

IMPACT OF LAND USE CHANGES ON THE TSUNAMI HAZARDS IN PART OF COASTAL KEBUMEN

DAMPAK PERUBAHAN PENGGUNAAN LAHAN TERHADAP BAHAYA TSUNAMI DI SEBAGIAN PESISIR KABUPATEN KEBUMEN

*Bagus Pamungkas**

Program of Geo-Information for Disaster Management,
The Graduate School, Universitas Gadjah Mada

Djati Mardiatno and Arry Retnowati

Faculty of Geography, Universitas Gadjah Mada

Submitted: 2023-01-04; Revised: 2023-04-04; Accepted:2023-06-08

ABSTRAK

Penelitian ini dilakukan untuk menganalisis perubahan penggunaan lahan tahun 2016 hingga 2022 dan dampaknya pada zona bahaya tsunami di sebagian pesisir Kabupaten Kebumen. Penginderaan jauh, sistem informasi geografis (GIS), dan uji statistik diterapkan pada citra satelit Sentinel-2A untuk analisis perubahan penggunaan lahan. Bahaya tsunami disimulasikan menggunakan pemodelan inundasi tsunami berdasarkan data spasial penggunaan lahan dan Data DEM Nasional (DEMNAS) yang diolah menggunakan GIS. Perubahan penggunaan lahan terjadi cukup signifikan pada area penelitian terutama di Kecamatan Mirit. Jalur Jalan Lintas Selatan (JJLS) dan kondisi morfologi pesisir dinilai memengaruhi pola perubahan penggunaan lahan. Perubahan penggunaan lahan berdampak pada perubahan zona bahaya tsunami terutama pada penggunaan lahan hutan cemara dan tambak udang. Hasil temuan penelitian dapat dijadikan masukan untuk pengembangan rencana mitigasi bencana tsunami dan perencanaan detil tata ruang di pesisir Kabupaten Kebumen.

Kata kunci : *Perubahan Penggunaan Lahan; Bahaya Tsunami; JJLS; Citra Sentinel-2A; DEMNAS*

ABSTRACT

This research was conducted to analyze land use change from 2016 to 2022 and their impact on the tsunami hazard zone on the coast of Kebumen Regency. For land use change analysis, remote sensing, geographic information systems (GIS), and statistical tests were applied to Sentinel-2A satellite imagery. The tsunami hazard was simulated using tsunami inundation modeling based on land use spatial data and DEMNAS processed using GIS. Land use changes occurred significantly in the study area, especially in Mirit District. The Southern Cross Road (JJLS) and coastal morphological conditions influence land use change patterns. Land use changes impact changes in the tsunami hazard zone, especially in the use of fir forests and shrimp ponds. The research findings can be used as input for developing a tsunami disaster mitigation plan and detailed spatial planning on the coast of Kebumen Regency.

Keywords: *Land-use Change; Tsunami Hazard; JJLS; Sentinel-2A Imagery; DEMNAS*

*Corresponding author: bagus.pamungkas@mail.ugm.ac.id

Copyright ©2023 THE AUTHOR(S). This article is distributed under a Creative Commons Attribution-Share Alike 4.0 International license. Jurnal Teknosains is published by the Graduate School of Universitas Gadjah Mada.

INTRODUCTION

The south coast of Java Island has a tsunami threat that needs to be watched out for. Tsunamis are a series of sea waves with a large-scale impact from earthquakes, landslides, and volcanic eruptions that occur spontaneously in the sea [1]–[3]. Some of the southern coasts of Java Island have records of occurrence and potential for tsunamis with run-up heights of up to 15 m [4]–[9]. On July 17, 2006, a tsunami-triggered earthquake (Mw 7.7) occurred at a depth of 34 km and, centered 225 km off the south coast of Pangandaran Regency (9,2220°S, 107,3200°E), had an impact extending to the south coast of Kebumen Regency [6], [10], [11]. On the coast of Kebumen Regency, 12 people died, 46 people were missing, 27 people were injured, and 1388 people were evacuated to a safe place [6], [11]. Tsunami inundation modeling for tsunami hazard assessment on the coast of Kebumen Regency conducted by several researchers resulted in a tsunami inundation of 600 m to 3,300 m from the coastline [12], [13]. Several tsunami risk studies have shown that parts of the coast of Kebumen Regency are at high risk [14]–[16].

The coast is a strategic area for people's lives and livelihoods. The coast is a meeting zone of land, sea, and atmospheric systems with unique physical conditions and natural resources [1], [17]. Utilization of natural resources results in the development of infrastructure to support economic and social activities [18]–[20]. Road infrastructure is one of the factors triggering land use changes in regional development [21], [22]. The Southern Cross Road (JJLS) was built in parts of the coast of Kebumen Regency, Central Java Province, from 2016 to 2019 [23]. JJLS causes

an increase in land prices and land use changes on the Kebumen coast [24].

JJLS is designated as a strategic area in the 2011-2031 Regional Spatial Plan (RTRW) of Kebumen Regency, which can be a trigger for regional development [25], [26]. Land use change is an impact of regional development that can be identified with multitemporal spatial data. This study aims to analyze land use changes from 2016 to 2022 and their impact on the tsunami hazard zone on the coast of Kebumen Regency. A further aim is to identify the types and spatial patterns of land use that affect changes in the tsunami hazard zone. It is hoped that the findings of this research can become input for developing a tsunami disaster mitigation plan and detailed spatial planning for the coast of Kebumen Regency.

METHOD

The research location is part of the coast of Kebumen Regency, covering the coastal area to the JJLS area (figure 1). JJLS at the research location is approximately 1 km from the coastline. Coastal areas can be identified from the topography, lithology, and hydrology conditions resulting from fluvial, marine, and aeolian geomorphological processes [27]. Specifically, the research location is located between the estuary area of the Lukulo River to the estuary area of the Wawar River with flat to gentle slope conditions [16], [28], [29]. The coastal lowland lithology is a segregated loose sand beach sediment formation zone. Common landforms at the study site include beach ridges, swales, lagoons, coastal plains, and floodplains [30]. The research locations are included in three districts, namely Buluspesantren, Ambal, and Mirit.

