Littoral drift analysis based on long-term observation of mesotidal beach profile in Kuta Beach, Bali for coastal retreat assessment

R. R. Rahmawati¹, A. H. S. Putro², and J. L. Lee¹*

¹Graduate School of Water Resources, Sungkyunkwan University, Suwon, Republic of Korea
²Directorate General of Water Resources, Ministry of Public Works and Housing, Indonesia

*jlee6359@hanmail.net

Abstract. The beach profile survey in the intertidal zone is crucial for a temporal variability study of shoreline and beach profile change for coastal management. The combination of numerical modelling and field data has proven to be successful in identifying the primary hydrodynamic and sediment transport processes such as littoral and cross-shore drift. Those parameters are relevant to the sandbar migration process and shoreline changes. The purpose of the present study is to analyse the littoral drift that caused temporal variability shoreline change in mesotidal beach for coastal retreat mitigation. Beach profile data of Kuta Beach was analyzed by 7 years of long-term field observation data both east monsoon and west monsoon situation. The shoreline definition used mean sea level (MSL) 1.3 m and high water level (HWL) 2.6 m as reference. By using the MeEPASoL program as a graphical user interface program, shoreline changes converging to an equilibrium state can be simulated by taking into account the existing breakwater. Temporal shoreline position resulting from littoral drift and beach width change from its initial position is estimated for coastal erosion analysis. The result showed that dominantly, the littoral drift pattern moved from south to north. Furthermore, this study can be used in the process of identifying the primary hydrodynamic analysis in erosion disaster management as assessment of the beach erosion.

1. Introduction
The world's beaches are classified into micro-tidal beaches, mesotidal beaches, and macro-tidal beaches based on their tidal range. Cartography of the University of Sydney [1] issued the global tidal distribution map that depict the three types of beaches in Indonesia. Indonesia beaches are more dominated by meso beaches and macro tidal beaches, especially in the central to the eastern part of Indonesia.

On the meso-macro tidal coast, the hydrodynamic processes that occur in the surf zone are influenced by tides elevation fluctuation [2]. Pluriannual cycles occur in the lower intertidal zone, while the upper coast are dominated by seasonal cycles. It means, sediment is eroded from the shore at high tide and then returns to lower energy levels. Erosion and accretion rate play an important role in determining erosion and accretion above or below the Mean High Water Neap (MHWN). So that the top of the beach will be more dynamic than the bottom. As a result, the beach slope will increase linearly with the width of the surf zone, and transport rates will increase [3]. If the tidal range is <2m the tidal effect will be
minimal, but its influence will increase with tidal height so that it will increase the mobility of the coastline following the tidal level [4].

Erosion occurs when the sediment budget on the coast is not balanced [5]. Where during seasonal variations, storms and waves are the main factors causing erosion. While for long-term stability, erosion is caused by littoral transport [6]. Several cases of erosion in Japan were accelerated by various factors such as the presence of coastal protection structures (groins, breakwaters) and the presence of objects in front of the shoreline (reef, island), as well as the effect of littoral transport. In the case of erosion caused by detached breakwaters or artificial reefs, the existence of breakwaters and artificial reefs is still a matter of debate. This is because littoral transport affects the direction of the waves which can reduce the level of protection against the beach. After all, it will erode the downcoast part while sand which deposited then allocated in the shadow zone. Putro and Lee (2020) [7] in their research on the longshore drift pattern drift in Nusa Dua Beach found a strong correlation between the predominance of wave direction and littoral drift, so to reduce this littoral effect, the gradient from shoreline orientation must be reduced. Furthermore for the long-term trend of erosion and accretion is influenced by many factors, including sand transport which leads to loss of sediment diminishing beach volume, resulting in shoreline retreat [4].

The main purpose of this research is to analyze the littoral drift effect in Kuta Beach of Bali, Indonesia. Thus, this study investigated the temporal variability change in both profile and shoreline of the intertidal zone in mesotidal environment for shoreline retreat analysis by using cross-shore beach profile data monitoring. By considering the tide as the one main reference for shoreline position definition in highest water level (HWL) and mean sea level (MSL) also littoral drift as the main factor for sediment transport agent. Then, the temporal beach width trend change induced by littoral drift can be observed for shoreline retreat analysis. Overall the result from this study could be a reference and guidance for future coastal development and management considering the erosion problem.

