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Characteristics of Sediment at Littoral Zone of Anoi Itam Beach (Eastern Weh Island, Indonesia) Based on Seasonal Changes

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Abstract – Anoi Itam Beach (AIB), located in the eastern part of Weh Island, has the sediment characteristic of dark-sand color. Climatologically, the beach is influenced by two seasons, i.e., south-west (SW) monsoon and northeast (NE) monsoon. Sediment data are collected in the upper and lower littoral zones that are divided into six stations alongshore. Data were collected on October 2016 and April 2017, representing post-SW monsoon and post-NE monsoon events. To examine the effect of seasonal, sediments statistics, e.g., mean, sorting, skewness, and kurtosis, have been calculated. AIB was characterized as well sorted to poorly sorted sediment. Sediments were identified as mesokurtic in October, varied to leptokurtic and platikurtic in upper littoral and lower littoral, respectively, in April. Grain size in both upper and lower littoral had increased from October to April. The impact on sediment sortation was minor due to the seasonal difference. Sediments in the upper littoral vary slightly skewed than lower littoral, which response to a more positively skewed during seasonal change from SW-monsoon to NE monsoon. The results suggested that lower littoral provide high variability of sediment characteristics depend on the season.

Keywords: Anoi Itam, Sabang, sediment, grain size

Introduction

Anoi Itam Beach (AIB) is located on the western coast of Weh Island and administratively located at Gampong Anoi Itam, Sabang City, Aceh Province. Anoi Itam in the local language means black sand due to dark-colored sediment. The dark color of the coastal sediments is derived from the mineral content of iron found in the sediment, allegedly resulting from volcanic activity in the ancient era (Dwipa et al., 2006; Ueshima et al., 2013).

Weh Island, located at the northern part of the Sumatra Island, is highly influenced by monsoonal of the Indian Ocean, i.e., the south-west monsoon (SW) from June through September and the northeast monsoon (NE) from December through February (Rizal et al., 2012; Setiawan et al., 2018). The Indian Ocean's monsoonal is generated by specific wind conditions along the season (Hellerman and Rosenstein, 1983). The condition of formed wind stress resulting in the wind flows westward during March and eastward during September (Shankar et al., 2002). In monsoon, the current is closely related to wind movement, produces summer monsoon current flows eastward, and winter monsoon current flows westward (Schott and McCreary, 2001; Schott et al., 2009). Shankar (Shankar et al., 2002) added that the monsoon pattern analysis requires adequate data input, wherein the eastern boundary of the Bay of Bengal (Weh Island located adjacent to the Indian Ocean), the data was insufficient. High-resolution data was provided by Diansky et al. (2006), showed the monsoonal conditions of currents around the northern waters of Sumatra Island, which moved from the southeast in January, while the current turned toward the Southwest from the Andaman Sea in July.

The sediment classification processes in an aquatic environment play an essential role in providing information on sediment's origin and transport (Armstrong-Altrin et al., 2014; D'Haen et al., 2012). A specific sediment distribution pattern results from various energy available in the aquatic environment related to climatology (Sajeev et al., 1996). The distribution and uniformity of sediment size can be used as an indicator of sediment transport behavior in aquatic environments (Abdulkarim et al., 2011; Purnawan et al., 2018; Purnawan et al., 2015; Verney et al., 2013; Vijayakumar et al., 2011). Various oceanographic parameters, e.g., waves, currents, tides, streams, and wind, may affect lifting and sinking the sediment (Delpey et al., 2014; Vousdoukas et al., 2009).

The intertidal region was subjected to be an appropriate area to observe sediment changes over a period (Stauble, 2005). Furthermore, a different season is poised to affect the various environmental parameters, leading to the difference in environmental conditions of sediment on the beach (Charkin et al., 2011; Curtiss et al., 2009; Scott et al., 2011; Staub et al., 2000). The response to seasonal changes can also be seen from coastal morphology changes (Joevivek and Chandrasekar, 2014). Recently Purnawan et al. (2018) noted differences in beach slope concerning different seasons on Anoi Itam. On a seasonal basis, Samsuddin (1989) clarified changes in the texture of coastal sediments, particularly to the sediment mean size at the littoral zone, gave a response to wave energy variation. On the other hand, intertidal areas have been influenced by tides, although no significant sediment movements are produced by tidal currents (Curtiss et al., 2009). Yet it is difficult, several details become crucial to be performed, e.g., sediment grain sizes, nearshore bathymetry, wave transformation, and alongshore sediment transport, to understanding change patterns of coastal at the local scale (Limber et al., 2017; Utizi et al., 2016).

The research on the distribution of sediments associated with seasonal changes in Indonesia is still rare. Thus it is seemingly no data were recorded. This research aims to examine the distribution of sediment grain size at Anoi Itam and the effect of seasonal changes on sediment statistics parameters.

