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Effect of Rainfall and Groundwater Level on Sandy Beach Profile

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Abstract. In Malaysia, rainfall distribution patterns are normally influenced by seasonal wind flow patterns coupled with local topographic features. Heavy rain spells and storms during the Northeast Monsoon will affect groundwater table elevation and the beach profile. The aim of this paper is to investigate the relationship between rainfall and groundwater elevation and their effect to beach profile change. This work was undertaken at the Desaru Beach, Johor. The rainfall, groundwater table, tides and beach profiles data were measured at the site. As a result, the findings revealed that the groundwater table is affected by rainfall intensity; higher during wet season and lower during dry season. Groundwater table near the coastline is also affected by the tides. However, the data showed that there is a lag time between rising and falling of groundwater table and tides. Finally, the beach profile was found to be eroded as the groundwater elevation increased on the beach.

Introduction

The swash zone is the part of the beach or nearshore which is alternatively covered and exposed by wave up-rush and backwash. Hydrodynamic processes in the swash zone are very complicated and challenging for researchers and engineers to understand and model. The area is characterised by strong and unsteady flows, high turbulence levels, large sediment transport rates and rapid morphological changes [1]. The characteristics of shallow, aerated, turbulent and rapidly varying swash flow certainly provide difficulties for even the most advanced and robust field hydrodynamic equipment during monitoring works. Processes like wave up-rush and backwash in the swash zone can contribute significantly to onshore and offshore sediment transport which is the dominant factor for beach accretion and erosion. The up-rush motion moves sand on to the shore while the backwash transports sediment offshore.

An understanding of the interaction between the water and the groundwater flow within the beach is necessary to be able to make a good prediction of beach evolution, especially in the swash zone. The groundwater level can be assumed as a continuation of the mean surface water into the beach, and therefore to have the same elevation as the tide [2]. However, decoupling might occur between the tidal elevation and the groundwater level due to the elevated groundwater exit point and the shoreline (Fig. 1). This occurs due to the rapid drop of tidal elevation compared to the gravity influenced drop of the groundwater level [2]. Water seepage will develop below the exit point at the beach face and can be identified by visual observation of a glassy surface. The groundwater elevation within the beach is affected by the tidal, waves, and to an extent the rainfall and also sediment properties such as size, shape, sorting, porosity and permeability [3]. Water infiltrates or exfiltrates from the beach surface during up-rush or backwash, depending on the beach material, permeability and the degree of soil saturation [4]. The up-rush and the backwash on the swash will affect the groundwater table by altering the degree of saturation on the beach face [5]. The relationship between beach groundwater and swash hydrodynamics provide an important control for swash zone sediment transport, which affects the morphology of the coastline especially by controlling the potential for offshore or onshore sediment transport. The position of beach groundwater table will affect the swash zone saturation degree and infiltration/exfiltration flow velocity on the bed.

Most of beach groundwater studies for swash zone sediment transport processes have found that beaches with a low groundwater table are likely to accrete and beaches with a high groundwater table tend to erode. However, the beach groundwater table cannot respond with the rapid swash up-rush and backwash especially for finer sandy beaches due to the low value of hydraulic conductivity. In all beach groundwater table elevations, the differences of water level between coarse and fine sands reduce towards the sea. The results of the model simulations from the 'BeachWin' which is a process-based model have been developed for studying swash sediment transport and beach profile changes under influence of infiltration/exfiltration. It shows that the model is capable of simulating accretion effects of low beach groundwater tables on beach profile changes [6]. Based on the results of laboratory experiment [7], onshore sediment transport was enhanced when the groundwater level was lowered under both accretionary and erosive wave conditions, whereas higher groundwater level promoted offshore sediment transport.

The significance of this paper is to present the first research of field observation on hydrological effects like rainfall and groundwater level to sediment transport in the swash zone under Malaysia seasonal variation. The aim of this paper is to investigate the relationship between rainfall and groundwater elevation and their effect to beach profile change.

