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SANDY BEACH PROFILE EVOLUTION

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Abstract: Erosion and accretion of beach profile mostly occur on surf and swash zone. Beach profile evolution is affected by tide, wave, beach material and slope. However, rainfall and groundwater level may also affect the profile changes. Low groundwater level during dry season enhances infiltration of seawater into the beach hence increase the potential for accretion while high groundwater level during wet season saturate the beach and will potentially contribute to beach erosion. In Malaysia, the Northeast monsoon (wet season) carries more rainfall than the Southwest monsoon (dry season) hence this affect the groundwater level. Fieldworks were conducted at Desaru beach where three monitoring wells were installed perpendicular to the beach, together with a rain gauge and a tide gauge station in order to monitor the variations of groundwater levels, rainfall and tides. Fieldworks were conducted during low tides (ebb) on spring and neap tides about 4 to 6 times yearly starting on the year of 2013 to 2015. The results showed that beach profiles accreted on the dry season while eroded on the wet season. It is believed that the rainy season on Northeast monsoon cause the groundwater level to increase and enhancing erosion on the beach apart from the storm and high waves during the monsoon. Recent fieldwork also showed that the beach suffered massive erosion causing the shoreline to move landward and beach become steeper during the 2015 wet season. Due to that storm event, the beach profile was not getting back to its dry season profile as found in previous few years. It can be concluded that various process will affecting beach profiles on sandy beaches.

Keywords: *Groundwater, profile change, rainfall, tides, beach, waves, monsoon*

1.0 Introduction

Groundwater is identified as underground water that found in the cracks, spaces, soil, sand and even rock. Since groundwater found almost everywhere under the Earth's surface, its important cannot be neglected. Groundwater level is also not static and able to move freely. Groundwater properties are important as they may affect the groundwater behaviour itself. Beach groundwater system is classified as highly dynamic and unconfined aquifer that flows are subjected to change in both saturated and unsaturated beach by tides, waves, current, rainfall and interaction with deeper aquifers (Horn, 2002; Horn, 2006).

Beach groundwater has a significant impact on shaping the beach profiles during the tidal cycle. Generally, lower groundwater level will cause the accretion while higher groundwater level will influence erosion on the beach profile (Grant, 1948; Sato, 1991; Baird and Horn, 1996; Ataie-Ashtiani *et al*., 2001; Bakhtyar *et al*., 2011). There are two types of interaction involving the groundwater in the swash zone. First, when the beach groundwater is lower than seawater, uprush flow will naturally infiltrate into the unsaturated beach (see Figure 1(a)). Li *et al*. (2002) and Jamal (2011) stated that this infiltration is capable of reducing the duration and velocity of the backwash flow, thus will decrease the sediment transport within the beach profile. Second, when the beach groundwater is higher than the seawater, the backwash flow will mix with an addition of water rising to the surface or the seepage face and therefore will produce a greater backwash flow (Horn, 2002), as shown in Figure 1(b). This scenario enhances offshore sediment transport as it increased the velocity and depth of the backwash flow.

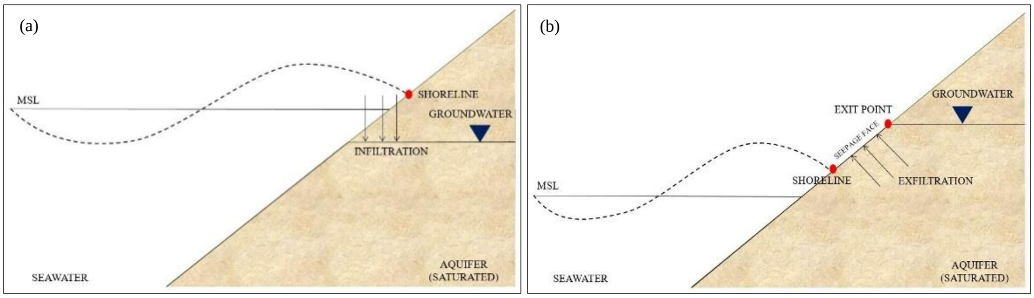

Figure 1: Beach Groundwater System. (a) Infiltration and (b) Exfiltration

Located approximately 2° above the equator, Malaysia experiences an equatorial climate which is hot and humid throughout the year. Malaysia receives the influence of two monsoon seasons which are the Northeast monsoon and the Southwest monsoon. The Northeast monsoon starts from November to February while the Southwest monsoon starts from May to August. Normally, the Northeast monsoon (wet season) carries more rain compared to the Southwest monsoon (dry season). The impact of the Northeast monsoon, especially to the east coast beach, is erosional due to large waves and strong onshore winds while the same beach tends to accrete largely during the Southwest monsoon (Wong, 1981; Mastura, 1987).