In this paper, the work is structured as follows: The characterization of study and data are described first to provide an overview in Section 2. Then theoretical background used for analysis the data is discussed next in Section 3. This is followed by the material and method in Section 4 and the result discussion of temporal variability of beach profile change that linear with the shoreline change in intertidal zone provided in Section 4. Finally the main conclusion of littoral drift analysis that caused shoreline retreat in the last chapter.

2. Study area and methodology
2.1. Study area characteristic
The southern part of Bali Province is a popular beach tourism center including Nusa Dua, Sanur, Kuta, and Tanah Lot [7]. Kuta Beach is one of the most popular tourist destinations in Bali which stretches as long as 81.35 km from coordinates 8°42'90"S to 8°43'48"S and 115°9'40"E to 115°10'10"E longitude as shown in Figure 1.

![Study area overview with 2 nearest tide station position](Image)
Kuta Beach condition is influenced by the east monsoon (June-September) and the west monsoon (December-March), having an average D$_{50}$ of 1.07 mm with the distribution of gravel and sand in front of the breakwater area and fine sand in the area behind the breakwater [8]. In order to reduce erosion in Kuta beach, the government built 3 breakwaters as shown in Figure 2. The breakwater was built using the headland methodology by applying a static stable sandy beach [9]. In Tsuchiya (1994) [9] research, using either 2 or 3 headlands was able to maintain shoreline stability so that a stable coral-sand beach was formed between the 2 headlands. Kuta beach is directly opposite the reef as shown in Figure 3, where coral reefs are indeed part of the marine ecosystem that is mostly found in tropical waters [10]. As similar case with other beaches in Bali, Kuta Beach experiences considerable erosion every year. From the previous research by using a one-line model shown shoreline changes along the Kuta coast for 25 years with erosion of 1 to 2 meters per year [11]. Kuta beach has experienced considerable erosion since the construction of Bali's Ngurah Rai Airport in 1968[9].

For this research purpose, beach profile survey data from 2008 to 2015 both in east monsoon and west monsoon were obtained. The data based on the terrestrial survey conducted by from the Ministry of Public Works and Housing, Directorate of Water Resources, Indonesia. The data consists of 13 cross-shore beach profile monitoring along 700 m of Kuta beach. Tidal is the main reference for determining shorelines using data obtained from www.tide.big data in Benoa port. By analyzing the tide, the MSL value is 1.3 m and the HWL value is 2.6 m.

2.2. Equilibrium shoreline and MeEPASoL.
Crenulated-shaped bays can be found on many beaches in the world, one of them is Bali. In concept, the crenulated-bay is formed between the two headlands, and for checking the stability of the crenulated-shape bays the Hsu and Evans (1989) [12] model is widely used. The model formulated the form of static equilibrium crenulated-bay with a parabolic relationship as the following equation (1) where $C_0$, $C_1$ and $C_2$ are coefficients that depend on wave or incident wave and R is the radius from the control point to the beach line with an angle $\theta$.

$$\frac{R}{R_0} = C_0 + C_1 \left(\frac{\theta}{\theta_0}\right) + C_2 \left(\frac{\theta}{\theta_0}\right)^2$$

(1)

From the concept above, Gonzalez and Medina [13] found a formula to locate the downcast starting point by defining the minimum downcast limit of PBSE on the coast which has a dominant diffraction...
effect. In order to predict shoreline equilibrium of Kuta’s shoreline, tools MeEPASoL was used in this research based on the concept of Parabolic Bay Shape Equation (PBSE) [7][14]. MeEPASoL can determine the direction of the predominant incident angle of the wave as shoreline orientation. By adding 90 degrees to determinant wave direction clockwise from the north, shoreline slope could be obtained with equation (2) below.

\[
\alpha = \beta + 90^\circ
\]

Where \(\alpha\) is the angle at downdrift control point and \(\beta\) is main wave angle.

Figure 4. Illustration of MeEPASoL user interface (left) and predominant wave direction (right)

2.3. Importance of shoreline data.

The shoreline is the boundary between land and sea, while the shoreline data is very useful in an erosion-accretion investigation [15]. By using the beach profile survey, a shoreline can be obtained by performing discrete interpolation and referencing a tidal datum such as high water level (HWL) so that it can provide high accuracy for defining the shoreline. It is also stated by Crowel (1991) [16] that HWL is the best indicator to define shoreline as well as the study from Tax and Leatherman (2002) [17]. Shoreline measurement with a beach profile survey in a short-term change in shoreline can be a source of error in calculating long-term changes such as aerial maps [18].

