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COASTAL VULNERABILITY INDEX MODELING FOR WESTERN COAST OF PANGANDARAN

PEMODELAN INDEX KERENTANAN PESISIR DI PANTAI BARAT PANGANDARAN

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ABSTRACT

Western coast of Pangandaran Sub-district became a popular destination either for domestic or international tourists since it offers many attractive activities and is supported by plenty of hotels, homestays, restaurants and other facilities. However, those advantages were not related with environmental condition, which is characterized by erosional features and dilapidated semi-permanent buildings in several areas with insufficient numbers of coastal protection structures. The combination of poor protection in highly exploited beach pose a threat to local residents, tourists and also the environment. This study is aimed to assess the risk that is faced by Pangandaran Bay. We apply vulnerability assessment in western coast of Pangandaran by integrating two methods: Smartline and CVI (Coastline Vulnerability Index). The result shows the coastal vulnerability index for the study area ranges from 16.43 to 129.9 that are classified into 5 categories; 1) Very low (0.4 km, Sodonglandak Headland - Parigi Bay), 2) Low (0.7 km of Parigi Bay), 3) Moderate (1.2 km, west - east part of Parigi Bay), 4) High (0.3 km, south of Pangandaran Village), and 5) Very High (2.1 km, Pangandaran Village - Pananjung Village). The result of this study is imperative for local governments and stakeholders as a basis for further coastal developments in the western coast of Pangandaran in term of tourism.

Keywords: Coastal vulnerability, CVI, smartline, western coast of Pangandaran.

ABSTRAK

Pantai barat Pangandaran menjadi salah satu tujuan favorit bagi para wisatawan, baik yang datang dari dalam dan luar negeri, karena banyaknya aktivitas menarik yang didukung oleh tersedianya hotel, homestay, restaurant serta fasilitas lainnya. Namun, semua kelebihan yang dimiliki pantai barat Pangandaran tidak berbanding lurus dengan kondisi kawasan pesisirnya, di mana terdapat bukti-bukti erosi dan kerusakan bangunan-bangunan semi-permanen yang ditemukan di sepanjang garis pantai dengan jumlah pelindung pantai yang tidak memadai. Kombinasi dari kondisi pelindung pantai dan tingginya pemanfaatan kawasan pantai berpotensi membahayakan penduduk, wisatawan dan lingkungan pantai barat Pangandaran. Penelitian ini bertujuan untuk menaksir resiko yang dihadapi oleh Teluk Pangandaran. Penilaian kerentanan pesisir pantai barat Pangandaran ini dilakukan dengan mengintegrasikan 2 metode yaitu Smartline dan CVI (Coastal Vulnerability Index). Hasil penelitian menunjukkan bahwa indeks kerentanan di Pantai Barat Pangandaran berkisar antara 16,43 sampai 129,9 yang terbagi dalam 5 kelas kerentanan; 1) Sangat rendah (0,4 km, Tanjung Sodonglandak - Teluk Parigi), 2) Rendah (0,7 km dari Teluk Parigi), 3) Sedang (1,2 km, bagian barat – timur Teluk Parigi), 4) Tinggi (0,3 km, di selatan Desa Pangandaran), dan 5) Sangat Tinggi (2,1 km, Desa Pangandaran - Desa Pananjung). Hasil dari penelitian ini sangat penting bagi pemerintah daerah dan pemangku kepentingan sebagai dasar untuk pengembangan wilayah pesisir pada masa yang akan datang dalam aspek pariwisata.

Kata kunci: Kerentanan pesisir, CVI, Smartline, pantai barat Pangandaran.