The objective of this study is primarily to understand the influence of groundwater on the beach profile changes. The study focuses on determining the relationship between groundwater and rainfall, the relationships between groundwater and tides and the beach profile changes resulting from the three seasons within the period of 2013 to 2016.

2.0 Methodology

2.1 Field Site

Johor is categorised as one of the longest coastline facing the South China Sea on the east coast of Peninsular Malaysia. Johor experiences the greatest amount of eroded beaches in Peninsular Malaysia which is 29 beaches with 234.8 km beach length (Rahim, 2014). The fieldwork was conducted at a well-known main tourist destination in the northeast of Johor: Desaru. Desaru was chosen as the field site because, in part, it represents one of the areas having a lot of development in the state.

2.2 Preliminary Study

Desaru beach stretches between latitudes 1°35’N-1°25’N and longitudes 104°18’E-104°15’E. The climate at Desaru is an equatorial monsoon. Temperature is consistently high all over the year. The dry and wet seasons are not particularly well-marked as heavy rainfall may occur during the dry season whereas dry spells may occur during the wet season. Sediment size along the Desaru beach is distributed by sand varying from 0.33 mm to 0.35 mm with average porosity of 0.43 and the average density of 2635 kg/m^3 (Berahim, 2014).

2.3 Data Collection

Three monitoring wells (BH1, BH2 and BH3) were installed in a line perpendicular to the shore, as shown in Figure 2. The latitude and longitude coordinates for BH1 are; 1°32´44" and 104°15´51", BH2 are; 1°32´44" and 104°15´51", and BH3 are; 1°32´43" and 104°15´50". BH1 is located at the upper part of the beach, BH2 is located at 29.51 m from BH1 while BH3 is located at 18.46 m from BH2, towards the shore. However, groundwater measurements were not taken from BH1 due to high-pressure head in the aquifer. These monitoring wells consisted of piezometer of 10 m in length and 100 mm in diameter, with a perforated lower end of 0.45 m. In the standpipe piezometer, a tube was inserted with a porous filter element on the end, to avoid sand from entering the tube.

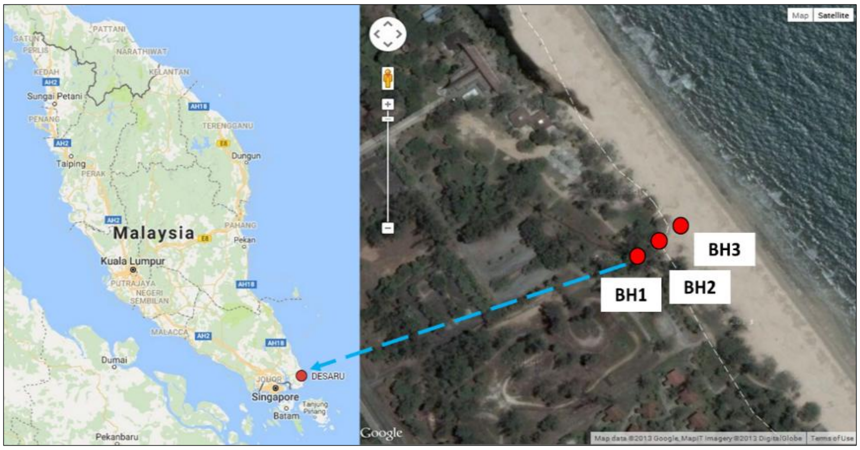

Figure 2: Location of Desaru

Water level logger, Rugged TROLL 100 was used in this study to record the groundwater levels inside the monitoring wells (Figure 3(a)). This water level logger designed to monitor and record the changes in water level, pressure and temperature for long and short-term recordings. The groundwater levels from BH2 and BH3 recorded simultaneously for every 15 min. During the measurements, the water level logger was hanged by a back shell hanger from a suspension wire at the top of the well. The instrument was lowered into the monitoring well until it reached the groundwater table. After that, the data recording will be retrieved and analysed using Win-Situ program. The groundwater data were validated manually by the water level indicator attached with measurement tape. The water level indicator was lowered into the monitoring well and sounded when it reached the groundwater table. The groundwater table depth relative to the top of the well could then be read from the measurement tape.