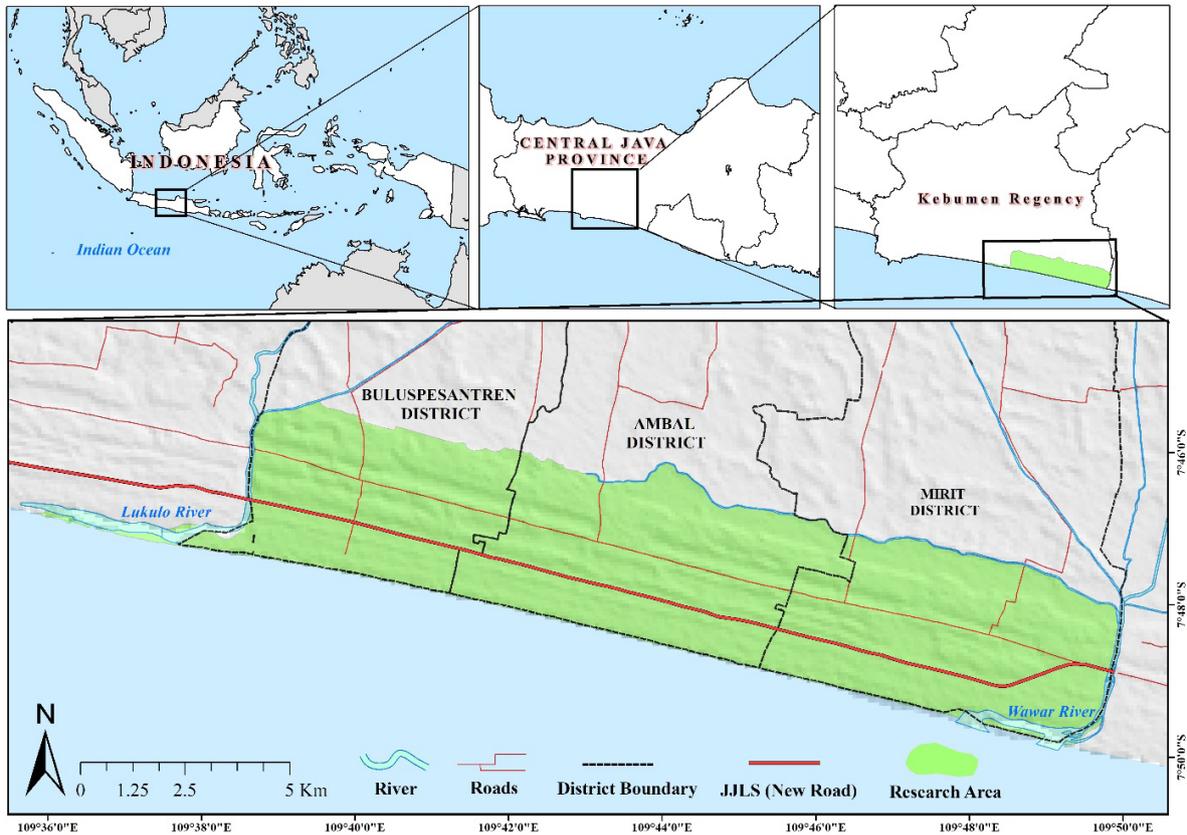


Figure 1.
 Research Areas
 Source: Author Analysis (2022)

The first spatial data used in this research is Sentinel-2A satellite imagery in 2016 (before JJLS was built) and 2022 (after JJLS was completed), which were downloaded via <https://earthexplorer.usgs.gov/>. Visual interpretation of Sentinel-2A satellite imagery with a spatial resolution of 10 m is used to identify land use. The 2014 national land cover classification standard [31] is used for land use classification. The confusion matrix method was used to test the accuracy of land use data, and the stratified proportionate random sampling method was used to determine field check samples [32], [33]. The first analysis used an overlapping technique based on a geographic information system (GIS) to determine land use changes in area and distribution. The second analysis was carried out by logistic regression statistical

tests to determine the effect of JJLS on changes in land use [34]–[36].

The second spatial data used in this research is the National Digital Elevation Model (DEMNAS) provided by the Government of Indonesia obtained from the Geospatial Information Agency (BIG) via <https://tana-hair.indonesia.go.id/demnas/#/>. DEMNAS with a spatial resolution of approximately 8.3 m or 27-arc-second is converted to a Digital Terrain Model (DTM) using GIS filtering techniques. The DTM accuracy test was conducted according to the 2019 base map accuracy guidelines [37] based on field elevation measurements using a GNSS Receiver [38].

DTM and Sentinel-2A were processed using GIS to identify coastal morphology and then used as material for analyzing the third pattern of land use change through the GIS overlapping technique. DTM is convert-

ed using GIS to generate slope data. Spatial data (raster) of land use in 2016 and 2022 are converted into surface roughness coefficients (table 1) based on expert judgment [38]–[41].

Data on slope gradient, surface roughness (2016 and 2022), and a 15 m wave height scenario on the shoreline based on previous research [6], [13], [14] are calculated using the formula developed by Berryman (2006) to create a tsunami inundation model. A spatial model of tsunami inundation refined using GIS to generate tsunami hazard zones for 2016 and 2022 [41], [42]. The 2016 and 2022 tsunami hazard zones were compared with the GIS overlay technique to analyze hazard zone change patterns. The Hawke’s Bay equation is shown in equation 1 [39].

$$H_{loss} = (176 n^2 \div H_0^{1/3}) + 5 \sin S \dots\dots \text{(Equation 1)}$$

where H_{loss} is the loss of tsunami water height per 1 m of inundation distance, H_0 is the height of the tsunami waves at the shoreline (m), S is the slope (in degrees), and n is the surface roughness coefficient [10], [39]. The Manning coefficient for surface roughness (n) in several land use classes is shown in Table 1.

The results of the analysis of land use change, tsunami hazard, suitability of land use to the RTRW, and morphology are used as the basis for preparing a land use pattern structuring plan. Literature studies on mitigation strategies by selecting land use in areas that have experienced a tsunami and environmental impacts are also considered in preparing a plan for structuring land use patterns [43]–[46].

Table 1.

Manning Coefficient for Surface Roughness (n) in Several Land Use Classes

No	Landuse	Surface Roughness Coefficient
1	River	0.007
2	Shrimp	0.008
3	Coastal Swamp	0.015
4	Mangrove Forest	0.06
5	Shrubs	0.04

No	Landuse	Surface Roughness Coefficient
6	People’s Forest	0.07
7	Coconut Gardens	0.035
8	Mixed Garden	0.035
9	Fir Forest	0.045
10	Agricultural Field	0.03
11	Residential Yard	0.04
12	Settlements	0.05
13	Industry-Trade	0.035
14	Bush	0.03
15	Salt Ponds	0.008
16	Sand beach	0.018
17	Pavement	0.01

Sources: [38]–[41] and Data Analysis (2022)

RESULTS AND DISCUSSION

Land Use Change

The results of land use identification in 2016 obtained 16 classes and increased to 17 land use classes in 2022. The accuracy test of land use data based on 210 field check samples has an overall accuracy of 84.8%. Using Sentinel-2A satellite imagery for land use identification has the same accuracy value as several similar studies [47], [48]. The analysis of land use change found that there had been extensive changes in several land use classes in the three districts of the research area (figure 2). The highest percentage of land use change occurred in Mirit District is 5.4%. While the Ambal District is 2% and the Buluspesantren District is 1.7%. The land use that increased the most in the area was a 107-ha shrimp pond. Agricultural land is the land use that has decreased the most in the area (174 ha). Many shrimp ponds were built in Mirit District (84 ha) and Ambal District (32 ha) on land previously serving as agricultural fields. There has been a change in agricultural land use to become shrimp ponds because the productivity potential of shrimp ponds is more economically profitable [49]. The second order of land use that has increased in the area is the trade-industry sector of chicken farming and commercial buildings in coastal tourism (33 ha). Industrial trade development is evenly distributed in Mirit,

Ambal, and Buluspesantren districts. Many chicken-trading industries were built on land that previously functioned as coconut plantations and mixed gardens. Other land uses

that experienced an increase in area sequentially from largest to smallest were shrubs (30 ha), pavement (19 ha), fir forests (19 ha), shrubs (14 ha), mangrove forests (8 ha), salt ponds (5 ha), and settlements (3 ha).

