Seasonal variability on cross-shore profile in meso-tidal settings due to lunar cycle effects in Kuala Terengganu Coast

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Abstract

Kuala Terengganu, one of the coastal zones in Malaysia, is prone to natural hazard factors, such as coastal erosion. The impacts of coastal erosion alternate the morphological structure of the beach in Terengganu. The beach morphological changes were driven by the seasonal monsoon such as Northeast Monsoon (NEM) and Southwest Monsoon (SWM) season. Hence, to understand the short-temporal morphological response of meso-tidal beaches during spring tide events throughout the lunar cycle phase, the study was investigated in Batu Buruk beach, Kuala Terengganu. The tidal cycles, particularly during spring tide (Full Moon and New Moon phases) were collected from five transects starting on October 2020 to October 2021. The monitoring of cross-shore was conducted by using RTK to measure the cross-sectional area and sediment volume changes. The data collected were computed by using profiler 3.2XL software. Numerical modelling such as MIKE-21 was used to simulate tidal elevation within the period of this study. The study showed significant impact by the lunar cycle on sediment gain and loss. The cross-sectional analysis revealed positive sediment gains during the Full Moon. However, the New Moon erosion seemed to take place around the upper swash zone area. This provides an insight into the spring tide and contributes to beach recovery processes.

1. Introduction

Dramatic coastal morphology changes over the course of time are often affected via factors, including waves, currents, tide and sediment transport upon natural beach system (R. G. Davidson-Arnott et al., 2005; Pradhan et al., 2022; Suanez et al., 2023). Temporally, the dynamics of the changes are constantly shifted in response to the seasonal monsoon variations, whereby the exposed coastal zone experiences higher intensity of the aforementioned factors (Castelle & Harley, 2020). Mother nature is known to have equilibrium response in altering the coastal morphology. The dynamic nature of sandy beaches is typically developed in areas that are subjected to cycles of erosion and accretion (Deepika & Jayappa, 2017). Therefore, while intense volume of factors during one season is eroding the surface, inversely it is recovered (accretion) during the other calm season to regain sediment facilitated by wind action (Kaiser & Frihy, 2009; Quartel et al., 2008). Additionally, external factors, especially outside of the earth planetary system, such as lunar cycle is also factored to be accounted for morphology changes during monsoon variations (Banno & Kuriyama, 2020a; Pye & Blott, 2008; Ramos & Ranieri, 2021).

The lunar cycle can be characterized as the moon's changing phases, which affect various natural phenomena on the earth hydro-lithosphere, such as Earth's tides through gravitational forces. Prior research most likely predominately focused on the effect of “spring tide” towards coastal region, but not documented well on the implication influence particularly during the phases Full Moon and New moon in meso-tidal settings (Brand et al., 2020; Leung Chee et al., 2014; Qian et al., 2019). During a Full or New Moon period, the forces exerted by the moon and the sun on the earth reinforce each other, resulting in the largest tidal range, known as ‘spring tide’. However, during the half-moon phases, these forces oppose each other, resulting in the minimum tidal range in a lunar cycle, known as ‘neap tide’ (Singh & Jha, 2012). Difference in the tidal type also affects the strengths of tidal currents, influencing the water movements due to the shorter/longer time between high and low tide (Mohd Yusoff et al., 2015). These tidal fluctuations can influence the behaviour of ocean currents, which in turn, potentially influences the coastal area (Banno & Kuriyama, 2020b; Barnard et al., 2015, 2017; Gratiot et al., 2008). Such phenomena and their attitude are crucial to be investigated, especially for maritime country, such as Malaysia.

Malaysia, a maritime-based country located in the vicinity of the South China Sea, is naturally subjected to prevailing winds from offshore, inducing occurrence of seasonal monsoons (Kok et al., 2019; Shariful et al., 2020). For instance, the eastern part of peninsular Malaysia is vulnerable to seasonal monsoons, especially during the Northeast Monsoon (NEM) which lasts from October to the middle of March. Moreover, moderate waves are produced along Peninsular Malaysia's east coast during the Southwest Monsoon (SWM), which occurs from the middle of May to September (Ariffin et al., 2016). In addition, the occurrence of spring tide events induces responses at the beach in Terengganu.

Specifically, Terengganu, a state with shoreline of 224 km facing the South China Sea (Muslim et al., 2019), is experiencing increasing threat due to erosion. Several morphological structure attempts to mitigate the driven forces, such as waves and tide (Ariffin et al., 2018; Norsakinah Selamat et al., 2019) were done, but not covering all affecting factors. Over the past few decades, the issue of coastal erosion on the Terengganu coast has been a threat to the surrounding community (Dong et al., 2023; Ghazali, 2006). Batu Buruk beach was well known as a tourism destination, which attracts people for recreational activities. The local authority did implement beach nourishment for sustained the beaches area from erosion effect (Ghazali, 2000; Narashid et al., 2021). However, the importance of monitoring profile in natural sandy beaches ensures a deeper understanding of the processes underlying coastal geomorphology and how natural beach systems respond to environmental stress. Without a proper understanding, this could lead to false interpretations about the meso-tidal beaches when adapting to changing conditions. This short temporal time frame provided an insight into understanding the lunar cycle effects on these beaches morphological changes during spring tide. Therefore, in this research, we monitored the cross-shore profile by measuring changes during the beginning of the Northeast Monsoon (NEM) (October 2020) and the post-monsoon period (October 2021). Additionally, hydrodynamics modelling simulations were carried out to identify the short-temporal beach morphological reaction during spring tide events through the lunar cycle phase along Batu Buruk beach, Kuala Terengganu.

