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SPATIAL DYNAMICS OF TSUNAMI PRONE AREAS IN KALIANDA SUB-DISTRICT, SOUTH LAMPUNG REGENCY

Dita Wahyu Primastuti[1], Mangapul P. Tambunan[2], Triarko Nurlambang[3]. Marlina Adisty[4]
[1,2,3] Department of Geography, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Indonesia
[4] Education and Training Center, National Management Disaster Agency, Indonesia
Email: dita.wahyu01@ui.ac.id

ABSTRACT

Kalianda Sub-District is one of the areas that is vulnerable to earthquakes and tsunamis because it is located on the west coast of Sumatra Island and the Sunda Strait has a potency from the eruption of Anak Krakatau Volcano. Increasing population growth also increases the risk of disaster impacts that are difficult to predict. This research aims to analyze the spatial dynamics of tsunami-prone areas in Kalianda District. This research uses multi-temporal land cover data, driving data on built-up land development factors, existing roads, slope, distance from the coastline, and distance from rivers. The method used is Cellular Automata Markov Chain which is used to model the development of built-up land, and the Berryman method for tsunami hazard analysis . Based on modeling results for 2031, the type of built land cover will experience a large increase. The tsunami danger level in Kalianda District is dominated by the low level covering an area of 4,741.80 ha, then the high level covering an area of 3,047.29 ha and the medium level covering an area of 1,243.66 ha. According to research results, the number of tsunami-prone areas increases every year. Therefore, we need to improve education and outreach to the public about tsunami dangers and effective evacuation procedures. The development and maintenance of evacuation support infrastructure, as well as the implementation of a reliable early warning system, are also very important to increasing community preparedness for tsunami disasters.

KEYWORDS	*Cellular Automata Markov Chain, Tsunami, Spatial Dynamics, GIS*

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INTRODUCTION

The increase in population and the need for settlement land demands the expansion of the area to be used as settlement area, so that the coastal area becomes a priority for the development of settlement in Kalianda district, South Lampung district. (Supriatna et.al., 2020; Rakuasa et.al., 2022). Good development planning cannot guarantee that a region is free from natural and social disasters, so consideration of the threat of disaster must be well integrated and based on the concept of Sustainable Development Goals.

According to the Meteorological, Climatological and Geophysical Agency's Climate Change Catalogue, the Kalianda catastrophe has a potential for tsunamis caused by earthquakes and volcanic eruptions. Thro history, the waters of the Sundar Strait have suffered several times. According to Gutscher and Westbrook (2007), the tsunami-induced tsunami is generally associated with a slow subduction zone that normally produces a mega-thrust earthquake (M>8.2). The potential tsunami of the volcano is usually caused not only by its eruption, but also by the fall of volcanic products discharged into the sea or the collapse of part/all of its body into the ocean (White, 2007). According to the 2023 Disaster Risk Index of Kalianda district, Lampung South district has a high risk index for tsunami disasters. Proved geographical, geological and demographic conditions affecting this region are very vulnerable to tsunami as a disaster that is difficult to predict its arrival.

The major tsunami disaster that occurred on December 22, 2018 reached a maximum height of 13 meters (Muhari et al., 2019) was produced in the Sunda Strait. There are three districts in the province of Lampung affected by the tsunami, namely Lampung South District, Tanggamus District, and Pesawaran District. Based on the geographical conditions of the Kalianda district, which is vulnerable to earthquake and tsunami disasters, with increasing population growth then the awakened land will grow even more, this can increase the risk of earthquakes and tsunamis as a disaster that is difficult to predict. Based on this, there is a need for a prediction of the spatial dynamics of tsunami-prone areas in Kalianda district that can be done with the Cellular Automata Markov Chains (CA MC) model. The CA MC model is used to predict the land cover patterns of Kalianda Districts in 2031, this model shows how large and where the change in land cover occurs. (Mustafa et.al., 2021).

