor differences between October 2014 and May 2015, with coarse sand being observed at B2 in the north. Furthermore, with fine sand being observed at B6 in the south. However, the distribution of sediment size is opposite to the pattern observed by Rosnan and Mohd Lokman (2005), who found fine and coarse sand at the northern and southern site respectively. In 2005, the northern studied area did not have any compact coastal structures or development compared with their the years after 2010 when rapid development took place (Muslim *et al*., 2011).

6.5.2 Recovery of Morphology after the Monsoon Effect

The Kuala Terengganu beaches are affected by seasonal monsoon whereby storm condition during northeast monsoon and calm conditions during southwest monsoon (Ariffin *et al*., 2016; Rosnan and Ariffin, 2010; Rosnan and Mohd Lokman, 2005; Rosnan and Mohd Zaini, 2009). However, the northeast monsoon induced a storm are believed to be an important driver behind beach erosion in Kuala Terengganu beaches. In contrast, during southwest monsoon tend to calm condition exhibited the accretion or recovery on the beach (Ariffin *et al*., 2016; Rosnan and Mohd Lokman, 2005; Rosnan *et al*., 2003). Furthermore, the erosion still can be existing either the large waves are not presented (Coco *et al*., 2014). Hence, the human activities on the beach are responsible for the erosion where they are introducing changes in the beach system (Taaouati *et al*., 2011).

Based form the illustrations of DEM (bed level changes) evolution, B2 and B6 exhibited a differentiate pattern of recovery the morphology (Figure 6.6 and 6.7). As presented B2 do not has any interference human activities on the beach and contrast at B6 reveals a revetment on the berm or dune (Transect 1 to 3). The trend of bed level changes at B2 shows accretion to erosion during northeast monsoon and opposite during southwest monsoon whereas shows erosion to accretion. This trend reveals that the B2 presented as equilibrium beach which tend to erosion during northeast monsoon and accretion during southwest monsoon (Ariffin *et al*., 2016; Rosnan and Mohd Lokman, 2005; Rosnan *et al*., 2003).

However, Figure 6.6a(v) shows the beach representing as accretion, it is because in this northeast monsoon do not reveal any storm however, the erosion trend still can observe with the approximately 1 m of wave height. In contrast, Figure 6.6b(v) shows the beach as erosion during southwest monsoon. However, the erosion reveal as minor eroded (the rest shows accretion) and presented chances on the beach become to recovery.