Materials and Methods

The data were collected at AIB in October 2016 and April 2017, representing post-SW monsoon and post-NE monsoon. Both times were selected to examine each prevailing season's effects on sediment condition on Weh Island's littoral zone. A total of 6 sampling stations (200 m in the distance) were selected to investigate the study's location at each season (Figure 1).

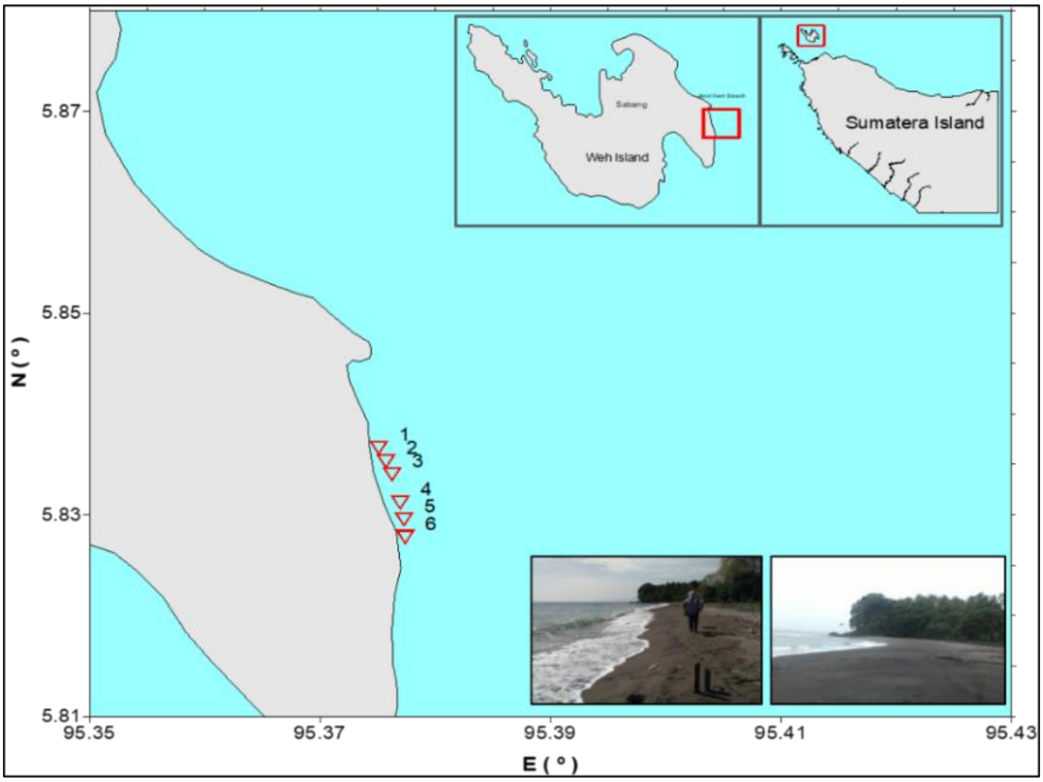


Figure1. Sampling Sites at AIB, located in Weh Island, Aceh Province.

Samples were collected vertically using a diameter of 2.5 inches PVC pipes based on the standard of the American Society for Testing and Materials D4823-95 (ASTM, 2014). This littoral zone has been selected as this zone experiences a significant impact on oceanographic conditions changes (Stauble, 2005). To provide more adequate descriptions of seasonal responses, the littoral zone was divided into two sections, i.e., lower and upper littoral. The data collected in the upper and lower littoral zones was done during high and low-tide, respectively.

The separation was done using a wet sieve method which consists of: -1φ; 0φ; 1φ; 2φ; 3φ; 4φ; 5φ; and pan. Value of φ is determined by $\varphi = -log_2 d$, where d is the diameter of the sediment in mm. Folk's triangle diagram was used to determine the sediment type, based on the composition of mud, sand, and gravel in each sample. The calculation and classification of the mean grain size (Mz), sorting (δ), skewness (SK), and kurtosis (K) parameters follow the formula of Folk and Ward, and done using computing software Gradistat V8 (Blott and Pye, 2001).

Results

Sediment Distribution

The sediment samples' composition consists of sand and gravel, though muds were found in tiny amounts (<1%). Predominantly the type of AIB sediment produced from sand and gravel mixture, e.g., sandy gravel, gravelly sand, slightly gravelly sand, and sand (Table 1 and Table 2). Textures of sediments are somewhat increased in April as the enhancement of coarser coarser-grained changes are found in 1φ for upper littoral and -1φ for lower littoral.

