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THE EFFECT OF COASTAL PROTECTIONS ON THE SHORELINE EVOLUTION AT KUALA NERUS, TERENGGANU (MALAYSIA)

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Abstract: Coastal erosion is among the major threats for coastal dwellers, where the hard structure has been favourably applied to protect the shore. Applying coastal protection structures require adequate knowledge of local beach dynamics. This research attempts to quantify the impact of the structures toward shoreline and current pattern changes in Kuala Nerus, Terengganu. In 2016, coastal protection structures were built on the beach of Kuala Nerus, after a series of erosion events. Two timelines of coastal protection structure were chosen, the 2004-2016 (pre-construction) and 2016-2017 (post-construction). Combined images from Google Earth and Unmanned Aerial Vehicle (UAV) were used and measured using Digital Shoreline Analysis System (DSAS) to quantify the shoreline changes through statistical analysis of End Point Rate (EPR) and Net Shoreline Movement (NSM) on the multi-year shoreline layers. Numerical model of current movements has been made using MIKE 21 software to determine post-construction current changes. The result showed that most of the eroded shore during pre-construction has recovered with post-construction of the structure. However, some parts of the shore were eroded due to current circulation- altering structure. The findings of this study are significant in assisting the planning of effective coastal protection structures especially in monsoon dominated coast.

Keywords: Coastal structures, DSAS, coastal erosion, Google Earths, UAV.

Introduction

Shoreline is a line where a shore and a large body of water interfere, like an ocean, lake or rivers (Misra & Balaji, 2015; Selamat *et al*., 2019). Globally, it is an area of high interest with rich resources especially in the coastal area, where within 100 km of the shoreline the population density is higher compared to other living area (Small & Nicholls, 2003). The ever growing population in coastal areas stimulates the requirement for knowledge on shoreline changes which has become more than a topic of scientific interest (Moore, 2000).

Any disturbance on coastal dynamic either by means of anthropogenic activity or natural event will eventually change the shape of the shoreline over time through erosion or accretion processes (Prasad & Kumar, 2014). Coastal erosion is a worldwide phenomenon occurring around the globe and affecting the livelihood of coastal community. This causes many coastal countries to initiate coastal protection structure with the objective to stop, alter, or minimize the waves or currents energy going onshore (Fulton-Bennet & Griggs, 1986). Any structures constructed on a shore will eventually reshape the shoreline whether it is a coastal protection structure or non-protection structure (Vaidya *et al*., 2015).

Studies on the influence of coastal protection structures are vital to determine whether the structures show positive or negative impacts towards the coastal dynamics. The coastal protection structures include the groyne, breakwater and revetment, built purposely to protect the shoreline. A groyne (Figure 1 (a)) is a structure built from the coastal shore or river

Figure 1: a) the groyne structure of Mengabang Telipot; b) The breakwater of Tok Jembal.

bank that interrupts the flow of water and limits the movement of sediment.

A groyne was built with various designs and projections which produce mixed results based on the physical-affecting factors in an area as studied by Özölçer and Kömürcü (2006). Apart from that, breakwaters can also cause setback by introducing or worsening an erosion issue (Balaji *et al*., 2017). Usually, a breakwater was built in front (offshore) of an affected shoreline to mitigate the issue as seen in Figure 1 (b). However, studies on erosion caused by these coastal protection structures have not been well documented (Balaji *et al*., 2017). A few earlier studies on coastal defence structure in Malaysia was conducted at Carey Island, Malaysia where it was found that there have been changes in sea bed volume in the vicinity of low-crested breakwater (Fitri *et al., 2015*). There is also a study on breakwater design by using physical model of breakwater in Kuantan (Geng & Zhang, 2012) and submerged breakwater tested in laboratory experiments (Desa *et al*., 2016a; 2016b). Another documented study relating to coastal protection structure around Malaysia is concerning mangrove rehabilitation (Hashim *et al*., 2010; Stanley & Lewis, 2011).

Although studies on the multiple coastal protection structure in Kuala Nerus are few, several studies were carried out on the after-effects of the construction of Sultan Mahmud Airport runway on the morphology changes in Kuala Nerus by Muslim *et al*. (2011) and Ariffin *et al*. (2016). Both studies found that erosions occurred in the northern part of the runway, where coastal protection structures were pursuantly constructed in 2016. Henceforth, a precise monitoring of shoreline delineation is vitally needed which requires multi-year shoreline maps for coastal monitoring and assessment in Kuala Nerus region using image satellite and aerial photograph as the input data. (Muslim *et al*., 2007; 2011).

