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Coastal Erosion Prone Area Assessment in Klungkung Regency - Bali Coastal Area, Indonesia.asiite

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ABSTRACT

Coastal hazards affect the majority of sandy shores, and are responsible for damage to, and destruction of settlements, infrastructures, public services and sacred places in Bali's shorelines. However, there is an absence of information regarding the extent of the erosion hazard in Klungkung Regency coastal area. This study aims to assess the suitabilityerosion prone area components and method for assessing them for Klungkung Regency Coastal Area based on available secondary data. Literature review is conducted to evaluate the existingerosion setbacks and previous studies of the location. Then the available information iscorresponded with the erosion components required. For the study location, several erosion setback components that need to be assessed include short-term erosion component, long-term erosion component, sea level rise, dune stability component, and factor safety. Subsequently, shoreline response model is utilized for assessing short-term erosion component, whilst dune scarp migration is conducted to evaluate long-term erosion component. Furthermore, Bruun's Rule is applied to estimate the sea level rise component. It is expected that for future study, a different approach of erosion prone area assessment will be conducted, so the result from this study can be compared with. Additionally, the result of this study is expected to provide the information about coastal erosion assessment methods and reference about coastal erosion for future study.

Keywords: coastal hazards; coastal erosion; erosion prone area; erosion prone area assessment

1. INTRODUCTION

For Balinese, the coastal area holds important roles. Many economic activities such as rice-farming, fisheries, tourist-hospitality, seaweed farming, and sand or gravel mining are conducted in these areas [1-4].Not only providing places to carry out these activities, the coastal area also is an ideal place for settlements. Moreover, the coastal area is a sacred place for Balinese. Most sacred temples where religious services are conducted, are located in the coastal[5].

However, according to reports, 187 km of Bali's coastline is threatened by coastal erosion and needs careful handling [6]. Moreover, several studies, which have been conducted to assess the coastal erosion phenomena in Bali, claimed that coastal erosion has occurred in several parts in Bali, including Jembrana Regency, Gianyar Regency, Denpasar City, Karangasem Regency, and Buleleng Regency [7-11]. Thus, settlements, public services, infrastructure and religious sites in these places are threatened by coastal erosion.

Similar to other coastal areas in Bali, Klungkung Regency coastal area has a variety of land-cover including rice fields, settlements, sacred temples, and traditional ports for fisheries and strait crossings [12]. A study conducted to assess coastal dynamics in Gianyar and Klungkung Regency claimed that the area had been eroded with a rate of approximately 0.88 meter per annum [9]. As a result of this problem, the local communities, property owners and local government are currently considering appropriate responses. However, there is an absence of information regarding the extent of the erosion hazard. Consequently, an uncertain risk assessment might further exacerbate the problem. This study aims to assess the suitable erosion prone area componentsand methods by linkingthe available data from previous studies and erosion prone area setback required for an erosion assessment.

2. METHODOLOGY

A. Study area

The location of the research is based in the Klungkung Regency coastal area of Bali, Indonesia. The location is situated on the northeastern side of Denpasar, Bali. The research location coordinates are 115°22'12"E to 115°28'47"E and 8°34'30"S to 8°33'02"S. The length of coastline in the study area is approximately 11 km.

Figure 2.1Study Location

Source: ArcGIS Pro, 2019

A.1. Beach Type

The study area is a flat beach, which has a low to moderate beach slope (0° to 10°) [13]. The width of the beach is between 3 meters to 15 meters, behind the back of the beach is a secondary crop field [13]. The beach material in the study area is composed of volcanic sand because the fluvial sand is supplied from volcanic mountains [13]. Therefore, the sand found there is black and smooth.

A.2. Water Level

Tides in this location are mixed semi-diurnal types [14]. Based on the analysis high tide occurred twice in a day as did low tide[14]. The highest high-water level (HHWL) is 3,796 m and mean high water level (MHWL) is 2,047 m [14]. Moreover, the highest astronomical tide generated from tidal analysis is 3.9m [14].

A.3. Wave Climate

The height of the average wave in Bali reaches approximately 2.0 to 2.5 m on north Bali and 2.5 to 3.0 m on south Bali [15]. High waves around 2.5 to 3 m are found in south Bali and to the north of Nusa Penida Island where waves come from the southeast [16]. This means that the southern part of Bali, including the Lombok Strait, is directly influenced by the wave energy of the Indian Ocean (from the south). Moreover, the Indian Ocean, which is located south of Java and Bali, has the highest trend of mean significant wave height (SWH) with 5.05 m for January [17].