Table 1. Sediment weight percentage at upper littoral

St	-1φ	0φ	1φ	2φ	3φ	4φ	5φ	Type
				October				
1	9.30	13.51	**42.11**	29.23	3.34	2.53	0.00	Gravelly Sand
2	0.00	0.08	12.45	**51.03**	35.17	1.08	0.19	Sand
3	0.32	0.74	40.02	**44.40**	13.48	0.89	0.15	Slightly Gravelly Sand
4	0.39	1.60	0.22	**82.17**	15.46	0.15	0.00	Slightly Gravelly Sand
5	0.88	0.97	27.72	**66.70**	3.48	0.25	0.00	Slightly Gravelly Sand
6	3.71	0.41	5.73	**52.18**	37.48	0.47	0.02	Slightly Gravelly Sand
avg	*2.43*	*2.89*	*21.37*	*54.28*	*18.07*	*0.90*	*0.06*	
				April				
1	0.07	0.42	18.78	**44.09**	31.79	4.39	0.45	Slightly Gravelly Sand
2	0.18	2.71	41.89	**49.42**	4.37	1.19	0.24	Slightly Gravelly Sand
3	5.89	12.63	**56.45**	22.61	1.80	0.52	0.10	Gravelly Sand
4	0.32	1.54	34.13	**61.06**	2.45	0.44	0.07	Slightly Gravelly Sand
5	0.00	0.27	30.31	**64.50**	4.75	0.13	0.04	Sand
6	5.78	0.19	8.01	**62.89**	22.91	0.19	0.03	Gravelly Sand
avg	*2.04*	*2.96*	*31.59*	*50.76*	*11.35*	*1.14*	*0.15*	

Bulk quantity of gravel at lower littoral in a particular manner was found significantly, thus contrasting to upper littoral. Most of the sediment at the upper littoral zone have a mode on the medium sand fraction (2φ), while in the lower littoral zone, the mode on sediment samples are varied at specific fractions (-1φ, 1φ, 2φ, and 3φ). Also, the number of gravel (-1φ) mode at lower littoral was increased in April.

Table 2. Sediment weight percentage at lower littoral

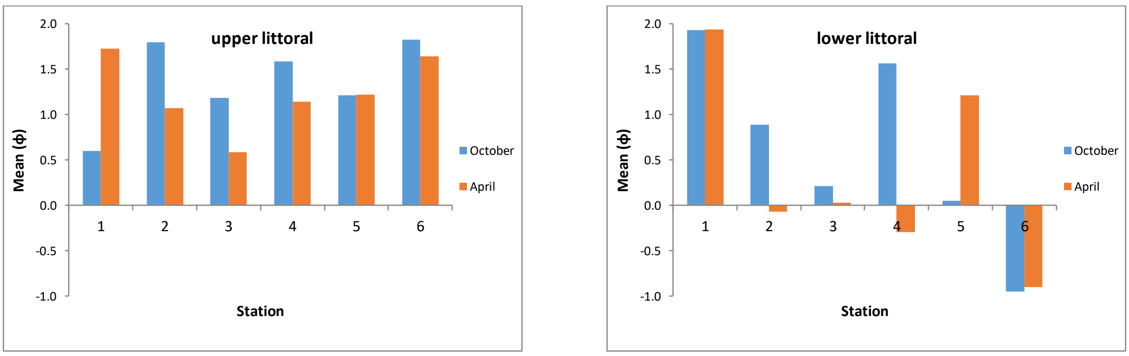
St	-1φ	0φ	1φ	2φ	3φ	4φ	5φ	Type
				October				
1	2.38	1.00	3.13	**49.32**	39.17	4.86	0.14	Slightly Gravelly Sand
2	26.51	9.64	5.12	20.29	**35.81**	2.61	0.03	Gravelly Sand
3	**28.72**	11.91	28.46	20.10	6.11	4.29	0.40	Gravelly Sand
4	5.42	2.89	5.53	**67.88**	17.80	0.34	0.13	Gravelly Sand
5	20.90	13.53	**48.60**	15.21	1.17	0.56	0.04	Gravelly Sand
6	**51.47**	37.48	10.58	0.33	0.14	0.00	0.00	Sandy Gravel
avg	*22.57*	*12.74*	*16.90*	*28.86*	*16.70*	*2.11*	*0.12*	
				April				
1	4.12	1.45	5.28	**42.87**	38.72	7.03	0.53	Slightly Gravelly Sand
2	**41.24**	12.98	19.96	13.45	10.89	1.32	0.16	Sandy Gravel
3	28.84	13.78	**35.08**	19.60	2.57	0.13	0.00	Gravelly Sand
4	**46.62**	6.23	26.72	19.35	0.98	0.07	0.03	Sandy Gravel
5	2.04	4.55	25.65	**54.71**	12.20	0.83	0.02	Slightly Gravelly Sand
6	**74.37**	0.45	22.57	2.40	0.15	0.06	0.00	Sandy Gravel
avg	*32.87*	*6.57*	*22.54*	*25.40*	*10.92*	*1.57*	*0.12*	

Note: values marked with bold are the mode of grain size distribution in each sediment sample.

