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Original Paper

Numerical Simulation on Shoreline Change in Western Region of Badung Regency, Bali, Indonesia

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***Abstract*:** Shoreline change is considered the most dynamic processes in coastal region. Coastal erosion is a global problem where 70% beaches around the world are recessional. Almost all coastal area in Bali is potential to suffer from erosion. Badung Regency in Bali has many beaches that famous as tourism area where from about 64 km shoreline length, 11,5 km were recorded suffered by erosion in 1985 and 12,1 km erosion in 2007. This study aims to determine the value of shoreline changes that occur in western of Badung Regency from 2001 to 2010 based on the predicted wave data using monthly wind data from Ngurah Rai, Tuban, Badung, Bali meteorological station. Shoreline change simulation measured the forward (accretion) or backward (erosion) distance of the shoreline on the East-West direction. Bali has wind patterns that influenced by the Northwest monsoon from November-April and Southeast monsoon from May-October. In 2001-2010, dominant wind in this region was coming from east, southeast, and west. Geographically western coast of Badung influenced by incoming winds from the west, southwest, and south. Wind blow towards the coast in 2001-2010 are dominantly come from the west with wind speed range was about 1,7-4,7 m/s. Simulation indicated that generally shoreline tends to experience accretion in the north and erosion in the south. From 16000 m of study shoreline, along 7100 m of shoreline tend to suffer by erosion. Oppositely, along 8900 m of shoreline tend to have accretion.

***Keywords*:** wind distribution pattern; shoreline change; accretion; erosion

1. Introduction

Shoreline change is considered to be one of the most dynamic processes in the coastal area and the change in shoreline is caused by physical process as well as anthropogenic process and has large environmental significance (Chen et al. 2005). Bird (1985) mentioned that coastal erosion is a global problem. At least 70% sandy beaches around the world are recessional.

Erosion is potential for all coasts in Bali. Based on research that made by Bali Work Secretariat of Environment Rescue and Conservation (SKPPLH) in 2011, it was recorded that erosion occurred almost in 40% coastal area of Bali. According to Directorate General of Water Resource, Public Works, Bali (2007), Bali Island has shoreline along 436,8km and 91km of them were damaged. Construction of coastal protection was developed along this shoreline.

Badung is one of regency that located in Bali Island Indonesia. It has many beautiful beaches that famous as tourism area. Badung Regency has 64km shoreline length. Of the total, beach erosion was noted along the 11,5km in 1987 and 12,1km in 2007 (Directorate General of Water Resource, Public Works, Bali, 2007).

In the coastal regions, there are several natural forces that can cause shoreline changes, such as waves, currents, and wind. Wind wave is primary agent in coastal erosion due to their generation, transfer, travel and eventually breaking at the coastline which result in a rearrangement of the shoreline change (Komar, 1983).

Bali has the similar wind patterns with Indian Ocean where the wind is influenced by the monsoon.It is also influence the western region of Badung Regency that faces directly to the Bali Strait. The northwest monsoon occurs from November to April. In this season wind blows from west. On the other hand, the southeast monsoon occurs from May to October and wind blows from the east (Wyrtki, 1961). This pattern occurs every year.

The longshore current which is induced by waves, transports the beach sediments. It potentially moves the sediments for many kilometers in the longshore direction and termed as the littoral drift.Shoreline models is the evaluation of the quantities of sand entering and leaving shoreline cells, and resulting changes in the shoreline position due to balance of input-output. The littoral drift is usually the main cause of sand moving from one cell to another.

Based on Eryaniet al.(2009)'s research about the characteristic of coastal damage, random sediment samples from coastal area of Badung Regency shown that most of this beach can be categorized as sand beach. Research on PantaiKuta that located in the western coast of Badung Regency shows that abrasion at Kuta beach had removed the beach about average 30m. The erosion occurred at Kuta Beach is mainly because of two reasons (Lennartet al.,2004 inHandoko, 2007): 1. Obstruction of currents pattern from south to north by the airport runway disturbed the sediment transport, and 2. Increase wave attack through the gully.

This research was made for evaluating the characteristic of changes along Badung Regency's western shoreline. The objectives of this research are as follows; Determine the wind distribution in Badung Regency during the year 2001 to 2010; Determine the shoreline changes which are the forward (accretion) and backward (erosion) distance of the shoreline on the East-West direction that occur in Badung Regency; Provide an understanding and explanation about the phenomenon of accretion and erosion based on the relation between wind distribution and amount of shoreline changes.