Study Area

The prominent coastal features observed along the East coast of Malaysia, particularly in the Terengganu regions, are described by mesotidal sandy beaches. The location of the study area Fig. 1 is situated at Batu Buruk beach, Kuala Terengganu, which is a natural beach unaffected by anthropogenic activities. Five transects have been set up and positioned along Batu Buruk beach to investigate the morphodynamic response during the different seasonal monsoons: Northeast Monsoon (NEM), Southwest Monsoon (SWM), and Intermonsoon (IM).

2. Methodology

The assessment was aimed to evaluate the morphological response of the beach and conducted at Batu Buruk Beach, Kuala Terengganu. The research methodology comprised of several components, including field monitoring, hydrodynamics modelling, and statistical analysis, which was carried out from

October 2020 to October 2021. These methods were used to identify the influence of seasonal variation of the lunar cycle on the observed beach dynamics.

2.1. Field Monitoring

The data was collected through field measurements by using RTKGPS (Topcon GR-5 GNSS) technology in kinematic mode to obtain profile data directly throughout the sampling period and to enable measurement of cross-shore profile. These types of surveys were used to investigate the natural processes of beach morphology due to the influence of seasonal variation. The monitoring was conducted on spring tide (Full Moon and New Moon) events during low tide throughout the sampling session. Five transects were positioned along Batu Buruk beach, Kuala Terengganu with each transect at 50m intervals (Fig. 2). The profile was measured below the Mean Sea Level (MSL), starting at a fixed reference point benchmark located at the backshore area and all measurements were taken perpendicular to the shoreline from the reference point. All heights were relative to the Land Survey Datum (LSD), the standard Malaysia reference level. The levelling of the beach elevations corresponded to the datum level at the Land Survey Datum (LSD), which comprised of mean high-water springs, mean sea level and mean low-water spring (MHWS, MSL and MLWS are 3.28m, 2.22m, and 1.12m). Then, the data intake was analyzed by using profiler 3.2XL to calculate the cross-shore profile and the volumetric analyses by each of the transects, and baseline survey profiles for October 2020 of all transects.

2.2. Hydrodynamics Modelling

The hydrodynamics modelling setup was simulated by using MIKE21, which was applied by using Flow Model Flexible Mesh (Flow Model FM). The model simulation was used to characterize the water level condition during lunar cycle phases upon different seasonal variations. The mesh grid was comprised within the range of 5.9-4.95^{o}N to 102.8-103.7^{o}N in the Terengganu shoreline (Fig. 3). The bathymetry data was utilized by using CMap in DHI Mike to compute the numerical model. As for model input, a series of wind data was obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF, 2017), which was located offshore. The forcing factor of water level was imported into three open boundaries, such as boundary 2 (south), boundary 3 (east), and boundary 4 (north), and was set up based on the projection of global tide model prediction by Mike-21 (Ariffin et al., 2020; Awang et al., 2014). The tidal elevation was computed throughout the MIKE-21 simulation from October 2020 to October 2021. The result was used to validate the MIKE-21 simulation to interpret the tidal influence on beach morphology, particularly during the spring tide period simulated by using computational calculation using MIKE-21 software with 1-hour time intervals. The data extraction from the simulation was taken monthly, for instance October 2020, March 2021, August 2021, and October 2021. This simulation period included one lunar cycle which focused on the Full Moon and New Moon phases.

2.3. Statistical Analysis

The data collected was subjected to rigorous statistical analysis with the help of specialized software, in particular XLStat (ver. 2019, USA) and R version 4.0.4 (R Development Core Team, 2011). The core objective of this analysis was to discern the impact of lunar cycles, specifically the Full Moon and New Moon phases, on beach volume across distinct transects as influenced by varying seasonal monsoons. The Shapiro-Wilk method was utilized to conduct a meticulous normality test on all samples, with a significance level of 95%. A deviation from the normal distribution for the dataset under consideration was discovered during the normality assessment for the dataset under consideration. Given that the normality hypothesis was not met ($p < 0.05$), the subsequent analysis adopted non-parametric methods. Principally, the Kruskal-Wallis test, accompanied by the Dunn test as a post-hoc procedure, was employed to examine potential disparities in beach volume across the different transects within various seasonal monsoons while simultaneously considering the influence of lunar cycles.

Furthermore, the Mann-Whitney test ($p < 0.05$) was deployed to discern significant distinctions between the two independent variables of interest: the impact of lunar cycles within each transects and the contrasting beach volume outcomes between the distinct lunar phases, namely the Full Moon and New Moon. This scientific investigation presents a complete and meticulously executed analysis that deepens the complex relationship between lunar cycles and beach volume through various transects exposed to diverse seasonal monsoons. The applied statistical procedures, encompassing normality testing and non-parametric tests (Kruskal-Wallis and Mann-Whitney), augmented by post-hoc analysis (Dunn test), were instrumental in illuminating significant disparities in beach volume attributable to the lunar cycle and the specific phases of the Full Moon and New Moon. Throughout the analysis, a significance level of 0.05 was maintained, which justified the statistical significance of the findings below this critical level.

3. Results and discussion

Figure 4 demonstrates the beach profile and beach volume, and Table 1 summarizes the changes in beach volume for five transects within the selected study months. The characteristics of the tide were obtained from the model simulation to portray the information of the tide pattern and the water level, which were interconnected to beach volume. The statistical analysis was conducted to dictate the influence of seasonal variation and lunar cycle on beach volume in Batu Buruk Beach, Kuala Terengganu.

3.1. Seasonal monsoonal variation effects on beach volume dynamics

The understanding of variation in cross-shore profile patterns and volume changes that occur along a coast is facilitated by the analysis of beach profile data. The interpretation of natural beach response to coastal processes is based on providing information data, such as geometric and volumetric assessment. The result of the survey in Fig. 4, from October 2020 to October 2021 demonstrated relative differences in cross-shore length and accretion/erosion rate for each of the transects. Hence, the beach width oscillated between 30m to 58m from the reference point. The profile of the baseline survey (October 2020) was compared with the final profile (October 2021).