The direction of wave propagation is strongly influenced by the wind direction. The effective waves fetch from three dominant courses which are the Flores Sea (northeast of Bali), the Lombok Strait (east Bali), and the Indian Ocean through the Lombok Strait (southeast Bali) [18]. While the biggest wind fetch is from the Indian Ocean also (southeast Bali) with a course direction of 135° [18].

A.4. Extreme Wave and Storm Tide

The maximum distance of inundation in the South Bali coastal area, if storm wave and swell occur, is 623.5 m, the run-up vertical height is 1.02 m and the depth of maximum inundation in the area is 0.46 m[19]. Moreover, extreme waves occur around the Indian Ocean, which is south of Java and Bali, is caused by the swell from the direction of Western Australia, and are highly associated with monsoon cycles, from Asia and Australia [20, 21]. The positive result of this phenomena is that the wave is colder in this area and contains more nutrients [22].

B. Erosion Setback Components and Data Required

Coastal erosion prone area is a composition of several coastal hazard seatback assessments [23, 24].

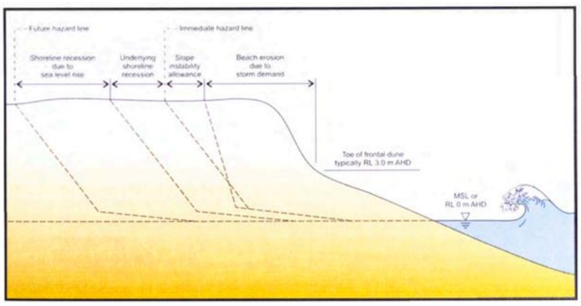

Figure 2.2Erosion setback components

Source: Mariani et al. ,2012

B.1. Short-term erosion (S1)

Short term erosion component is obtained from the assessment of the probability of occurrence of storms, which have been recorded statistically [23]. During a storm event, significant wave height and storm tide level factors interact with the coastline for a length of time (duration). Assessment, of the horizontal slump of the beach associated with storm events, with the techniques available varies from purely empirical procedures to those combinations of practical and theoretical considerations. Several methods to predict beach instabilities in response to erosive phenomena during storm events are presented on the Table 2.1.

Table 2.1Short-term setback model assessment

Source: Kinsela&Haslow, 2013; Mariani et al, 2012.

No	Name	Type	Data Input	Description
1	SBEACH	deterministic process	- beach profile or dune profile - nearshore bathymetry - offshore wave parameters - water levels sediment properties	Two-dimensional cross shore transport based on cross shore transport sand
2	XBeach	deterministic process	- beach profile or dune profile - near shore bathymetry - offshore wave parameters - water levels - sediment properties	Two-dimensional storm impact model of wave propagation, long waves and mean flow, sediment transport
3	Probabilistic Coastline Recession	statistical process	statistical observation data of - wave climate - water level - periods between storms	Analysis and calculation of a long set of realistic erosion and its recovery
4	Shoreline Evolution Model	deterministic process	- beach profile or dune profile - near shore bathymetry - offshore wave parameters - water levels - sediment properties	It has capacity to simulate short geological time scale of shore evolution and investigate sea level rise impact
5	Shoreline Response Model	statistical process	- water level (tide, surge, sea level rise) - wave input (significant wave height, period and direction) - sediment properties	Combination of both longshore, cross-shore sediment transport, and estimation response of the beach to sea level rise
6	Geometric Profile Models	deterministic process	water level input (including extreme events)	Two-dimensional cross with estimated sand loss due to storm events

B.2. Long-term erosion (S2)

Underlying recession component is known as long-term erosion component. It happens due to persistent loss of beach and dune sediments to onshore, offshore, and alongshore or sediment sinks [23]. It can be interpreted from the historical trend of shoreline position shifting towards the inland. Here are approaches to assess long-term erosion setbacks.

