The synthetic study of coastline change using one-line numerical model

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Abstract. The beach is a boundary between the ocean and land changes with time due to erosion and sedimentation events. The study of beach changes aims to understand the condition of the coast towards the factors that influence it, such as wave height, wave angle of arrival, beach area, depth, and groin. The study used synthetic beach conditions data. Furthermore, changes in shoreline caused were modelled with one-line models using numerical method solutions. Modeling results show that shoreline changes increase with time, and are strongly influenced by wave height, wave angle and the distance of waves breaking to the beach. Changes in the coastline are also influenced by the location of the beach structures, the structures of the beach that are parallel to the coast will provide better results to prevent the coast than the structure located off the coast.

1. Introduction

The erosion events that occur on most coastlines result in increasingly reduced land area in the coastal areas. Therefore, an action is needed to prevent the impact of the loss that is increasingly widespread. For this reason, it is necessary to have one method, namely beach nourishment [1]. Beach nourishment is the placement of a large amount of sand suitable to the sea along the coastline which aims to inhibit shoreline reduction by erosion [2].

Some of the beaches in Indonesian have undergone many coastline changes due to abrasion and accretion. Many studies have been carried out regarding changes in shoreline such as by detecting satellite images [3, 4], using direct measurements [5, 6], predictions using a mathematical approach [7, 8] and the study of coastal changes due to beach nourishment [9, 10]. Beach nourishment along the coast provides considerable benefits, the wider the area of landfill, the better the function of the area as a buffer that protects the land from large waves and storms and other benefits as a coastal recreation area. The amount of shoreline changes due to the influence of large waves and strong littoral currents causes the coast to experience erosion [11].

The effect of erosion has a negative impact on communities around the coast [12, 13]. However, how beach nourishment has an effect on shoreline changes will be studied numerically through a finite difference approach by adjusting wave height, wave breaking distance and wave angle.

2. Method

Numerical Solution

In mathematical (numerical) solutions with the explicit finite difference method. The coastline was discretized into uniform grids with a width of Δx divided along the reference coastline and time...
intervals of $\Delta t$ [14]. By using explicit finite differences by implying forward in space and time scheme approach, the discretized equations of beach nourishment are obtained as:

$$\frac{y^{(n+1)} - y^{(n)}}{\Delta t} + \frac{1}{(h_i + B)} \left[ \frac{Q^{(n+1)} - Q^{(n)}}{\Delta x} \right] = 0$$

(1)

$$y^{(n+1)} = y^{(n)} - \frac{\Delta t}{(h_i + B)} \left[ \frac{Q^{(n+1)} - Q^{(n)}}{\Delta x} \right]$$

(2)

Then the discretization of the longshore sediment transport equations is produced:

$$Q_i^n = G \sin(\beta_i^n - \alpha_i)$$

(3)

where

$$G = \frac{KH^2 C_1^2 C_0^{1.2} \cos^{1.2}(\beta_0 - \alpha)}{8(s-1)(1-p)C_k^{0.4}}$$

(4)

$$\beta_i^n = \mu - \frac{\pi}{2} - \tan^{-1}\left( \frac{y^{(n)} - y^{(n-1)}}{\Delta x} \right)$$

(5)

$$\alpha_i = \beta_0 - \sin^{-1}\left( \frac{C_s}{C_0} \sin(\beta_0 - \alpha) \right)$$

(6)

Initial condition

The initial conditions are given when time is zero ($t = 0$), where the initial coastline is:

$$Y(x, t_0) = \begin{cases} y_0, & i \in [m, n] \\ 0, & i \not\in [m, n] \end{cases} \text{ for } i = 1 \text{ to } 180$$

and the sediment transport $Q$ is zero.

Boundary condition

The boundary conditions applied in this model are in the left and right boundaries of the beach, the model is considered to be equilibrium, meaning that the coast is relatively immovable throughout the period of simulation or $\frac{dy}{dt} = 0$ for $t > 0$, $x = 1$, $y = 0$, $x = 100$, $y = 0$ and $Q(1) = Q(2)$; $Q(101) = Q(100)$.