The results obtained from five transects during the Full Moon phase in the pre-monsoon period (Oct 20- Mar 21) indicated accretion rates at transect 3 with 17.25m^3/m (33.52%), showing the deposition of sediment. However, transect 2 and transect 5 appeared to undergo minor erosion rates at -3.13m^3/m (-4.61%) and – 3.63m^3/m (-4.19%), respectively. From the data in Table 1, it was apparent that during pre-monsoon, most of the transect at the site underwent an accretion process from March 2021 to October 2021. Interestingly, during the pre-monsoon period in the New Moon phases, all the transects were to be found lost in sediment, except transect 3. Transect 3 revealed sedimentation occurred at 11.62 m^3/m (22.76%) of accretion rate. In the post-monsoon period, most of the transect experienced an accretion process, indicating sediment deposition. However, transect 1 and transect 3 showed erosion, with erosion rates of -4.40m^3/m (-5.72%) and – 2.07m^3/m (-2.77%), respectively. In comparison, for the Full Moon and New Moon phase, the Full Moon phase had the highest accretion rate with 82.89 m^3/m and 49.62 m^3/m, respectively. However, the result revealed that during the New Moon, the erosion rate was slightly higher with an erosion rate of -6.48m which corresponded to the Full Moon erosion rate of -1.87m^3/m.

The findings of the beach volume analysis conducted along the coastal area during the Full Moon and New Moon phases, spanning from October 2020 to October 2021, for five designated stations, are presented in Table 1. Notably, the quantified beach volume at Pantai Batu Buruk exhibited a range between 4.688 m^3/m (T1) and 0.076 m^3/m (T5) across the designated transects (T1 to T5). Throughout the Full Moon phase, the beach volume showcased the most substantial variability, with values ranging from 4.668 m^3/m (T4) as the highest to 0.076 m^3/m (T1) as the lowest. Remarkably, the collective average beach volume for all five transects was computed to be 2.594 m^3/m. To ascertain any statistically significant distinctions in the spatial and temporal analyses between the Full Moon and New Moon phases, a Kruskal-Wallis test, followed by the Dunn post-hoc analysis, was executed. The results of this rigorous statistical assessment revealed that all transects exhibited negligible differences in beach volume when compared to each other (Kruskal-Wallis test, $p = 0.0001$). This signified that the beach volume remained relatively consistent across the cyclic monsoonal season, with no significant variations discerned between the different transects.

Throughout one full cyclic monsoon season, most of the transects experienced accretion and erosion trends in both phases (i.e., Full Moon and New moon). However, the result highlighted that during the pre-monsoon period, the beach experienced a greater erosion rate during the New Moon phase, distinct to Full Moon phases. In contrast, the volume profile results on Full Moon Phases had greater accretion rate during pre-monsoon and post-monsoon period. The distinctive monsoon season influenced the beach response, thereby affecting the dynamics of beach volume in each of the transects at the Batu Buruk beach areas.

The higher trends of erosion resulted on New Moon phases during pre-monsoon. During pre-monsoon (Oct 20- Mac 21), the beach experienced substantial sediment loss, distinguishing it from post-monsoon season. The NEM monsoon generated high energy of waves, tides and currents which depleted beach volume (Azid et al., 2015). The combination of spring tide force and monsoonal influence especially during NEM led to a substantial loss of beach volume (Qian et al., 2019) at most transects during New Moon. On Full Moon phase, the beach volume result showed a substantial gain in sediment during pre-monsoon compared to New Moon phases during pre-monsoon (Oct 20-Mac 21). Our findings diverged from prior research, which associated beach erosion with Full Moon phase due to rise of wave energy and tidal ranges (Banno & Kuriyama, 2020b; Darsan, 2013). The interplay of these natural physical forces, such as waves, tides, and winds, alongside the seasonal monsoonal variations, underscores the complex and dynamic nature of coastal processes in the studied region. Understanding these mechanisms is crucial for coastal management and conservation efforts, as it provides valuable insights into the response of the coastal environment to various climatic conditions and highlights the importance of considering these factors when assessing coastal vulnerability and implementing appropriate mitigation strategies.

Table 1

Calculate accretion (Acc) and erosion (Ero) values in m2 in all transects for the survey throughout survey pe

Transects	Baseline	FULL MOON										
		Oct 20 – Mar 21				Mar 21- Aug 21				Aug 21- Oct 21		
		Acc	Ero	Total	%	Acc	Ero	Total	%	Acc	Ero	Total
T1	0.147	7.38	-6.10	1.28	1.82	5.65	-4.08	1.57	2.19	10.69	-0.29	10.40
T2	-0.347	4.36	-7.54	-3.18	-4.61	6.30	-0.83	5.47	7.67	6.44	-0.16	6.28
T3	0.082	17.25	0	17.25	33.52	5.42	-0.03	5.39	7.85	0.80	-0.67	0.13
T4	0.009	20.14	0	20.14	29.35	4.89	-0.02	4.87	5.49	2.95	-0.06	2.89
T5	0.205	0.93	-4.56	-3.63	-4.19	11.45	-0.33	11.12	13.41	1.67	-0.65	1.02
TOTAL		**50.06**	**-18.20**	**31.86**		**33.71**	**-5.29**	**28.42**		**22.55**	**-1.83**	**20.72**
Transects	**Baseline**	**NEW MOON**										
		Oct 20 – Mar 21				**Mar 21- Aug 21**				**Aug 21- Oct 21**		
		Acc	**Ero**	**Total**	**%**	**Acc**	**Ero**	**Total**	**%**	**Acc**	**Ero**	**Total**
T1	0.147	7.10	-7.19	-0.09	-0.12	2.66	-7.06	-4.40	-5.72	9.92	-0.24	9.68
T2	-0.347	3.10	-12.82	-9.72	-13.15	8.66	-1.74	6.92	10.80	6.00	0	6.00
T3	0.082	11.62	0	11.62	22.76	12.21	0	12.21	19.48	0.24	-2.31	-2.07
T4	0.009	4.87	-5.93	-1.06	-1.18	4.17	-0.56	3.61	4.07	2.59	-0.07	2.52
T5	0.205	1.00	-7.29	-6.29	-7.24	8.66	-0.91	7.75	9.62	6.55	-0.10	6.45
TOTAL		**27.69**	**-33.23**	**-5.54**		**36.36**	**-10.27**	**26.09**		**25.3**	**-2.72**	**22.58**