Statistical analysis

Statistical analysis of the sediment grain size distribution in Anoi Itam was performed on mean, sorting, skewness, and kurtosis. Mz's average value is lower in April compared to October, both in the upper littoral and lower littoral regions, which is interpreted as an increase of sediment grain size following season (Figure 2). Different mean grain size (Mz) values were recorded at upper littoral, the merely small number following different seasons. Sufficient change of mean grain size (Mz) value occurred at lower littoral concerning a different season.

The sediment sorting values ranged from 0.46 to 1.72, which classified as well-sorted categories to poorly-sorted. Sediment in the upper littoral zone has a better-sorted condition than the lower littoral. Thus only one station is categorized as poorly sorted in the upper littoral zone. The sorting parameters of sediment recorded a less significant difference between October and April (Figure 3). Upper littoral has an average sorting value of 0.75 and 0.76 during October and April, respectively. The average sorting values were increasing at lower littoral, which obtained 1.12 for October and 1.15 for April. Sorting parameter values can be seen in Figure 3.



(a) **(b)**

Figure 2. Result of measuring mean grain size: (a) upper littoral; (b) lower littoral

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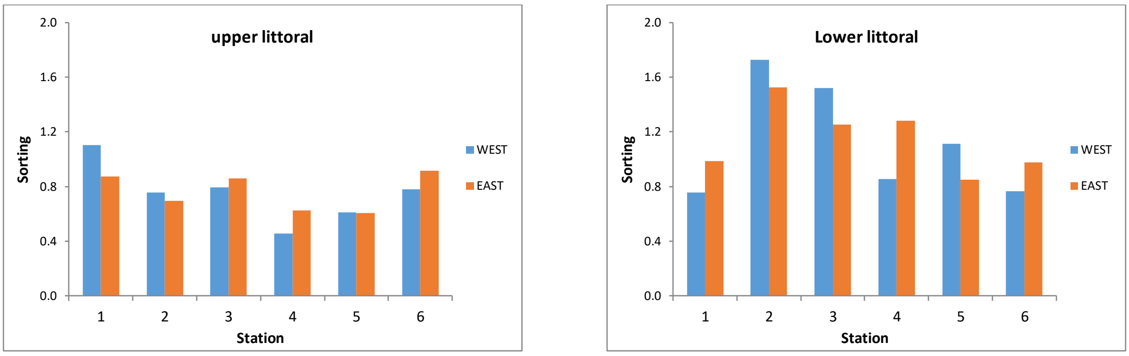
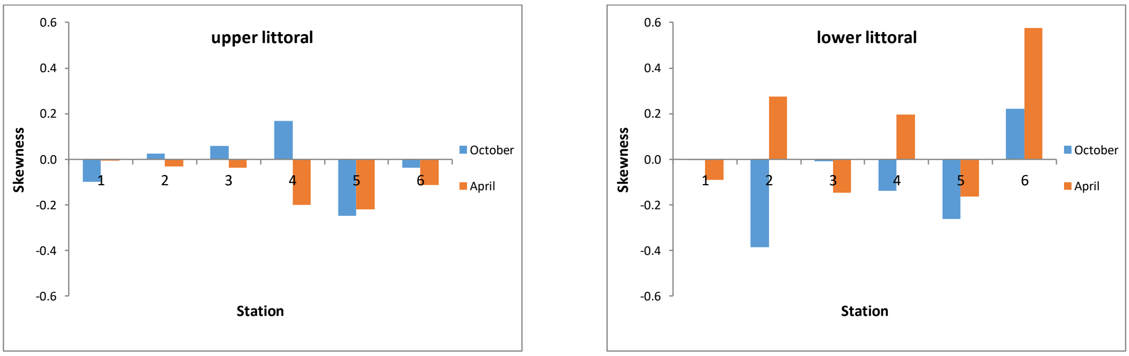


(a) (b)

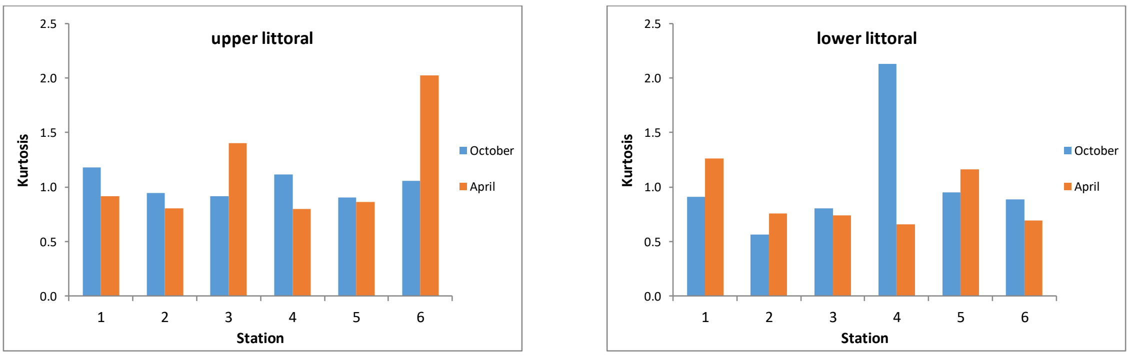
Figure 3. The result of measurement of sorting values: (a) upper littoral; (b) lower littoral.