The type of land cover awakened in 2023 and the results of the CA MC modeling in 2031 will be overlaid with tsunami hazard maps obtained from the variable-variable overlay results that affect a tsunami-exposed area such as coastline, land use, wave height, and slope bending. The results of this research are very important as information in policy-making related to setting up a space based on mitigation of tsunami disasters in Kalianda district. The purpose of this research is to analyze the spatial dynamics of tsunami-prone areas in Kalianda Sub District, South Lampung regency, Lampung province.

RESEARCH METHOD

The research was carried out in Kalianda district, Lampung South district of Lampung Province, which has an area of 226.05 km^2 (Central Agency of Statistics, 2021). The study uses data from the 2019 and 2023 Sentinel 2A images that have been masked in the cloud using the Google Earth Engine (GEE) platform and a 2015 pan-sharpened Landsat 8 level 1C image to analyze changes in land coverage in the Kalianda district obtained from the BAPPEDA South Lampung. Data on inclination of slopes, height of land, obtained from DEMNAS - Geospatial Information Agency data processing results, data on distance from roads and distance from the economic activity center obtaining from the data Processing results of RBI District of Lampung South - Geospacial Information Agency.

The research work consists of processing land cover data, processing tsunami hazard data, and processing of settlement data for 2023 and model results for 2031 that are in the tsunami-prone area in Kalianda district. Land cover analysis begins with geometric correction, interpretation and digitization as well as classification on existing multitemporal satellite images referring to SNI 7465:2010 (National Standards Body, 2010), which is simply classified into 5 classes namely settlements, open land, swamps, plantations, and water bodies.

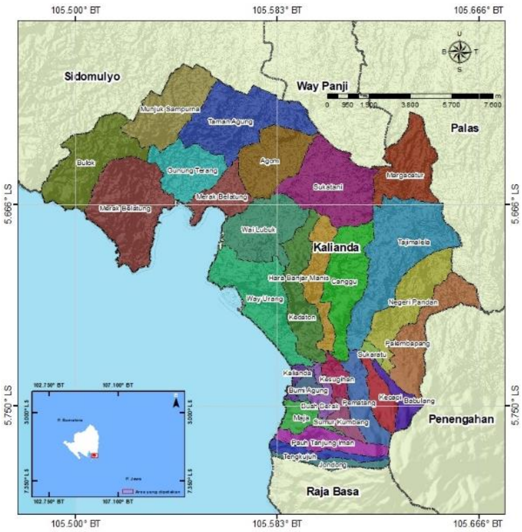


Figure 1. Study Area

The driving factor used in the study consists of the slope slope, the height of the ground, and the distance from the road. Factor driving data is classified and weighted based on the level of suitability of settlement development. (Lisanyoto et.al., 2019). The driving factor variable can be seen in Table 1.

Table 1. Classification of Driving Factors

Variable	Class	Score
Land Height	0-7 m dpl	1
	8-25 m dpl	3

	26-100 m dpl	2
	>100 m dpl	1
Slope	4-15%	2
	>15%	1
Distance from Road	0-100 m	3
	101-1000 m	2
	>1000 m	1

The already classified driving factor data is then converted to a fuzzy value, and then a Fuzzy overlay process is carried out to combine all the data. Fuzzy is a logical system that aims to formulate estimates of assessments reflected in the form of levels of interest that have a range of values 0-1 (Boolean) (Espitia et al., 2021). According to Ghosh dkk. (2017), fuzzy logic is an excellent method to define data obtained continuously, effectively and efficiently, which is a very good process to perform modeling based on Cellular Automata (CA) considering using parallel computing that consists of interrelated cells and has a continuous value so in this study the author processes the data of drivers by applying the concept of fuzzi logic.