2. Research Methodology

2.1. Research study area

The study area is located along the western shoreline of Badung Regency from Jimbaran to Seseh Beach as shown in Figure 1.

2.2. Data collection

The data used in this research are as follows;Average monthly wind data from 2001 to 2010 obtain from Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) in NgurahRai, Kuta-Badung, Bali, sediment porosity and median size

(D50) of Badung beaches from previous research report by Eryani,etal., (2009), shoreline data from Bali Central Agency on Statistic (BPS).

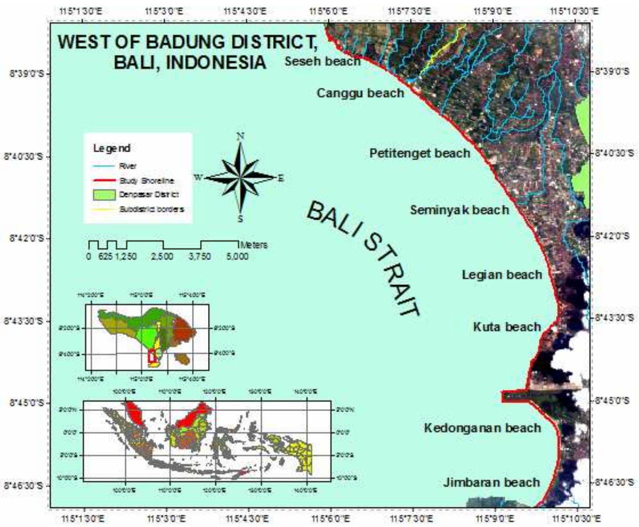

Figure 1. Study Area

2.3. Data analysis method

This study was conducted in two stages. The first is calculating wave parameters using wave prediction from averaged monthly wind data. Second is dividing the coastline into 160 cells with the same width along the shoreline from Jimbaran to Seseh beach. The framework of this research can be seen in Figure 2.

Wind data were adjusted by four steps (USACE, 2008) as follows: Level or elevation, Duration, Overland or over water, and Stability. Wave was predicted in the deep water and growth with fetch. The equation governing wave growth with fetch is (Demirbilek, Bratos, and Thompson (1993) in USACE, (2008)

$$\frac{gH_{mo}}{u_*^2} = 4.13\times10^{-2}\left(\frac{gX}{u_*^2}\right)^{\frac{1}{2}} \quad (1)$$

$$\frac{gT_p}{u_*} = 0.651\left(\frac{gX}{u_*^2}\right)^{1/3} \quad (2)$$

$$u_*^2 = C_D U_{10}^2 \quad (3)$$

$$C_D = 0.001(1.1 + 0.035U_{10}) \quad (4)$$

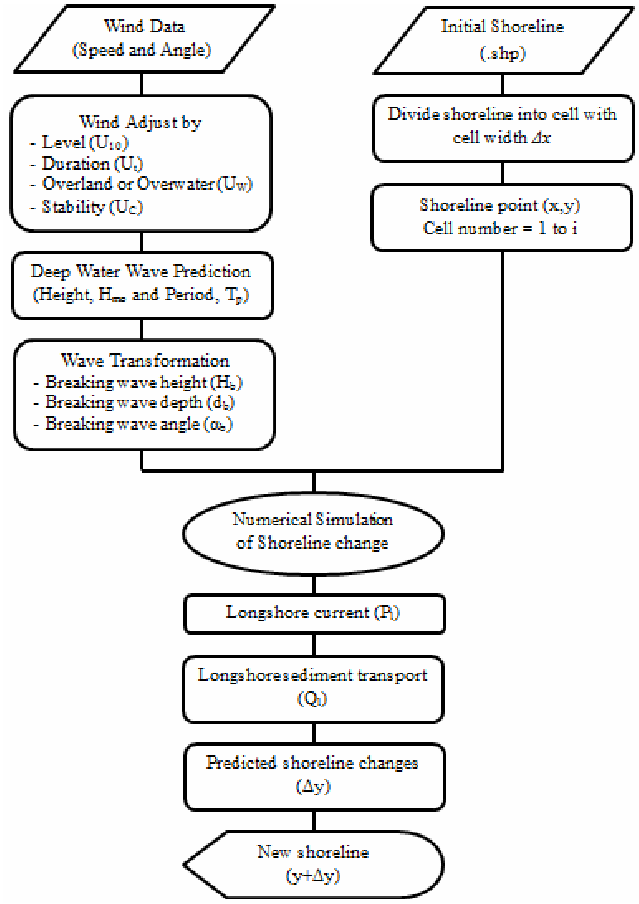

Figure 2. Research Framework

where X = straight line fetch distance over which the wind blows (m), Hmo = energy-based significant wave height (m), C_D = drag coefficient, U_{10} = wind speed at 10 m elevation (m/sec), $u*$ = friction velocity (m/sec).