The obtained values ranged from -0.39 to 0.58 for the skewness parameter in the AIB. Thus sediments are categorized as very coarse skewed to very fine skewed (Figure 4). Symmetrical and coarse skewed sediments are found in common from the upper littoral. Analogs to varying conditions in lower littoral, from very fine skewed to very coarse skewed, season differences give a significant change of average skewness value. Anoi Itam Sediment in October was identified as mesokurtic, with an average of 1.02 (upper littoral) and 1.04 (lower littoral). These conditions were changed during April; whereas the upper littoral tends to be leptokurtic, sediment in the lower littoral showed a platykurtic (Figure 5).



(a) (b)

Figure 4. The result of skewness value measurement: (a) upper littoral; (b) lower littoral.



(a) (b)

Figure 5. Kurtosis values measurement results: (a) upper littoral; (b) lower littoral.

Discussion

The mean grain size was initially recorded responding to seasonal changes since the particle size is strongly correlated to various factors in the oceans (Dora et al., 2011; Ohta, 2008; Purnawan et al., 2016; Purnawan et al., 2015; Wachecka-Kotkowska and Kotkowski, 2011). Changes in slopes, beach hydraulic conductivity, estuaries runoff, swash processes can also lead to changes and variations in sediment grain composition in coastal areas (Kulkarni et al., 2004; Reis and Gama, 2010). Sediment samples in April provide a more coarse grain (0.77φ on average) compared to October (0.99φ on average), which induced as coarse-grained sediments in April was formed by high-energy oceans activity (Poate et al., 2013). Located in the eastern part of Weh Island, AIB is directly opposite to the wind moving from the east with higher intensity, especially during NE monsoon. Rizal et al. (2010; 2012), using advanced numerical modeling, elucidates the current movement NE monsoon produced a higher intensity from the Andaman Sea and the Malacca Strait towards the west through Weh Island. While during the SW Monsoon, the Andaman Sea's water masses moved in a wide circulation closer to Malaya Peninsula and met the Malacca Strait current. Thus generate a recirculating regime before it enters the Indian Ocean through the northern Sumatera Island.

In general, the sediment composition of Anoi Itam was dominated by sand content, where several numbers of gravel fractions were found in the lower littoral. The occurrence of gravel in a higher portion led to distinguish sediment type, which led to a change in the mean grain size. Sediment size is coarser in the lower littoral zone compared to the upper littoral. A higher percentage of gravel fractions in the lower littoral zone might result from the high energy level works (Poate et al., 2013). The lower littoral zone, mostly covered by seawater, has gained influence from the ocean in swash, waves, and currents, lifting up fine fine-grained sediment and moving to another environment with lower energy levels, which allow for precipitation.

The lower littoral zone seemingly more significant changes of mean grain-size value due to seasonal differences, compared with the upper littoral that has less changed. It can be argued that the influence of the season has a significant impact on the lower littoral zone, as has already been mentioned earlier, that the lower littoral region has more consistent contact with the sea than the upper littoral region (Austin and Buscombe, 2008). The shallow seawater coverage on the intertidal zones would allow the ocean's energy to penetrate deeper into the sediment bed. This energy becomes lower as it reaches the enclosed area above the mean sea level (Wood and Widdows, 2002).

Beach morphology can partially re-construct wildly wave activity during any event, which can result in beach erosion (Coco et al., 2014; Senechal et al., 2015). On the other hand, the beach step also plays an essential role in controlling the swash dynamic (Larson and Sunamura, 1993), where the upper beach gains less action (Buscombe and Masselink, 2006). Purnawan et al. (2018) recently noted beach slopes in AIB were increased in April, as well sediment size increased. Later on, the slope change can be the impetus resulting in coarser grains (Austin and Buscombe, 2008).