2.4. Tide concept.

The intertidal zone is the area between high water spring (HWS) and HLW where the coast is dominated by waves with a tide level > 1m. Intertidal processes are important to understand because used as main area for investigate coastal stability and also in understanding erosion processes [19]. In the lower intertidal zone, a pluriannual cycle occurs, while in the upper beach it is dominated by a seasonal cycle. In other words, sediment is eroded from the foreshore during high tide and then returns to a lower energy state [2]. As a result, the beach slope will increase linearly with the width of the surf zone, and the transport rate will increase [3]. Masselink and Short (1983) [19] in their research formulate the relationship between wave relative to tide range where \(RTR\) is relative tide range, \(TR\) is a range of spring tide and \(H_b\) is average wave breaker height. With this \(RTR\), information is obtained that if the tide range is <2m the effect of the tidal effect will be minimal, but the effect will increase along with the height of the tide range so that it will increase shoreline mobility following the tidal level [4].
RTR=TR/Hb

2.5. Definition of shoreline position.
The definition of shoreline according to Kraus and Rosati (1997) [20] is divided into 6 standards which are distinguished according to the measurement procedure and the relationship with the tidal level Mean High Water (MHW). Besides MHW, there is the term mean high water level (MHWL), where MHW relates to permanent local benchmarks while MHWL is the intersection between MHW and alongshore. HWL is not a reference to elevation like MSL but represents the upward limit of the water whether it is run-up or tidal. Otherwise some shoreline positions using MSL as the reference because it used to deduct the possibility of shoreline change induced by high wave, storm, and wave set up [21]. There are several ways to obtain shoreline data, among them is the beach profile survey. The beach profile survey measures the beach profile perpendicular to the shoreline, so to define the position of the shoreline, a reference/benchmark is needed to define the shoreline.

2.6. Shoreline rate changes.
Precision in calculating shoreline rate changes is an important factor in determining the quality of the estimation results. Therefore, there are several ways for calculating shoreline changes rate such as linear regression (LR), endpoint rate (EPR), Average of Rates (AOR), and Jackknife (JK). Based on these methods, the effectiveness of the method depends on the purpose of the modelling. If it is intended to investigate the effect of episodic events then LR and Jackknife are recommended [22]. LR uses the least square method by calculating the slope of the data to estimate the shoreline rate of change. The use of LR in the analysis of shoreline rate changes is also reinforced by research Douglas et all (1998) [16] regarding long-term shoreline position prediction. In their research, the LR method is widely used in forecasting shoreline position. The LR method assumes the shoreline position y is linearly related to the power of time.

\[ y_i = a + bt_i + noise_i, \text{ where } i=1,\ldots,k \]  

In matrix notation the above equation (4) becomes

\[ Y = AX + N \]  

2.7. Beach volume calculation.
Based on the profile data, the beach volume can be calculated in order to calculate the amount of sand lost or added. The calculation used to identify the time of erosion and accretion during survey monitoring period. This volume calculation is based on the calculation of area (A) with the trapezoid method multiplied by the depth (x) of the profile as shown in the following equation (6).

\[ V^t = \sum_{i=1}^{n} \frac{A_i^t + A_{i+1}^t}{2} x (x_{i+1} - x_i) \]  

where \( A_i^t \) calculated from E as elevation position data with distance x, and D is the offshore distance between point as equation (7) below

\[ A_i^t = \sum_{i=1}^{n} \frac{(E_i^t + E_{i+1}^t) x (D_i^t + D_{i+1}^t)}{2} \]  

2.8. Littoral sediment transport.
Littoral sediment transport can be calculated by equation (8). In a study conducted by Putro and Lee (2020) [7], the relationship between littoral sediment transport and predominant wave direction using MeEPASoL was obtained. Based on their study, littoral sediment transport correlated with shoreline
angle and represented the potential tendency of littoral sediment transport in the sub-cell area so that littoral drift patterns could be identified.

\[
\frac{\Delta V}{\Delta t} n = \Delta Q_n = Q_{n-1} - Q_n
\]  

(8)

Where \( \frac{\Delta V}{\Delta t} \) is the rate of volume change during monitoring, \( Q_{n-1} \) is the amount of sediment transport from the previous sublittoral cell, and \( Q_n \) is the amount of sediment transported out of the control volume. However Walton Jr. an Dean [23] define that littoral drift potential \( Q_p \) correlated with the wave change induced by weather and climate in the coast where shoreline orientation is depend on the incoming predominant wave direction \( (\alpha_s) \) and the bearing of wave breaking \( (\alpha_b) \) as equation (9)

\[
Q = Q_p \sin[2(\alpha_s - \alpha_b)]
\]