Data processing is carried out in several stages, namely: (1) Preparation of satellite image data of Sentinel 2A 2019 and 2023 that covers mosaics and cloud masking, this process is done based on cloud in the Google Earth Engine (GEE) platform, (2) Landsat 8 image masking to produce a better spatial resolution (15 m2/px), should use the same image between the two years, but because of the limits of images Sentinels 2A that are clear coverage for the years 2015 and 2016 then the alternative used is Landsat image 8 that has been performed space resolution masking. This process is carried out in Arcmap 10.8. Classification supervised land closure in 2015 and 2019, this process is done in Envi 5.3. Land cover modeling for the year 2023 based on land cover data 2015 and 2019 controlled by the existing road variable as the driving variable of change. This process is carried out in the TerrSet 2020/Idrisi application. Land cover modeling of the year 2031 in this study using cellular automata and markov chain methods. Markov Chain Cellular Automata Modeling combines two different methods namely the Markovchain, which is an empirical/statistical model, whereas cellular automatata is a dynamic model embedded in the GIS platform. (Marko et.al., 2016).

The cellular analysis process of automta markov chain to predict land cover change in 2031 assumes that patterns of land cover changes or trasilation probability occurring from 2015 to 2019 and from 2019 to 2023 can be used to forecast the change pole from 2023 to 2031. Then validate the land cover model of 2023 using the existing land cover data of 2023, and if the model accuracy test (Kappa Coefficient) >75% then it can be predicted for the year 2031. (Marko et.al., 2016)

Tsunami hazard variable processing refers to the tsunami calculation technique used by BNPB in the mathematical calculation developed by Berryman (2006) based on the calculation of tsunami height loss per 1 m of standing height based on distance to slope and surface rigidity values. The mathematical equation developed by Berryman (2006) is based on the calculation of the tsunami height loss per 1 m of the Hloss height range used, i.e. where;

$$H_{loss} = \left(\frac{167\, n^2}{{H_0}^{1/3}}\right) + 5\, Sin\, S$$

Sumber: Berryman, 2006

Hloss = loss of tsunami height per 1 m of distance
n = surface rigidity index
H0 = the height of the tsunami wave on the coastline
Sin S = the size of the surface slope

In this equation, the sin value of slope inclination (Sin) is required so that the degree value of the slope needs to be converted into radians. The conversion is done with the data of slopes inclinations with the unit of degrees multiplied by 0.01745 (the result of π/180). N shows the value of the surface rigidity index obtained from land use.

Table 2. Roughness Coefficient by Land Use Type

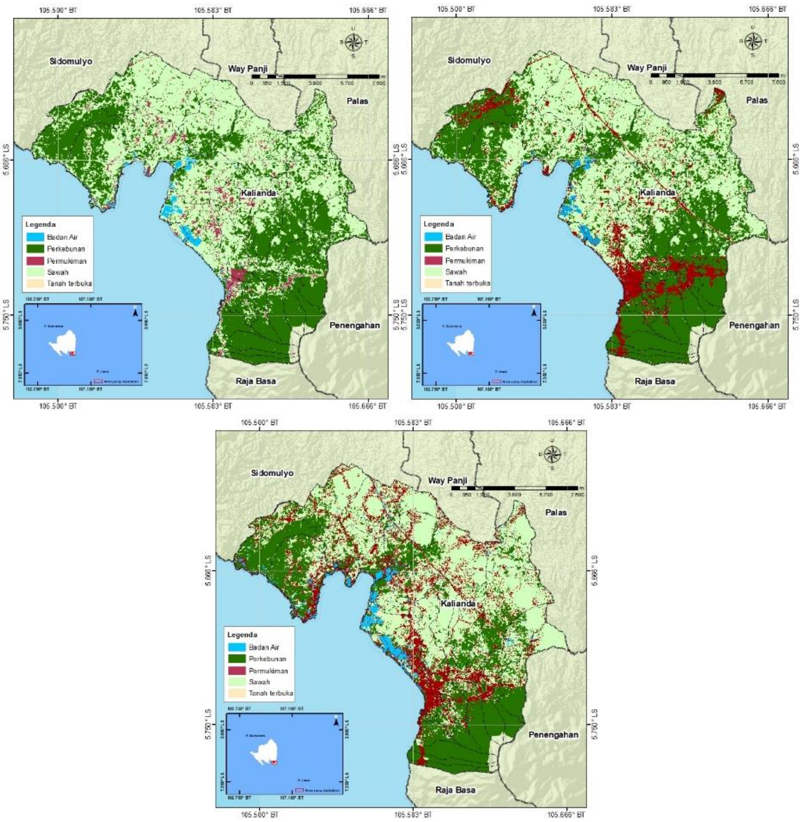
Types of Land Use	Surface Roughness Coefficient
Water Bodies	0,007
Swamp	0,0015
Dam	0,007
Pond	0,010
Shrubs/Bushes	0,040
Forest	0,070
Garden	0,035
Tegalan/Farm	0,030
Paddy	0,020
Settlements/Land Built	0,050