Table 2. post-hoc test of beach volume by within transect (Full Moon and New Moon)

3.2. Interpretation of lunar cycle impact of beach volume changes and sediment exchanges

The hydrodynamics simulation presented in Fig. 5(a)-(d) showcased the results in the vicinity of Kuala Terengganu, particularly on the tidal elevation data for each month during the Full Moon and New Moon phase. This data serves to demonstrate the spring tide condition. The model simulation and predicted water level showed the suitability of the water level condition which corresponded to field conditions.

The analysis revealed that the water level showed significant variations in the tidal range between the Full Moon and New Moon phases in the vicinity of Kuala Terengganu. Based on the data collected during the Full Moon phase, October 2020 showed the lowest tidal range, whereas August 2020 recorded the highest tidal range, with 1.121m, and 2.076m, respectively. On the other hand, focusing on the New Moon phase, the result revealed that October 2021 displayed the lowest tidal range while August 2021 showcased the highest tidal range. The values for these tidal ranges were recorded at 1.323m and 2.003m, respectively.

Figure 4 revealed the changes of baseline October 2020-October 2021, that during new moon phases, most of the transect showed sediment loss around the upper swash zone part. As transect 2 shows the highest value of erosion rate with $-2.44m^3/m$ during new moon phases while transect 4 shows the highest value of accretion rate during the full moon with $27.90m^3/m$. Through interpretation, the deposition of the sediment was settling at transect 3 in the both phases. The sediment movement was carried out from the north to south region of the study area. In the analysis, the accumulation of sediment where the sediment was settled down around the transect 3 area in both phases.

The present study focuses on investigating the influence of lunar phases, specifically the Full Moon and New Moon phases, on beach volume variations during the seasonal monsoon period, which encompasses the IM, SWM, and NEM (Fig. 6.a). The research was conducted from October 2020 to October 2021, covering an extensive time frame to capture the effects of different lunar phases and monsoon seasons. At the selected survey site, beach volume measurements were obtained across five designated stations during both the Full Moon and New Moon phases. The beach volume data recorded during the Full Moon phase ranged from 4.688 m^3/m to 0.076 m^3/m, while during the New Moon phase, the beach volume varied between 4.701 m^3/m and 0.058 m^3/m. A noteworthy observation was made in March 2021, when the lowest beach volume value of 0.058 m^3/m was recorded, indicating a potential correlation between lunar phases and beach volume dynamics. To rigorously analyse the data and explore potential variations between spatial and temporal analyses, a Kruskal-Wallis test was performed, followed by the Dunn post-hoc analysis.

The results revealed that stations T1, T3, and T5 exhibited distinguishable beach volume changes throughout the seasonal monsoon, leading to an insignificant difference in the temporal studies (X^2 = 40.22, d.f = 3, p = 0.0001). However, stations T2 and T3 showed significant results with relatively similar beach volume changes during the Full Moon phases (X^2 = 6.209, d.f = 3, p = 0.0001). In contrast, during the New Moon phases, the beach volume changed across all transects, demonstrating a consistent pattern throughout the seasonal monsoon, with the exception of station T3, which exhibited relatively different changes (Kruskal-Walis test, p = 0.001). Moreover, it was evident that the impact of beach volume changes during the New Moon phase was comparatively less significant on a limited number of transects compared to the Full Moon phase. The Full Moon phase exerted the most substantial effect on transects at the survey site, potentially suggesting that lunar phases might play a crucial role in modulating beach volume dynamics during the monsoonal season.

To quantify the difference between the Full Moon and New Moon phases (Fig. 6.b) with respect to beach volume changes, a Wilcoxon signed-rank test was employed. The statistical analysis yielded a highly significant difference between the Full Moon and New Moon phases in terms of beach volume variations ($p < 0.0001$), reinforcing the notion that lunar phases indeed influenced beach volume dynamics during the monsoonal season.

The spring tide events during the lunar cycle phase induced modification to the beach and led to the sediment exchange in cross-shore profile and littoral cell region. Cross-shore sediment exchange predominantly corresponded with erosion during New Moon phase and accretion at Full Moon phase. Littoral sediment exchanges were demonstrated as the sediment appeared to show deposition pattern from northern to southern region along the coast of Batu Buruk beach. The analysis highlighted that there was a significant variation of beach volume dynamics between spatial (i.e., transects) and temporal factor, which was lunar phases.

One of the key factors of sediment accumulations along the cross-shore profile took place during Full Moon phase due to the low wave notion. These lower energetic wave condition generated longer swell waves which developed small transferring force, which facilitated deposition sediment within the upper swash zone region (R. G. D. Davidson-Arnott & Bauer, 2021). In contrast, during the New Moon phase, most transects experienced erosion within the upper swash region. Interestingly, earlier investigation has suggested that the New Moon phases tend to generate more substantial tidal action compared to the Full Moon phase (Abarca et al., 2013). This interconnection of coastal influence (e.g., Storm surge and large wave) could elevate the sediment loss (David Kriebel & Dean, 1993).This research contributes valuable insights into the intricate relationship between lunar phases, tidal dynamics, and their consequential impact on beach morphology and volume. Understanding these complex interactions is of utmost importance in comprehending coastal processes.