The simulation

All the simulation was run for 1-, 5- and 10-years period and three case studies were taken as case of wave height, case of wave breaking distance and case of wave angle variation. All the case studies are explained below.

1. Case of wave height

   To see the rate of erosion with respect to wave height, a simulation was carried out with varying wave heights, namely 0.5 m and 1 m high. The angle of wave arrival is 90 degrees, the wave breaks at a distance of 5 m offshore and the beach was dumped on the grid 40 to 60 with a distance towards the sea of 40 m.

2. Cases of waves breaking distance

   To see changes in the coast line due to the effect of the distance of the offshore breaking waves, a simulation was given at varying distances 2 m and 6 m of the coast. the initial beach nourishment was located on the grid 40-60, the length of the beach fill towards the sea was 40 m, the coming angle of the wave is 90$^o$ and wave height of 2 m.
3. Cases of wave angles variation
The beach nourishment was located on grid 40-60 with a distance of 40 meters toward the sea, wave height of 2 meters and waves breaking at a distance of 5 meters offshore was set. In this case the simulated wave angle varies from 15° and 45°.

3. Result and Discussion
1. Wave height case study
On this case the higher of wave the faster and more erosion occurred. The simulation results show that the coming wave height has a considerable influence on the beach profile. Figure 1 shows how wave height act to shore nourishment that move sediment more rapidly when initial wave height is developed overthought no other element changed (wave angle and the distance of wave breaking are the same).

The beach profile is influenced by the magnitude of the incoming wave height, varying coming wave heights resulting in changes in different beach profiles. Changes in beach profile are caused by wave movements that transport eroded sediments from a nourishment place into another direction, if this condition occurs for a long period of time then a landfill will experience erosion on the tip of land fill and the accumulation of sand material on the other side.

![Figure 1. The profile of shoreline changes over time due to the increasing wave height](image)

For the case of varying wave heights, it can be seen at 0.5 m wave height (left side of Figure 1), the shoreline reduction is still considerably small compared to 1 m wave height, even though erosion increases as the simulation time increases. In this case the speed of erosion depends on the simulated wave height, the higher the wave, the faster erosion occurs on the shoreline. This happens because the higher the wave, the greater the energy released by the wave [15], so that the turbulent force and sediment transport force at the base will be greater, if the intensity of the wave is lower than the material will settle. For sand material that is lost at the beach dumping site, it can be seen that the material is transported to the area around the coast below it so that the coastline around the landfill site increases towards the sea.

2. Wave breaking distance case study
On this case the closer of wave breaking distance from shoreline can result in more eroded shoreline as it shown on Figure 2. When the wave breaks at a distance of 2 m offshore (right side of Figure 2) it can be seen that erosion occurs rapidly compared to the distance of breaking waves at a distance of 6 m offshore. It is also seen that for a longer distance the erosion rate is getting smaller. This is because the closer, the higher energy of the wave hit the sediment and the energy transferred by the wave gets bigger, consequently the stirring force or turbulence gets bigger, so the force of the shear increases [16]. Therefore, to obtain a better beach profile and reduce erosion, the planning of breakwater structures should be placed at more distance offshore wave energy that reaches the coast will decrease as reducing wave energy will reduce erosion in coastal areas.
3. Wave angle case study

Wave angle also influence the changes of shoreline. Figure 3 shows how the incident of wave angle toward shoreline alters the coastline. The result of this case informs that wave angle of $45^\circ$ has more effective in changing the shore than the wave angle of $15^\circ$. From the results of simulation, it shows that the greater the angle of wave arrival, the greater the speed of erosion. Where the greatest erosion velocity occurs at the $90^\circ$ angle of incidence or perpendicular to the beach.

4. Conclusion

The shoreline change increases with time, where the effect of changes in wave height in longshore sediment transport is greater than the effect of changes in the wave angle. In this case, the higher the wave comes, the greater the beach changes that occur. Erosion rates are faster when the waves break at a shallower depth. Beach nourishment in the direction of the coast provides better results than offshoredlandfill.

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