In particular, sediment conditions' changes generate a specific condition between October and April on kurtosis parameters. The upper littoral region experienced a condition change from mesokurtic to leptokurtic; meanwhile, the lower littoral changed to platikurtic. Seasonal changes produce a shift in sediment composition at each fraction, notably the composition of coarse sand (1φ) in the upper littoral was found increased from October to April. Further, it turns the sediment into leptokurtic. The lower littoral region also has an improved coarser sediment composition in April, specifically gravel (-1φ), resulting in platykurtic. The composition shift was reinforcing the notion of an increase in energy in April. Lower littoral was receiving a significant impact by the NE monsoon regime, characterized by increasing gravel (-1φ) in April. The upper littoral zone was not receiving such a considerable impact, with respect to the upper position at which the swash mechanism provided a minor role. In this case, the increase in energy was limited to coarse-sand (1φ) grain.

Samsuddin (1989) noted that no significant change of skewness in Northern Kerala sediment to seasonal variation, while on AIB sediment skewness was affected by seasonal change. There are differences in conditions between the upper littoral and lower littoral regions, as seen in the average value (Table 2). The upper littoral has a more negative skew in April, although categorized as symmetrical as October. The sediment distribution mode in the upper littoral is dominantly found in medium sand fraction (2φ), and there is no significant change as the season's change. On the other hand, the lower littoral zone shifts into a more positively skewed; it averaged -0.10 in October to 0.11 in April. Increased gravel fraction in April also generates skewness value to be more positive (fine skewed).

Each season provides relatively similar sorting values: the upper littoral is categorized as moderately sorted, with an average value of 0.75 for October and 0.76 for April; whereas in the lower littoral zone, both seasons has poorly sorted categories, with average values of 1.12 and 1.15 for the west and east seasons, respectively. The different categories obtained from the upper and lower littoral zone may be related to the energy variations on both zones due to the higher variability of ocean dynamics produced in the foreshore.

Conclusions

The sand fraction is the main constituent of sediments on the Anoi Itam Beach, with gravel in a decent portion found in some locations, especially in the lower littoral. The seasonal difference resulted in grain size changes, skewness, and kurtosis, whereas no significant change in sediment sortation. Changes in sediment conditions due to season are prevalent in the lower littoral region.

References

Abdulkarim, R., Akintoye, A.E., Oguwuike, I.D., Imhansoeleva, T., Philips, M., Ruth, F.B., Olubukola, S.O., Rasheed, J.O., Oluwaseun, A., Philips, M., Ruth, F.B., Olubukola, S.O., Rasheed, J.O., and Oluwaseun, A. 2011. Sedimentological variation in beach sediments of the barrier bar lagoon coastal system, South-Western Nigeria. Nature and Science, 9(9):19–26.

Armstrong-Altrin, J.S., Ramasamy, N., Lee, Y. Il, Juan, K.Z., and Córdoba-Saldaña, L.P., 2014. Geochemistry of sands along the San Nicolás and San Carlos beaches, Gulf of California, Mexico: implication for provenance. Turkish Journal of Earth Science, 23: 533–58. https://doi.org/10.3906/yer-1309-21

ASTM. 2014. D4823–95 Standard Guide for Core Sampling Submerged, Unconsolidated Sediments. ASTM International, West Conshohocken.

Austin, M., and Buscombe, D., 2008. Morphological change and sediment dynamics of the beach step on a macrotidal gravel beach. Marine Geology, 249: 167–183.

Blott, S.J., and Pye, K. 2001. GRADISTAT: a grain size distribution and statistics package for the analysis of unconsolidated sediments. Earth Surface Processes and Landforms, 26(11): 1237–1248. https://doi.org/10.1002/esp.261

Buscombe, D., and Masselink, G. 2006. Concepts in gravel beach dynamics. Earth-Science Reviews, 79(1–2): 33–52. https://doi.org/10.1016/J.EARSCIREV.2006.06.003

Charkin, A.N., Dudarev, O. V, Semiletov, I.P., Kruhmalev, A. V, Vonk, J.E., Sánchez-Garcia, L., Karlsson, E., and Gustafsson, Ö. 2011. Seasonal and interannual variability of sedimentation and organic matter distribution in the Buor-Khaya Gulf: the primary recipient of input from Lena River and coastal erosion in the southeast Laptev Sea. Biogeosciences, 8: 2581–2594. https://doi.org/10.5194/bg-8-2581-2011

Coco, G., Senechal, N., Rejas, A., Bryan, K.R., Capo, S., Parisot, J.P., Brown, J.A., and MacMahan, J.H.M. 2014. Beach response to a sequence of extreme storms. Geomorphology, 204: 493–501. https://doi.org/10.1016/j.geomorph.2013.08.028

Curtiss, G.M., Osborne, P.D., and Horner-Devine, A.R. 2009. Seasonal patterns of coarse sediment transport on a mixed sand and gravel beach due to vessel wakes, wind waves, and tidal currents. Marine Geology, 259(1–4): 73–85. https://doi.org/10.1016/J.MARGEO.2008.12.009