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INTRODUCTION

Pangandaran is one of ten sub-districts in Pangandaran Regency which is located in between Sidamulih and Kalipucang Sub-District, and situated 25 km to the southeast of the capital, Parigi Sub-District. As a bay that opens to the Indian Ocean, Pangandaran is one of coastal attractions in West Java (Pratiwi, 1995; Rahmafitria, 2017), particularly in the Pananjung Village (Figure 1). Tourism activities that are offered by the area also include wildlife sighting of Pananjung Conservation that is the home of rare flora, such as Rafflesia patma, and fauna, such as the long-tailed macaque (*Macaca fascicularis*), the silver leaf monkey (*Trachypithecus auratus sondaicus*), and banteng (*Bos javanicus*) (Rosleine & Suzuki, 2012); water sports in the Green Canyon; sightseeing along Citumiang river; and tasting local delicacies.

The attractions of Pangandaran comes with natural dangers in the form of the seasonal strong current and waves (Muntaib *et al*., 2018) that poses a threat to the permanent structure and semi-permanent structures crowding the coastline. The presence of the structures reflects the increase of visitors to the area, as was reported by Akbar & Sujali (2012). The growth of coastal populations may increase pressure on the shore (Brown & McLachlan, 2002) that expected to impact ground water intake (Ferguson & Gleeson, 2012). In addition, a certain area with extensive groundwater intake in decades may lead to land subsidence (Teatini *et al*. (2005), Teatini *et al*. (2006), Shen & Xu (2011)) and saltwater intrusion to the coastal aquifer (Bear *et al*., (1999), Antonellini *et al*., (2008)).

Geographically, Pangandaran is positioned in the southern of Java that potentially will be impacted by earthquake triggered by subduction zone between Indo-Australian and Eurasian Plates. The worst tsunami to occur in Pangandaran is the 2006 tsunami (Bisri, 2011) that killed hundreds of people, with 15.7 m wave height and hundreds of meters of inundation (Husrin *et al*., 2015). Due to the relatively flat morphology of the western coast of Pangandaran (Figure 2), a tsunami wave can easily reach Cikembulan River, that is located 750 m inland (Amijaya *et al*., 2006).

Pangandaran is well-known as the center of marine tourism in West Java. The development of marine tourism after tsunami in 2006 has changed beach landscape of Pangandaran. The emergence of semi-permanent tourism facilities not only obstruct the view, but also pose a threat to the marine tourism itself such as the increase of visitors and waste volumes (Komsary *et al*., 2018) which may change the physical aspects of the area. During the observation in August 2016 in the study area, it was known from the local people that the season change affected the coastal condition. Pangandaran coastal condition changes seasonally: during the northeast monsoon (December to April), the coastline position is further to the ocean, and during the southwest monsoon (May to October), the coastline is very close to the mainland (Figure 3). These seasonal changes were obtained by digitizing Landsat-8 OLI TIRS multi-temporal imageries. Evidence of coastal erosion in the form of steep sand dune and derelict semi-permanent structures (Figure 4) were observed during the field work that was conducted on August 2016.

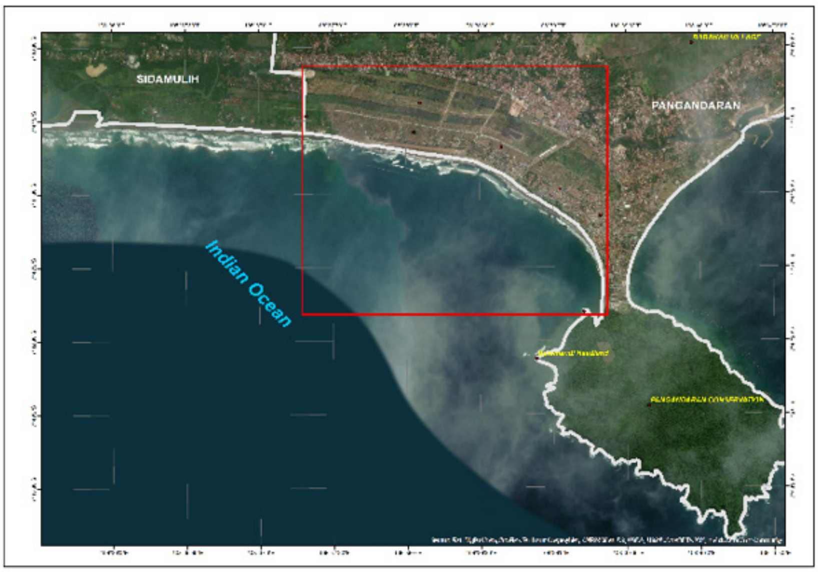

Figure 1. Pangandaran Sub-District.