(9)

3. Result and discussion
3.1. Beach profile data analysis.
In order to reflect the position of the beach profile with respect to changes in tidal level and waves, the results of the monitoring survey on LK1-13 were analyzed to obtain the average beach profile per year. The data obtained from 2008-2015 were carried out during both monsoon west monsoon (December-March) and the east monsoon (June-September), then the results of the beach profile are presented in Figure 5-7. The profile data was divided into three parts based on the location such as southern area (LK1-5), center zone (LK6-10), and northern area (LK9-13) for temporal variability analysis. It was found that southern area had the same scheme of prograde, retreat, then returned to the same position and repeated as well as in the northern zone. In the northern zone especially in the LK12 showed that the profile dramatically prograde. It found that the LK12 located in shelter zone of detached breakwater so deposition occurred. Meanwhile in the center zone, only seasonal variations in accretion and erosion occurred (eroded significantly from LK6 to 8). The beach profile result analysis showed that the area with low wave potential which faced directly with wave direction eroded easily, however in the shelter zone (bordered or protected by certain structure) such as LK12 deposition occurred.

Figure 5. LK 1,3
Table 1. Mean position (m) shoreline rate (m/yr) in every LK

| Tide/LK | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  | 13  |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Mean HWL (m) | 90.1 | 64.3 | 91.40 | 90.81 | 95.75 | 117.6 | 87.30 | 77.3 | 77.4 | 69.8 | 75.2 | 104.2 | 74.0 |
| rate of HWL (m/yr) | -0.13 | -1.25 | -0.31 | -2.34 | -0.33 | -0.99 | 0.71 | 0.13 | 0.04 | 0.04 | 0.04 | 3.30 | 0.05 |
| Mean MSL (m) | -78.7 | 105.3 | 105.7 | 110.0 | 135.4 | 101.8 | 91.5 | 91.8 | 84.2 | 89.7 | 142.6 | 73.3 |
| rate of MSL (m/yr) | -0.83 | -0.10 | -1.03 | -0.12 | -1.37 | 0.38 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | - | 0.04 |
| HWL/MSL (m) | 0.82 | 0.87 | 0.86 | 0.87 | 0.87 | 0.86 | 0.84 | 0.84 | 0.83 | 0.84 | - | 0.84 | - |
| Slope (m) | -11.0 | 10.75 | 11.47 | 11.01 | 13.69 | 11.16 | 10.9 | 11.1 | 11.0 | 11.1 | - | 1.11 | -0.56 |

*) minus (-) implies the erosion and positive (+) implies the deposition

Figure 6. LK 6,8

Figure 7. LK 10,12

Figure 8. Sand add/loss volume per year by using 2008 profile as initial condition
By using equation (4) and (5) shoreline change rate every LK in HWL and MSL are shown in the Table 1 above. The annual change in shoreline referenced in HWL has a maximum erosion rate of 2.34 m/year and deposition rate of 3.30 m/year. However, in MSL the maximum erosion rate is 1.37 m/year and the deposition rate is 0.38 m/year. From shoreline change result in HWL and MSL indicated that in south area erosion occurred from LK 1-6 (negative), however in the north area (LK7-13) deposition (positive) occur. The slope showed that beach relatively stable except in LK 6 which had dynamic condition. The result of HWL/MSL showed the profile mild especially the profile behind detached breakwater which include in shelter zone, thus deposition rapidly occurred.

Based on the profile presented in Figure 5-7 the volume of the beach profile can be calculated and analyzed for annual changes. As shown in the Figure 8, by using the volume in 2008 as an initial, it was found that the profile experienced accretion in 2008-2014 and experienced eroded again in 2015. If viewed per year, it was found that in from 2008 to 2010 the profile experienced accretion then experienced erosion in 2011 also same cycle occur with accretion again on 2013 and 2014 then eroded significantly on 2015. The sand loss indicated that profile retreat from initial year observation which have inflection point between HWL and MSL as the reference for shoreline position retreat analysis. Here HWL and MSL used to define the shoreline by year observation.

3.2. Littoral drift analysis
As reference for finding the equilibrium shoreline, MeEPASoL Matlab GUI developed by Beach and Shoreline Management Center Sungkyunkwan University was used for comparison with field observation. By using MeEPASoL the predominant wave angle is 288.2 degree. Obtained shoreline equilibrium position is the combination yellow and blue line as shown in the Figure 9. The equilibrium shoreline analysis is very important to evaluate the shoreline retreat or accretion [7]. Equilibrium means that the condition is stable and balance between internal and external force.