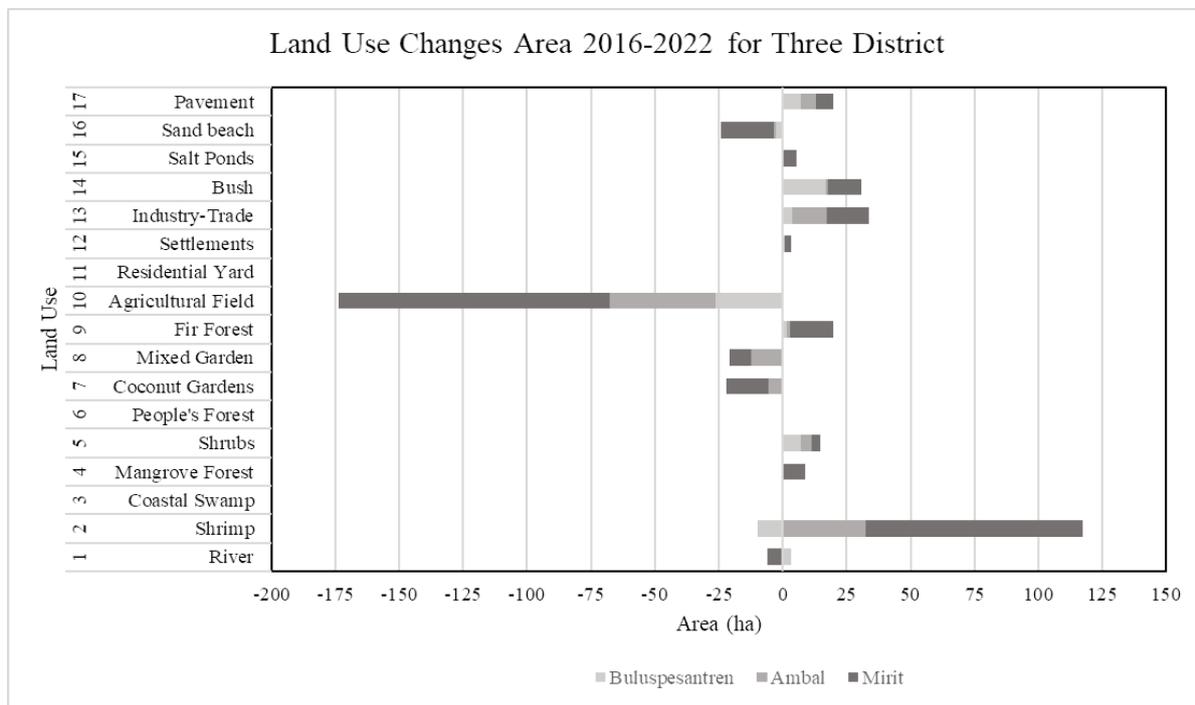


Figure 2.
Graph of Changes in Land Use Area in The Three Sub-districts in The Research Area
Source: Author Analysis (2022)

Analysis of the effect of JJLS on land use changes used a sample of land use that changed (Y=1) and did not change (Y=0) as the dependent variable (Y) and the distance (m) of the sample land use to JJLS as the independent variable (X). In Figure 3, 210 samples of land use are distributed (105 land use changes and 105 land use does not change) and used for statistical logistic regression tests. The simple logistic regression test results can be interpreted based on Table 2 (A and B). The significance value (sig.) in Table 2-A shows a value of 0.000 or less than 0.05 (sig <0.05), which informs that there is a significant influence of the independent variable (X) on the dependent variable (Y)

[34]. Then the Negelkerke R Square value in Table 2-B shows a coefficient of determination of 0.559, meaning that the independent variable (X) is a factor that influences 55.9% of changes in the value of the variable (Y) [34]. The overall meaning based on statistical tests shows a significant effect of JJLS on land use changes that occur in parts of the coast of Kebumen Regency. Other factors that trigger changes in land use should be taken into account because the focus of the research object is JJLS as a strategic infrastructure built in the vulnerable period of 2016 to 2022. JJLS is an infrastructure with great potential to support progress in various fields of economic and social activity [50], [51].

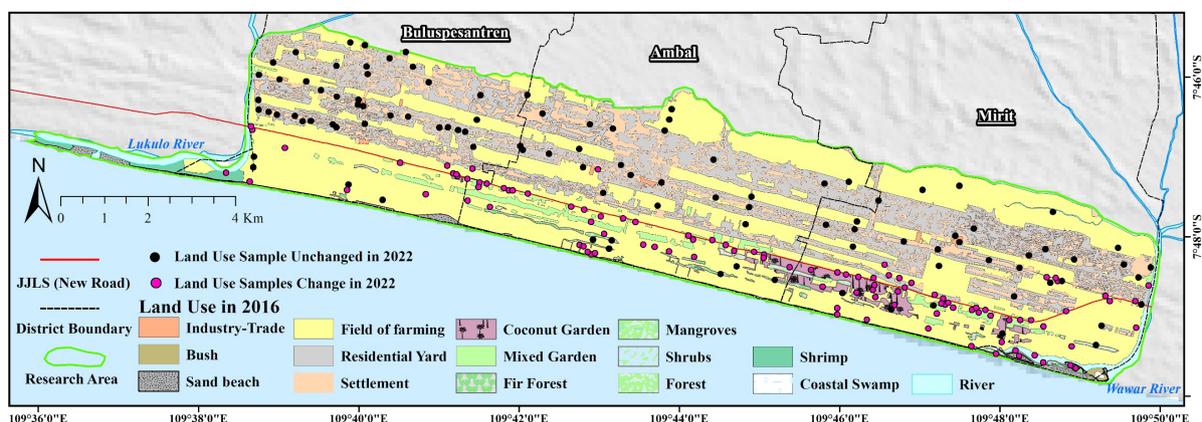


Figure 3.
Spatial Distribution of Land Use Change Sample Points for Statistical Tests
Source: Author Analysis (2022)

Table 2.
Logistic Regression Statistical Test Results of The Effect of JJLS on Land Use Changes in 2016-2022

(A) Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1 ^a	X1	-.004	.001	53.982	1	.000	.996
	Constant	2.518	.374	45.436	1	.000	12.406

a. Variable(s) entered on step 1: X1.

(B) Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Negelkerke R Square
1	176.881 ^a	.420	.559

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than .001.

Source: Data Analysis (2022)

DEMNAS is converted to DTM through a selection process (GIS-based filtering) based on land use data and maintains a spatial resolution of 8.3 m. Land uses with significant differences in elevation from the elevation of the ground surface, such as forests, plantations, and settlements, are subject to elevation adjustments. Land uses such as shrubs, agricultural fields, and beach sand are considered to have an elevation close to the ground level. The DTM accuracy test based on 131 elevation measurement points in the field (figure 4A) shows a vertical accuracy (LE90) of 4.8 m and a horizontal accuracy

(CE90) of 5.1 m. The DEMNAS accuracy test is based on the same 131 elevation measurement points, resulting in a vertical accuracy (LE90) of 6.2 m and a horizontal accuracy (CE90) of 5.1 m. Guided by SNI 8202-2019, DTM accuracy results are relevant to produce 1:25,000 scale maps, while DEMNAS accuracy is relevant to produce 1:50,000 maps. DTM is used to identify coastal morphology based on Standard Procedure Norms for Land System Mapping Criteria Scale 1:25,000/1:50,000 [52]. DTM is converted to hillside, slope, and geomorphic to help identify coastal morphology [53], [54].

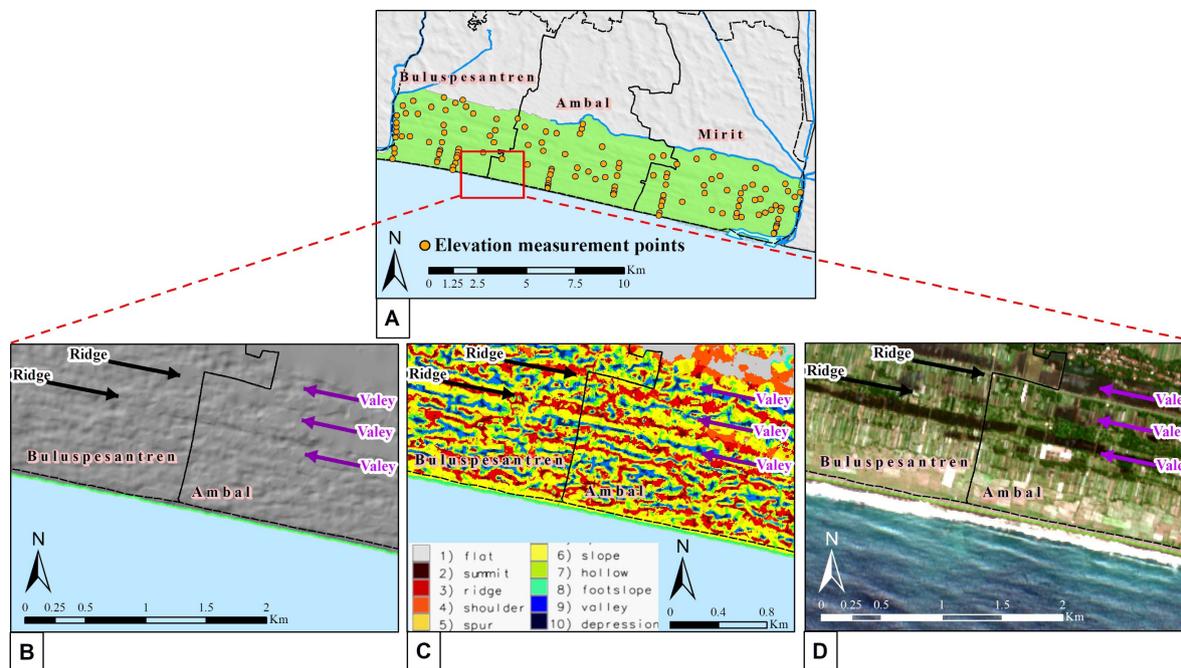


Figure 4.
 (A) Spatial Distribution of Elevation Measurement Points, (B) Hillshade, (C) Geomorphon, (D) Sentinel 2-A Imagery Recorded April 11, 2022
 Source: Author Analysis (2022)