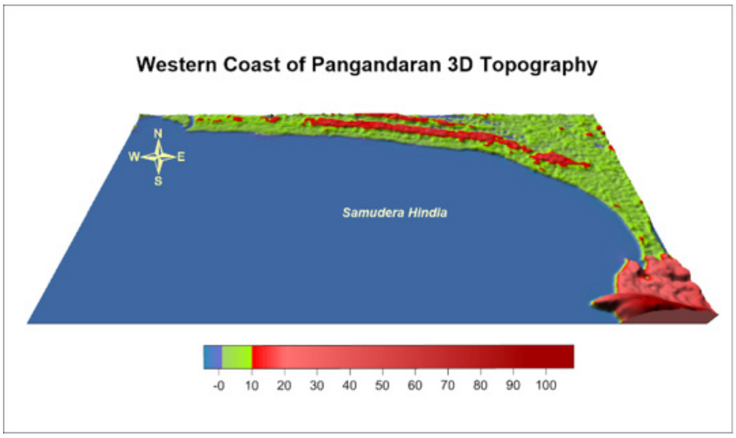

Figure 2. Western coast of Pangandaran 3D Topography.

Intense human activities and weather conditions affect coastal vulnerability (Putra *et al*., 2015; Abuodha & Woodroffe, 2006). The geographic location of Pangandaran with all the consequences in the form of weather, etc., and the robust tourism-related human activities on the area, give rise to the needs to re-evaluate marine tourism of this area. This paper presents the vulnerability of western coast of Pangandaran by employing smartline mapping method and CVI indexing method. This outcome of this study is to provide information for local authority and the stakeholders of tourism industry in order to maintain sustainable tourism in the western coast of Pangandaran.. According to the current tourism activities in Pangandaran, the development of marine tourism needs to be re-evaluated, especially for determining the impacts that resulted from anthropogenic and natural activities as well. Therefore, we surveyed this area to understand its vulnerability by employing smartline mapping method and CVI indexing method. This study expected to give a valuable information to the local government and those who in tourism industry for maintaining the western coast of Pangandaran sustainability.

METHODOLOGY

Smartline mapping procedure was introduced by Sharples *et al*. (2009) and was further developed by Lins-de-Barros *et al*. (2013) with modifications on several parameters. This study would adjust the parameters to fit local coastal characteristics. This mapping procedure was completed following the steps of Lins-de-Barros *et al*. (2013) in 13 observation points (Figure 3) along the study area:

Indicative mapping is the first step to identify coastal areas that are potentially prone to coastal