A few hindrances persist whereby satellite imagery data can be very expensive and sometimes it is almost impossible to get the imagery data due to safety reasons (Malarvizhi *et al*., 2015). Free satellite images from the United States Geological Survey (USGS) or Global Landcover Facility (GLCF) contain sufficient spectral information but it comes with certain limitations, where the images' spatial resolutions are at low or medium.

An alternative source for imagery products is from the Google Earth (GE) or Unmanned Aerial Vehicle (UAV) device, which provides feeless high resolution imagery data. The high spatial resolution images from GE makes it possible to visually see the images, buildings, boats, etc. which shows that the GE is suitable for regional land use/cover mapping (Malarvizhi *et al*., 2015; Hu *et al*., 2013). The drawback of GE images is that it can only provide a low multispectral band data of spectral information which is only useful for image classification. Nonetheless, the decision to use GE images in this study is based on the finding of Mohammed *et al*. (2013) whereby the horizontal accuracy of GE can be precise up to 1.80 m despite its spatial variation. Another alternative for satellite imagery is the UAV, such as the Mavic Pro to capture aerial images that provide fine spatial resolution. The Mavic Pro is categorized as micro UAV as termed by the Unmanned

Vehicle System (UVS) international categories (Eisenbeiss, 2004). Therefore, the imagery products from the combination of GE and UAV can produce a reliable map with fine spatial resolution.

Following, the numerical simulation software, MIKE 21 from Danish Hydraulic Institute (DHI) was used to assess the direction and velocity of current encircling the coastal protection structure. This study intends to complement the study by enhancing the correlation between current movement and the rate of erosion within the study area by using numerical simulation software. Hence, the aim of this study is to chart the alteration of shoreline evolution due to construction of the coastal defense protection structure at Kuala Nerus.

Study Area

Located by the shore, Kuala Nerus experiences economical boost, mainly due to the increasing tourism activities. This has led to urbanization activities such as the expansion of the Sultan Mahmud airport runway and followed by the coastal protection structure.

The study area, as depicted in Figure 2, extends from the northern part of Sultan Mahmud Airport runway to Mengabang Telipot for approximately 4 kilometres. The geographical coordinates extend from 600088.72 mN to 596653.13 mN and 287914.55 mE to 289766.78 mE. It includes the Tok Jembal, Universiti Malaysia Terengganu (UMT) and Mengabang Telipot beaches, as shown in Figure 2 (a).

As illustrated in Figure 2 (b), Terengganu experiences the monsoons every year with wind prevail from the southwesterly (southwest monsoon) and northeasterly (Northeast monsoon) which occurs during late May to September and November to March, respectively (Ariffin *et al*., 2016). The monsoons constitute strong wind waves that play an important role in sediment transport of the East Coast of Peninsular Malaysia (Philips, 1985). According to Ariffin *et al.* (2016) and Mirzaei *et al*. (2013), significant wave heights (H_s) of this region range from 1.0 to 2.0 m during the NEM while less than 0.8 m during the SWM. This region experiences micro to meso-tidal and semi-diurnal, with a Mean High Water Spring (MHWS) of 3.28 m and Mean Low Water Spring (MLWS) of 1.12 m (Ariffin *et al*., 2018a).

According to Mohd Radzi *et al*., (2014), the current velocities are higher towards the north of Sultan Mahmud Airport runway during the

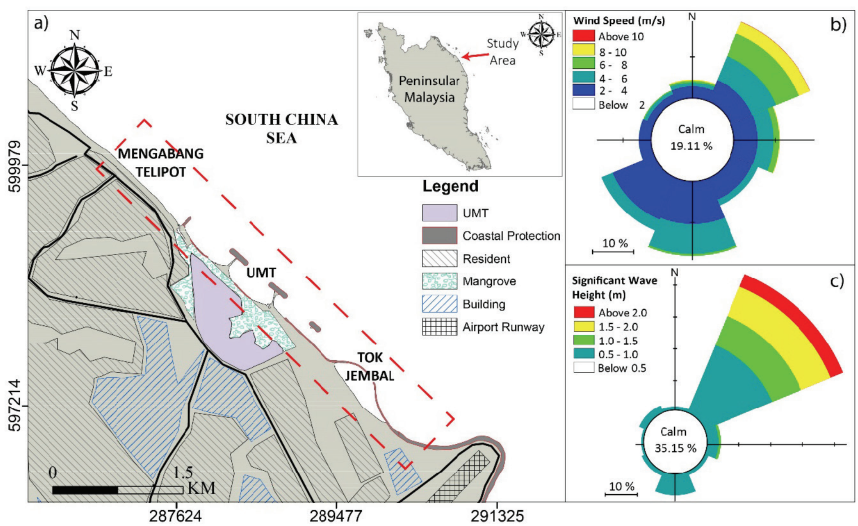

Figure 2 : The description of study area; a) the focus area extends from Tok Jembal until Mengabang Telipot; b) wind rose and; c) wave rose.