The dominant morphology identified at the research site was ridges and valleys, alternating in an elongated pattern parallel to the coastline (figure 4B-4D). The elongated morphology of the basin/valley is sometimes flooded during the rainy season, as seen in the Sentinel-2A satellite image (figure 4D). The morphological stretches of alternating ridges and basins for approximately 3 km from the shoreline can be classified as beach ridges and swales. The pattern alternates between the beach ridge and swale approximately 100 m to 300 m apart. Then there is a dominant morphology of broad plains with flat to gentle slopes, and there are small river flow patterns that can be classified as alluvial plains. Identified the morphology of the relatively narrow plains on the right and left sides of the river, which are sometimes stagnant with water, can be classified as a floodplain. Then identified lagoons and spit at the

estuary of the Wawar River and the estuary of the Lukulo River. The pattern of residential land use develops following the morphology of beach ridges starting from 1.5 km from the coastline. Most of the basin (swales) is used for agricultural land. Newly developed land uses such as industrial-chicken trading, and JJLS were also developed to suit the morphology of beach ridges. During the pattern of land use development for shrimp ponds, the majority lies in the morphology of elongated valleys (swales) starting from 500 m from the shoreline and partly located on a beach ridge near the estuary of the Lukulo River. Mangroves develop in lagoons and floodplains near the estuary of the Wawar River. Fir forests develop on the coastal plains associated with tourism sites. Figure 5 illustrates the spatial distribution of land use change on coastal morphology.

BAGUS PAMUNGKAS, DJATI MARDIATNO, AND ARRY RETNOWATI ❖ IMPACT OF LAND USE CHANGES ON THE TSUNAMI HAZARDS IN PART OF COASTAL KEBUMEN

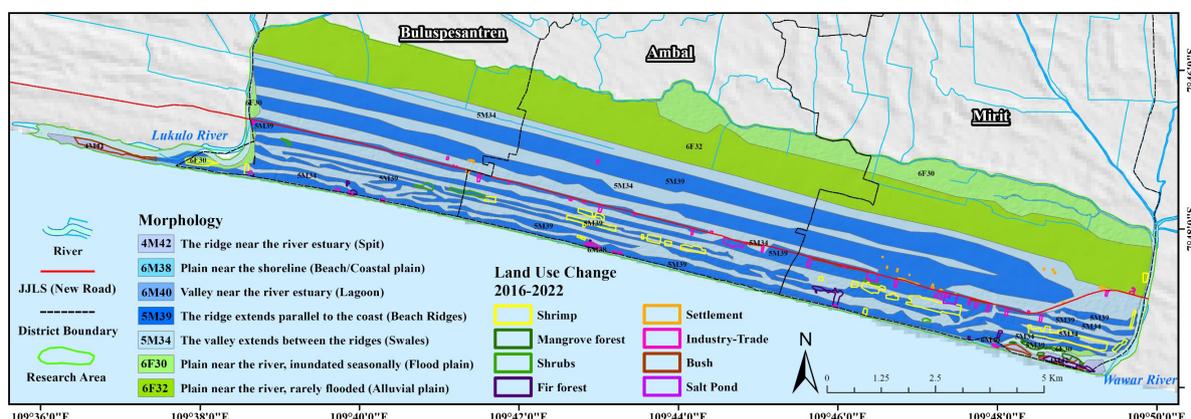


Figure 5. Spatial Distribution of Land Use Change to Coastal Morphology
Source: Author Analysis (2022)

Tsunami Hazard

The results of the tsunami inundation modeling in 2016 and 2022 resulted in a change in the area of the tsunami hazard zone (table 3). The 2016 tsunami inundation modeling resulted in a tsunami hazard zone of 1606.20 ha, and the results for 2022 increased to 1629.13 ha. The farthest range of tsunami inundation was 3.5 km from the coastline towards the Wawar River channel (figure 6). The most expansive tsunami hazard zone is in Mirit District. Changes in the tsunami

hazard zone (2016-2022) in Mirit District increased by 16.60 ha, Ambal District increased by 7.03 ha, and Buluspesantren District decreased by 0.7 ha. Agricultural land is the most significant land use in the tsunami hazard zone. Settlements that are included in the tsunami hazard zone are only found in Mirit District. Most industrial-commercial land uses included in the tsunami hazard zone are commercial buildings in tourism areas. Most shrimp ponds are included in the tsunami hazard zone because of their location close to the coastline.

Table 3. Changes in The Area of Tsunami Hazard Zone from 2016 to 2022

No	Landuse	Hazard Area - District (ha)						Hazard Area - Land Use (ha)	
		Buluspesantren		Ambal		Mirit		TOTAL	
		2016	2022	2016	2022	2016	2022	2016	2022
1	River	90.26	93.64	0.00	0.00	82.71	76.59	172.96	170.23
2	Shrimp	48.26	38.41	0.00	20.66	0.00	57.07	48.26	116.13
3	Coastal Swamp	0.00	0.00	0.00	0.00	4.16	4.16	4.16	4.16
4	Mangrove Forest	0.00	0.00	0.00	0.00	3.71	12.66	3.71	12.66
5	Shrubs	0.00	3.81	1.11	1.40	9.69	12.06	10.80	17.27
6	People’s Forest	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.08
7	Coconut Gardens	0.00	0.00	0.38	0.38	26.17	25.12	26.54	25.50
8	Mixed Garden	1.38	1.25	4.88	4.90	12.74	10.55	19.00	16.70
9	Fir Forest	2.88	4.30	43.83	45.51	24.03	40.50	70.74	90.30
10	Agricultural Field	285.22	268.67	361.93	344.71	379.24	328.62	1026.39	942.00
11	Residential Yard	0.00	0.00	0.00	0.00	12.25	13.51	12.25	13.51

No	Landuse	Hazard Area - District (ha)						Hazard Area - Land Use (ha)	
		Buluspesantren		Ambal		Mirit		TOTAL	
		2016	2022	2016	2022	2016	2022	2016	2022
12	Settlements	0.00	0.00	0.00	0.00	21.93	21.94	21.93	21.94
13	Industry-Trade	1.19	4.11	0.26	2.55	0.00	1.95	1.45	8.61
14	Bush	0.00	16.94	0.00	0.00	6.98	16.44	6.98	33.38
15	Salt Ponds	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	Sand beach	76.58	73.94	42.51	41.84	61.59	40.54	180.68	156.32
17	Pavement	0.00	0.00	0.00	0.00	0.33	0.33	0.33	0.33
TOTAL		505.76	505.06	454.91	461.94	645.53	662.13	1606.20	1629.13
Δ Area Landuse Change (ha)		-0.70		7.03		16.60		22.93	

Source: Author Analysis (2022)

Spatial analysis of tsunami inundation (2016 and 2022) shows that there have been several changes in the extent of the tsunami hazard zone from the coastline in several areas (figure 6). The farthest range of the tsunami hazard is 3.5 km through the Wawar River channel and inundating the area on the west side of the Wawar River for 600 meters. The reach of the tsunami hazard zone through the Lukulo River channel is 1.5 km.