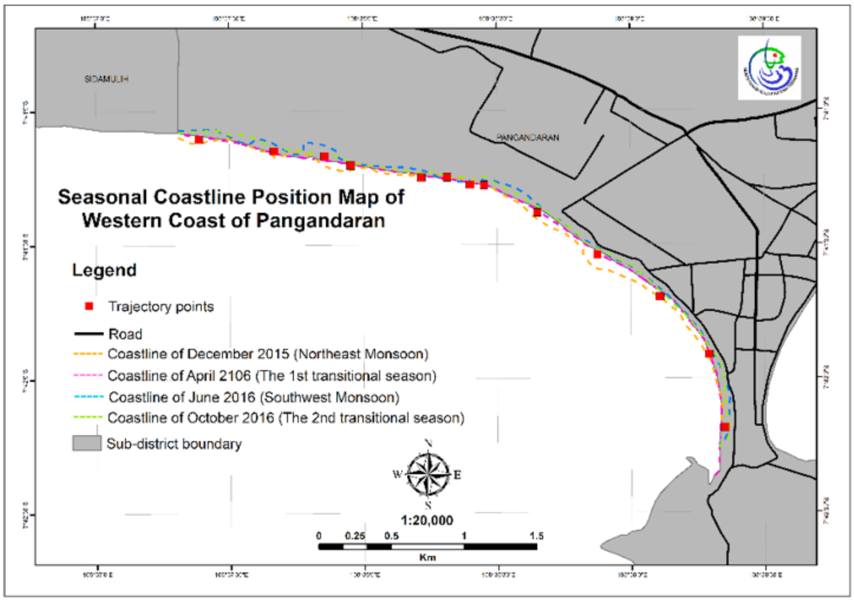

Figure 3. Coastline position due to seasonal changes.

Figure 4. Steep sand dune and derelict semi-permanent structures as evidence of beach erosion in Pangandaran.

hazards based on its type, geology or geomorphic, without considering the different pattern, rate, or magnitude of hazard impact in a different location. In this step, the observed parameters were beach material, wave exposure, and hinterland relief.

Regional assessment is an integration between coastal geomorphic and parameters that influence the vulnerability level which is more detail than the first steps and the impact pattern of the coastal hazards for different segments might also be estimated. Parameters for this step were berm feature and grain size.

Site-specifics assessment is used to identify geological parameters, geomorphic, topography, oceanography, and related climate factors that impact specific coastal area. The parameters included were berm height, beach face feature, wave height, and coastline changes.

Social vulnerability and risk assessment. This step involves mapping coastal population and its economy that might be jeopardized by the coastal hazards. This study applies observation of residential area density along the coastline as indicator of coastal population.

This mapping method is applied in two directions, along and across the coastline (Figure 5), to obtain detail information of the coastal characteristic. All parameters were acquired by in-situ observations except for the coastline changes processing by DSAS (Digital Shoreline Analysis System) (Thieler *et al*., 2009) and spectral wave modeling (Wisha *et al*., 2018). The spectral wave was modeled employed bathymetry, tidal forecast, and wind data as the model input. The modeling approach also gives an advantage in finding a solution to determine complicated problems effectively and efficiently in the hydrodynamic processes in the ocean (Cummins *et al*., 2012) which is applied in the wave simulation of western coast of Pangandaran. In the mapping process, every small change of the considered parameters in both directions should be marked (Lins-de-Barros *et al*., 2013), which results in many line segments in the final map.

The coastal vulnerability index by CVI (Coastal Vulnerability Index) formula (Gornitz *et al*. (1991), Gornitz *et al*. (1997)) was calculated to complete the assessment. CVI was applied by giving scores to all parameters by following the conditions in Table 1, where score 1 - 5 indicates increasing vulnerability. The scoring was utilized to calculate the vulnerability index using CVI formula:

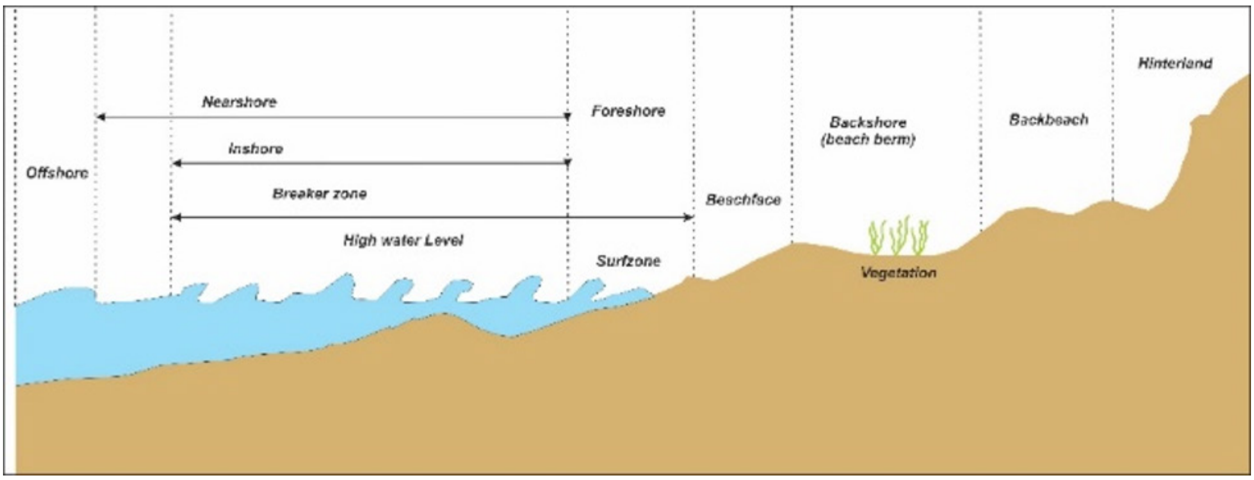

Figure 5. Coastal cross-profile (after Short & Woodroffe (2009).

$$CVI = \sqrt{\frac{x_1 * x_2 * x_3 * x_4 * x_5 * x_6 * x_7 * x_8 * x_9 * x_{10}}{10}}$$

where,
x_1= beach material
x_2= wave exposure
x_3= hinterland relief
x_4= berm feature
x_5= grain size
x_6= berm height
x_7= beach-face feature
x_8= significant wave height
x_9= coastline changes
x_10= residential area density

RESULTS AND DISCUSSION

Indicative mapping step for wave exposure parameter revealed that the sandy beach of the study area consists of (1) sheltered by the cliff of Pangandaran Conservation Area, (2) semi-exposed since the coastline was protected by low coastal structures and sand sacks (Figure 6), and (3) exposed segment or unprotected coastline that is located near Sidamulih Regency (Figure 7). Hinterland relief parameter shows that most of Pangandaran West Coast are hilly (green line) while certain place is low-lying plain (orange line) as shown in Figure 7.

The second mapping step yielded that the grain size of beach sediment was 100% medium sand, while the berm was covered by 8% forest and 92% urban area as displayed in Figure 8. The third step was presented as 2 maps, 3a (Figure 9) and 3b (Figure 10), owing to many involved parameters. Figure 9 shows that beach face of the study area was an open space area with berm height ranged between 0 – 5.0 m. Coastline changes and significant wave height are both displayed in 3b map (Figure 10), which shows the coastline changes in this area were predominantly low erosion ranged between -1.0 - +1.0 m/y and successively followed by stable change and accretion. Based on wave modeling, it was shown that the significant wave height in this area was less than 0.5 m as presented by the color bar. The last step illustrates the density of residential area nearby the western coast of Pangandaran (Figure 11) that about ±1.5 km was categorized as a very high populated area, ±1.2 km was high populated area, ±1.3 km was low populated area, and only ±1.1 km was a very low populated area.

Based on beach material, the very fine size is categorized as a vulnerable area because the sandy shore is very dynamic where wave's and tide's behavior determine community structure as defined by Brown & McLachlan (2002). Other factors that increased the coastal vulnerability in the study area are the sandy shore backed by the low-lying plain, unclaimed beach face feature, the low height berm, berm area functioned as the urban area as the berm feature, and the very high residential density. In contrast, the existence of coastal protection structures, the low significant wave height, the low erosion dominated area and the coarse grain size, may decrease the vulnerability degree, that is attributable to coarser sediment that provides greater obstruction of erosion than very fine material (Sharples, 2006). The combination of those parameters contributed to coastal vulnerability.