Near shore tidal elevation was derived from a tide gauge, which was installed at 0.39 m above the chart datum at a jetty located in Tanjung Balau, 8 km from the field site (Figure 3(b)). The instrument used for the tide gauge was Level TROLL 500 Water Level Data Logger, specified to record water level, pressure and temperature. For this study, the tides and water levels were measured at every 5 minutes intervals. Similar to the Rugged TROLL 100, the data were retrieved and analysed using the Win-Situ program. A rain gauge station installed at 200 m at the upper part of the beach (Figure 3(c)) in order to record the rainfall depth for every 5 minutes. The rainfall data measured for this study were validated with rainfall data taken at Bandar Penawar rainfall station provided by Department of Irrigation and Drainage (DID).

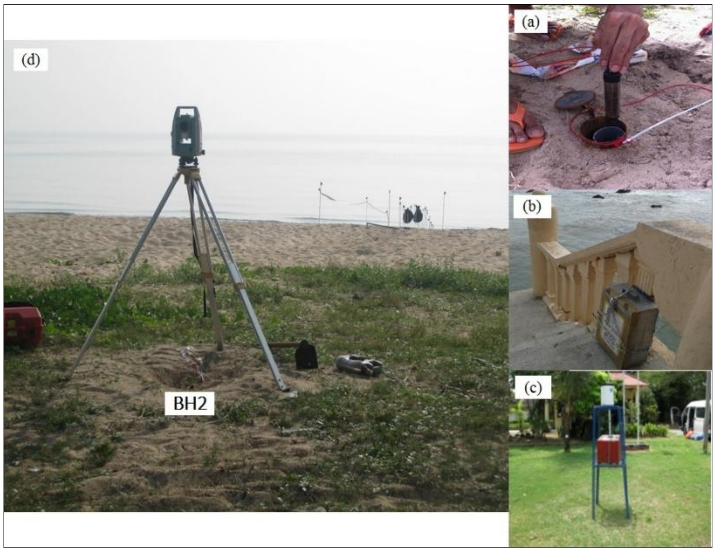

Figure 3: Fieldwork at Desaru (Othman *et al*., 2014). (a) Monitoring Well, (b) Tide Gauge, (c) Rainfall Gauge and (d) Cross-shore Surveying

Beach profiles were surveyed using a total station; see Figure 3(d), twice per year during spring and neap tides within the three years' period. Note that, during the spring tides, the low water is very low compared to the neap tide which allowed the measurements of beach profiles further seaward (Ahmad Kamal, 2014). The profiles were surveyed in a cross-shore direction starting from BH2 to BH3 and then points towards the shore based on standard surveying techniques. All data collections were converted from Admiralty Chart Datum (ACD) to Land Survey Datum (LSD).

The data collection for groundwater, tides, rainfall and beach profiles was measured during the dry season and wet season starting from 2013 to 2016. There were many measurements completed in three years but only six batches of the beach profiles and the corresponding groundwater, tides and rainfall were included in this analysis. Figure 4 shows the schematic diagram of equipment arrangement at the fieldwork. Acoustic Doppler Velocimeter (ADV) that used to measure swash velocities, Optical Backscatter Sensor (OBS) to measure turbidity, Pressure Transducer (PTs) to obtain swash water depths and Steel Rods to record the bed level changes were not included in this analysis. The wave and wind frequencies are also not included in this study.

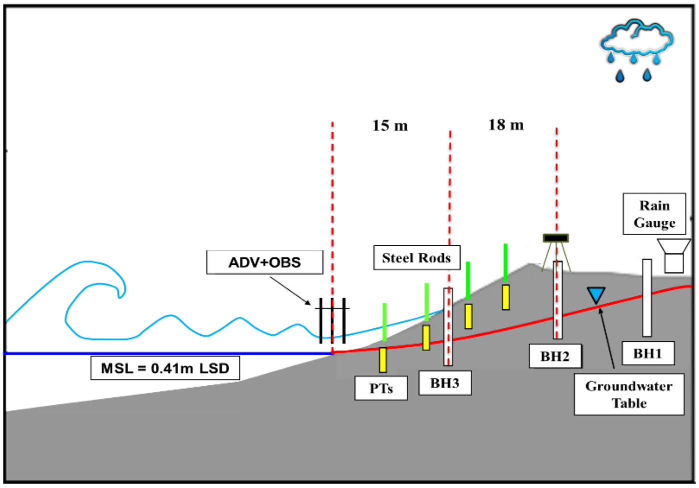

Figure 4: Schematic Diagram

3.0 Results and Discussion

3.1 Groundwater Level and Rainfall

Figure 5 illustrates the relationship of average beach groundwater at BH2 and BH3 monitoring wells with the monthly rainfall from May 2013 to December 2015. Figure 5 illustrates that the Southwest monsoon occurred from May to August every year with a total three years' rainfall of 1624 mm and the Northeast monsoon occurred from November to February every year with a total three years' rainfall of 1802 mm. These indicate that the Northeast monsoon or synonym as the wet season carried more rainfall than the Southwest monsoon (dry season).