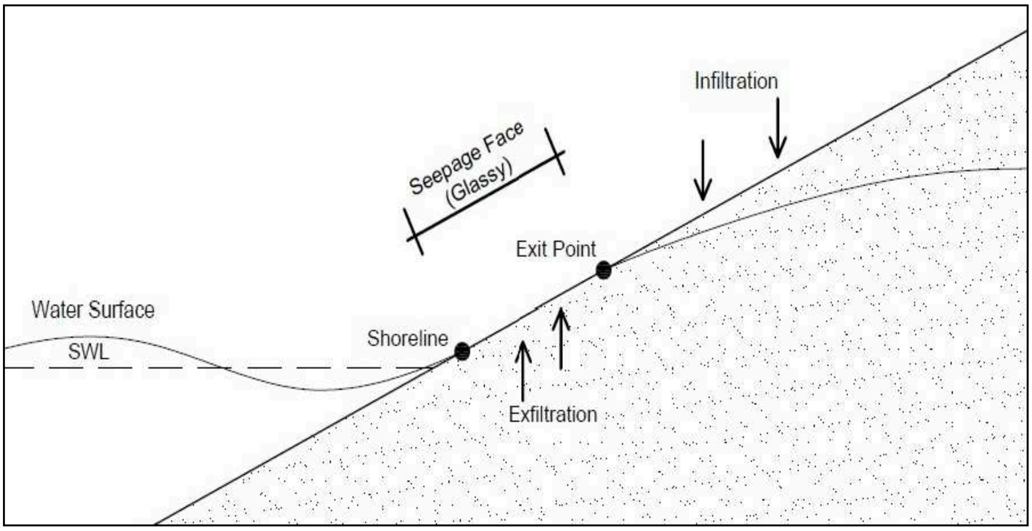

Figure 1. Groundwater and surface water on beaches (Source: [8])

Methodology

The field experiment was conducted at Desaru beach in Johor, Peninsular Malaysia, which is located about 400 km by road from Kuala Lumpur facing the South China Sea (Fig. 2). The beach is composed of fine sand with a median diameter, D_{50} of 0.2 – 0.4 mm. The beach experiences semidiurnal tide, with tide ranges of approximately 1.2 m. The upper beach is quite steep ($\tan\beta \approx 0.11$) and the lower beach is gentle ($\tan\beta \approx 0.03$).