A wave length L decreases and the wave height H increase as the wave approaches a beach. As a result the wave steepness H/L increases. Moreover, the wave breaks when it reaches a critical steepness. The critical steepness is a function of the relative depth d/L and the beach slope tan β. The wave breaking parameter, both qualitative and quantitative, is the needed in a wide variety of coastal engineering applications (USACE, 2003).

To predict the breaker height Hb, the breaker index is used to describe non-dimensional breaker height. There are two the breaker indices. One is the breaker depth index and the other is the breaker height index.

a. the breaker depth index (γb)

Weggel (1972) in USACE (2003) derived the following expression for the breaker depth index.

$$\gamma_b = b - a\frac{H_b}{gT^2} \tag{5}$$

For tan β 0.1 and *Ho/Lo* 0.06 where *T* is the wave period, *g* is gravitational acceleration. The parameters *a* and *b* are empirically determined functions of beach slope and given by

$$a = 43.75\left(1-\exp\left(-19\tan\beta\right)\right)$$
$$b = 1.56\left(1-\exp\left(-19\tan\beta\right)\right)^{-1} \tag{6}$$

Wave breaking height *Hb* can be estimated from the relationship between equivalent un-refracted deepwater wave height *H'o* and the following breaker height index Ω*b*.

$$H_b = H_0'\Omega_b \tag{7}$$

b. The breaker height index (Ω*b*)

Komar and Gaughan (1973) derived a semi-empirical relationship for the breaker height index from linear wave theory.

$$\Omega_b = 0.56\left(\frac{H_0'}{L_0}\right)^{-1/5} \tag{8}$$

H'o is equivalent un-refracted deepwater wave height. The equivalent un-refracted deepwater wave height *H'o* can be found from the refraction coefficient Kr (USACE, 2003).

$$H_0' = H_0 K_r \tag{9}$$

Ho is the wave height in the deepwater. The deepwater wavelength *Lo* is given by Eq.(10)

$$L_0 = \frac{gT^2}{2\pi} \tag{10}$$

By assuming a constant height-to-depth ration from the break point to shore, the depth of breaking waves can be measured by Eq. (11).

$$d_b = \frac{H_b}{\gamma_b} \tag{11}$$

The wave angle θ for a straight and parallel contour can be written as

$$\frac{\sin\theta}{C} = \text{constant} \tag{12}$$

The equation used to measure the wave angle at the breaking point is

$$\sin\alpha_b = \frac{\sin\alpha_0}{C_0}C_b \tag{13}$$

The above equation is equivalent with Snell's Law in optics. Where *Co* and *αo* are the wave speed and the angle at the deep water, *Cb* and *αb* are the breaking wave speed and the angle of it. *Co* was measured by using the deep water wave speed equation and *Cb* by shallow water equation as shown below.

$$C_0 = \frac{gT}{2\pi} = 1.56T \tag{14}$$

$$C_b = \sqrt{gd_b} = \left(\frac{gH_b}{\kappa}\right)^{\frac{1}{2}} \tag{15}$$

κ is the breaker index *Hb/db*.

Based on Komar and Inman's (1970) in USACE (2002), the longshore sediment transport rateis commonly correlated with the so-called longshore component of wave energy flux as shown in Eq.(16).

$$P_l = E_b C_{gb}\sin\alpha_b\cos\alpha_b \tag{16}$$

where *Eb* is the wave energy evaluated at the breaker line and given by Eq.(17).

$$E_b = \frac{\rho g H_b^2}{8} \tag{17}$$

and *Cgb* is the wave group velocity at the breaker line

$$C_{gb} = \sqrt{gd_b} = \left(g\frac{H_b}{\kappa}\right)^{\frac{1}{2}} \tag{18}$$

Volume transport rate was measured by using equation.

$$Q_l = \frac{K}{(\rho_s - \rho) g (1-n)} P_l \tag{19}$$

ρs is the mass density of the sediment grains; ρ is mass density of water, g = acceleration due to gravity; n = in-place sediment porosity. K is the dimensionless coefficient.K proposed by Komar (1988) as shown in Eq.(20) is used here.

$$K = 1.4 \exp(-2.5 D_{50}) \tag{20}$$

where *D50* is the median grain size of the beach sediment in millimeters.