The highest groundwater levels in both monitoring wells happened on December 2013 at 2.41 m LSD in BH2 and 2.03 m LSD in BH3, as marked in Figure 5. At the same time, rainfall gauge recorded the highest depth in December 2013 at 312.5 mm with 17.36 mm/day intensity. Thus, it can be stated that the higher rainfall intensity during wet season contributed to the higher groundwater levels in both monitoring wells. In contrast, the lowest groundwater occurred on July 2013 at 1.78 m LSD in BH2 and 1.14 m LSD in BH3, as marked in Figure 5. The rainfall in July 2013 was the third highest within the three years' period, which was 261 mm depth. The low intensity during this dry season was comparable with the low groundwater table. These indicate that the rainfall amount and intensity affect the degree of beach saturation where the beach was completely saturated during the wet season and unsaturated during the dry season (Iverson and Major, 1987).

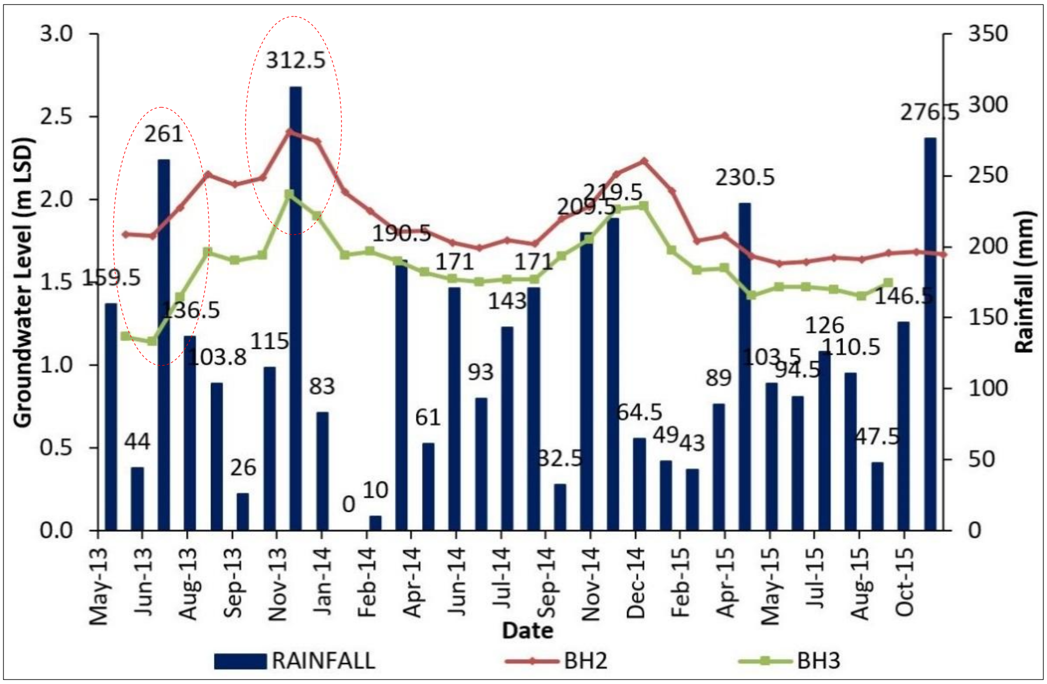

Figure 5: Relationship of Groundwater Level and Monthly Rainfall

Overall, the observations from both monitoring wells show that the groundwater surface was generally not flat but fluctuated with time. Even though there were differences in the amount and distribution of rainfall, the seasonal responded of beach groundwater in both monitoring wells were remarkably consistent from year to year.

3.2 Groundwater Level and Tides

Figure 6 presents the relationship between groundwater levels in monitoring well BH3 with tides for three days in December 2013. Only monitoring well BH3 is included because of its location is the nearest to the shoreline, thus showing more prominent affect than the BH2 well. The figure shows that there were two high tides and two low tides occurred every day and the fluctuation of tides behaves in a similar manner every day at Desaru. The two high tides and two low tides at unequal height occurred in one day characterised the mixed semidiurnal tidal cycle (Hoe, 2010) at Desaru.