In this present study area, sediment movement was observed to occur from north to south region. Previous research (Ariffin et al., 2019, 2020) has also demonstrated that seasonal variation contributes to sediment shifting from one area to another area. The reason why the sediment was settling down at transect 3 was justified by the spatial variation of cross shore profile which created a limitation of availability for the sediment to transport another transects (Tamura et al., 2010). The constant interaction between sediment movement, coastal currents, and wave action drives the dynamic nature of coastal profiles and sediment distribution.

4. Conclusion

These short temporal time frames provided an insight into understanding the lunar cycle effects on natural beach morphological changes during spring tide. The integration of tidal influence has significantly impacted beach morphology in meso-tidal setting changes in the upper swash zone and lower swash zone area to loss and deposit, respectively. The result of investigations showed reduction of sediment greatly during the pre-monsoon period in contrast with the post-monsoon period. The interpretation movement of sediment showed that the process of littoral current transported the sediment from north to south areas. The findings provided evidence based on the natural process of beach recovery as the ground research was distant from human intervention activities. This research will act as a base for future studies to mitigate the risk of coastal hazards, especially erosion on a regional scale on the East Coast of Malaysia. Furthermore, for the long-term coastal management and prediction of coastal hazards, it is crucial to comprehend the processes through which predictable water-level variations lead to beach erosion. Thus, this study suggests for a longer time frame of monitoring survey to reduce the gap in data for robust analysis to understand the dynamics of the beach.

Abbreviations

Northeast Monsoon (NEM)

Southwest Monsoon (SWM)

Intermonsoon (IM)

Declarations

Author contribution

Muhammad Fadhli Harris: Conceptualization,Writing – Original Draft, Methodology, Investigation, Visualization, Data Curation, Formal Analysis. **Muhammad Izuan Nadzri**: Writing – Review & Editing. **Ku Mohd Kalkausar Ku Yusof:** Writing – Review & Editing, Software, Formal Analysis, Validation, Resources. **Wan Amrul Jaahiz Abd Razak:** Investigation and resources. **Mohamad Hakim Mohd Shukri:** Investigation and resources. **Nor Bakhiah Baharim**: Writing – Review & Editing. **Azizi Ali**: Writing – Review & Editing, Validation, Resources. **Effi Helmy Ariffin:** Writing – Review & Editing, Investigation, Software, Validation, conceptualization, Supervision, Project administration, Funding acquisition.

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Competing interests

The authors declare that they have no competing interests.

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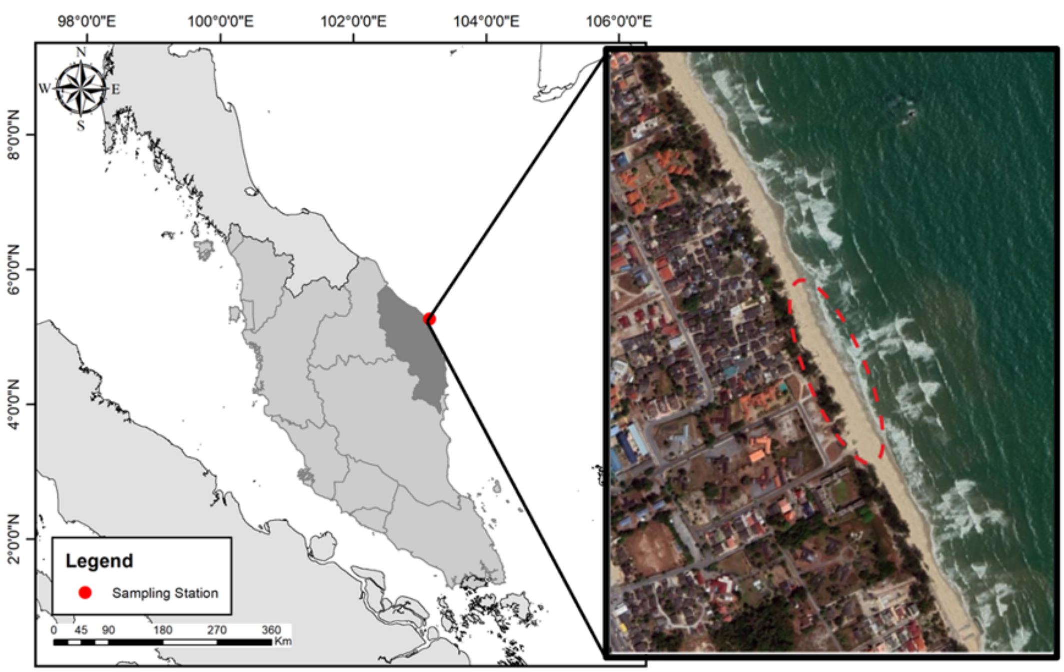
Figures



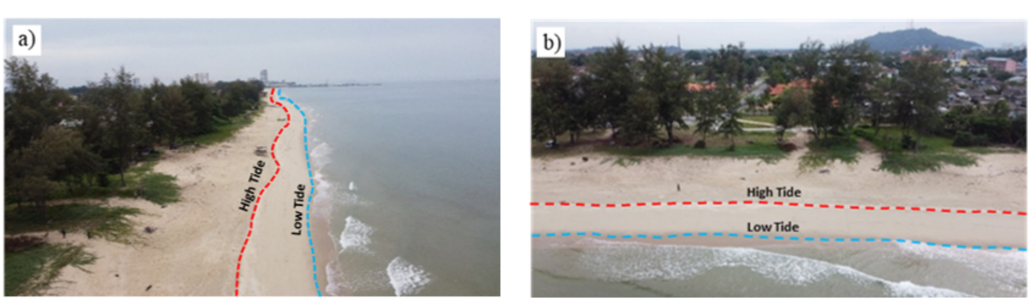


Figure 1

The location of the research ground, Batu Buruk beach, Kuala Terengganu. a) Northern view from sampling site b) Front view of Batu Buruk beach