Table 2.2 Methods of long-term erosion setbacks

Source: Kinsela&Haslow, 2013

No	Technique	Data input	Potential Limitations
1	Longshore sediment budget	- ground survey - LIDAR survey - beach profile	reliable quantification of longshore sediment budget is difficult to attain and often require long-term survey datasets
2	Dune-scarp migration (photogrammetry)	- time series aerial photographs - multi-temporal satellite images	the accuracy of magnitude and estimation from recent recession rates are low the confidence of projected estimation due to map scale is not rough
3	Profile-area-volume analysis (photogrammetry)	- time series aerial photographs - multi-temporal satellite images - beach profile - ground survey	the accuracy of magnitude and estimation from recent recession rates are low the confidence of projected estimation due to map scale is not robust
4	Dune-scarp migration and profile-area-volume analysis (photogrammetry)	- time series aerial photographs - multi-temporal satellite images - ground survey - beach profile	the accuracy of magnitude and estimation from recent recession rates are low the confidence of projected estimation due to map scale is not robust

B.3. Sea level rise (S3)

The sea level rise component is an uncertain element of coastal erosion because it needs future period planning as a consideration for parameter input. This is due to the time frame planning, which is beyond ahead, and the uncertainty of meteorological parameters included as data input to predict the sea level rise [25]. There are several methods that have been developed to estimate coastal response to sea level rise. Basically, these methods use a basic geometry principle or more complex process-based assessment. Here are several methods to estimate sea level rise component.

Table 2.3Approaches for sea level rise component assessment

Source: Mariani et al, 2013

No	Technique	Data input	Description
1	The Bruun rule	- water level - slope of the beach face - planning years	Based on assumption that as sea level is raised, the equilibrium profile is moved upward and landward conserving mass and original shape The major uncertainty is the definition of closure depth The limitation is the lack of any leg time between sea level change and profile response
2	Shore face translation model	- beach profile - planning years	It represents a pragmatic modelling approach based on simple geometric transformation and sediment budget principles the accuracy of the results depends on the user's understanding of the physical processes affecting a particular site
3	Komar geometric model	- water level - slope of the beach face - planning years	the results produced is parallel with short-term erosion component (S1) it is not suitable for assessing long-term profile where the accretion occurs
4	RD-A model (Davidson Arnott)	- beach profile - planning years	refusion of the Bruun Rule model it has not been compared with field or laboratory measurement
5	EShorance	- water level - slope of the beach face - planning years	it is similar with the Bruun Rule model, but it is for an estuarine environment
6	Process based model	- time series of storm waves - water level - beach profile	it presents a powerful framework, but without adequate site-specific data a significant uncertainty still remains
7	Shoreline response model	- beach profile - wave data - water level	It calculates the equilibrium or maximum response profile to a change in wave or water level condition and then incorporates an exponentially lagged response to simulate more natural response

B.4. Beach rotation (S4)

Beach rotation component comprises a returning cycle change in the alignment of a beach's planform due to changes in the wave course over medium (weeks to months) to long (decades) term time scales [23]. The significance of beach rotation for different sections of the coast is likely to vary with latitude, orientation, and length [23, 26]. Moreover, the requirement of differential sediment transport evokes a minimum embayment length, which exists for shoreline variability due to beach rotation [23]. Kinsela and Hanslowin 2013, provided several techniques to assess the beach rotation setback component in New South Wales, as shown on the Table 2.4 [26].

Table 2.4Techniques to determines beach rotation setback

Source: Kinsela&Hanslow, 2013

No	Technique	Description	Limitations
1	Reference beach state	It is utilized for hazard definition and represents average shoreline planform or future conditions that contribute to enhanced or moderate erosion	Do not reflect the potential for coincident medium term erosion and episodic storm-induced erosion
2	Mean wave direction variability	It is a linear shoreline planform from normal to incident waves for calculating potential rotation	Future wave climate remains uncertain
3	Photogrammetry	It analyses historical records for identifying any erosion or accretion records pattern	Frequency of aerial photograph capture remains low confidence for the isolated beach
4	Shoreline evolution model	It utilizes sampled model wave climate that considered to be representative of the exact condition of the location.	Do not provide full description of the range potential conditions particularly interdecadal wave climate and storm induced beach rotation.