![Figure 9. Equilibrium shoreline by using MeEPASoL](image-url)
Figure 10. Temporal variability shoreline change in Kuta Beach from 2008-2015 both in HWL and MSL reference

Based on tide data in the Benoa Port, the shoreline position used MSL 1.3m and HWL 2.6m as reference. Beach width change by year monitoring showed that the different shoreline position between HWL and MSL is around 10 m as described in Figure 11 and Figure 12. HWL position in 2015 clearly had the same position with beach shoreline in the same year with the satellite image as shown in the Figure 10. The result show that HWL position was more accurate with real condition in the field compare with MSL position. The HWL position showed that the shoreline eroded from initial observation in 2008. Moreover, the HWL position fit with the equilibrium shoreline generated using MeEPASoL, except in the center area LK 4-7 because the submerged breakwater which diffracted the wave direction and make shelter zone behind thus generated the deposition.

Figure 11. Beach width in HWL as reference
Figure 12. Beach width in MSL as reference

Figure 13 shows the 2008, 2011, and 2015 shorelines at HWL and MSL. It is judged that the rotation in the counterclockwise direction was made in 2011 compared to 2008, and it can be seen that due to this result, the littoral drift occurred from the left (south) to the right (north) based on LK7. Judging from the deformation of the shoreline, it is judged that it is caused by the change of the incident main wave direction. In 2015, compared to the coastline in 2008, the HWL coastline retreated, and the MSL shoreline showed erosion on the left (south) and sedimentation on the right (north), mainly due to the influence of coastal sedimentation. However, considering that the retreat width of HWL and MSL is small in the place where the artificial submerged structure is located, it is judged that the shoreline retreat in 2015 had a high wave effect at the level affecting HWL.

Overall, it is judged that the sand volume of the sedimentary system is well maintained, but as the main wave direction changes counterclockwise, the beach erosion will continue on the southern coast and deposition on the northern part, thus the general erosion is likely to occur without controlling such littoral pattern. In the observed data, the volume change, that was caused by beach nourishment from private party, such as hotel or resort, is included in the present analysis.

Figure 13. Shoreline changes in HWL and MSL levels

Figures 14 and 15 show vectors of littoral drift in HWL and MSL, respectively. Although there is a slight difference between HWL and MSL, littoral drift from south to north occurred between 2008 and 2011, and littoral drift from north to south occurred between 2011 and 2015. Considering the month of data collection, namely December 2008, June 2011, and July 2015, the results of the vector and shoreline change were strongly influenced by the western monsoon (December 2008) and the eastern monsoon
(June 2011 and July 2015) so that the resulting littoral drift pattern was different. By using the calculation of $Q$ in equation (9) the magnitude of littoral drift in $m^3/day$ obtained as shown in Figure 16. The littoral drift depth (berm height+closure depth) was considered to be about 6 m by referring to the beach section data.

![Figure 14. Littoral drifts through HWL](image)

![Figure 15. Littoral drifts through MSL](image)

![Figure 16. Magnitude of Littoral drifts (+:north to south; -:south to north)](image)

4. Conclusion
The beach profile survey, which was conducted by Ministry of Public Works and Housing, Directorate of Water Resources, Indonesia in Bali 2008-2015 provided two main information such as beach profile and shoreline change. The beach profile analysis results in each baseline monitoring showed that beach profile in HWL and MSL relatively stable, mild profile, and also well maintain sand volume. The annual
change in shoreline referenced in HWL has a maximum erosion rate of 2.34 m/year and deposition rate of 3.30 m/year. However, in MSL the maximum erosion rate is 1.37 m/year and the deposition rate is 0.38 m/year. Small shoreline change which almost similar with ideal or equilibrium condition indicates that the structure is quite capable of maintaining the stability of the coast. If beach nourishment from private party, such as hotel or resort is neglected and the sand volume of the sedimentary system is well maintained, but as the main wave direction changes counterclockwise, the beach erosion will continue on the southern coast and deposition on the northern part. Thus the general erosion is likely to occur without controlling such littoral pattern. Wave climates have an important role in determining the pattern of littoral drift movement. Therefore, the time of data collection in coherence with the condition of wave and winds direction are very important, thus can be used as ideas for further research.

Furthermore, temporal coastal profile surveys are very important in coastal management steps in order to obtain precise field data. Nourishment and the completion data information recommended to get the better result. This study can be used as input or applied in the assessment of coastal erosion as one of the strategic steps in determining mitigation measures.