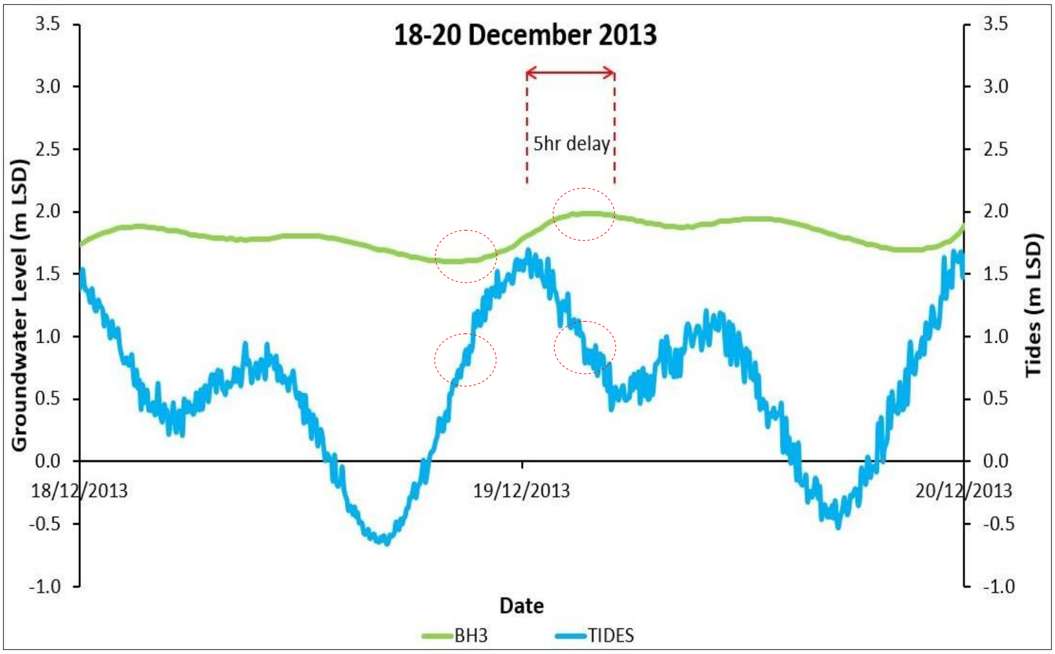

Figure 6: Relationship of Groundwater Level and Tides

It was found that the lowest groundwater level in BH3 well occurred on 18thDecember 2013 during high tide (flooding) while the highest groundwater level occurred on 19th December 2013 during low tide (ebbing), as marked in Figure 6. It seems that the groundwater level in BH3 lags approximately 5 hours behind the tides. The lag time is due to factors like the distance of monitoring well BH3 20 m from the shoreline, hydraulic conductivity of the beach sediment and the sediment composition of sand. Horn (2002) explained that farther distance of monitoring well from the shore has led the lag between the groundwater level and tides to increase and degree of groundwater level fluctuation to decrease. Nielsen (1990) indicated that the sandy beach groundwater level takes longer time than gravel beach due to its low value of hydraulic conductivity. Hence, the rising and falling of tides at Desaru may not directly affect the groundwater level in BH3 as the seawater takes the time to infiltrate/ exfiltrate (Othman *et al*., 2014).

3.3 Groundwater and Beach Profiles

Figure 7 shows the beach profile and groundwater levels for two separate seasons. Figure 7(a) illustrates the beach profiles during the dry season; 28th June 2013, 21st May 2014 and 8th June 2015 while Figure 7(b) illustrates the wet season; 9th December 2013, 25th December 2014 and 19th December 2015. The measurements were done from starting point at BH2 (distance, x = 0 m) and up to (x = 90 m) except for two measurements which were conducted on 9th December 2013 and 19th December 2015. This is because all of the measurements were conducted during the neap tides except those two that were measured during the spring tides, as marked in Figure 8.

Beach profiles during the dry season showed mainly erosion above mean higher high water (MHHW), accretion below mean higher high water (MHHW) and again erosion in between mean sea level (MSL) and mean lower low water (MLLW) (Figure 7(a)). In contrast, beach profiles during the wet season illustrate majorly erosion above the MSL (Figure 7(b)). Groundwater levels in BH2 and BH3 are higher during the wet season than the groundwater levels during the dry season (see Figure 5). Hence, it can be summarised that the profile with higher groundwater level during the wet season tended to erode while the profile with lower groundwater level during the dry season tended to accrete. These findings are consistent with the previous study by Grant (1948), Sato (1991), Baird and Horn (1996), Ataie-Ashtiani *et al*. (2001) and Bakhtyar *et al*. (2011).