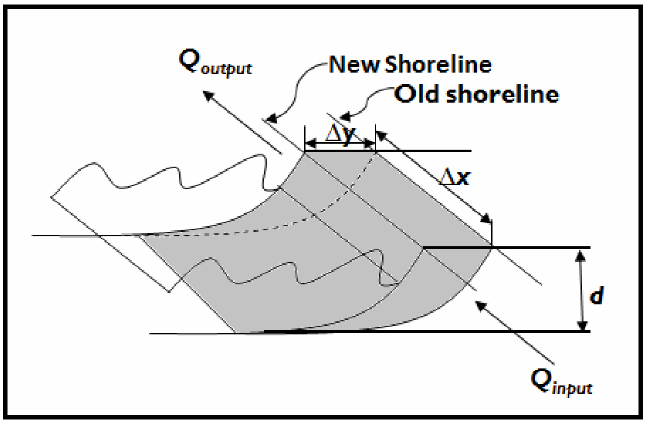

Figure 3. Sediment transport simulation

The simulation of shoreline change was made by modifying the model that was made by Komar (1983). The changes was measured by the volume sediment transport rate that coming inside and outside of each cell. Figure 3 represent the changes that occurred because of the input and output sediment. The shoreline change increment caused by this addition or reduction of transport sediment is calculated by the following equation.

$$\Delta y = (Q_{in} - Q_{out}) \frac{\Delta t}{d \cdot \Delta x} \tag{21}$$

3. Results and Discussion

3.1. Wind speed and direction distribution

Based on the data recorded from 2001 to 2010 shown in Figure 4, it can be seen that the dominant winds come from the east, southeast, and west. Each of this direction has the fastest wind speed more than equal to 10,8m/s which is dominant on the west direction. Wind Rose showed winds from the southeast have the highest number of events is 33% with a resultant vector of 136 degrees.

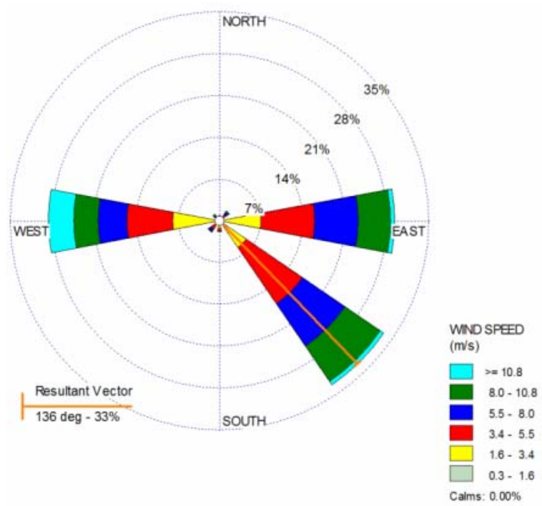

Figure 4. Wind Rose in Western of Badung Regency from 2001 to 2010

Geographically, beach along the western coast of Badung Regency influenced by the waves generated by the incoming winds from west, southwest, and south. In this graph (Figure 4), only wind from the west that shows the dominant direction during 2001 to 2010.

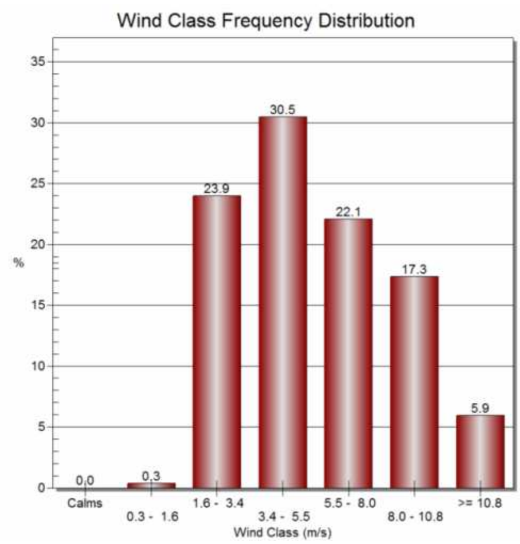

Figure 5. Wind frequency distribution in Western of Badung Regency from 2001 to 2010

Figure 5 shows the frequency distribution of wind speed in 2001 to 2010. The wind at ranging from 3,4 to 5,5 m/s frequently occurred. It has percentage of the occurrence about 30.5% of all.