pre-northeast monsoon season with the average speed more than 0.3 m/s which is sufficient to move sand, consequently causing erosion in the northern area. In 2014, a heavy storm occurred during the northeast monsoon resulting in the largest significant wave height (Hs) of ±1.5 m in that year (Ariffin *et al*., 2016). The event caused heavy erosion in the study area.

An erosion problem occurred since 2010 which worsened during in 2014-2016. Hence, in 2016, the government mandated the Department of Irrigation and Drainage to mitigate the erosion problem. As shown in Figure 3 (a), there were no structures built on the shoreline in 2004, whereas Figure 3 (b) shows that three types of coastal structures have been built, namely, the revetments, breakwaters and groyne.

Methodology

Data Collection and Processing

Five timelines were used in this study using images from two sources which are Google Earth (GE) and aerial photograph using the DJI Mavic Pro, a type of Unmanned Aerial Vehicle (UAV). The list of selected years and their image sources are shown in Table 1.

Table 1: List of timelines and the sources

Timeline	Source
2004	GE
2013	GE
2015	GE
2016	GE + UAV
2017	GE + UAV

The 2004 timeline is the period where no constructions were made on the shore of Kuala Nerus, and natural process such as waves and currents are the only elements affecting the shore. The first human-made coastal structure was the extension of the Sultan Mahmud Airport in 2008, which is within the selected 2013 post-construction timeline. The 2015 timeline selected is the year prior to the construction of coastal protection structure. The 2004, 2013, 2015 and 2016 timelines were used to assess the shoreline evolution during pre-construction while the 2016 and 2017 shorelines were used to assess the evolution during post-construction. All images used sources from GE, with the addition of UAV images for 2016 and 2017 as the UAV images on the study area were collected since 2016.

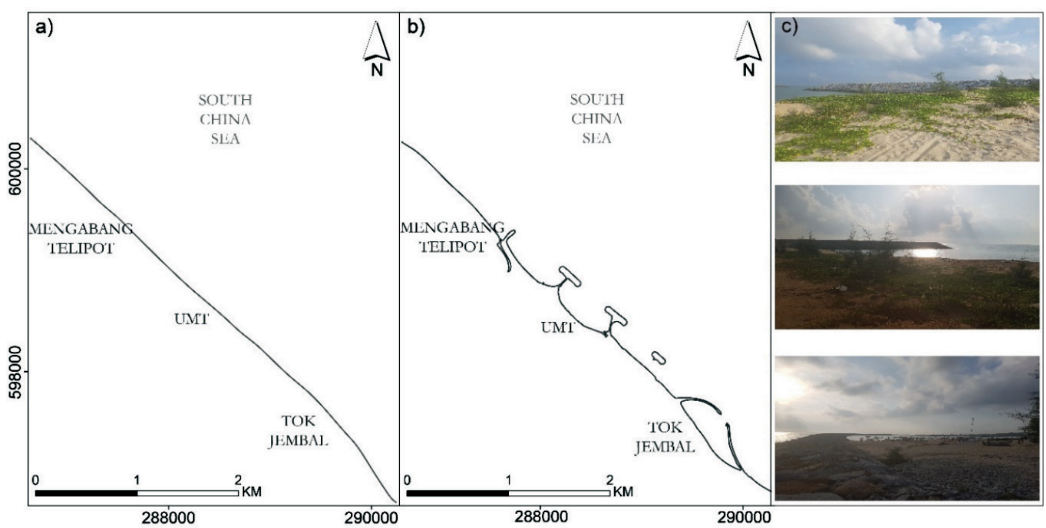

Figure 3 : Kuala Nerus beach; a) Shoreline of 2004; b) Shoreline of 2017 with the presence of breakwaters and groyne; c) Vegetation cover over the shoreline and tombolo of breakwater

About 4,500 images had been captured by using the Mavic Pro at the height of 160 m for the duration of 10-15 minutes of flight times totalling 13 flight area points. The GPS/GLONASS satellite positioning system equipped on the Mavic Pro enabled the projection information to be stored on each picture (DJI, 2018). The sharp Mavic Pro camera with sensor resolution of 12.71M is adequate in acquiring fine image resolution.