D'Haen, K., Verstraeten, G., and Degryse, P. 2012. Fingerprinting historical fluvial sediment fluxes. Progress in Physical Geography: Earth and Environment, 36(2): 154–186. https://doi.org/10.1177/0309133311432581

Delpey, M.T., Ardhuin, F., Otheguy, P., and Jouon, A. 2014. Effects of waves on coastal water dispersion in a small estuarine bay. Journal of Geophysical Research: Oceans, 119(1): 70–86. https://doi.org/10.1002/2013JC009466

Diansky, N.A., Zalesny, V.B., Moshonkin, S.N., and Rusakov, A.S. 2006. High resolution modeling of the monsoon circulation in the Indian Ocean. Oceanology, 46: 608–628. https://doi.org/10.1134/S000143700605002X

Dora, G.U., Kumar, V.S., Philip, C.S., Johnson, G., Vinayaraj, P., and Gowthaman, R. 2011. Textural characteristics of foreshore sediments along Karnataka shoreline, west coast of India. International Journal of Sediment Research, 26(3): 364–377. https://doi.org/10.1016/S1001-6279(11)60100-5

Dwipa, S., Widodo, S., Suhanto, E., and Kusnadi, D. 2006. Integrated geological , geochemical and geophysical survey in Jaboi geothermal field, Nangro Aceh Darussalam, Indonesia, in: Proceedings of the 7th Asian Geothermal Symposium, pp. 121–126.

Hellerman, S., and Rosenstein, M. 1983. Normal monthly wind stress over the world ocean with error estimates. Journal of Physical Oceanography, 13(7): 1093–1104. https://doi.org/10.1175/1520-0485(1983)013<1093:NMWSOT>2.0.CO;2

Joevivek, V., and Chandrasekar, N. 2014. Seasonal impact on beach morphology and the status of heavy mineral deposition - Central Tamil Nadu coast, India. Journal of Earth System Science, 123: 135–149. https://doi.org/10.1007/s12040-013-0388-6

Kulkarni, C.D., Levoy, F., Monfort, O., and Miles, J. 2004. Morphological variations of a mixed sediment beachface (Teignmouth, UK). Continental Shelf Research, 24(11): 1203–1218. https://doi.org/10.1016/J.CSR.2004.03.005

Limber, P.W., Adams, P.N., and Murray, A.B. 2017. Modeling large-scale shoreline change caused by complex bathymetry in low-angle wave climates. Marine Geology, 383: 55–64. https://doi.org/10.1016/J.MARGEO.2016.11.006

Ohta, T. 2008. Measuring and adjusting the weathering and hydraulic sorting effects for rigorous provenance analysis of sedimentary rocks: a case study from the Jurassic Ashikita Group, south-west Japan. Sedimentology, 55: 1687–1701. https://doi.org/10.1111/j.1365-3091.2008.00963.x

Poate, T., Masselink, G., Davidson, M., McCall, R., Russell, P., and Turner, I. 2013. High frequency in-situ field measurements of morphological response on a fine gravel beach during energetic wave conditions. Marine Geology, 342: 1–13. https://doi.org/10.1016/j.margeo.2013.05.009

Purnawan, S., Alamsyah, T.P.F., Setiawan, I., Rizwan, T., Ulfah, M., and El Rahimi, S.A. 2016. Analisis sebaran sedimen di Teluk Balohan Kota Sabang. Jurnal Ilmu dan Teknologi Kelautan Tropis, 8(2): 531–538.

Purnawan, S., Mailala, N.A., Karina, S., Muhammad, Setiawan, I., and Ilhamsyah, Y. 2018. The beach slopes and grain size distribution at Anoi Itam and Pasir Putih Beaches, Sabang City The beach slopes and grain size distribution at Anoi Itam and Pasir Putih Beaches, Sabang City, in: IOP Conference Series: Earth and Environmental Science 176. IOP Publishing, Bogor, p. 012013.

Purnawan, S., Setiawan, I., and Muchlisin, Z.A. 2015. Sediment grain-size distribution in the Lake Laut Tawar, Aceh Province, Indonesia. AACL Bioflux, 8: 161–164.

Reis, A.H., and Gama, C. 2010. Sand size versus beachface slope — An explanation based on the Constructal Law. Geomorphology, 114: 276–283. https://doi.org/10.1016/J.GEOMORPH.2009.07.008

Rizal, S., Damm, P., Wahid, M.A., Sündermann, J., Ilhamsyah, Y., Iskandar, T., and Muhammad. 2012. General circulation in the Malacca Strait and Andaman Sea: A numerical model study. American Journal of Environmental Sciences, 8(5): 479–488. https://doi.org/10.3844/ajessp.2012.479.488

Rizal, S., Setiawan, I., Iskandar, T., Ilhamsyah, Y., Mulyadi, A.W., and Musman, M. 2010. Currents simulation in the Malacca Straits by using three-dimensional numerical model. Sains Malaysiana, 39: 519–524.