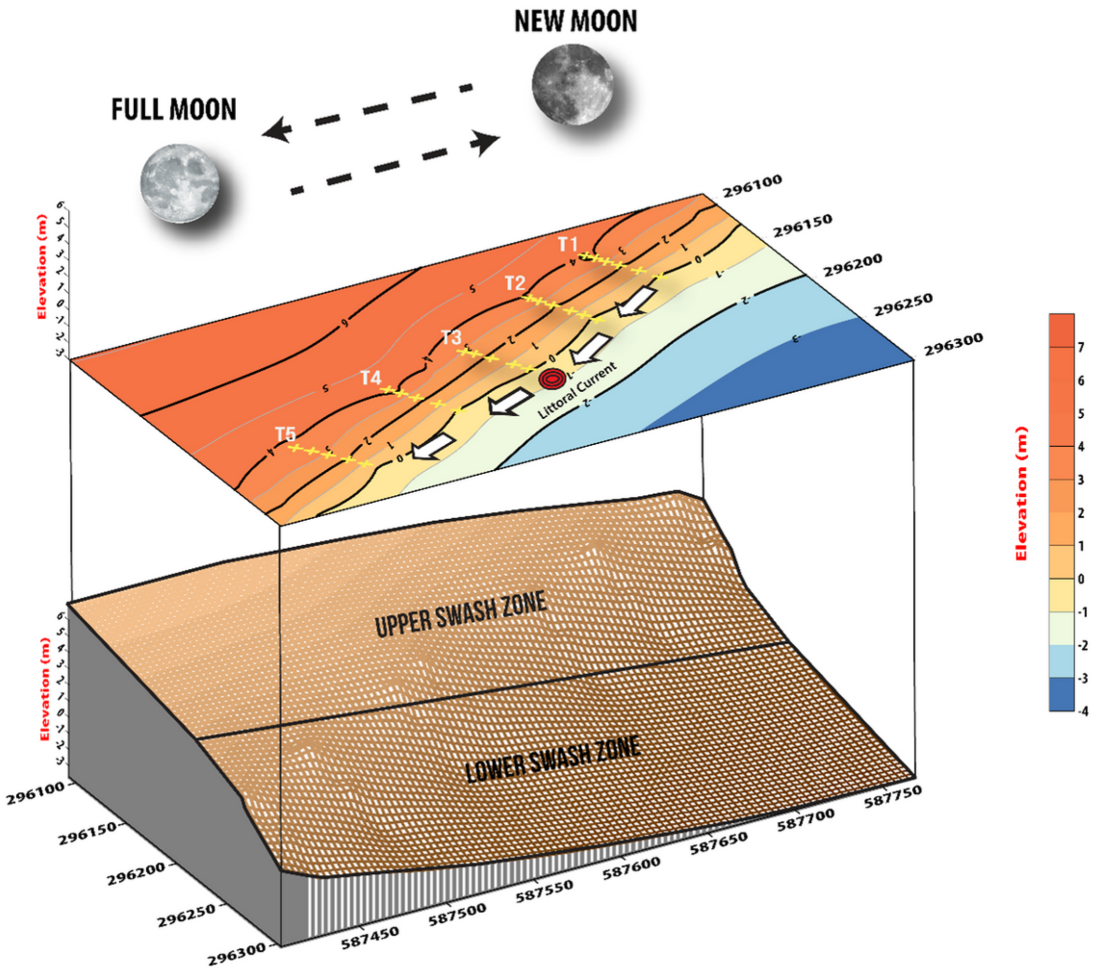


Figure 2

Illustration of beach profile of research ground

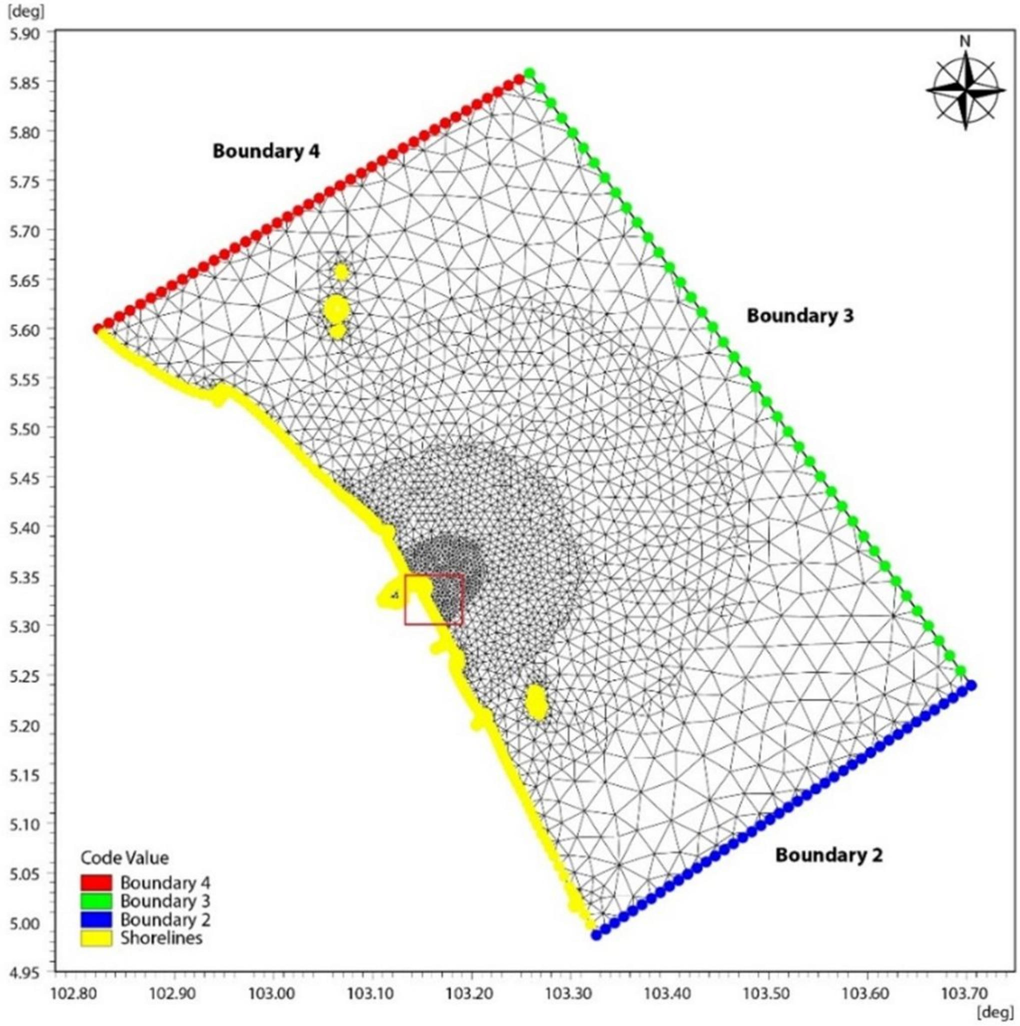


Figure 3

Mesh setup at Terengganu shoreline. The Red box shows the research ground area.