The computation result showed that the CVI value ranged between 16.43 to 129.9. This result then

Table 1. Parameter classification and scoring

Parameter/Score	Very low (1)	Low (2)	Moderate (3)	High (4)	Very high (5)
Beach material [2]	Rock	-	-	-	Sand
Wave exposure [2]	Sheltered	-	Semi exposed	-	Exposed
Hinterland relief [2]	Cliff	Hill/mountain	-	-	Low-lying
Berm feature [2] modified	-	-	Forest	Mangrove	Urban area
Grain size [4]	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand
Berm height (m) [1]	>30.1	20.1 – 30.0	10.1 – 20.0	5.1 – 10.0	0 – 5.0
Beachface feature [2]	Coastal protection structure	Unclaimed area	Settlement	Industrial	Agricultural
Significant wave height (m) [3]	<0.5	0.5 – 3.0	3.0 – 6.0	6.0 – 8.0	>8.0
Coastline changes (m/yr) [1]	≥ +2.1 accretion	1.0 – 2.0 stable	-1.0 – +1.0 low erosion	-1.1 – -2.0 moderate erosion	≤-2.1 high erosion
Residential area density	Unclaimed area	Very low	Low	High	Very high

Sources: [1] Abuodha and Woodroffe (2006), [2] Lins-de-Barros and Muehe (2013), [3] Özyurt (2007), [4] Wentworth (1922)

Figure 6. Sand bags that are arranged to protect the coastline wave erosion in western coast of Pangandaran.

manually classified into 5 classes, 16.5 – 39.5 (very low), >39.5 – ≤61.5 (low), >61.5 – ≤84.5 (moderate), >84.5 – ≤107.5 (high) and >107.5 (very high). The final map product in Figure 12 shows that around 44% or 2.1 km of the coastline experienced the very high vulnerability marked by the red line, exactly located in the well-visited beach of the western coast of Pangandaran, distributed from Pangandaran to Pananjung Village, about 1.2 km was classified into moderate vulnerability (yellow line) that mostly found around Parigi Bay, while the rest of the coastline were in low (0.7 km), very low (0.4 km) and high (0.3 km) vulnerability status. The area with high vulnerability status needs to be maintained properly in order to avoid any casualty and property damage. The action might be ranged from installation of coastal protection structures, observation of beach-face area, and green belt implementation in the western coast of Pangandaran.

CONCLUSION

This study revealed that western coast of Pangandaran has very low to very high coastal vulnerability which distributed along Pangandaran Village, Pananjung Village, and Wonoharjo Village. The safest area with the very low vulnerability were scattered in Sodonglandak Headland and some parts of Parigi Bay coastal area, while the Pangandaran and Pananjung Village have very highly vulnerable coastline. This result corroborates the assumption that very high vulnerability coast superimposed with the center of tourism area. This model reflects the real condition that was observed during field work. Our result is expected to provide essential information for

Figure 7. Material, wave exposure and hinterland relief map.

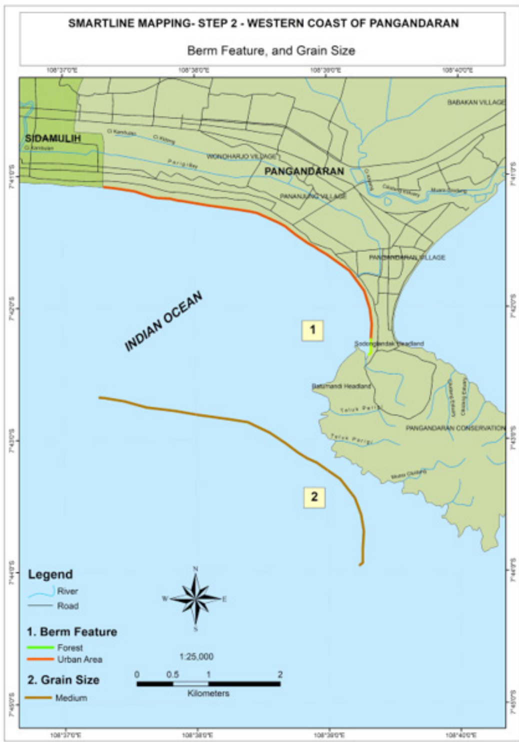

Figure 8. Berm feature and grain size map.