The difference in the range of the tsunami hazard in the two river channels is because the estuary of the Lukulo River is not parallel to the main river channel (the channel turns west near the coast). In contrast, the estuary of the Wawar River tends to be parallel to the main river channel. The farthest reach of the tsunami hazard zone is on the coast, which is not in contact with the river channel, about 780 m from the coastline.

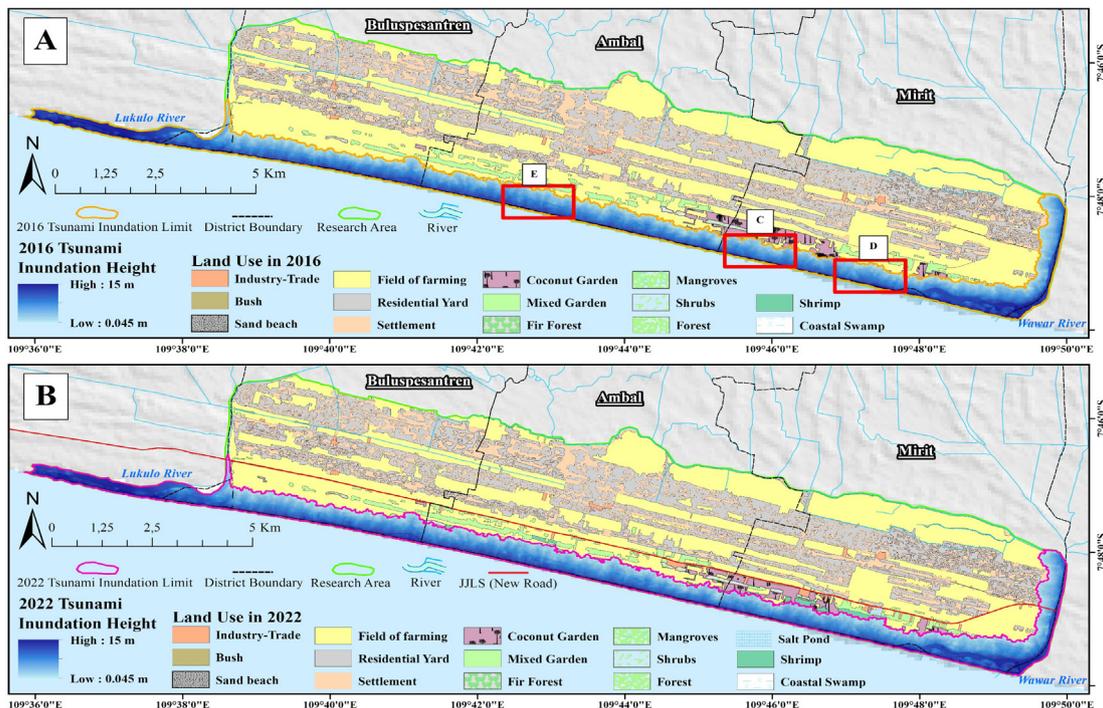


Figure 6.
 (A) Tsunami Inundation in 2016 and (B) Tsunami Inundation in 2022
 Source: Author Analysis (2022)

In some areas of land use change, the tsunami hazard range has also changed as far as 50 m to 80 m. On the part of the coast in Mirit District (figure 7C), the tsunami hazard range reached 550 m, then decreased to 500 m. Land use (figure 7C) has changed extensively from 70 m to 450 m, from agricultural fields to fir forests. Different conditions were found in other areas in Mirit District (figure 7D); the tsunami hazard range was 660 m, then increased to 730 m. Land use (figure 7D) has changed from agricultural fields to shrimp ponds at 550 m to 750 m. One comparative condition is located in Ambal District (figure 7E), showing that the change in tsunami reaches tends to remain around

675 m despite changes in land use. Land use change (figure 7E) occurred at 50 m to 100 m, where previously agricultural fields became fir forests and trade tourism; agricultural fields also turned into shrimp ponds at 550 m to 720 m. Analysis of the tsunami hazard zones from three different locations found that changes in the type and spatial pattern of land use impacted changes in the extent of the tsunami hazard zone. Types of land use, such as fir forest with a suitable surface roughness coefficient as a barrier to tsunami inundation, can be developed on the coast parallel to the coastline [45]. Then shrimp ponds that have a poor surface roughness coefficient as a barrier to the rate of tsunami inundation should be developed in the safe zone.

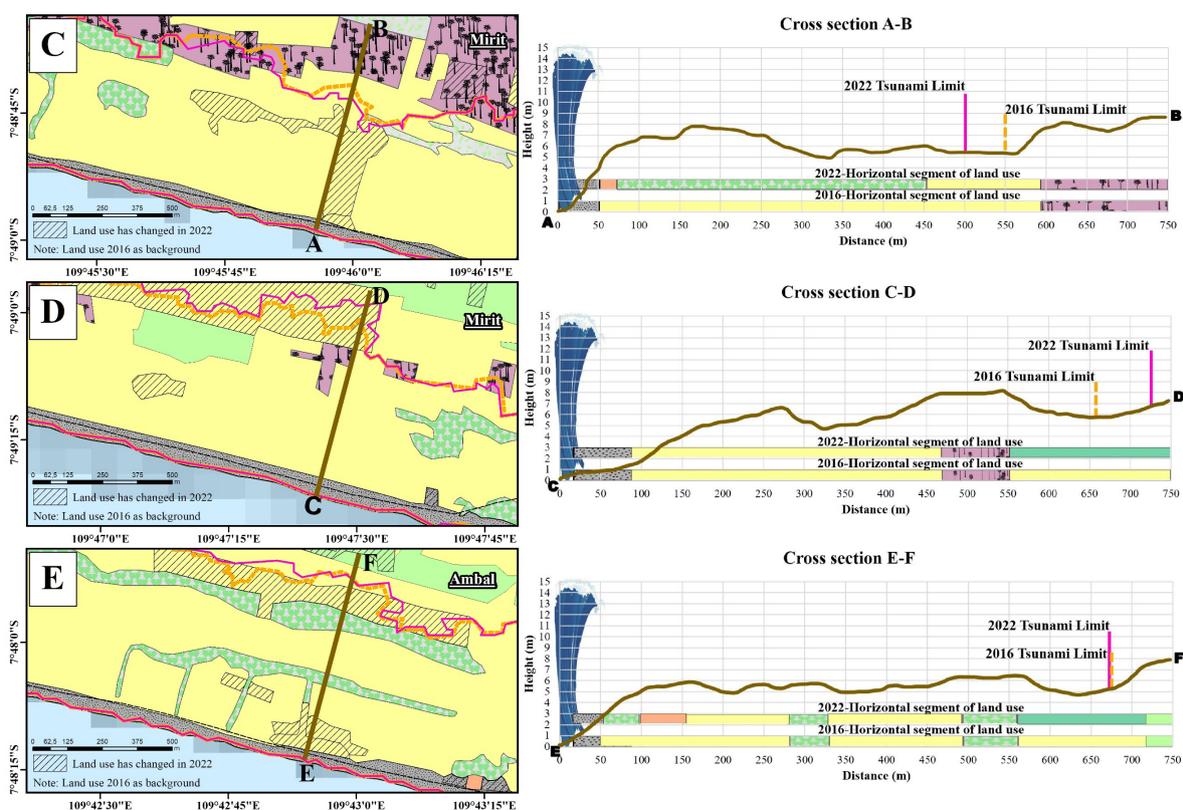


Figure 7. Cross Section of The Tsunami Inundation Range at Three Locations on The South Coast of Kebumen Source: Author Analysis (2022)

Most developments in land use from 2016 to 2022 followed the RTRW of Kebumen Regency, especially for agricultural fields, mangrove forests, and fir forests. Part of the research area (approximately 500 m from the coastline) is a defense and security area within the RTRW of Kebumen Regency, which has a strategic function for Indonesia. Some time ago, there was a conflict over land ownership and use between the community and the Indonesian National Armed Forces (TNI) in the area of defense and security [55]. According to facts from an interview with a community member in the field, most of the conflicts between the community and the TNI have been resolved peacefully and fairly.