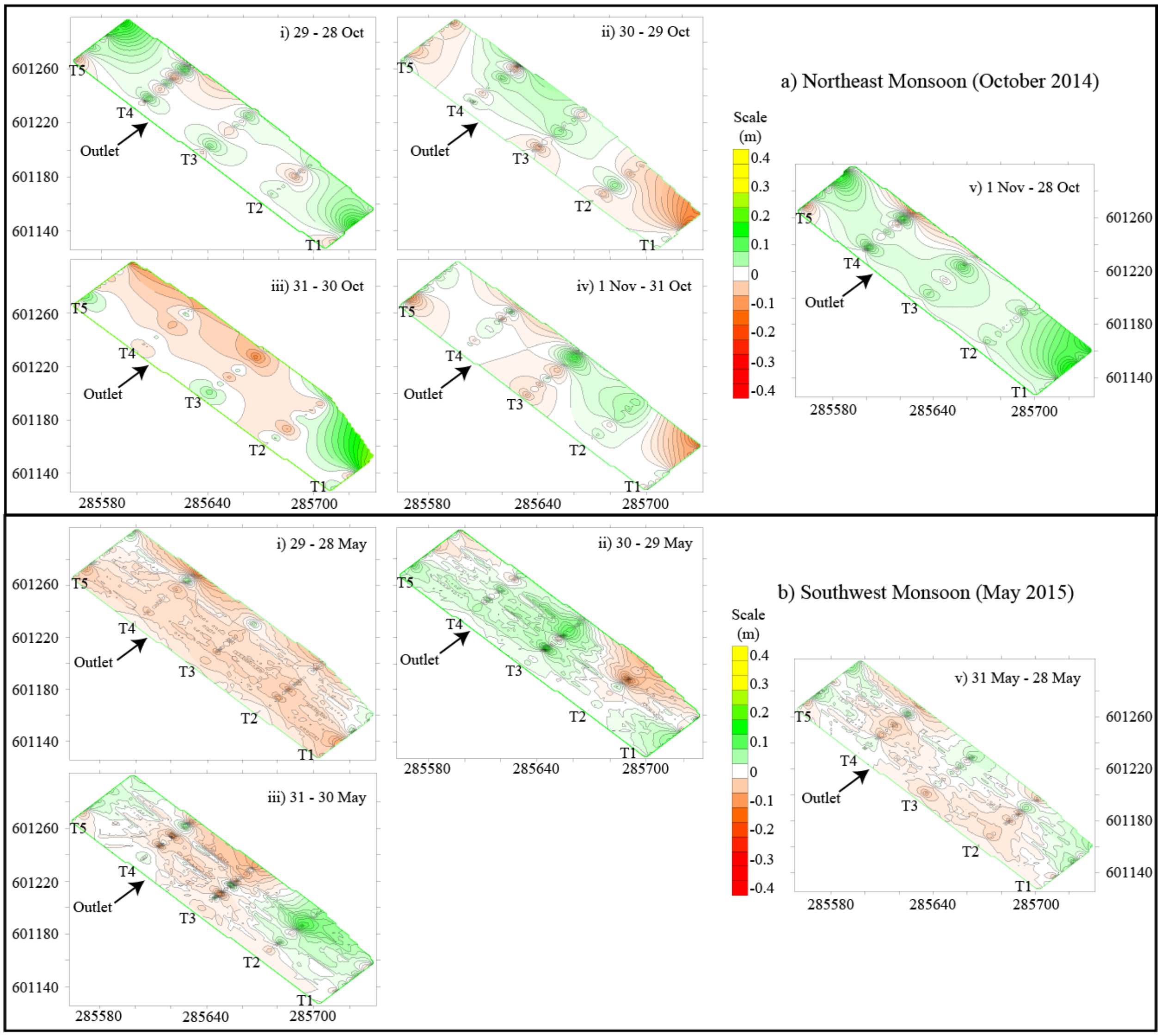

Figure 6.6: The DEM of the bed level change during a) October 2014 and b) Southwest 2015 at B2: Pengkalan Maras beach.

On the other hand, the result of bed level changes at B6 provide the trend erosion to erosion during northeast monsoon. In fact, the extensive eroded shows in comparison between 1 November and 29 October 2014 (Figure 6.7a(v)). While, the trend during southwest monsoon at B6 exhibited erosion to accretion which similar with B2. However, the beach still shows extensive eroded in comparison between 31 May and 28 May 2015. Hence, B6 need take a long time to recovery in beach system. In fact, the revetment on the berm/ dune make change on the equilibrium of beach processes. Furthermore, the artificial structures such as revetments are causing on removal of sediment from the coast (Masselink and Short, 1993)