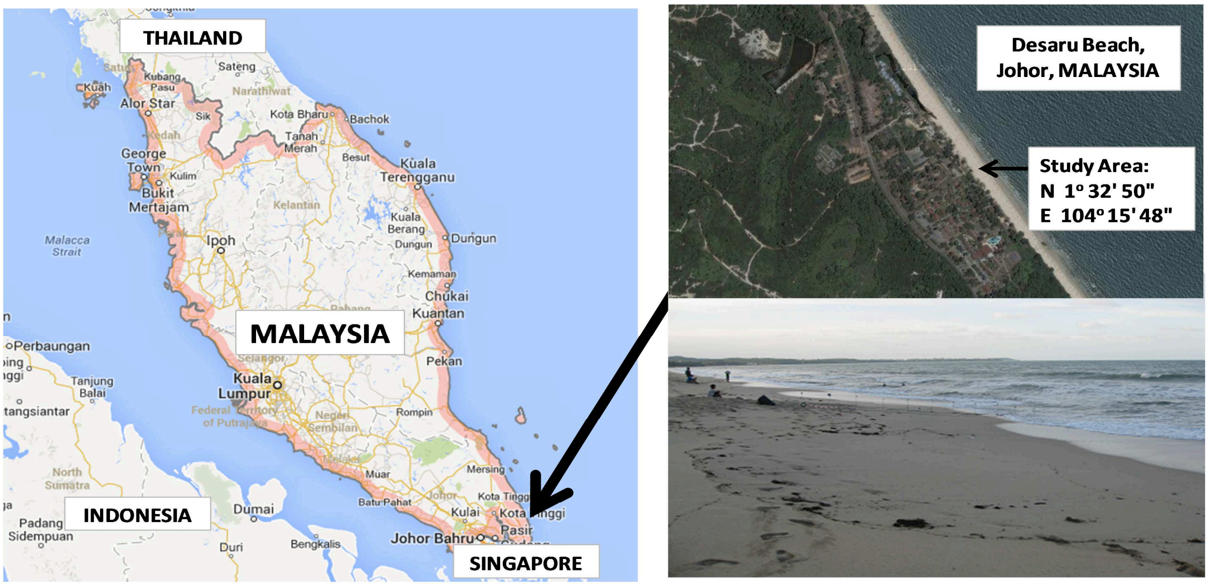

Figure 2. Location of Desaru beach

Steel rods with a spacing of 1 m were placed in a cross-shore transect. The beach level at the rods was measured monthly using a total station at low tides during spring tidal condition. For the effect of seasonal variation (dry season and wet season), one rain gauge station was installed within the field study to collect data of rainfall depth (every 10 minutes). For the beach groundwater table data, 2 monitoring wells were constructed and monitored during field data collection. The water tables were recorded using water level logger (also every 10 minutes). All equipment will be installed for 12 months starting from June 2013 until May 2014. For this paper, the results from the first six months (June – December 2013) of field data monitoring work will be presented and discussed. All the elevation data of beach profiles and groundwater were referred to the Land Survey Datum (LSD). The schematic diagram of the layout of the equipment installations is shown in Fig. 3.