Sajeev, R., Sankaranarayanan, V.N., Chandramohan, P., and Nampoodiripad, K.S.N. 1996. Seasonal changes of the sediment size distribution and stability along the beaches of Kerala, south west coast of India. ." Indian Journal of Marine Sciences, 25: 216-220.

Samsuddin, M. 1989. Influence of Seasonal Changes on the Texture of Beach Sands, Southwest Coast of India. Journal of Coastal Research, 5(1): 57–64.

Schott, F.A., and McCreary, J.P. 2001. The monsoon circulation of the Indian Ocean. Progress in Oceanography, 51: 1–123. https://doi.org/10.1016/S0079-6611(01)00083-0

Schott, F.A., Xie, S.-P., and McCreary Jr, J.P. 2009. Indian Ocean Circulation and Climate Variability. Rev. Geophysics, 47: 1–46. https://doi.org/10.1029/2007RG000245.1.INTRODUCTION

Scott, T., Masselink, G., and Russell, P. 2011. Morphodynamic characteristics and classification of beaches in England and Wales. Mar. Geol., 286: 1–20. https://doi.org/10.1016/J.MARGEO.2011.04.004

Senechal, N., Coco, G., Castelle, B., and Marieu, V. 2015. Storm impact on the seasonal shoreline dynamics of a meso- to macrotidal open sandy beach (Biscarrosse, France). Geomorphology, 228: 448–461. https://doi.org/10.1016/j.geomorph.2014.09.025

Setiawan, I., Rizal, S., Haditiar, Y., Ilhamsyah, Y., Purnawan, S., Irham, M., and Yuni, S. 2018. Study of current circulation in the Northern Waters of Aceh Study of current circulation in the Northern Waters of Aceh, in: IOP Conference Series: Earth and Environmental Science 176. IOP Publishing, Bogor, p. 012016.

Shankar, D., Vinayachandran, P.N., and Unnikrishnan, A.S. 2002. The monsoon currents in the north Indian Progress in Oceanography, 52(1): 63–120. https://doi.org/10.1016/S0079-6611(02)00024-1

Staub, J.R., Among, H.L., and Gastaldo, R.A. 2000. Seasonal sediment transport and deposition in the Rajang River delta, Sarawak, East Malaysia. Sedimentary Geology, 133(3–4): 249–264. https://doi.org/10.1016/S0037-0738(00)00042-7

Stauble, D.K. 2005. A review of the role of grain size in beach nourishment projects, in: National Conference on Beach Preservation Technology. Destin, Florida.

Ueshima, M., Muslim, D., and Shibayama, M. 2013. Gamma ray dose rates in the Weh Island, Indonesia. Memoirs of Osaka Kyoiku University. Ser. III, Natural science and applied science 61(2): 17–22.

Utizi, K., Corbau, C., Rodella, I., Nannini, S., and Simeoni, U. 2016. A mixed solution for a highly protected coast (Punta Marina, Northern Adriatic Sea, Italy). Marine Geology, 381: 114–127. https://doi.org/10.1016/J.MARGEO.2016.09.002

Verney, R., Jany, C., Thouvenin, B., Pairaud, I., Vousdoukas, M., Pinazo, C., Ardhuin, F., and Cann, P. 2013. Sediment Transport in the Bay of Marseille: Role of Extreme Events, in: Proceedings of Coastal Dynamics 2013 - 7th International Conference on Coastal Dynamics. pp. 1811–1822. https://doi.org/10.1017/CBO9781107415324.004

Vijayakumar, V., Vasudevan, S., and Pruthiviraj, T. 2011. Sedimentological characteristics of Perumal lake

Cuddalore District, Tamilnadu, South India. International Journal of Environmental Sciences, 1: 2018–2027. https://doi.org/10.6088/ijessi.00107020055

Vousdoukas, M., Verney, R., Dufois, F., Pinazo, C., Sauzade, D., Meulé, S., and Cann, P. 2009. Sediment dynamics in the bay of marseille, Gulf of Lions (France): Hydrodynamic Forcing vs. Bed Erodibility, in Conference: Coastal Dynamics 2009 - Impacts of Human Activities on Dynamic Coastal Processes.

Wachecka-Kotkowska, L., and Kotkowski, P. 2011. Grain-size distribution analysis of Quaternary sediments from the southern part of the Lodz region in Poland: a computational-methods approach. Geologos, 17: 205–219. https://doi.org/10.2478/v10118-011-0012-7

Wood, R., and Widdows, J.. 2002. A model of sediment transport over an intertidal transect, comparing the influences of biological and physical factors. Limnology and Oceanography, 47(3): 848–855. https://doi.org/10.4319/lo.2002.47.3.0848