Shoreline Digitizing

Figure 4 shows the flow chart of shoreline digitizing process from both UAV and GE images.

These images were combined and overlapped through mosaic technique using Photoscan from Agisoft LLC (Mancini *et at*., 2013). After the mosaic and georeferencing processes were performed on the image, the digitizing process was replicated for each timeline. This study required a digital images or vector image for the statistical measurement by DSAS to estimate the rate of changes on Kuala Nerus shoreline. ArcGis 10.3 was used to digitize the raster images of shoreline into vector format of shape file data.

Previously, various proxies were used by researchers to estimate the shoreline position in satellite and aerial images (Kankara *et al*., 2015). The variety of estimation include the use of vegetation line (Hoeke *et al*., 2001), line of high tide (Stockdon *et al*., 2002; Fisher and Overton, 1994), wet-dry line (Overton *et al*., 1999), line of dune (Stafford and Langfelder, 1971), cliff base or top (Moore *et al*., 1998), toe or berm of the beach (Norcross *et al*., 2002), line of mean high water (MHW) (Galgano & Leatherman, 1991) and line of high water (Fenster & Dolan, 1999).

In this study, it was not possible to reconstruct tidal conditions at the moment the image products were taken. It was assumed that the daily water line delineation was subjected to a maximum uncertainty of 3 m, taking into account the highest of the intertidal range of Kuala Nerus beach. The images were digitized based on the visible high water line (HWL) and vegetation cover along the shore, as shown in Figure 3. Since there was no evidence of storm events in any of the images used, the wave height effects were neglected.

Digital Shoreline Analysis System (DSAS)

Digital Shoreline Analysis System (DSAS) was used as a medium to calculate the rate of the delineation changes of shoreline from 2004 until 2016 (2004-2016 model) and the changes between 2016 and 2017 (2016-2017 model). The extracted shorelines from GE and Mavic Pro were divided into 273 transects, as shown in Figure 4, that were oriented perpendicular

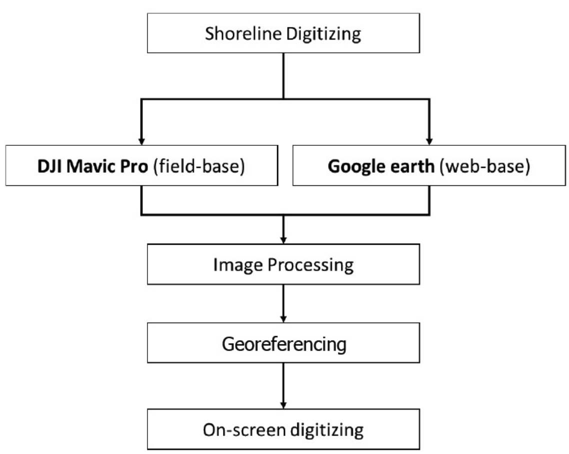

Figure 4: Extracting shoreline by using on-screen digitizing

to the baseline with 20 m interval and 4 km length along the study area. In DSAS system, a baseline is needed to monitor the amount of shoreline changes on each transect. The baseline used the 2004 shoreline as reference with 170 m of width and 4 km of length. The baseline will be the reference line for each transect, where seaward shift of shoreline is considered as accretion, while landward shift is considered as erosion.

Two statistical parameter values were used to measure the shoreline delineation over time. The End Point Rate (EPR) was calculated by dividing the distance of shoreline delineation by the time elapsed between the latest and oldest shoreline at each transect line. The Net Shore Movement (NSM) is a report that measures the distance between the farthest and closest shoreline to the baseline of each transect (Thieler *et al*., 2009). The rate change statistics for each transect is expressed in metres and presented according to the guidelines from the Department of Irrigation and Drainage (DID). As shown in Table 2, the rates were divided into three categories; low erosion (below than 0.99 m/year), medium erosion (1 to 3.99 m/year) and high erosion (more than 4.00 m/year) (DID, 2015).

Current Speed Pattern

Mike 21 by Danish Hydraulic Institute (DHI) model was used for simulation of the current speed. Flow Model HD FM was used in this study. The purpose of this assessment was to assess the capability of the coastal protection in reducing the current speed, hence, reduce the coastal erosion threat. Two models based on 2014 and 2017 shorelines were used to differentiate the projection and velocity of current induced by existence and absence of coastal protection structure.