The Cellular Automata Markov Chains (CA MC) modeling is expected to help the government policy of Lampung South district in setting up a space based on tsunami disaster mitigation ahead of it. This research aims to find out the spatial dynamics of tsunami-prone areas in Kalianda district.

RESULT AND DISCUSSION

Land cover in 2015, 2019 and 2023

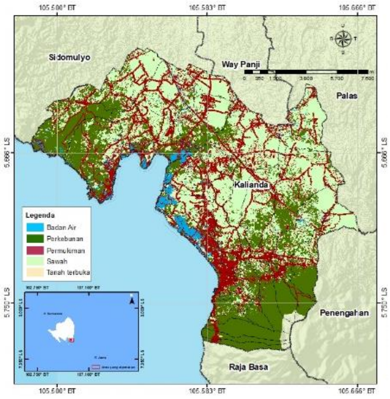
Changes in land coverage in Kalianda district, Lampung South district during the period 2015-2023 showed an increase in the type of land cover of settlements and open land, while in the types of agricultural land cover and non-agricultural soil coverage there was a decrease. High population gains can increase the land needs realized through physical development, economic or social facilities. The extent of the change in land coverage in Kalianda district in 2015, 2019, and 2023 can be seen in Figure 3 and Figure 4.

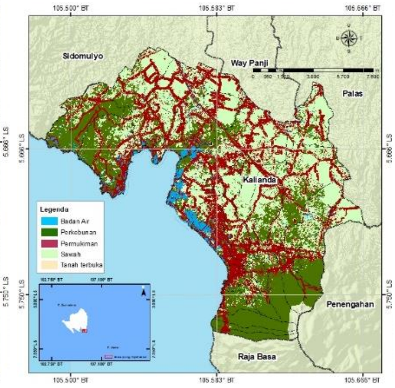


After the 2022 model is manufactured, the model must be tested for accuracy. The accuracy test is performed to determine whether the first resulting model can be applied to produce a second prediction model. The accuracy test was carried out using the existing land cover data of 2022 as reference data (Ghalehteimouri et.al., 2022) and the model data for the 2021 land cover prediction as a comparative image. A comparison of the 2022 model coverage results and the 2022 land coverage existing can be seen in figure 5. The accuracy test results can be obtained a kappa value (K standard) of 88% which indicates that this value is proven to be great and can be applied to modeling the land coverage of the Kalianda district in 2031.

Land Cover Models 2027 and 2031

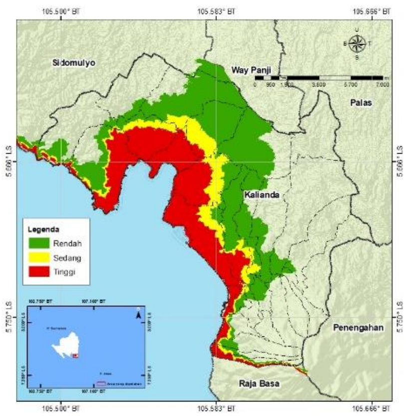
Based on the results of the modeling of land coverage of the Kalianda district in 2031 using cellular automatic method markov chains can be seen that there has been a wide increase in the land cover type of settlements and open land as well as the otherwise there is a decrease in the area of land Coverage of agricultural and non-agricultural areas while the type of water bodies land cover does not increase or decreases its size. One of the most influential factors in the increase in the area of settlements by 2031 is accessibility or distance from the highway. The higher the accessibility of a city to its people, the higher the productivity of the city, the more likely it will be to move forward, and vice versa. (Zhou et.al., 2022).