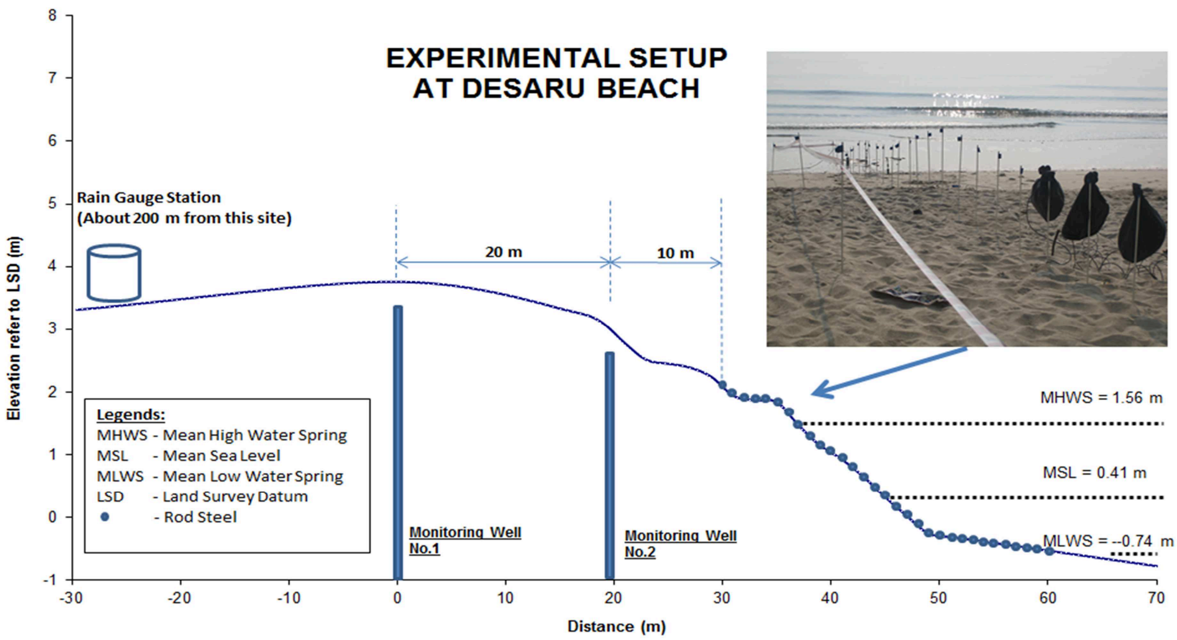

Figure 3. Profile of Desaru beach and the location of instruments

Results & Discussion

Fig. 4 and Fig. 5 show a relationship between the recorded data for daily rainfall depth and groundwater table for two monitoring wells in two periods of monitoring (July-August 2013 & November-December 2013). These two wells were located close to the shoreline. From these figures, both groundwater tables have been highly affected by the rainfall distribution especially during frequent and heavy rainfall events as shown in Fig. 5. The groundwater tables slightly dropped when there was no rain. The groundwater table monitoring well no. 2 is more fluctuated as this well is only about 15 m to the shoreline and the influence of tides may cause this fluctuation. The monitoring well no. 1 is located about 35 m from the shoreline which is further than well no. 2 and the pattern of this water table was less influenced by tides fluctuation. Also the pattern of groundwater table in well no. 1 shows that the rainfall distribution effect have played a major role for the fluctuation of water table readings which were considerably higher during heavy rainfall event (early December 2013) and slightly lower during no rainfall event. This higher water table has significantly made the swash zone more saturated and reduced the infiltration. This situation led the offshore sediment transport and erosive profile especially in the swash zone to be enhanced.