Model calibration was performed as a step to tune the model to an acceptable tolerance result by using water surface elevations parameter in this study. The calibration was done by using the value suggested by the DHI (2014).

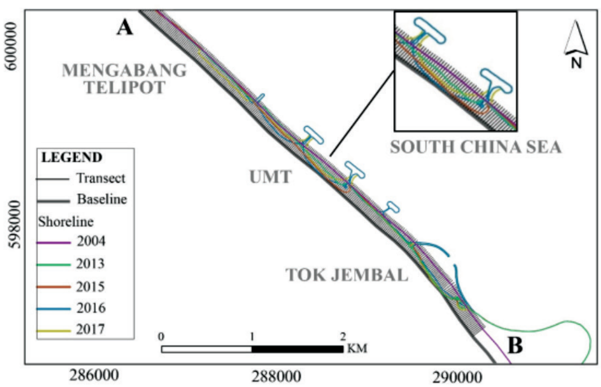

Figure 5: Transects line orientation layering on top of multiple shoreline years

Table 2: Physical parameter for coastline erosion rate

Parameter	Description	Erosion Rate (m/year)
Rate of shoreline retreat	Low erosion	≤ 0.99
	Medium erosion	1.00 to 3.99
	High erosion	≥ 4.00

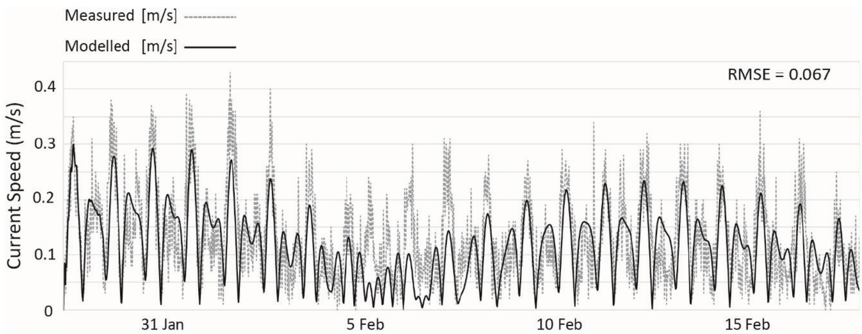

Figure 6: Comparison between modelled and measured current speed with RMSE value

Afterward, the root mean square error (RMSE) and bias value between measured current speed from a current profiler and simulated output value were calculated and compared in Figure 6. The validation period is from 29th January until 15th February of 2014. The bias value was -0.014 m/s and RMSE value of 0.067. The bias value was underestimated throughout the time series though, the trend fixed soundly with the measured current speed. Based on previous literature in the study area, with 0.29 (Latiff, 2014) and 0.15 (Daud & Akhir, 2015) of RMSE values, these provide adequate references for current study's value. Thus, this validated the model setting and simulation for further analysis.

Results

Rate of Shoreline Delineation

Through DSAS measurement, the EPR and NSM were used as statistical measure to identify the rate of the delineation changes over time. Overall, based on Figure 7 (upper), Kuala Nerus shoreline maximum retreat was -11 m/year and -150m of net shoreline changes for the period between 2004 and 2016, while the accretion occured less than +5 m/year with net accretion of +94 m/year.

The analysis of the result is discussed in the following paragraphs according to geographical aspect; Tok Jembal, UMT and Mengabang Telipot beaches. The second transect which projected the shoreline from 2016 to 2017 was carried out to measure the changes between these years as there was an advancing in shoreline delineation, which may be influenced by beach nourishment works in the area.

Tok Jembal: Pre-construction; the highest erosion rate was recorded within/on this beach especially in the bay area with approximately -10 m/year and net of -150 m eroded from 2004 until 2016. The only accretion is within the Tok Jembal southernmost beach with accretion less than +5 m/year net. Post-construction; mixed results were recorded within the bay of semi enclosed groyne (jetty groyne) at Tok Jembal. Erosion occurred in the middle of the bay with -40 m movement directly facing the opening between the two groynes although some accretion occurs within the bay. The accretion rate was up to 20 m a year within this area.

UMT: During pre-construction; the highest accretion rate is less than +5 m/year, where the accretion was seen on the formation of tombolo that naturally formed behind the face of breakwaters. This can be seen in the front of the UMT beach. Although there were formations of tombolo behind the breakwater, the UMT beach was showing significant erosion rate of -8 m/year and -110 m of net movement of shoreline. During post-construction; the shore of UMT showed positive result, marked with the green line indicating positive value showing accretion event recorded at more than 20 m in one year. The statistical measurement by DSAS shows that the UMT shore was gaining an accretion up to +80m over one year of movement.