Acknowledgments
This research was a part of the project titled Practical Technologies for Coastal erosion Control and Countermeasure’, funded by the Ministry of Oceans and Fisheries, Korea.

References
1. Short AD. Macro-meso tidal beach morphodynamics - an overview. J Coast Res. 1991;7(2):417–36.
2. Lemos C, Floc’h F, Yates M, Le Dantec N, Marieu V, Hamon K, et al. Equilibrium modeling of the beach profile on a macrotidal embayed low tide terrace beach. Ocean Dyn. 2018;69(9):1207–20.
3. Miles JR, Russell PE. Dynamics of a reflective beach with a low tide terrace. Cont Shelf Res. 2004;24(11):1219–47.
4. Brown AC, McLachlan A. Sandy shore ecosystems and the threats facing them: Some predictions for the year 2025. Environ Conserv. 2002;29(1):62–77.
5. Rosati JD. Concepts in sediment budgets. J Coast Res. 2005;21(2):307–22.
6. Valsamidis A, Figlus J, Ritt B, Reeve DE. Modelling the morphodynamic evolution of Galveston beach, Gulf of Mexico, following Hurricane Ike in 2008. Cont Shelf Res [Internet]. 2021;218(February):104373. Available from: https://doi.org/10.1016/j.csr.2021.104373
7. Putro AHS, Lee JL. Analysis of longshore drift patterns on the littoral system of nusa dua beach in bali, indonesi. J Mar Sci Eng. 2020;8(10):1–19.
8. Saputra H. Stufi Pola Sebaran Sedimen Dasar Arus Sepanjang Pantai di Sekitar Pemecah Gelombang Pantai Kuta Bali. J Oseanografi. 2013;2(2013):161–70.
9. Tsuchiya Y. Formation of Stable Sandy Beaches and Beach Erosion Control : a Methodology for Beach Erosion Control Using Headlands and Its Applications. Bull Disaster Prev Res Inst. 1994;44:139–73.
10. Davidson MA, Turner IL, Splinter KD, Harley MD. Annual prediction of shoreline erosion and subsequent recovery. Coast Eng [Internet]. 2017;130(September):14–25. Available from: https://doi.org/10.1016/j.coastaleng.2017.09.008
11. Makfiya N, Siladharmar IGB, Gede IW, Karang A. Analisis Perubahan Garis Pantai dengan Menggunakan Metode One-Line Model ( Studi Kasus : Pantai Kecamatan Kuta , Bali ). 2020;6(2):196–204.
12. Hsu JRC, Evans C. Parabolic bay shapes and applications. Proc - Inst Civ Eng Part 2 Res theory. 1989;87(c):557–70.
13. González M, Medina R. On the application of static equilibrium bay formulations to natural and man-made beaches. Coast Eng. 2001;43(3–4):209–25.
14. Lim C, Lee J, Lee JL. Simulation of bay-shaped shorelines after the construction of large-scale
13

structures by using a parabolic bay shape equation. J Mar Sci Eng. 2021;9(1):1–18.

15. Boak EH, Turner IL. Shoreline definition and detection: A review. J Coast Res. 2005;21(4):688–703.

16. Douglas BC, Crowell M, Leatherman SP. of Coastal Palm Royal Considerations for Shoreline Position Prediction. J Coast Res. 1998;14(3):1025–33.

17. Jean M, Leatherman S, Spring F, Pajakt MJ. of Coastal Palm The High Water Line as Shoreline Indicator fe. Education. 2010;18(2):329–37.

18. Smith GL, Zarillo GA. Calculating long-term shoreline recession rates using aerial photographic and beach profiling techniques. J Coast Res. 1990;6(1):111–20.

19. Masselink G, Short AD. The effect of tide range on beach morphodynamics and morphology: a conceptual beach model. J Coast Res. 1993;9(3):785–800.

20. Kraus, Rosati. Technical note Technical note. 2016;30328(July):1–17.

21. Jaramillo C, Jara MS, González M, Medina R. A shoreline evolution model considering the temporal variability of the beach profile sediment volume (sediment gain / loss). Coast Eng. 2020;156(November 2019).

22. Dolan R, Fenster MS, Holme SJ. Florida Accretion. J Coast Res. 1991;7(3):723–44.

23. Walton TL, Dean RG. Longshore sediment transport via littoral drift rose. Ocean Eng [Internet]. 2010;37(2–3):228–35. Available from: http://dx.doi.org/10.1016/j.oceaneng.2009.11.002