Profiles during the dry season showed well-developed berms around x = 17-34 m and increase in gradient, thus widen the beach face (10 m wide). Unlike the dry season, the wet season beach profiles are quite erosive. The erosion had cut back the beach face (8 m wide), flattened the berms and smoothed out the beach face. Normally the eroded sand from the beach is stored in offshore bars (Hyndman and Hyndman, 2006), however, it is not presented in Figure 7(b) due to the limited profiles survey.

It is shown that the beach erosion continues within three years' period, except at the upper part of beach face (x = 20 m on 25th December 2014) where a small berm has developed, as presented in Figure 7(b). By physical observation on 25th December 2014, it seemed that this berm has developed by large uprush flow during the measurement on that day. Meanwhile, beach profile on 19th December 2015 indicates the worst erosion. Figure 7(b) illustrates clearly that the beach profile eroded at x = 18 m until the top of BH3 has exposed. The erosion height from the bed to the top of BH3 was approximately 1 m. The mean groundwater levels on 19th December 2015 in BH2 and BH3 were 1.67 m LSD and 1.5 m LSD respectively.

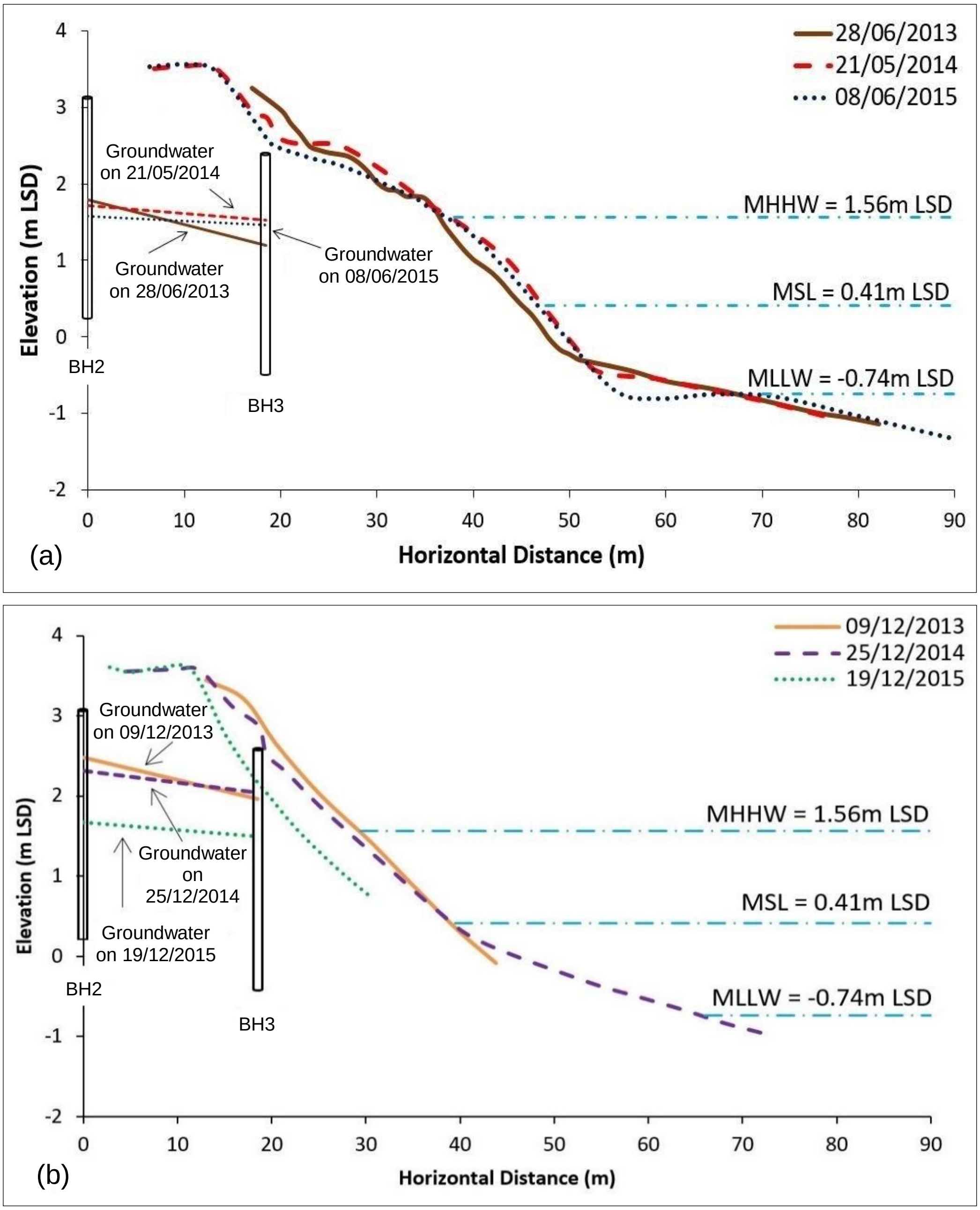

Figure 7: Beach Profile. (a) During the Dry Season and (b) During the Wet Season

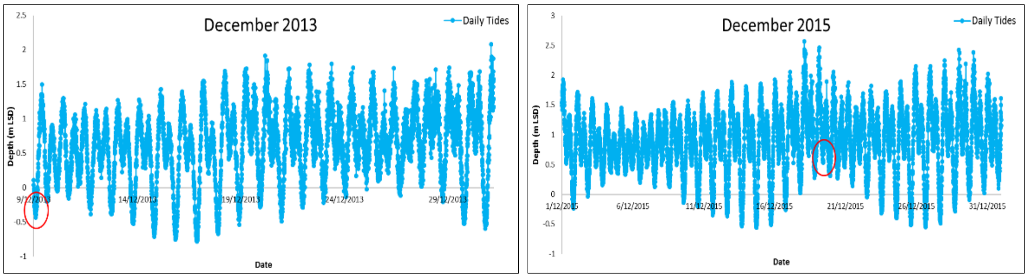

Figure 8: Daily Tides on December 2013 and December 2015

3.4 Beach Profiles

Figure 9 illustrates the transition of beach profile starting on 2013 to 2016.Profile on the 28thJune 2013 was chosen as a baseline of all transition. Figure 9 shows the beach profile transition between dry season and monsoon/wet season starting from the dry season of 28thJune 2013 up to the dry season of 8th August 2016.From the figure, the erosion and accretion occurred mostly above the MSL. The beach profiles were in equilibrium state on dry and wet season repetitively every year as they looks the same from the dry season 2013 to 2015. However, huge storm occurred on the site during monsoon season of2015 that cause massive erosion on the beach. Therefore, on dry season of 2016, the profile was not getting back to its equilibrium state as previously happened. This also means that the shoreline has retreat due to the Northeast Monsoon of 2015.