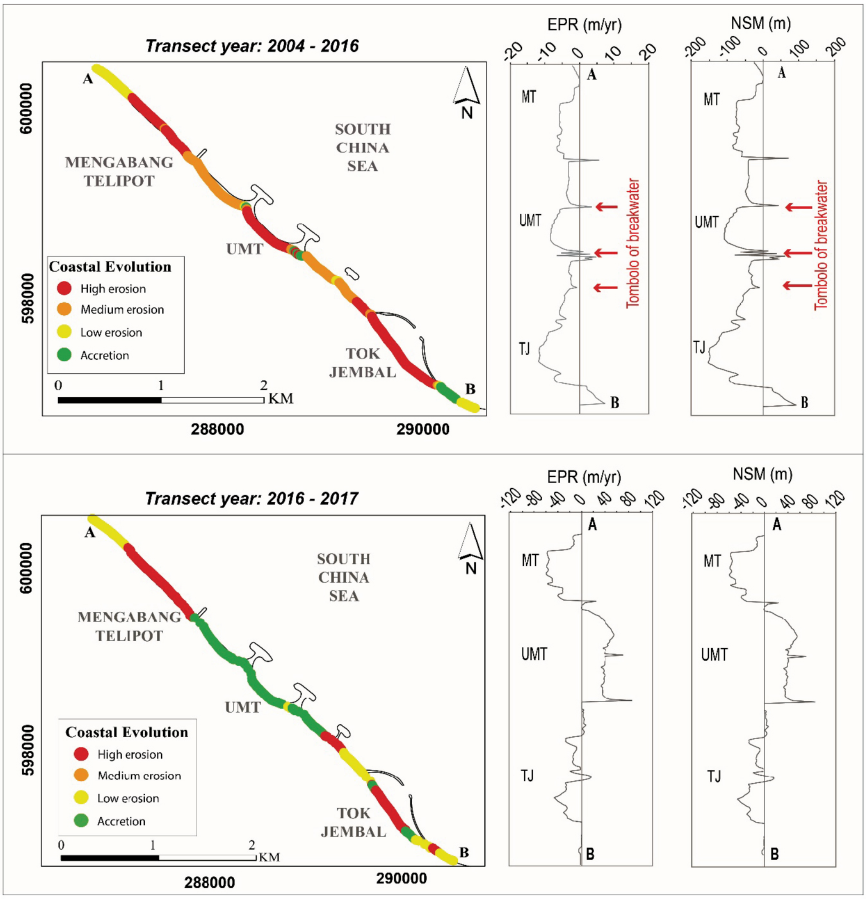

Figure 7: Upper column shows shoreline changes rate between 2004 until 2017 (pre-construction) while lower column shows the rate of shoreline changes between 2016 and 2017 (post-construction)

Mengabang Telipot: Pre-construction; the erosion rate at Mengabang Telipot shore was -6 m/year and -80m of net shoreline movement and wider area eroded as there were no coastal protection structures until recently. On transect 2: the shore retreated at the rate of -50m over a year timeline. Based on the transect pattern, the northern area was having a high erosion rate ranging between -20 m/year to -40 m/year in one year.

Overall, most of the eroded areas were gaining positive result with accretion taking place from 2016 until 2017. It may be caused by the coastal protection structure being constructed in 2016.

Current Speed

Figure 8 illustrates the current moving northward with the speed ranging from 0.06 m/s to 0.20 m/s in 2014 when the coastal protection structure was still not built. The shore is perceived to receive stronger current movement during the period as compared to 2017 where the coastal protection structure was in place. The shoreline received less impact in 2017 since the incoming current had been slowed down and altered by the coastal protection structure, especially at Tok Jembal and UMT beaches. A current recirculation can be seen in the lee of the coastal protection structure. The recirculation is observable on the left side of the breakwater in front of UMT's beach with current speed below 0.02 m/s.