During 2001-2010, Northwest monsoon (November-April) wind was dominantly coming from the west with speed range 1,7-4,7m/s and total frequency distribution about 28%. In Southeast monsoon (May-October), wind was dominantly come from east and southeast with speed range 2,0-4,7m/s and frequency distribution 29-33%.

3.2. Wind predicted wave

Figure 6 shows the distribution of wind speed and it relation with wave height. It only presents the predicted wave that direction move towards the shoreline. Wave height shows the occurrence of incoming waves dominantly in the first months and the last months of the years.

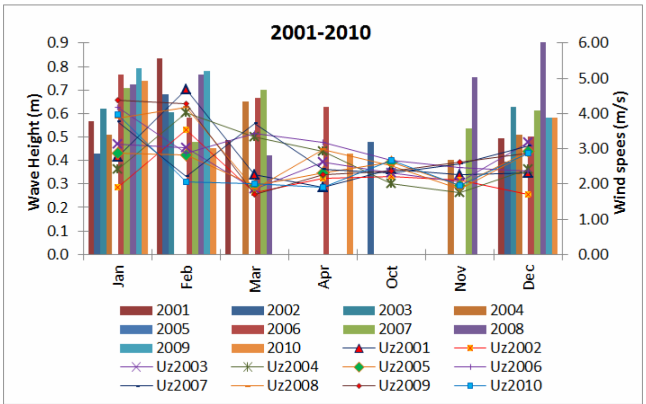

Figure 6. The relation between incoming wind speed and wave height prediction in Western of Badung Regency from 2001 to 2010

The graph shows the predicted waves caused by the incoming wind come from the west. The occurrences of these winds were during the northwest monsoon that occurs on November until April in the Bali Strait. In October 2002, there were unordinary incoming winds that came from west and move towards the Badung Regency shoreline.

Influenced by the northwest monsoon, wind speeds tend to be faster at the beginning of the year (January to April). The range of the wind speed is (1,7-4,68m/s) and at the end of the year (November to December) the wind range is (1,7-3,19m/s). This has a direct impact on the range of high waves in the beginning of the year which is about 0,42 – 0,84 m and 0,39-1,05m at the end of the year.

Generally the relationship between wind speed and wave height shows that the increasing of wind speed affects to the increasing of wave height. This relationship did not happen in the end of 2008 when the slow speed wind influence the development of high wave height. This condition occurs because generally the waves move towards the shoreline is coming from the west while in the end of 2008 waves generated by winds from the southwest.

3.3 Wave propagation

Wave propagation was measured on the same months and year of the prediction wave height. Wave breaking height (*Hb*), breaking angle (*αb*) and depth (*db*) are used as an input for shoreline change simulation.

Wave breaking height has higher height rather than the wave height in the deep water. The range of wave breaking height is 0,44-1,18m. The lowest wave occurs in December 2002 and the highest occurs in December 2008.

Wave breaking angle influence the direction of sediment transport that change the shoreline. In 2003 and 2009, the incoming wave move towards the shoreline only occur three months on January, February, and December while in 2005 until 2008 there are five months that shows the incoming wave move towards the shoreline. These indicators represent that in 2003 and 2009 the contribution of waves to the shoreline is only occur in shorter period rather than in 2005 until 2008.

3.4 Shoreline changes

Simulation of shoreline change from 2001 to 2010 shows that shoreline of Badung Regency from

Jimbaran to Seseh beach experienced accretion and erosion. For description, shoreline change was divided into four group of cell (Figure 7). Figure 8 shows the distribution of changes along the shoreline. This figure shows that group of cell A and B are suffered from erosion while B and D tend to be accretion.