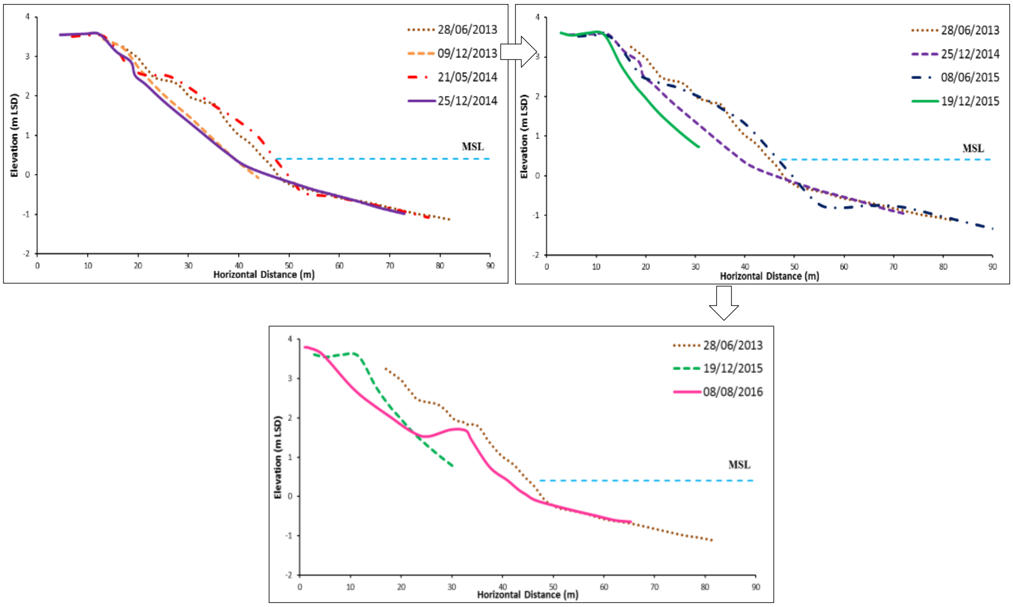

Figure 9: Beach Profiles Transition

4.0 Conclusions

The present study showed that the coastal environment of the east coast is seasonal in character. As expected, the Northeast monsoon or the wet season carried more rainfall than the Southwest monsoon or the dry season. It is found that the effect of tides on the groundwater level in BH3 was delayed by approximately 5 hours. Beach profiles during the wet season were predominantly erosive in character but accretive during the dry season. In general, the profile with higher groundwater level during the wet season tends to erode while the profile with lower groundwater level during the dry season tends to accrete. Sediment budget between the erosion and accretion is a natural process that occurs within the swash zone. However, this study showed that the beach face suffered landward migration and consequently becomes steeper due to the massive erosion in 2015 wet season.

5.0 Acknowledgements

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References

Ahmad Kamal, N.I. (2014). *Cross Shore Profile Change of Desaru Beach*. Master Thesis, UniversitiTeknologi Malaysia, Johor Bahru, 88 pp.

Ataie-Ashtiani, B., Volker, R.E. and Lockington, D.A. (2001). Tidal Effects on Groundwater Dynamics in Unconfined Aquifers. *Hydrological Processes*, 15, 655-669.

Baird, A.J. and Horn, D.P. (1996). Monitoring and Modeling Groundwater Behavior in Sandy Beaches. *J. Coast. Res.*, 12, 630–640.

Bakhtyar, R., Brovelli, A., Barry, D.A. and Li, L. (2011). Wave-Induced Water Table Fluctuations, Sediment Transport and Beach Profile Change: Modelling and Comparison with Large-Scale Laboratory Experiments, *Coastal Eng*., 58, 103–118.

Berahim, M. (2014). *Longshore Sediment Transport in the Swash Zone at Desaru Beach*. Master Thesis, UniversitiTeknologi Malaysia, Johor Bahru, 90 pp.

Grant, U.S. (1948). Influence of the Water Table on Beach Aggradation and Degradation. *Journal of Marine Research*, 7*:* 655-60.

Hyndman, D. and Hyndman, D. (2006). Waves, Beaches and Coastal Erosion: Rivers of Sand. Brooks Cole Publishing Company, 32 pp.

Hoe, T.S. (2010). The Malaysian Sea Level Monitoring Network. Third Issue of GLOSS Bulletin, *Afro-America GLOSS News*.

Horn, D.P. (2002). Beach Groundwater Dynamics. *Geomorphology*, 48, 121-146.

Horn, D.P. (2006). Measurements and Modeling of Beach Groundwater Flow in the Swash Zone: A Review. *Continental Shelf Research* 26, 622-652.

Iverson, R.M. and Major, J.J. (1987). Rainfall, Ground-water Flow and Seasonal Movement at Minor Creek Landslide, North-western California: Physical Interpretation of Empirical Relations. *Geological Society of America Bulletin*, 99, 579-594.

Jamal, M. H. (2011). *Modelling Coarse-Grained Beach Profile Evolution*. PhD thesis, University of Plymouth, UK, 221 pp.

Li, L., Barry, D.A., Pattiaratchi, C.B. and Masselink, G. (2002). BeachWin: Modelling Groundwater Effects on Swash Sediment Transport and Beach Profile Changes. *Environmental Modelling and Software*, 17(3), 313–320.

Mastura, S. (1987). Coastal Geomorphology of Desaru and Its Implication for Coastal Zone Management. Bangi: Penerbit Universiti Kebangsaan Malaysia.

Nielsen, P. (1990). Wave Setup: A Field Study. *Journal of Geophysical Research*,93 (C12), 15643-15662.

Othman, N., Abd Wahab, A.K., A. and Jamal, M.H. (2014). Effects of Seasonal Variations on Sandy Beach Groundwater Table and Swash Zone Sediment Transport. *Coastal Engineering Proceedings*, 34, 12 pp.

Rahim, N.S. (2014). *Influence of Groundwater on the Beach Profile Change*. Master Thesis, UniversitiTeknologi Malaysia, Johor Bahru, 100 pp.

Sato, M. (1991). Underground Water Table and Beach face Erosion. *22nd International Conference on Coastal Engineering*, Delft, the Netherlands, 2644–2657.

Wong, P.P. (1981). Beach Changes on a Monsoon Coast, Peninsular Malaysia. *Geol. Soc. Malaysia Bulletin*, 14 December 1981, 59-74.