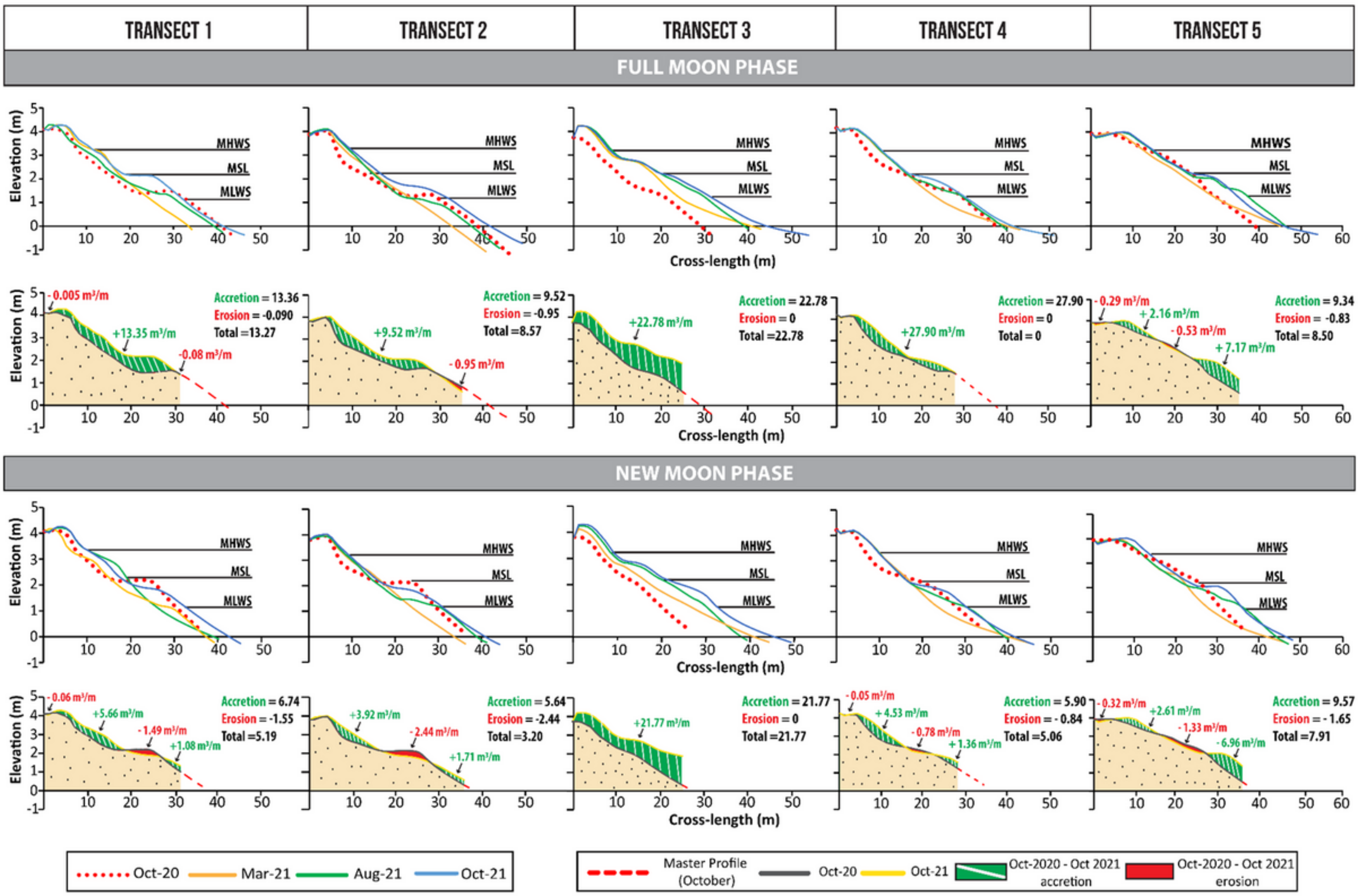


Figure 4

Shows the Full Moon and new Moon beach profile (left side) and volume profile changes (right side) of Pantai Batu Buruk, Kuala Terengganu. a) Transect 1 (b) Transect 2 (c) Transect 3 (d) Transect 4 (e) Transect