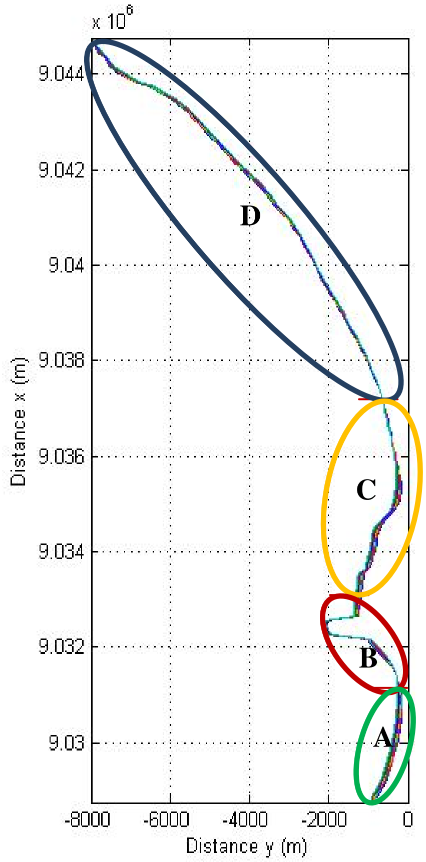

Figure 7. Location of group of cell from A to D in Western of Badung Regency shoreline

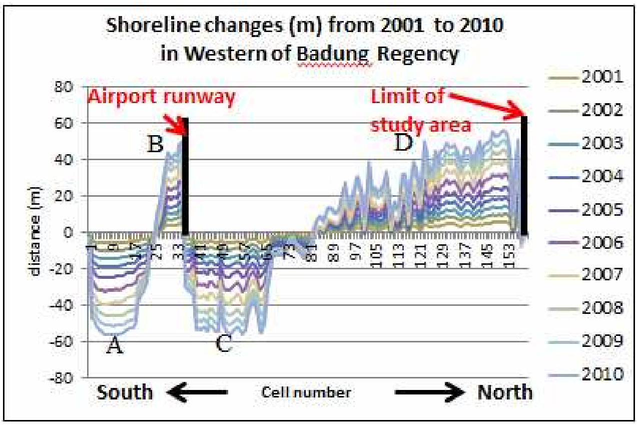

Figure 8. Distance of shoreline changes in Western of Badung Regency from 2001 to 2010

Table 1 show the accretion and erosion distance in the western region of Badung Regency. Group A is located in the range of cell 1 to 24 or around Jimbaran beach. This region is suffered from erosion about 55 to 56,1m from 2001 to 2010. Cell number 25 to 35 or group B is experiencing accretion with range of changes about 0,4-49,9m. This region is located around Kedonganan beach.Group C shows the rate of erosion around Kuta Beach. The backward distance was about 4,7-56m. The last Group D was represents the shoreline around Legian to Seseh Beach. This group shows the accretion distance about 1,2-56m.

Table 1. Accretion and erosion in Western Region of Badung Regency from 2001 to 2010

Group	Cell No,	Length (m)	Shoreline changes(m)
A	1 to 24	2400	5,5 - 56,1 (erosion)
B	25 to 35	1100	0,4 - 49,9 (accretion)
C	36 to 82	4700	4,7 – 56 (erosion)
D	83 to 160	7800	1,2 – 56 (accretion)

Simulation results shows that generally the shoreline tends to experience accretion in the northern part and erosion in the southern part. This is consistent with Lennart et al. (2004) about sediment transport patterns from the south to the north that lead to erosion in Kuta beach. The existence of the airport runway and the northern boundary of the study area limit the sediment transport that lead to sediment accumulation and accretion occur.

4. Conclusions

The distribution of wind data shown that in western region of Badung Regency from 2001 to 2010, the dominated incoming wind direction was from east, southeast, and west. Shoreline was attacked by the incoming wave predicted by the wind influenced by northwest monsoon.

Shoreline model results shown the farthest erosion distance in western region of Badung Regency from 2001 to 2010 is 56,1 m while the accretion distance is 49,9m. From 16000m shoreline length in this region, about 7100m of shoreline tend to suffer from erosion. It occurs around Jimbaran beach about 5,5 to 56,1 m and Kuta Beach about 4,7-56m. Oppositely, along 8900 m of the shoreline tend to have accretion. The range of changes about 0,4-49,9 m around Kedonganan beach and 1,2-56 m around Legian to Seseh Beach.

The incoming wind direction and the shape of western of Badung Regency shoreline determine the longshore sediment transport direction. Simulation of shoreline change shows the accretion and erosion pattern. From 2001 to 2010, wind speeds in the northwest monsoon tend to transport the sediment from south to north. In result, erosion tends to occur in the southern part and accretion in the northern part.

Acknowledgments

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