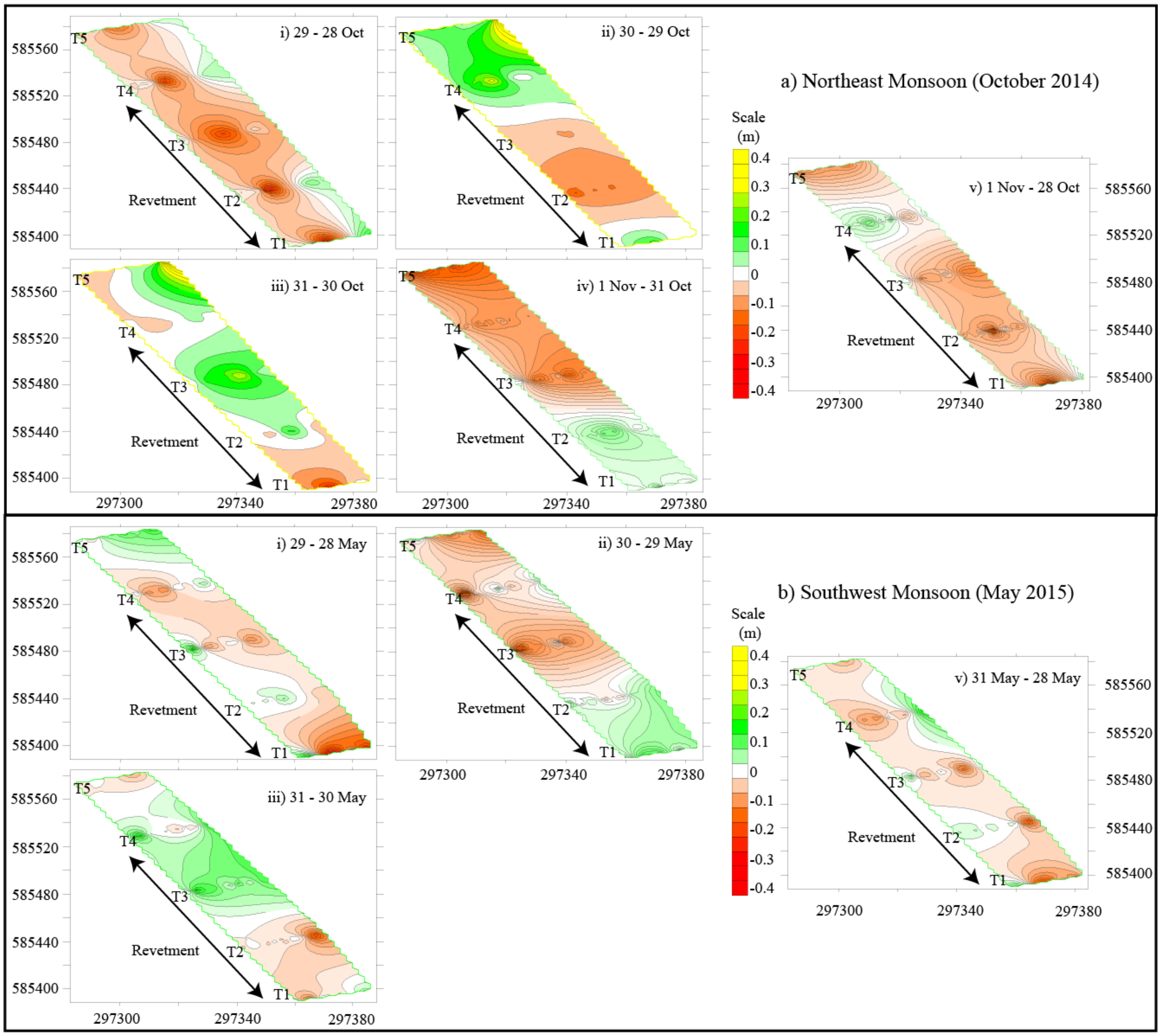

Figure 6.7: The DEM of the bed level change during a) October 2014 and b) Southwest 2015 at B6: Kuala Ibai beach.

It also supported in beach volume results, whereas during October 2014 at the onset of the northeast monsoon, the beach recovery is observed at B2 associated with the accretion of sediment volume in the months after the southwest monsoon of 2014 (Ariffin *et al*., 2016).

However, in May 2015 (during the southwest monsoon 2015), B2 beach shows a slight decrease in sediment volume, due to the impact of the previous northeast monsoon of 2014 – 2015. During the southwest monsoon 2015, the beach starts its build up and recovery, which is in turn dependent on the sand volume available at the site. Therefore, the erosion of beaches is the main source of sediment supplying on the long shore transport system on the Terengganu coast (Rosnan and Mohd Lokman, 2005).

Hence, based on the beach state and bed level change observations, B2 shows a tendency to be in equilibrium with the natural of wave energy conditions and a low constant beach gradient. However, in B6 represents a disequilibrium beach since it does not exhibit any beach recovery and always shows erosion phenomena with the similar pattern of bed level changes in both of monsoon. Hence, the hydrodynamics on B6 is modified by the presence of a revetment, with the result that the H_s is higher during the southwest monsoon (calm conditions) (Kaliraj *et al*., 2013; Masselink and Short, 1993).

6.6 Summary

This study highlights a critical awareness that beach morphodynamics can be modified whenever there is some interference due to the presence of artificial structures on a given beach. When comparing the two studied beaches, B2 displays a closer approach to equilibrium than B6 (which has a revetment on the backshore zone). During the southwest monsoon, the hydrodynamics at B6 changes to a higher wave energy environment in contrast to calmer conditions at B2.

This study also shows that recovery processes on B6 are impaired during the typical southwest monsoon. To address the issue of poor beach recovery, it would be wise to avoid or prohibit (perhaps through legislation) the building of ripraps/ revetments or coastal defences, and favour coastal developments based on berms or vegetation. This type of development may take some time to bear fruit, but, with hindsight, we can be certain that at least it would not have a negative impact on the morphodynamics of the surrounding area, while allowing the beach to resume its normal evolution towards recovery.

CHAPTER SEVEN: GENERAL DISCUSSION

Contents:

7.1 General Discussion

According to Bird (1985), erosion in coastal areas is a worldwide concern, since at least 70% of sandy beaches across the globe are currently being eroded as a result of numerous influences linked to factors such as natural processes and anthropic activities. However, the natural factors such as storm activity depend on coastal types according to wave height and tidal range (Masselink and Hughes, 2003). Since waves are generated by wind (Chiang *et al*., 2003a; Mirzaei *et al*., 2013), the worldwide distribution of wave regimes displays a strong latitudinal control reflecting global climate zones (Davies, 1980; Young, 1999). In fact, there are three main types of influence on wave regimes: storm waves, tropical cyclones and monsoons (Masselink and Hughes, 2003).

Normally, storm waves are located at higher latitudes in temperate and polar zones, while the influence of tropical cyclones (hurricanes) and monsoons occurs at lower latitudes in temperate and tropical zones (Masselink and Hughes, 2003; Young, 1999). However, the influence of tropical cyclones (hurricanes) and monsoons also depends on the tidal range. The influence of tropical cyclones normally occurs in macro tidal regimes, while the influence of monsoons is associated with micro to meso tidal regimes (Masselink and Hughes, 2003).

The influence of storm waves is briefly discussed here, as the studied beach areas are located in a monsoon-dominated zone.

For example, the coastline in India is being severely eroded under high-energy wave conditions of the southwest monsoon, and shows build-up/recovery during the low-energy conditions of the northeast monsoon (Black *et al*., 2008; Mishra *et al*., 2011; Rajawat *et al*., 2015; Sanil Kumar *et al*., 2006). In a similar environment and under monsoonal conditions on the west coasts of Thailand and Peninsular Malaysia (west), erosion and accretion occur during the southwest and northeast monsoons, respectively (Mokhtar and Ghani Aziz, 2003; Nor Hisham, 2007; Thampanya *et al*., 2006). In contrast, on the east coasts of Thailand and Peninsular Malaysia (east), high-energy (northeast monsoon) and low-energy (southwest monsoon) conditions are associated with erosion and build up/recovery, respectively (Ariffin *et al*., 2016; Noraisyah *et al*., 2015; Rosnan and Mohd Zaini, 2009).