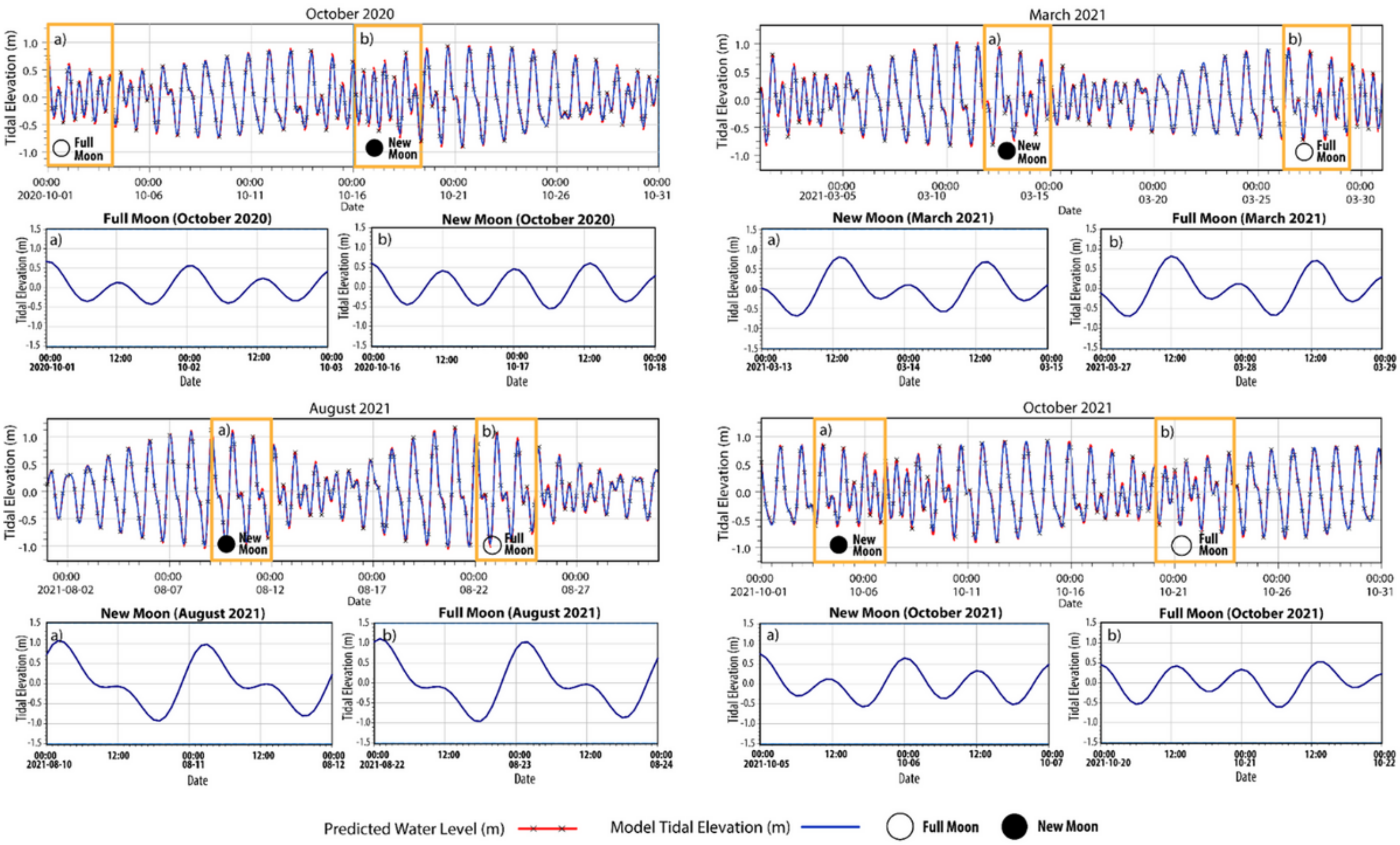


Figure 5

The water level fluctuation at Batu Buruk beach area (a) October 2020 (Full Moon and New Moon) (b) March 2021 (Full Moon and New Moon) (c) August 2021 (Full Moon and New Moon) (d) October 2021 (Full Moon and New Moon)

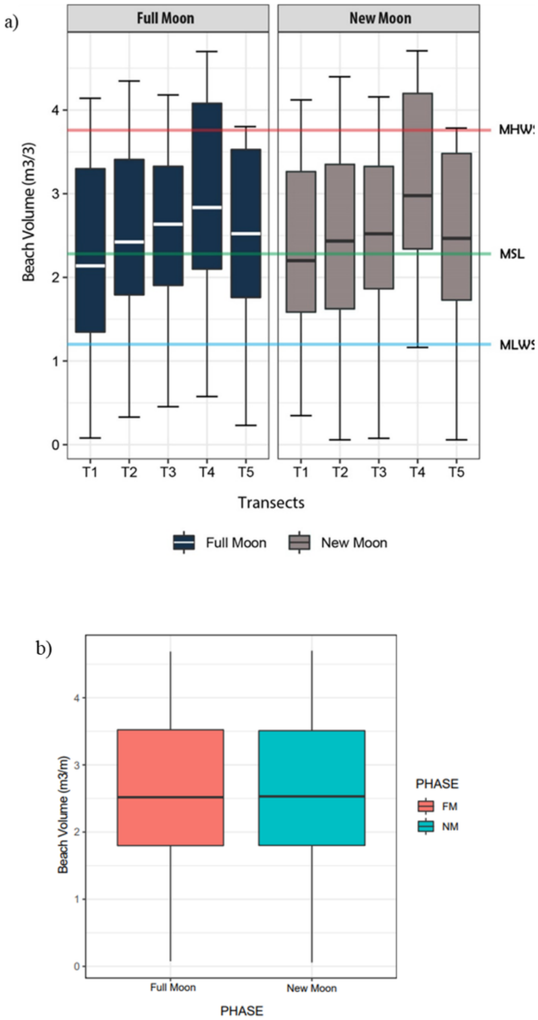


Figure 6

a) Beach volume on the Full Moon and New Moon between transects b) Beach volume in Full Moon and New Moon