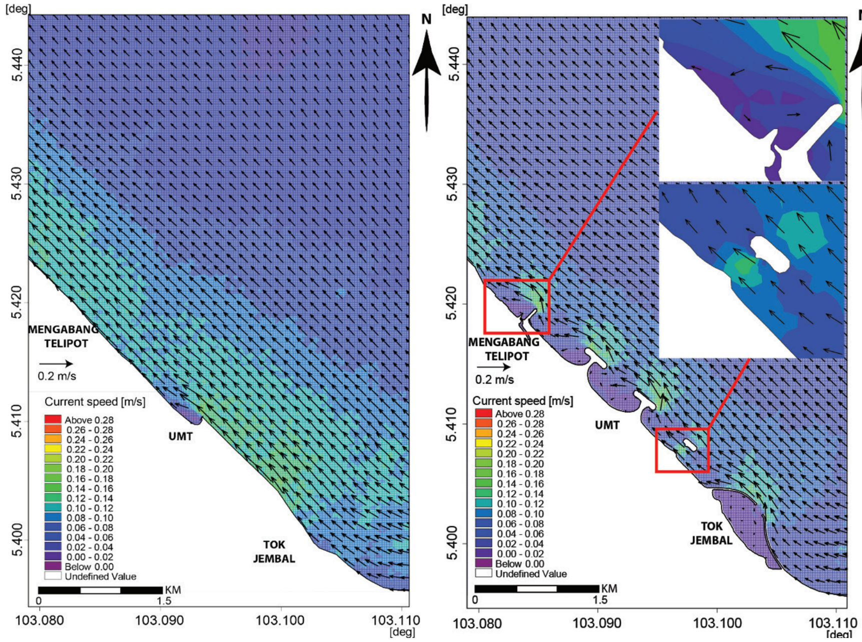

Figure 8: Current Speed during 2014 (left) and 2017 (right)

Although the current might have slowed down in most area, some area still received high current speed as shown in Figure 8 (right) with two areas experienced strong movement. Although there was no recirculation observed, the current passing through the curved groyne of Tok Jembal directly hit the near shore area, causing the disappearance of tombolo features behind the southernmost breakwater. As for the groyne of Mengabang Telipot, the current deflected caused recirculation on the shore side.

Discussion

The trend of shoreline movements at Kuala Nerus has changed since the construction of the airport runway in 2008 (Muslim *et al*. 2011; Ariffin *et al*. 2016). Since then, Kuala Nerus beach faced a continuous shoreline retreat before the mitigation measures were taken by the authority by constructing the coastal protection structures along the affected area.

Normally, the beaches of Terengganu will face erosion issues annually before recuperation process took place, returning the shore to its initial delineation. However, the study by Ariffin *et al*. (2016) found that the shore of the Kuala Nerus is not in an equilibrium state. This may be due to developed beach could not recover from post-storm conditions as quickly as an undeveloped beach (Hill, 2004; Quartel *et al*., 20018). In 2016, the proposed protection structures were constructed to combat erosion issues and currently there is no available local update concerning the changes caused by these structures to the beach morphology. Hence, this study intends to assess the impacts made by coastal protection structure on shoreline by using DSAS and current speed model.

Digital Shoreline Analysis System

The statistical result reveals that the Kuala Nerus shoreline delineation has drastically changed from 2004 to 2016. An erosion event had taken place along the shore of Kuala Nerus, especially on UMT and Tok Jembal beaches. This event is related to the action of wave and current circulation in the vicinity of the protection structures with the influence of seasonal monsoon.

However, since 2017, the erosion has slowed down and accretion seems to occur indicating positive result especially for coastal community around UMT and Tok Jembal beaches. This shows positive gain of coastal protection structure in this area, although the beach nourishment work in UMT beach might also be an influencing factor. The southernmost beach of UMT is the only beach to be eroded despite being already protected with revetment, which means the shoreline movement will be halted in this area, if the revetment endures for the possible incoming threats toward them such as storms. The north part of Mengabang Telipot beach and Tok Jembal are the areas that have significantly experienced high erosion rate. The high erosion rate at both sites is related to the current movement within this area.

Current Speed

The Terengganu current movement is influenced by monsoonal wind system (Dale, 1956; Wyrtki, 1961; Akhir & Yong, 2011; Kok *et al*., 2015). Annually, the east coast of Peninsular Malaysia (ECPM) wind prevail from northeasterly during Northeast monsoon (NEM) and southwesterly during Southwest monsoon (SWM). Meanwhile, the current moves northward during NEM and Southward during SWM depending on the intensity of prevailed wind (Daud *et al*., 2016). The periodic tide also plays an important role in driving the current movement on EPCM as stated by Saadon and Camerlongo (1997).