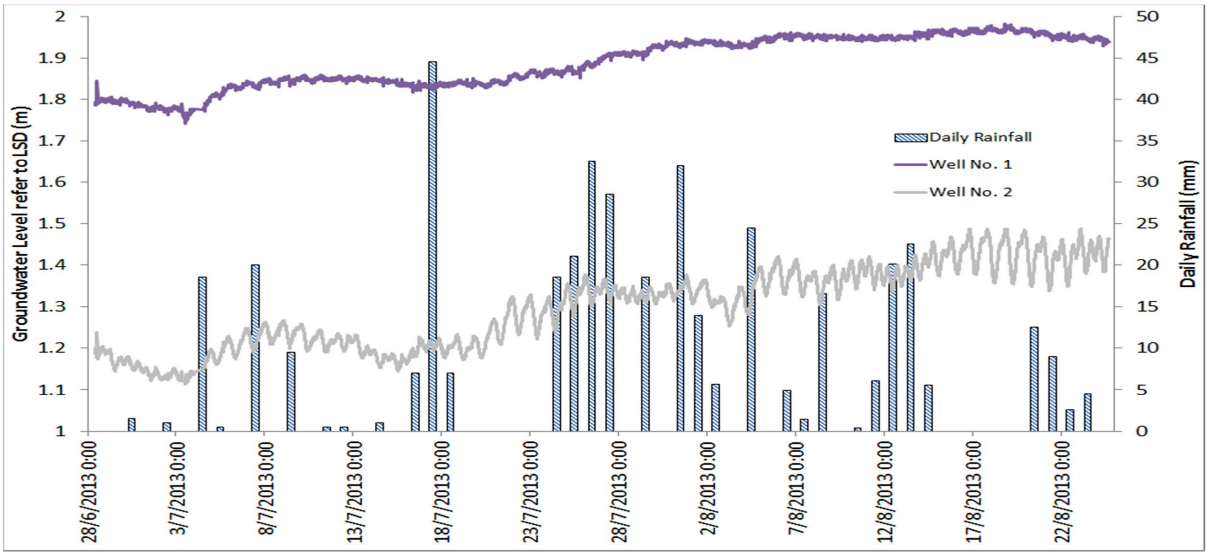

Figure 4. Daily rainfall & groundwater level from July to August 2013

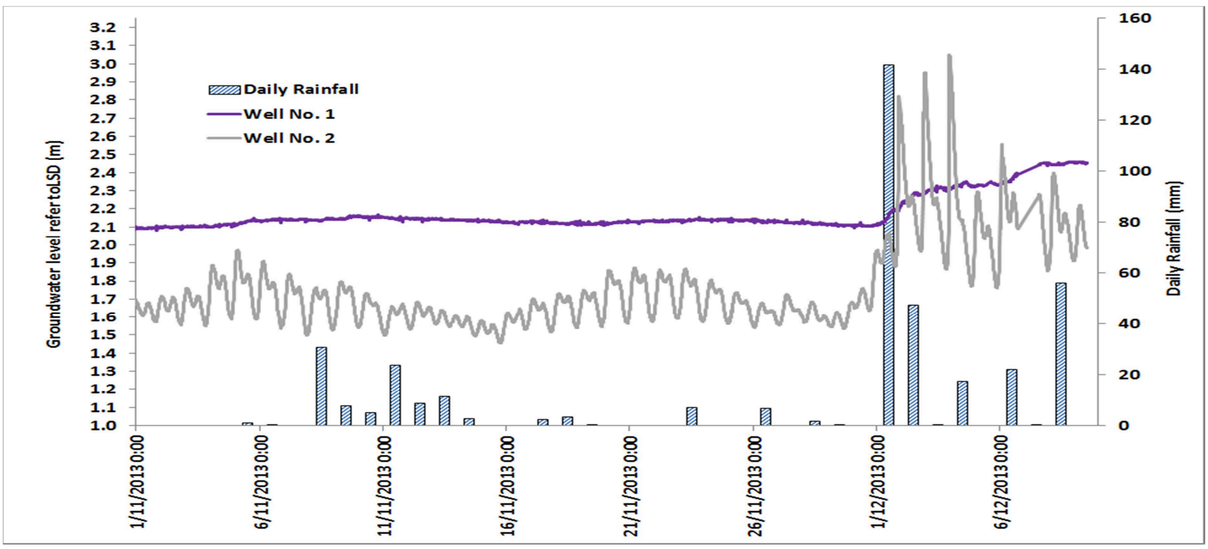

Figure 5. Daily rainfall & groundwater level from November to December 2013

Fig. 6 shows a relationship between tides and groundwater level on monitoring well no. 2 for the selected 4 days of monitoring. It was found that the lowest groundwater table is on flood and the highest groundwater table is on ebb. This lag time of about 6 hours could be due to the location of the well which was far from the shoreline and the minimum of up-rush effects at this point during the high tides. This situation was also largely contributed by the material of the beach (fine sand) and significantly decreased the groundwater flow in the beach due to lower hydraulic conductivity value. Therefore, rising or falling tides may not directly affect the groundwater table as the infiltrated water need time to fill and leave the soil.