Then the development of shrimp ponds and the chicken-trading industry still needs to be considered regarding its environmental impact and space allocation [25]. However, based on the results of an interview with one of the informants in the field, it is known that business actors and the local government have agreed on the area for the development of shrimp ponds and the chicken-trading industry to be allocated in the south side of JJLS. The results of community participation and agreement can be used to compile land use arrangements to reduce disaster risk [56]. Open shrimp ponds would be better devel-

oped with the concept of side-by-side with forestry/plantation plants (*silvofishery*) as a tsunami mitigation strategy [43]. A comprehensive environmental impact assessment is needed by related parties so that environmental damage does not occur due to the development of shrimp ponds and the chicken-trading industry [57]. Then the development of mangrove forests, fir forests, and community forests in the suitable locations can function as a greenbelt/natural barrier to tsunami waves [43], [45].

According to the results of the 2016 and 2022 tsunami inundation model, JJLS is located in a relatively safe location parallel to the coastline. The road network can function as a barrier to tsunami waves, thereby minimizing losses in vulnerable areas based on the concept of structural mitigation [43], [44]. Then the alternating pattern of coastal morphology between the beach ridges-sand dunes and the valleys (swales) that extend parallel to the coastline can serve as a natural barrier to tsunami waves. Wise use of the natural topography of an area can be useful for preventing a tsunami disaster [46]. Conceptually and based on literature studies, an alternating pattern of land use that inhibits tsunamis and productive land use can be developed as an alternative input for tsunami mitigation and spatial planning (figure 8).

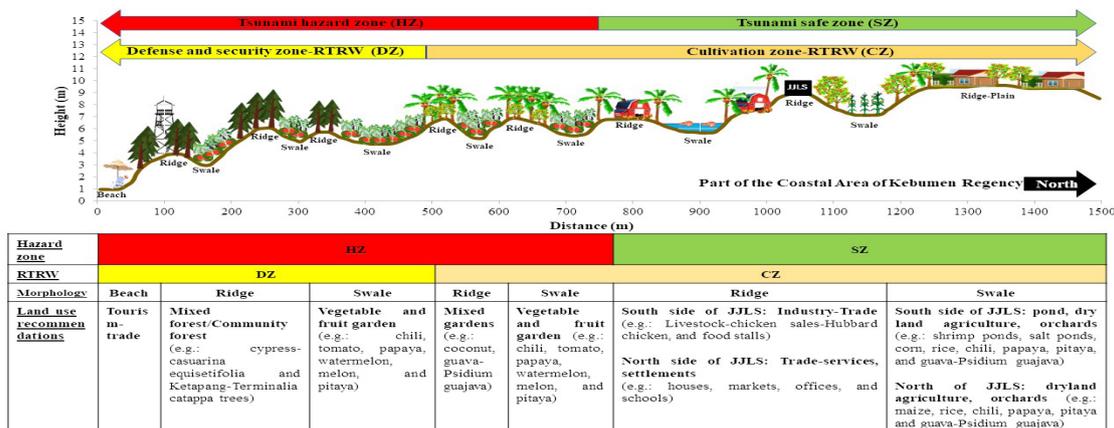


Figure 8. The Concept of Structuring Land Use Patterns in Parts of The Coast of Kebumen Regency Source: Author Analysis (2022)

CONCLUSION

Road infrastructure is a factor that has a significant effect on land use changes. Multitemporal satellite imagery is very effective in identifying land use changes. Land use change can be used as a parameter for tsunami hazard analysis. Therefore, changes in the tsunami hazard zone are influenced by changes in land use on the coast. Changes in coastal morphology are physical parameters for tsunami hazard assessment that can be used for more comprehensive analysis in future studies.

The development of new land uses can have both positive and negative impacts on the potential tsunami hazard. Land use, such as shrimp ponds near the coast, is a land use that is not good at preventing tsunamis. If the land use for shrimp ponds develops in the tsunami hazard zone, the tsunami hazard zone will further expand inland. Therefore, the concept of structuring land use patterns can be used as a strategy in tsunami mitigation. The concept of land use arrangement can also be developed in more detail in the detailed spatial planning document.

ACKNOWLEDGMENTS

The funding source for this research came from the Ministry of National Development Planning of the Republic of Indonesia/National Development Planning Agency (Bappenas) through the "Karyasiswa Pusbindiklatren-Bappenas" scholarship program. This research is part of the master's research at the Graduate School, Universitas Gadjah Mada, Yogyakarta. The author would like to thank Pusbindiklatren-Bappenas, Universitas Gadjah Mada, Ministry of Agrarian Affairs and Spatial Planning/National Land Agency, Kebumen Regency Government, and all parties who have supported data collection until the manuscript was written.

BIBLIOGRAPHY

- [1] Davidson-Arnott, R. 2010. *An Introduction to Coastal Processes and Geomorphology*. 1st ed. New York: Cambridge University Press.
- [2] Fine, I. V., Rabinovich, A. B., Bornhold, B. D., Thomson, R. E., and Kulikov, E. A. 2005. The Grand Banks Landslide-Generated Tsunami of November 18, 1929: Preliminary Analysis and Numerical modeling. *Marine Geology*, vol. 215, no. 1-2 SPEC. ISS., pp. 45-57. Doi: 10.1016/j.margeo.2004.11.007.
- [3] Maramai, A., Graziani, L., and Tinti, S. 2005. Tsunamis in The Aeolian Islands (Southern Italy): A review. *Marine Geol*, vol. 215, no. 1-2 SPEC. ISS., pp. 11-21. Doi: 10.1016/j.margeo.2004.03.018.
- [4] Dewi, R. S., and Dulbahri. 2014. "Bencana Tsunami," in *Penaksiran Multirisiko Bencana di Wilayah Kepesisiran Parangtritis*. Sunarto, Marfai, M. A. and Mardiatno, D. Eds. Yogyakarta: Gadjah Mada University Press, pp. 57-78.
- [5] Horspool, N., Pranantyo, I., Griffin, J., Latief, H., Natawidjaja, D. H., Kongko, W., and Thio, H. K. 2014. A Probabilistic Tsunami Hazard Assessment for Indonesia. *Natural Hazards and Earth System Sciences*, vol. 14, no. 11, pp. 3105-3122. Doi: 10.5194/nhess-14-3105-2014.
- [6] Lavigne, F., Gomez, C., Giffó, M., Wassmer, P., Hoebreck, C., Mardiatno, D., and Paris, R. 2007. Field Observations of The 17 July 2006 Tsunami in Java. *Natural Hazards and Earth System Sciences*, vol. 7, pp. 177-183. Available: <http://www.nat-hazards-earth-syst-sci.net/7/177/>
- [7] Kongko, W. and Schlurmann, T. 2011. The Java Tsunami Model: Using Highly-Resolved Data To Model The Past Event And To Estimate The Future Hazard. *Coastal Engineering Proceedings*. 1(32), management.25. Doi: <https://doi.org/10.9753/icce.v32.management.25>.