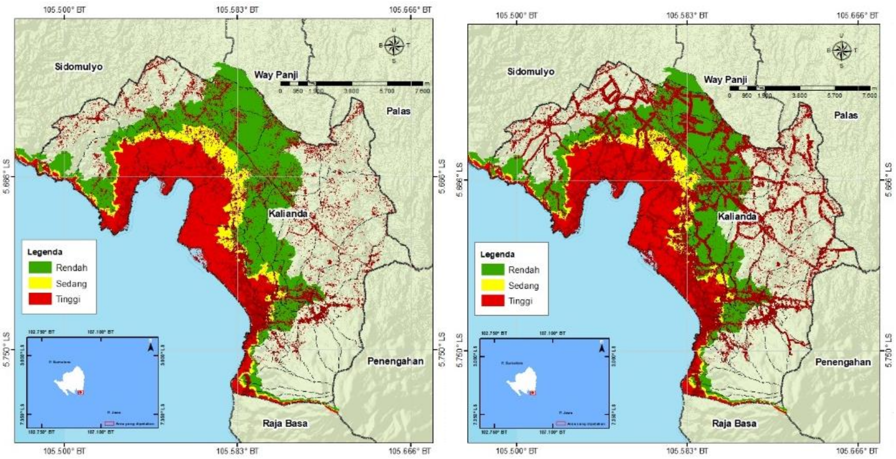
Tsunami hazard level

The area affected by the tsunami was treated on the basis of a tsunami calculation technique used by the BNPB using mathematical calculations previously developed by Berryman. (2006). In this study, the modeling used a scenario based on the last tsunami with wave heights of 13 meters (Muhari et.al., 2019) resulting in an area of the area exposed. According to the tsunami hazard maps produced, there are 16 villages that are partly or entirely in the high tsunami risk class, and as many as 19 villages which are partially or fully in the moderate tsunami danger class.



Spatial Dynamics of Land Dispersion Recovered in 2023 and 2031 in a tsunami-prone area in Kalianda

Based on the results of tsunami hazard management and supported by past tsunami records, the majority of Kalianda districts are at moderate hazard intensity. Tsunami disasters are a top priority threat that must be anticipated in order to minimize the adverse impact of both deaths and damage to buildings. One form of anticipation is to estimate the extent of the settlements that have been analyzed using the markov-chain cellular automata located in the tsunami area. In this study, the tsunami hazard class is divided into three, namely low, medium and high. Each class is overlayed with land awakened in 2023 and land awake in 2031 CA MC modeling results. Kalianda district is a tsunami vulnerable area because it is located on the coastline and directly bordered with the Banda Sea. Based on the results of the analysis of the area of land wakened in 2022 and 2031 which is in the tsunami hazard class in Kalianda Districts it was concluded that there was an increase in the area awakening in the zone vulnerable to tsunami. This is because the area of awakening will continue to increase as the population grows and the high demand for land to build and settle. The area of wakening that is in the area vulnerable to tsunami has a direct relationship with the years of development of the land awakened, so that as the year increases the size of land of the settlements that are in the zone vulnerable tsunami also increases.



CONCLUSION

The change in land coverage in the Kalianda district from 2015 – 2023 occurred dynamically. The increase in the type of coverage of awakened land and open land occurred significantly and consistently from the period 2015 – 2023. The results of the forecast of land coverage in 2031 indicate that even awakened land will continue to experience widespread increase with population growth and high demand for land resources. The analysis of tsunami hazard maps in Nusaniwe district indicates an increase in the area of awakening land in the tsunami-prone area in 2022 and 2031. This is because the area of awakening land will continue to increase as the population grows and the need for land to build is increasing.

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