As the current moves northward as predicted in the simulated model, the different colour tone indicates the current speed dynamic. The current movement is compared to two situations; the pre- and post-construction of the coastal protection structure. The comparison was done to examine the effects of protection structure on the shoreline evolution.

Pre-construction (2004-2014): during this period, heavy erosion occurred at Kuala Nerus beach (Ariffin *et al.,* 2018b). The direct impact received from the incoming current movement initiated the heavy erosion, resulting in loss of UMT research station situated on the beach as well as the natural view of sandy beach.

Post-construction (2017): The constructed structure seems to reduce the intensity of incoming current. However, the structures also caused the formation of recirculation current, which led to the formation of rip current which has the possiblity of driving sediment transport beyond the surf zone (Pattiaratchi *et al*., 2009; Scott *et al*., 2016), which in turn, limits the sediment supply to the shore. On north part of Mengabang Telipot the presence of recirculation current in the lee of the groyne might explain the heavy erosion in the area. Another re-circulation current is seen inside the jetty groyne with clockwise circulation representing an embayed circular rips current (Castelle *et al*., 2016). The embayed-circular rips formed in an embayed beaches is associated with shore erosion, especially with occurrence of storm event (Loureiro *et al*., 2011). As shown in Figure 9, despite having revetment structure, the shore

Figure 9: The jetty groyne of Tok Jembal facing shore erosion despite having revetment protection

Figure 10: Revetment on the shore of Tok Jembal, with offshore breakwater on the middle of water

had been eroded due to the re-circulation current with around -20 m/year have been eroded between 2016 and 2017.

Meanwhile, the shoreline around the southernmost breakwater receives strongest current movement among the study areas. This might be due to the design of Tok Jembal groyne that is projecting the current direction, leading to the disappearance of the tombolo as shown in Figure 10. Despite receiving strong current movement, the shoreline is less threatened due to the armouring effect of the shore through revetment as shown in Figure 10. Generally, the coastal protection structure shows mixed results that have successfully stopped the erosion within the area, while mitigating the erosion to another place, unending chain of problem.

A study in Colombia by Rangel-Buitrago *et al*. (2015) reflects the importance of shoreline change study in this area, especially in this similarly dense coastal population and its urbanization (Ariffin *et al*., 2018b). The unanticipated impact of the extreme shoreline evolution on open beach is critical to be studied as it involves local communities. In Thailand, an extreme coastal erosion event affecting coastal communities in Nakhon Si Thammarat province, have compelled the community to be involved in designing the coastal protection to mitigate the problem (Saengsupavanich *et al*., 2009). In Malaysia, coastal protection management had engaged the coastal communities, especially the fishermen as they understood and experienced the local process of monsoon dynamics (Ariffin et al., 2018b).

Many studies have proved the negative impact of coastal protection on shoreline. Studies were carried out, for example, (Williams *et al*., 2018), Percé, Canada (Bernatchez & Fraser, 2012), Pilio, Greece (Tsoukala *et al*., 2015) and in Terengganu, Malaysia (Ariffin et al., 2019). The previous case studies contributed to best practices in designing effective coastal protection (Prukpitikul *et al*., 2018).

Furthermore, this study may be used as reference for future coastal development on sandy beaches area, especially in area influenced by monsoon seasons. Authorities and developers need to contemplate and be accommodative of the possibility of changes in current flow at sandy beach resulting from coastal area construction since the current can heavily reconstruct the face of a beachfront. As an area facing the South China Sea, this study discussed the impact of the construction of coastal structures on open sandy beach area. Total coastal erosion of the shoreline that might significantly affect the coastal community may be avoided, but perhaps at the cost of the aesthetic value of beaches.

Conclusion

In general, the erosion issues of Kuala Nerus shoreline have been slowed down by the protection structure, but some parts of the shore were still being eroded. Besides, the effectiveness of the coastal protection structures is questionable as the accretion in the shore of UMT might be the influenced by the beach nourishment program, although the numerical modelling shows a slower current movement indicating the possibility of accretion of shoreline. Although the erosion rate had slowed down over the year, the erosion seemed to migrate to the upper part of the Kuala Nerus shore, possibly due to the recirculation current and the presence of the coastal structure that acts as a buffer for incoming longshore transport. The structure has turned out to be ineffective to fully mitigate the erosion issues. It clearly shows the importance of understanding the coastal dynamics and sediment supply along the shore. The study on beach morphology is crucial and has widely been performed. However, the information on cross-shore transport on monsoon coast is also vital, but is still limited. The transport might be associated with the coastal dynamic during the northeast and southwest monsoons.

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