- [8] Widiyantoro, S., Gunawan, E., Muhari, A., Rawlinson, N., Mori, J., Hanifa, N. R., and Putra, H. E. 2020. Implications for Megathrust Earthquakes and Tsunamis from Seismic Gaps South of Java Indonesia. *Scientific Reports*, vol. 10, no. 1. Doi: 10.1038/s41598-020-72142-z.
- [9] Pusat Gempabumi dan Tsunami. 2019. *Katalog Tsunami Indonesia Tahun 416-2018*. Jakarta: Kedeputan Bidang Geofisika Badan Meteorologi Klimatologi dan Geofisika.
- [10] Mardiatno, D., Malawani, M. N., and Nisaa', R. M. 2020. The Future Tsunami Risk Potential As a Consequence of Building Development in Pangandaran Region, West Java, Indonesia. *International Journal of Disaster Risk Reduction*, vol. 46. Doi: 10.1016/j.ijdr.2020.101523.
- [11] Marfai, M. A., King, L., Singh, L. P., Mardiatno, D., Sartohadi, J., Hadmoko, D. S., and Dewi, A. 2008. Natural Hazards in Central Java Province, Indonesia: An overview. *Environmental Geology*, vol. 56, no. 2, pp. 335-351. Doi: 10.1007/s00254-007-1169-9.
- [12] Farhan, M. D. 2022. Zonasi Wilayah Bahaya Tsunami Dengan Pemodelan Run Up Tsunami Kabupaten Kebumen, Jawa Tengah. *Skripsi*. Universitas Gadjah Mada, Yogyakarta. Available: http://etd.repository.ugm.ac.id/home/detail_pencarian/208230
- [13] Fauziah, N. 2021. Pemodelan Run-Up Tsunami Dikaitkan Dengan Tingkat Risiko Di Bidang Sosial Di Sebagian Kawasan Pesisir Kabupaten Kebumen. *Skripsi*. Universitas Gadjah Mada, Yogyakarta. Accessed: Oct. 27, 2022. [Online]. Available: <http://etd.repository.ugm.ac.id/penelitian/detail/198410>
- [14] Badan Penanggulangan Bencana Daerah. 2022. *Kajian Risiko Bencana Kabupaten Kebumen Tahun 2021-2025*. Kebumen: BPBD Kebumen. Accessed: Mar. 09, 2022. [Online]. Available: https://bpbd.kebumenkab.go.id/index.php/web/download_process/7
- [15] (Deutsche Gesellschaft für Internationale Zusammenarbeit - German Internationale Cooperation) GmbH GIZ. 2010. *Tsunami Kit - Peta Bahaya Tsunami Jawa Tengah*. https://www.gitews.org/tsunami-kit/id/id_tsunami_hazard_map_central_jawa.html (accessed Mar. 09, 2022).
- [16] Islam, F., Subiyanto, S., and Sabri, L. M. 2014. Penentuan Resiko Dan Kerentanan Tsunami di Kebumen dengan Citra ALOS. *Jurnal Geodesi Undip*, vol. 3, no. 1. Accessed: Mar. 09, 2022. [Online]. Available: <https://ejournal3.undip.ac.id/index.php/geodesi/article/view/4719>
- [17] Sunarto, M. A. Marfai, and M. A. Setiawan, *Geomorfologi Dan Dinamika Pesisir Jepara*, 1st ed. Yogyakarta: Yogyakarta: Gadjah Mada University Press, 2014.
- [18] Bagheri, M., Ibrahim, Z. Z., Mansor, S., Manaf, L. A., Akhir, M. F., Wan Talaat, W. A., and Pour, A. B. 2021. Land-use Suitability Assessment Using Delphi and Analytical Hierarchy Process (D-AHP) Hybrid Model for Coastal City Management: Kuala Terengganu, Peninsular Malaysia," *ISPRS International Journal Geo-information*, vol. 10, no. 9. Doi: 10.3390/ijgi10090621.
- [19] Mardiatno, D., Wahyu Permatasari, C., Ngainul Malawani, M., and Nuraini Sekarsih, F. 2016. Tsunami Risk Evaluation Based on Land Suitability for Settlement in Pacitan Coastal Area, East Java. *The 1st International Conference on Geography*

- and Education (ICGE 2016), vol. 79, pp. 48–52.
- [20] Sumbangan, B. 2012. *Perencanaan Tata Guna Lahan dalam Pengembangan Wilayah: Pendekatan Spasial dan Aplikasinya*, 1st ed. Yogyakarta: Penerbit ANDI.
- [21] Abdullahi, S., Pradhan, B. and Al-sharif, A. A. A. 2017. *Spatial Modelling and Assessment of Urban Form Analysis of Urban Growth: From Sprawl to Compact Using Geospatial Data*. Gewerbestrasse 11, 6330 Cham, Switzerland: Springer International Publishing AG. DOI: 10.1007/978-3-319-54217-1.
- [22] K. Malarvizhi, S. V. Kumar, and P. Porchelvan, "Urban Sprawl Modelling and Prediction Using Regression and Seasonal ARIMA: A Case Study for Vellore, India," *Model Earth Syst Environ*, 2021, doi: 10.1007/s40808-021-01170-z.
- [23] Haris Kebumen. 2021. *JALUR JALAN LINTAS SELATAN (PANTAI SELATAN) KEBUMEN – Knowing and sharing*. Jul. 05, 2021. <https://hariskebumen.wordpress.com/2021/07/05/jalan-jalan-lintas-selatan-pantai-selatan-kebumen/> (accessed Jun. 17, 2022).
- [24] Rakhmat, B. 2022. Pemanfaatan Citra Penginderaan Jauh Untuk Mengekstraksi Parameter Yang Digunakan Untuk Mengetahui Estimasi Perubahan Harga Lahan Akibat Pembangunan Jalur Jalan Lintas Selatan (JJLS) Kabupaten Kebumen. *Skripsi*. Universitas Gadjah Mada, Yogyakarta. Accessed: Mar. 09, 2022. [Online]. Available: <http://etd.repository.ugm.ac.id/penelitian/detail/184529>
- [25] Pemda Kebumen. 2021. *Peraturan Daerah Kabupaten Kebumen Nomor 7 Tahun 2021*.
- [26] Pemda Kebumen. 2022. *Peraturan Daerah Kabupaten Kebumen Nomor 23 Tahun 2012*. 2012. Accessed: Mar. 09, 2022. [Online]. Available: <https://pusdataru.jatengprov.go.id/dokumen/RTRW-Prov/27-Kab-Kebumen/PERDA-23-TAHUN-2012-RTRW-KAB-KEBUMEN.pdf>
- [27] Kurnianto, F. A. 2019. Keberagaman Bentuk Lahan Di Wilayah Pesisir Dan Kaitannya Dengan Karakteristik Proses Geomorfologi. *Majalah Pembelajaran Geografi*, vol. 2, no. 2, pp. 197–209. Accessed: Jun. 18, 2022. [Online]. Available: <https://jurnal.unej.ac.id/index.php/PGEO/article/view/14136>
- [28] Nandika, M. R. 2022. Laporan Studi Kerentanan Fisik Pesisir Kabupaten Kebumen Jawa Tengah. *Skripsi*. Universitas Brawijaya, Malang, 2015. Accessed: Mar. 09, 2022. [Online]. Available: <http://repository.ub.ac.id/id/eprint/133993>
- [29] Rahmasari, P. 2016. Pemanfaatan Citra Penginderaan Jauh Dan Sistem Informasi Geografis Untuk Penentuan Indeks Kerentanan Pesisir (IKP) Di Kabupaten Kebumen. *Skripsi*. Universitas Gadjah Mada, Yogyakarta, 2016. Accessed: Mar. 09, 2022. [Online]. Available: <http://etd.repository.ugm.ac.id/penelitian/detail/101437>
- [30] Nugroho, A. W. 2017. *Silvikultur Rehabilitasi Pantai Berpasir Kebumen*, 1st ed., vol. 1. Surakarta: UNS Press.
- [31] BSN. 2014. *SNI 7645-1:2014*. [Online]. Available: www.bsn.go.id
- [32] P. Danoedoro, *Pengantar Penginderaan Jauh Digital*. Yogyakarta: Yogyakarta: Penerbit ANDI, 2012.
- [33] Gulo, W. 2002. *Metodologi Penelitian*. Jakarta: Gramedia Widiasarana Indonesia.
- [34] Santoso, A. B. 2017. Semua Tentang Regresi Logistik. Apr. 06, 2017.