However, apart from the hazards arising from natural phenomena, anthropogenic influences have contributed significantly to the erosion of coastlines. Uncontrolled development within or very close to the active zones of the beach are found to be the source of erosion problems (El Mrini *et al*., 2012; Mokhtar and Ghani Aziz, 2003; Nor Hisham, 2007). Anthropogenic influences including projects ranging from channel dredging, construction (harbours, dams), reclamation and sand extraction have caused modifications to the natural coastline, which in turn have severely affected beach morphodynamics.

Other human influences include coastal defence structures such as revetment/riprap, breakwaters, seawalls, etc., which also affect the beach morphodynamics if their construction is not under good management and planning (Hsu *et al*., 2007; Masselink *et al*., 2015; Mohanty *et al*., 2012; Saengsupavanich, 2012; Saravanan and Chandrasekar, 2010; Vaidya *et al*., 2015). To implement an effective management strategy to combat the coastal erosion problem, we require a knowledge of historic shoreline evolution trends and hydrodynamic influence (Jonah, 2015).

In this study, several parameters are identified which allow us to discuss anthropogenic influences on beach morphodynamics during seasonal monsoon. However, to achieve the objectives, it is necessary to discuss the relationship between beach morphology and hydrodynamic evolution in parallel with the monsoon environment.

7.1.1 Identification of Storm Conditions during Monsoons

On the east coast of Peninsular Malaysia, especially in Terengganu, storms occur during the northeast monsoon (Ariffin *et al*., 2016; Noraisyah *et al*., 2015; Norzilah *et al*., 2016; Rosnan and Mohd Zaini, 2009), which takes place from the end of October until the end of March each year. Over the observation period, a number of severe storms were identified with inshore significant wave heights exceeding 2 m; these events can be characterized as monsoon storms according to many studies on monsoon-dominated coasts (Mishra *et al*., 2011; Nor Hisham, 2007; Prasad *et al*., 2009; Shanas and Sanil Kumar, 2014). However, the storm depends on wind wave conditions, which are influenced by the wind force (Chiang *et al*., 2003a; Young, 1999).

The present study reveals a trend towards increasing wind force from 2005 to 2006 (Figure 7.1a), when, under favourable conditions for erosion, the study area had only a few artificial structures along the coastline. However, heavy erosion occurred between 2011 and 2012, and the lower wind force nevertheless produced a high impact on the coastline. The heavy erosion was caused by the construction of Kuala Terengganu airport with a 1-km runway extension jutting out into the sea. This influence is demonstrated by the relationship between wind speed and significant wave height, which shows a poorer correlation compared to northeast monsoons before the 2010s (Figure 7.1b).

As a solution, the authorities built a revetment on the coastline in 2012. Unfortunately, the erosion shifted to the north during the northeast monsoon of 2013 – 2014, with lower wind force associated with a weaker correlation compared to the 2014 – 2015 season (Figure 7.1). According to Koutrakis *et al*. (2011), an Environmental Impact Assessment (EIA) needs to be implemented in coastal projects to take account of community and ecological risks as well as coastal management.