B.5. Dune stability (S5)

Dune stability factor encompasses a setback component relating to the geotechnical stability of dunes [23]. According to Ramsay et al. in 2012, the generic formula to determine dune stability factor is applying thirty degrees slopes in the calculation[25].However, in a tropical area with a humid climate, a dune is rarely found. Beach profile commonly found in tropical climate area consists of sandy beach with low beach ridge and little transgressive dune development [27]. The lack of dunes development in humid tropical area is due to the high intensity of precipitation on the area, meager sediment sorting in the beach and nearshore zone and low wind energy at the shoreline due to the nature of the coastal orientation [27, 28].

B.6. Factor safety (FS)

Factor safety (FS) is the calculation procedure adopted for erosion prone area width determinations and are consistent with current engineering practice in this field but are subject to uncertainties and limitations. Typically, it is associated with the calculation of short-term erosion, ongoing recession component, and sea level rise[23]. However, in NSW, the calculation procedures of factor safety are used for short term erosion, continuous recession component, and sea level rise and dune stability component[26].

C. Data analysis

Literature review from previous research on the location are performed to generate available data. Cross tabulation data are conducted to check the available data with the required data in each presented technique. Suitable method is applied based on the availability data.

3. RESULTAND DISCUSSION

A. Short-term erosion component (S1)

The available data generated from previous studies are presented on the table below

Data	Available	Source
Beach Profiles	Not available	-
Dune profile	Not available	-
near shore bathymetry	Not available	-
Offshore wave parameters	Not available	-
Water level / tidal level	Available	Indonesia Geospatial Information Agency
Sediment properties	Available	(Parawangsa, Arthana, & Ekawaty, 2018; San-Nami et al., 2013)
Wave climate statistical data	Not available	-
Periods between storm	Not available	-
Wave input (significant wave height, period, and direction)	available	(Bachtiar & Novico, 2012)
Extreme events	available	(Ningsih et al., 2012)

Based on the table above, the available data assessed for this component are tidal level, sediment properties, wave input data, and extreme events data. Hence, the component is assessed using shoreline response model.

B. Long-term erosion component (S2)

While for the long-term erosion component, the existing data are shown on the table

Data	Available	Source
Ground survey	not available	-
LIDAR survey	not available	-
Multi-temporal satellite images	available	Google earth (2003, 2005, 2013, 2015, and 2019)
Aerial photographs	available	Indonesia Geospatial Information Agency (1994)
Beach profile	not available	-

Multi-temporal satellite images are utilized to evaluate this component. Aerial photograph is not employed for calculating due to unmatched scale and image distortions. Dune scarp migration technique is performed to analyze this component.

C. Sea level rise component (S3)

The available data toevaluate sea level rise component is presented on the table below

Data	Availability	Source
water level	available	Indonesia Geospatial Information Agency
slope of the beach face	available	(San-Nami et al., 2013)
planning years	available	generic set for 2050 and 2100
beach profile	not available	
wave data	not available	

Water level data, slope of the beach face and planning year are obtained to predict this component. Bruun's Rule is selected to estimate the future sea level rise on the study location.

D. Beach rotation component (S4)

No available data is presented for this component and it can be seen on the table below

Data	Availability	Source
high resolution aerial photography	not available	-
recording videos of the location in a period time	not available	-
beach profile	not available	-

No data available to calculate this component, therefore this component is disregarded.

E. Dune stability component (S5)

Required data for this component is slope of the beach face. To obtain this component on-screen measurement on Google Earth from water face to vegetation line is implemented.

F. Factor safety (FS)

No particular data is required to assess this component because the calculation is subjected to the calculation of other setback components such as short-term erosion setback (S1), long-term erosion setback (S2), and sea lever rise setback (S3). Hence this component is an uncertainty factor of prior setbacks calculation. Therefore, this component is included into computation.

4. CONCLUSIONS

A coastal prone area component for Klungkung Regency is generated from four seatback components and uncertainty factor, including short-term erosion component, long-term erosion component, sea level rise component, dune stability component, and factor safety. Subsequently, shoreline response model is applied to assess the short-term erosion component, while dune scarp migration is utilized to evaluate the long-term erosion component. Moreover, the Bruun's rule is employed to estimate the sea level rise component. The setback components are established on the availability of secondary data, whilst the presented methods are based on previous studies. Hopefully, the result of coastal erosion prone area assessment using these setback components can be applied as information source about coastal erosion study for future research.

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