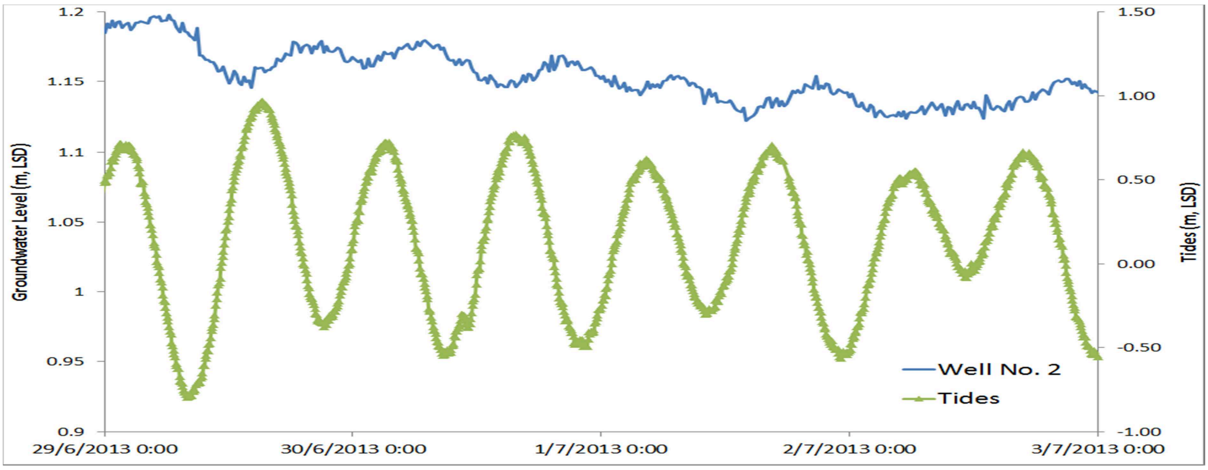

Figure 6. Groundwater table and tides

Fig. 7 shows the groundwater level and measured profiles of Desaru beach on 27th June 2013, 24th August 2013 and 9th December 2013. The increase of groundwater level is due to the increase of rainfall depths during the corresponding months. This situation resulted in the beach to be more saturated due to rainfall effect and enhanced the offshore sediment transport as the profile was eroded especially above the MSL. The beach was mainly eroded on the upper part and accreted on the lower part especially below the MSL. The highest erosion rate occurred in December due to the heavy rainfall depth with recorded data about 300 mm for 8 days in that month and this condition significantly increased the beach groundwater level. This time also shows the effect for length of up-rush flow further to the upper part of the beach due to decrease of infiltration flow on the saturated swash zone area.

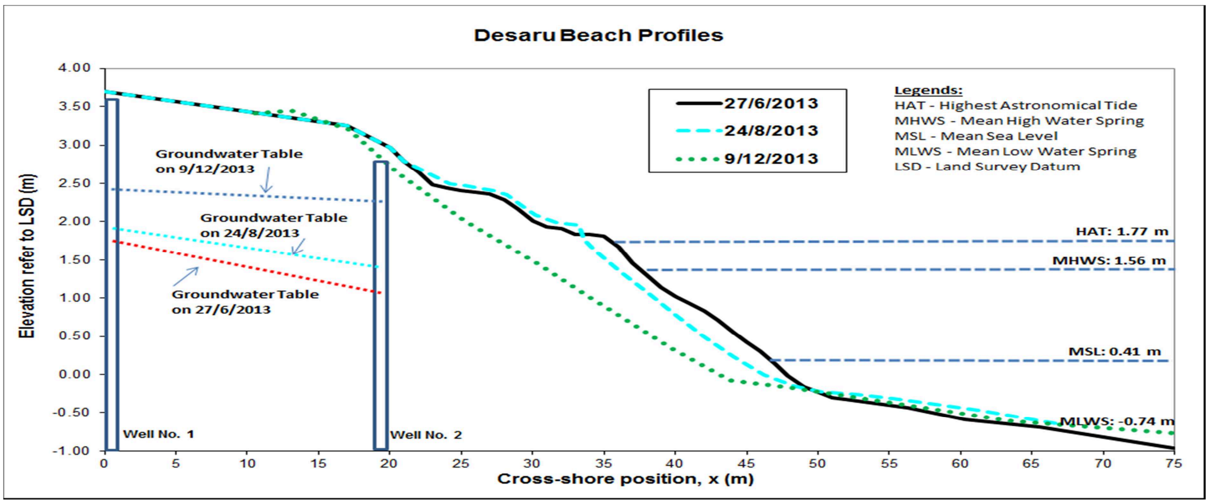

Figure 7. Relationship of groundwater and beach morphology

Conclusions and Recommendation

Conclusions that can be drawn from this study are as follows:

- Beach groundwater table was highly affected by the patterns of rainfall distribution (increase on wet period and decrease on dry period).
- Near to the shoreline, groundwater level is affected by tidal fluctuations.
- Higher groundwater level caused the beach to be eroded.

Field studies or research in the swash zone have been relatively few in numbers (none in Malaysia) and there is a clear need to improve current available field equipment in order to get high quality data for better understanding of this complex process. Current work will continue the field observation and monitoring for dry season in order to get a clear view of beach accretion process due to the lower groundwater table.

Acknowledgements

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