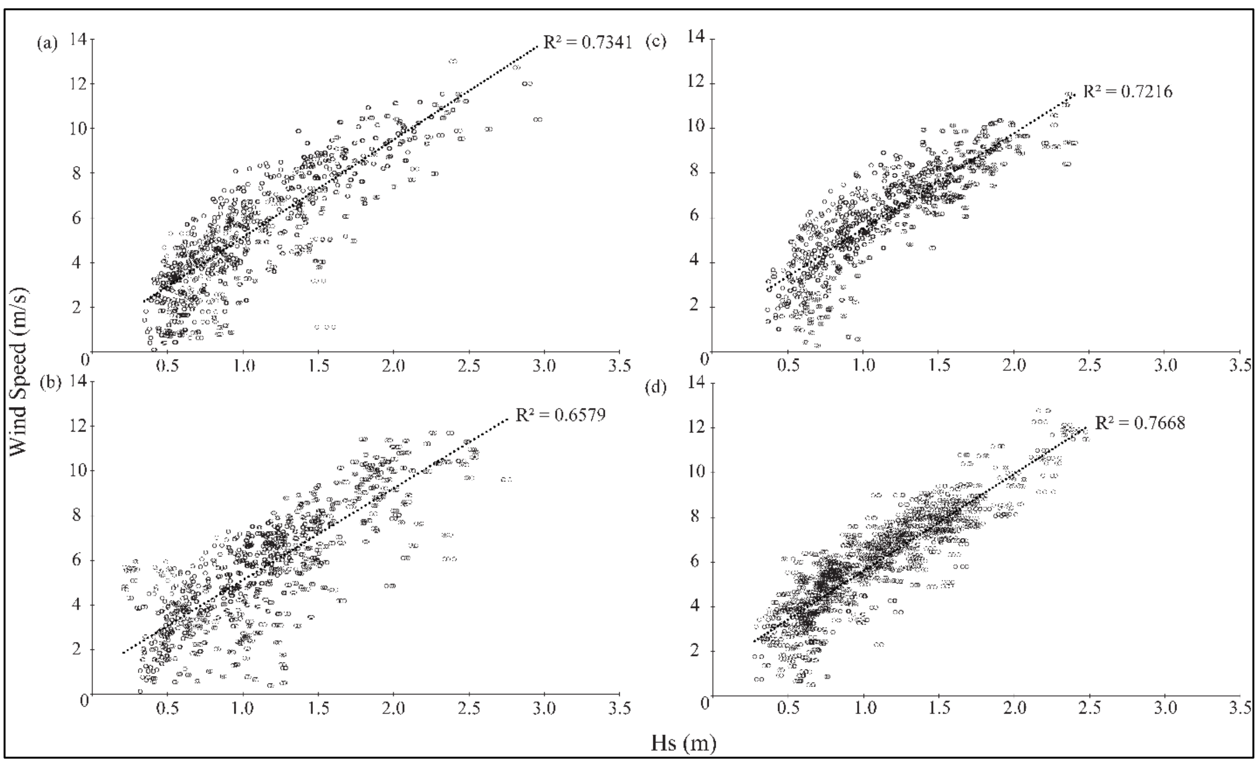

Figure 7.1: Correlation between wind speed and significant wave hight (H_s) during northeast monsoon seasons: (a) 2005 – 2006; (b) 2011 – 2012; (c) 2013 – 2014; and (d) 2013 – 2014.

However, the wave parameters recorded during the 2013 – 2014 northeast monsoon show that three storms occurred (with wave heights exceeding 2 m) in December 2013 and January 2014. During the 2014 – 2015 northeast monsoon, there were three storms with a duration of one week in December 2014. In fact, during the 2013 – 2014 northeast monsoon, there was more erosion compared to the 2014 – 2015 monsoon season.

On the other hand, no storm events can be identified from short-term observations of morphological changes in October, when the northeast monsoon is still in its early stages, whereas an extreme storm is observed in December and January of each year. Furthermore, no signs of any storm can be identified from short-term observations, while no erosion is seen in beach areas impacted by anthropogenic pressures (Aouiche *et al*., 2016; El Mrini, Maanan, *et al*., 2012; Gelfenbaum and Kaminsky, 2010; Lazarus *et al*., 2015).

7.1.2 Anthropogenic Influence on Monsoonal Morphodynamic Behaviour (Inter-site Comparison)

Differences in beach morphodynamic behaviour are revealed by an analysis of hydrodynamic (wave and current parameters), morphological and volumetric changes as well as sediment characteristics at seven beaches (divided by zone) along the Kuala Terengganu coast. As reported by many studies on the east coast of Peninsular Malaysia, the most significant changes are observed after northeast monsoon storms of high intensity and frequency (Ariffin *et al*., 2016; Mohammad Fadhli *et al*., 2014; Mohd Zaini *et al*., 2015; Muslim *et al*., 2011; Noraisyah *et al*., 2015; Rosnan and Mohd Lokman, 2005; Rosnan *et al*., 1994; Rosnan and Mohd Zaini, 2009).

However, the division into zones can be clearly discussed/justified in terms of the beach morphodynamic changes, whether the factor concerned is solely of natural origin or due to an anthropic influence. Overall, there are three zones with Zones A and B in the north separated from Zone C in the south by the Terengganu River.

Zone A

North of the Terengganu River – North of Airport: the shorelines of this area show heavy erosion, especially just north of the airport tarmac extension. However, the shorelines in the northern sector are more stable. The most significant changes are observed after the major storms during the northeast monsoon of 2011 – 2012. Construction of the airport tarmac extension in 2010 led to a parallel retreat of the shoreline as described by many studies on hard coastal structures (Elmoustapha *et al*., 2007; Stive *et al*., 2002; Vaidya *et al*., 2015).

The beach volume variations show a similar shoreline evolution, indicating a tendency to erode during the northeast monsoon. However, frequent episodes of erosion are recorded during the storms of the northeast monsoon of 2013 – 2014 compared to the 2014 – 2015 season (storm just once a week in December). The erosion episodes do not necessarily coincide with the storm events (northeast monsoon); in fact, erosion can still be observed during calmer periods (southwest monsoon: see Fig. 7.2b) especially on the UMT beaches (B3).

This sector is also characterized by the presence of many artificial and natural barriers as shown in Figures 7.1b and 7.1c. Despite the weaker correlation between wind speed and significant wave height, there is still some heavy erosion (El Mrini *et al*., 2012). Furthermore, the reduction in sediment supply is another factor evoked by Black *et al*. (2008) in their study of the Kerala coast, which shows a strong net longshore drift but an absence of significant sediment supply to other areas (closed dynamic sediment budget).

Hence, there is a complete change in the beach morphodynamic behaviour, with erosion tending to occur during the northeast monsoon (storm) as well as during the southwest monsoon (calm). As presented in many studies, the morphodynamic model shows a cycle with erosion occurring during storms and accretion/recovery during calm seasons (Ariffin *et al*., 2016; Corbella and Stretch, 2012; Prasad *et al*., 2009; Rosnan and Mohd Lokman, 2005; Suanez *et al*., 2012; Vousdoukas *et al*., 2012; Yu *et al*., 2013).