- <https://agungbudisantoso.com/pengertian-tutorial-dan-interpretasi-regresi-logistik-dengan-spss/> (accessed Oct. 29, 2022).
- [35] Hosmer, D. W., Stanley. Lemeshow, and Sturdivant, R. X. 2013. *Applied Logistic Regression*, 3rd ed. Hoboken, New Jersey: New Jersey: John Wiley & Sons, Inc.
- [36] Yunanto, M. A. and Susetyo, C. 2018. Prediksi Perubahan Penggunaan Lahan Akibat Pembangunan Gerbang TOL Krian dan Driyorejo di Kecamatan Driyorejo, Kabupaten Gresik. *Jurnal Teknik ITS*, vol. 7, no. 2, pp. C223–C230, 2018, Accessed: Mar. 04, 2022. [Online]. Available: <https://repository.its.ac.id/id/eprint/54748>
- [37] BSN. 2019. *SNI 8202-2019*.
- [38] Fauzi, Y. 2021. Pemodelan Potensi Genangan Tsunami Berbasis pada Ancaman Gempa Bumi di Zona Subduksi Selatan Jawa. *Dissertation*. Universitas Gadjah Mada, Yogyakarta. Accessed: Mar. 04, 2022. [Online]. Available: <http://etd.repository.ugm.ac.id/penelitian/detail/196914>
- [39] Berryman, K. 2006. *Review of Tsunami Hazard and Risk in New Zealand*. New Zealand: Institute of Geological & Nuclear Sciences Limited.
- [40] Khomarudin, M. R. 2010. Tsunami Risk and Vulnerability: Remote Sensing and GIS Approaches for Surface Roughness Determination, Settlement Mapping and Population Distribution Modeling. *Dissertation*. Ludwig-Maximilians-Universität München, München. Doi: 10.5282/edoc.12381.
- [41] Badan Nasional Penanggulangan Bencana. 2018. *Modul Teknis Penyusunan Kajian Risiko Bencana Tsunami*, 1st ed. Jakarta: Direktorat Pengurangan Risiko Bencana BNPB.
- [42] Badan Nasional Penanggulangan Bencana. 2012. *Peraturan Kepala Badan Nasional Penanggulangan Bencana Nomor 02 Tahun 2012*. Indonesia: Jakarta: BNPB. Accessed: Mar. 09, 2022. [Online]. Available: <https://bnpb.go.id/produk-hukum/peraturan-kepala-bnpb/peraturan-kepala-bnpb-no-02-tahun-2012>
- [43] Agussaini, H., Sirojuzilam, Rujiman, and Purwoko, A. 2022. A New Approach of the Tsunami Mitigation Strategies for the City of Banda Aceh, Indonesia. *Indonesian Journal of Geography*, vol. 54, no. 1, pp. 62–69. Doi: 10.22146/ijg.66500.
- [44] Syamsidik, Tursina, Suppasri, A., Al’Ala, M., Luthfi, M., and Comfort, L. K., 2019. Assessing The Tsunami Mitigation Effectiveness of The Planned Banda Aceh Outer Ring Road (BORR), Indonesia. *Natural Hazards and Earth System Sciences*, vol. 19, no. 1, pp. 299–312. Doi: 10.5194/nhess-19-299-2019.
- [45] Mardiatno, D. 2013. A Proposal for Tsunami Mitigation by using Coastal Vegetations. *Journal of Natural Resources and Development*, vol. 3, pp. 85–95. Doi: 10.5027/jnrd.v3i0.07.
- [46] Tamura, T. and Seto, M. 2021. Settlement Location and Relocation History of a Tsunami-prone Area in Northeastern Japan: Differential Selection in the Use of Geomorphic Resources. *Journal of Geography (Chigaku Zasshi)*, vol. 130, no. 2, pp. 261–287. Doi: 10.5026/jgeography.130.261.
- [47] Helber, P., Bischke, B., Dengel, A., and Borth, D. 2019. Eurosat: A Novel Dataset and Deep Learning Benchmark for Land Use and Land Cover Classification. *IEEE Journal of Selected Topics in Applied Earth Observations Remote Sensing*, vol. 12, no. 7, pp. 2217–2226. Doi: 10.1109/JSTARS.2019.2918242.

- [48] Stéphane, D., Laurence, D., Raffaele, G., Valérie, A., and Eloise, R. 2020. Land Cover Maps of Antananarivo (Capital of Madagascar) Produced by Processing Multisource Satellite Imagery and Geospatial Reference Data. *Data in Brief*, vol. 31. Doi: 10.1016/j.dib.2020.105952.
- [49] Bayuaji, G., Damayanti, A., and Handayani, T. 2017. Utilization of Quickbird Imagery to Identify Shrimp Pond Area in Determining Potential Location in Brebes District. *Seminar Nasional Geomatika 2017: Inovasi Teknologi Penyediaan Informasi Geospasial untuk Pembangunan Berkelanjutan*, pp. 81–88. Accessed: Oct. 28, 2022. [Online]. Available: <https://cloud.big.go.id/index.php/s/Prosiding2017#pdfviewer>
- [50] Wafiana, M. 2017. *Dampak Pembangunan Jalur Jalan Lintas Selatan Terhadap Perekonomian Di Sektor Pertanian Dan Pariwisata Kabupaten Kebumen*. <http://blog.unnes.ac.id/wafiana/2017/12/03/dampak-pembangunan-jalur-jalan-lintas-selatan-terhadap-perekonomian-di-sektor-pertanian-dan-pariwisata-kabupaten-kebumen/> (accessed Mar. 09, 2022).
- [51] Sudaryadi. 2007. *Dampak Pembangunan Jalur Jalan Lintas Selatan Terhadap Output Sektor Produksi Dan Pendapatan Rumah Tangga Jawa Tengah (Simulasi SNSE Jawa Tengah 2004)*. Thesis. Universitas Diponegoro, Semarang. Accessed: Mar. 09, 2022. [Online]. Available: <http://eprints.undip.ac.id/17971/1/Sudaryadi.pdf>
- [52] Badan Informasi Geospasial. 2015. *Norma Standar Prosedur Kriteria Pemetaan Sistem Lahan Skala 1:25.000/1:50.000*, 1st ed. Cibinong, Indonesia: Cibinong: Pusat Pemetaan dan Integrasi Tematik Badan Informasi Geospasial (BIG).
- [53] Jasiewicz, J. and Stepinski, T. F. 2013. Geomorphons-a Pattern Recognition Approach to Classification and Mapping of Landforms. *Geomorphology*, vol. 182, pp. 147–156. Doi: 10.1016/j.geomorph.2012.11.005.
- [54] Listyaningrum, N. 2021. *Penilaian Risiko Ekologi Berbasis Geoinformatik untuk Penataan Ruang Pada Bentanglahan Gumuk Pasir Parangtritis*. Thesis. Universitas Gadjah Mada, Yogyakarta. Accessed: Mar. 04, 2022. [Online]. Available: <http://etd.repository.ugm.ac.id/penelitian/detail/199807>
- [55] Cahyati, D. D. 2018. *Pembentukan Wilayah Pertahanan Dan Persoalan Agraria Di Pesisir Selatan Kebumen-Cilacap*. *BHUMI: Jurnal Agraria Dan Pertanahan*, vol. 3, no. 1, pp. 1–16. Doi: <https://doi.org/10.31292/jb.v3i1.87>.
- [56] Crowley, K., Jackson, R., O'Connell, S., Karunarthna, D., Anantasari, E., Retnowati, A., and Niemand, D. 2022. Cultural heritage and risk assessments: Gaps, challenges, and future research directions for the inclusion of heritage within climate change adaptation and disaster management. *Climate Resilience and Sustainability*, vol. 1, no. 3. Doi: 10.1002/cli2.45.
- [57] Firmantika, L. 2020. *Kerusakan Lingkungan Dan Alternatif Solusinya Studi Di Pantai Selatan Kabupaten Kebumen*. *Jurnal Spasial: Penelitian, Terapan Ilmu Geografi dan Pendidikan Geografi Nomor*, vol. 7, no. 3, pp. 84–89. [Online]. Available: <http://ejournal.stkip-pgri-sumbar.ac.id/index.php/spasial>