In terms of morphodynamic classification, all the beaches in Zone A have a more or less similar response to incident waves, indicating an intermediate state tending towards dissipative and reflective type during northeast and southwest monsoon, respectively, associated with spilling breakers. In this case, the storm profile (northeast monsoon) shows higher values for the dimensionless fall velocity and lower values for the surf similarity parameter, due to the increase in foreshore slope value (El Mrini *et al*., 2012; Jackson *et al*., 2005; Saravanan *et al*., 2011).

Zone B

North of the Terengganu River – South of Airport: the shorelines of this area exhibit heavy accretion, especially just south of the airport tarmac extension. However, the shorelines in the southern sector reveal slight erosion. The most significant changes are observed after the major storms of the 2011 – 2012 northeast monsoon, with two patterns of accretion in the area where the airport tarmac extension was built. These patterns show that sediment is trapped between the airport tarmac extension and the Terengganu River/ breakwater (high intensity of accretion close to Terengganu River/Breakwater). The sediments are increasingly trapped close to the airport tarmac extension during the northeast monsoon of 2013 – 2014.

As presented in previous studies, the longshore drift on the northern sector of the Kuala Terengganu coast is towards the north (Mohd Lokman *et al*., 1998; Rosnan and Mohd Lokman, 2005; Rosnan *et al*., 1994). Hence, many studies show that hard coastal structures (jutting out into the sea) lead to sediment trapping by blocking the longshore drift (Kudale, 2010; Mohanty *et al*., 2012; Patsch and Griggs, 2008; Vaidya *et al*., 2015).

The beach volume variations show a similar shoreline evolution, indicating a tendency for accretion to occur during northeast monsoons on Teluk Ketapang beach. Hence, the beach morphodynamic changes indicate a net trend towards accretion during the northeast monsoon (storm) and erosion during the southwest monsoon (calm periods) (Figure 7.2). By contrast, on Seberang Takir beach, the morphodynamic changes shows natural processes of erosion and accretion during northeast and southwest monsoons, respectively (Ariffin *et al*., 2016; Rosnan and Mohd Lokman, 2005).

In fact, Teluk Ketapang beach is protected from NE waves by the airport tarmac extension and is exposed to ESE waves, while the Seberang Takir beach is partially sheltered from ESE waves by the breakwater at Terengganu River and exposed to NE waves. A similar situation is also reported by El Mrini *et al*. (2012) in Morocco: two beaches are sheltered by two headlands, (coastal landforms) as shown by the beaches at Cabo Negro (north), which are exposed to ENE waves, and Sidi Abdeslam (south), which are sheltered from waves coming from the ESE.

In terms of morphodynamic classification, all the beaches in Zone B have a more or less similar response to incident waves, indicating an intermediate state tending towards dissipative and reflective type during northeast and southwest monsoons, respectively, with spilling breakers on Teluk Ketapang beach and plunging breakers on Seberang Takir beach. In this case, the storm profile (Northeast Monsoon) shows higher values for the dimensionless fall velocity and the surf similarity parameter, due to the decrease in foreshore slope (Seberang Takir beach: increase in foreshore slope).

Zone C

South of the Terengganu River: the shorelines are quite stable in this area where there is minimal urban development. However, dynamic processes are observed near coastal landforms and artificial structures. The beach volume variation shows a similar shoreline evolution with erosion observed at coastal structures such as revetments (Kuala Ibai beach) and breakwaters (Marang beach). Nonetheless, a natural beach morphodynamic model is applicable in this area (Figure 7.2).

On the other hand, in terms of morphodynamic classification, there is more or less similar response to incident waves. However, the beach classification is the opposite compared to Zone A and B, indicating an intermediate state tending towards reflective and dissipative type during the northeast and southwest monsoons, respectively, associated with plunging breakers. In this case, the storm profile (northeast monsoon) shows lower values for the dimensionless fall velocity and higher values for the surf similarity parameter, due to the increase in foreshore slope.

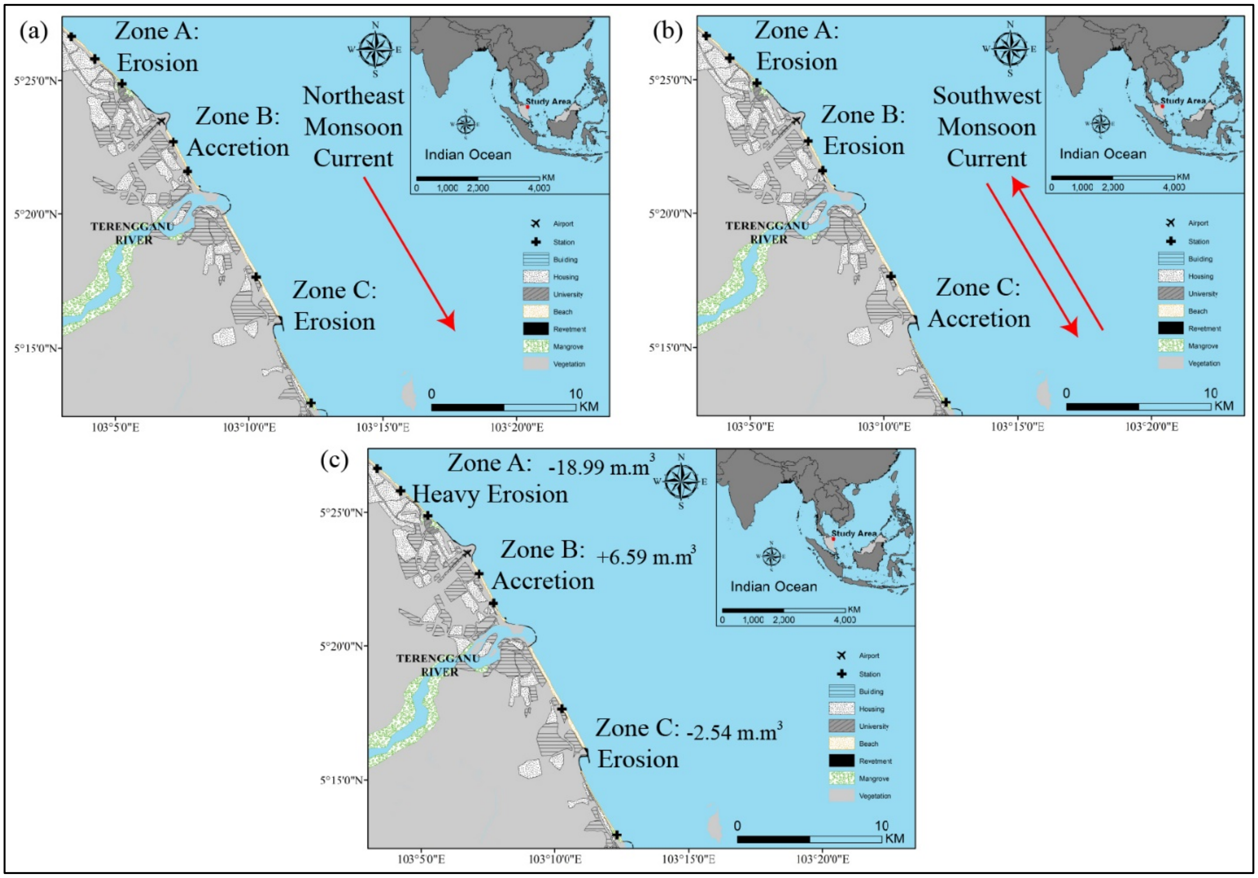

Figure 7.2: Morphodynamic model for the Kuala Terengganu coast during (a) northeast monsoon, (b) southwest monsoon and (c) two years of beach morphodynamic changes (beach volume).

CHAPTER EIGHT: CONCLUSION AND RECOMMENDATION

Contents:

8.1 Summary of Main Findings

This chapter summarizes the main findings in fulfilment of the initial research objectives set out in Chapter 1. The effectiveness of the research process is based on estimating shoreline evolution by aerial photography followed by mid-term (monthly) and short-term (daily) monitoring of morphodynamics on the Kuala Terengganu coast. The results are corroborated with physical simulations (modelling) to improve our understanding of the physical processes linked to monsoon storm events. Each main chapter (Chapters 4 to 6) summarizes the changes in beach morphology on the Kuala Terengganu coast. Furthermore, Chapter 7 focuses on Zones A and B in the study area, giving a description of the interactions in this sector affected by dynamic processes (Zone C is considered as a normal environment). Zones A and B are located to the north and to the south of the airport tarmac extension (on the northern part of the Kuala Terengganu coastline). However, the short-term observations presented in Chapter 6 as regards Zone A and Zone C are discussed in Chapter 7 because of the distribution of selected beach areas.

i) Identifying historical coastline changes and associated processes

The historical coastline changes (shoreline evolution) are investigated in Chapter 4 through the comparison of aerial photographs taken between 2006 – 2012 and 2012 – 2014.

However, this chapter presents the shoreline evolution in relation to seasonal monsoons before and after the airport tarmac extension was constructed. The interactions of beach morphodynamics with anthropogenic influence occur in two phases i.e.: i) after construction of the airport tarmac extension in 2010 and ii) following installation of coastal defences after the heavy erosion observed in 2012.

The results show that beach areas to the north (Zone A) and to the south (Zone B) of the airport tarmac extension tend to exhibit heavy erosion and accretion, respectively. Erosion is observed in the northern sector from 2006 – 2012, and the amount of landward retreat reaches a maximum of – 15.84 m. However, from 2012 – 2014, the landward retreat increases to a maximum of – 46.50 m. On the other hand, the area south of the airport tarmac extension exhibits heavy accretion with a maximum of 21.32 m and 26.48 m for 2006 – 2012 and 2012 – 2014, respectively. Throughout these years, the hydrodynamic regime was higher in Zone A and lower in Zone B.

As we know, the erosion problem started after the airport tarmac extension was constructed in 2010. Because of this, coastal defences were constructed along the coastline (northern beach areas). Subsequently, coastal defence structures such as revetment have succeeded in slowing down erosion in the southern sector (Zone B), but it appears to continue in the north (Zone A).

ii) Identifying and quantifying coastal processes occurring during seasonal monsoons and their impact on beach dynamics

The pattern of beach morphology changes on the Kuala Terengganu coast shows erosion during the stormy northeast monsoon and accretion or recovery during the calm period of the southwest monsoon. However, as discussed in Chapter 5, this pattern has been disturbed by the airport tarmac extension that has also modified the hydrodynamic regime in this area. Hence, while a normal pattern of morphological change is seen in Zone A, accretion and erosion occur in Zone B during the northeast and southwest monsoons, respectively.

The cumulative changes in beach volume to the north (Zone A) of the airport tarmac extension indicate heavy erosion (collapse of beach at B3 station in September 2014) which decreases northward. However, the opposite case is observed to the south (Zone B) of the airport tarmac extension, where there is heavy accretion which decreases in intensity southward. It can also be concluded that the severe wave conditions have a major effect on the beach morphology changes in Zone A compared to Zone B; where the wave conditions are of medium and low intensity. Finally, the beach morphodynamics on the Kuala Terengganu coast show an increase in beach state during the northeast monsoon and a decrease during the southwest monsoon.

iii) Identifying short-term beach morphodynamic changes in relation to the two monsoon seasons

In Chapter 6, the beach areas are selected for detailed study based on the presence of coastal defence structures. The Pengkalan Maras and Kuala Ibai beaches (with revetments on the berm) were selected in Zone A and Zone C, respectively. The onsets of the northeast and southwest monsoons are selected to identify any storms occurring during the survey periods. There is no sign of storms (affecting the pattern of beach morphology changes) during the survey periods covering both monsoon seasons. However, differences can still be observed in the seasonal pattern of beach morphology changes across the selected study area.

As shown in the results, at the onset of the northeast monsoon (October 2014), the Pengkalan Maras beach shows accretion and recovery from the previous southwest monsoon (May – September 2014). However, a different situation is observed at Kuala Ibai beach where only Transect 4 shows accretion, since this beach area is protected by a revetment and the other transects tend to show erosion. However, during the southwest monsoon (May 2015), the Pengkalan Maras beach shows slight accretion and records an impact from previous conditions developed during the northeast monsoon (October 2014 – March 2015). On the other hand, over the same period, the Kuala Ibai beach profile continues to exhibit erosion.

The erosion at Kuala Ibai beach could be due to the fact that the beach morphodynamics has been modified, especially in terms of beach slope. The hydrodynamic regime at Kuala Ibai beach was modified by the presence of a revetment, with significantly higher wave heights compared to Pengkalan Maras beach during the southwest monsoon (calm conditions).

8.2 Final Conclusion

A variety of methods are used to examine the coastline evolution (coastline history) and beach morphodynamics along the Kuala Terengganu coast. The results from each method combined together allow us to identify the driving factors of coastline evolution. An examination of the natural and anthropogenic beach profiles shows that the main factors controlling changes of beach morphology are hydrodynamic parameters and sediment supply. Therefore, the construction of the airport tarmac extension totally changed the hydrodynamic parameters in parallel with the seasonal monsoon environments. In this way, the airport tarmac extension jutting 1 km out into the sea blocked the sediment supply coming from the south.

Although a series of coastal defence structures have been implemented, these structures are found to be ineffective for reducing erosion (the erosion has shifted to other areas). However, it is clear that there is a need of management strategy involving a good understanding and an integrated view of beaches and coastal dynamics, as well as defence strategies covering not only the beaches but also the dunes (berm) and the nearshore zone. It is proposed here that sand by passing Teluk Ketapang beach, where heavy accretion has occurred, could provide sediment input to areas subject to erosion in the sector north of the airport tarmac extension. Finally, the results and conclusions presented in this thesis are used in an attempt to address the objectives set out in Chapter 1.

8.3 Recommendations for Future Research

This thesis provides results which allow us to explore the shoreline evolution and beach morphodynamics along the Kuala Terengganu coast. Since there has been relatively little previous research on beach morphodynamics in this region, the present study contributes to a better understanding of the beach morphology and processes involved on the East Coast of Peninsular Malaysia. Future research regarding beach morphodynamics would provide valuable information for academic purposes and could have important implications for coastal management. However, it is strongly recommended that further research should be conducted to extend the present study in the following ways:

i. To study sediment transport in order to identify the processes of sediment transport and supply from the terrestrial and marine environment to the coastline.

ii. To investigate the rehabilitation or protection of dunes using nature-based methods such as Algo-Box, to improve our understanding of beach classification and hydrodynamic factors.

iii. To study the *in-situ* physical parameters (waves, currents and tide), which may help to establish better correlations between physical parameters and beach profile changes.

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Publication List

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Ariffin, E.H.; Sedrati, M.; Mathew, M.J; Akhir, M.F.; Awang, N.A; Yaacob, R.; and Husain, M.L. (2017). Coastal Erosion through Integrated Management: A Case of Terengganu Coast of Malaysia. In Ramkumar *et al*. (Ed.), *Coastal Zone Management: Global Perspectives, Regional Processes, Local Issues*. Amsterdam: Elsevier. (Accepted)

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