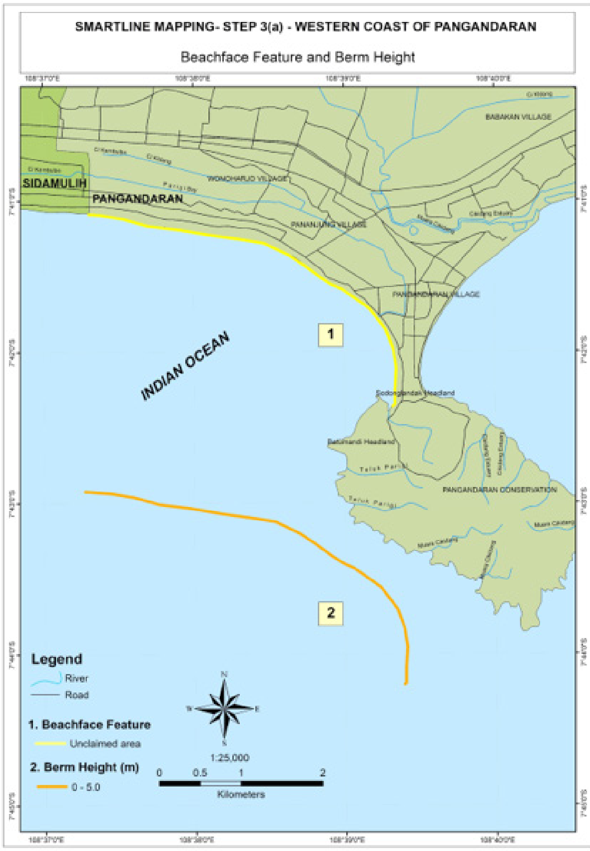

Figure 9. Beach-face feature and berm height.

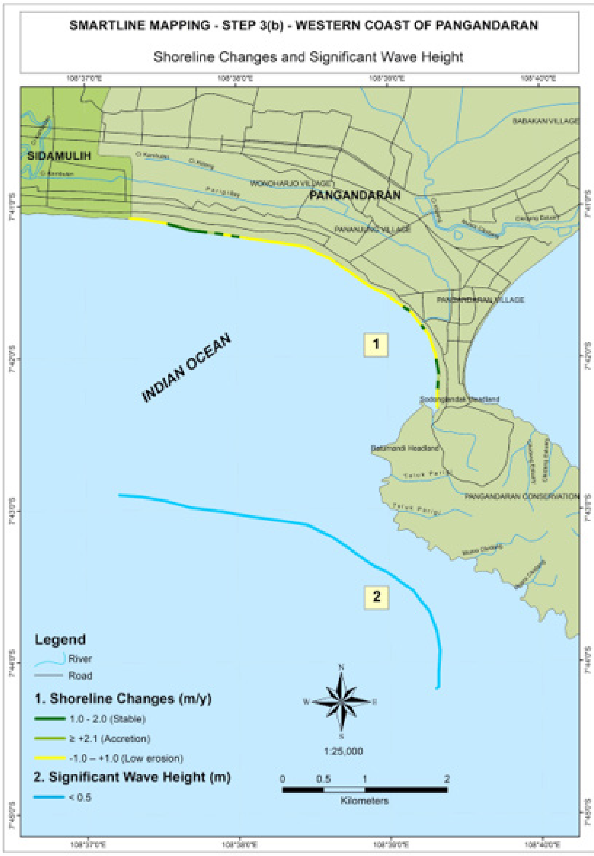

Figure 10. Shoreline changes and wave height map.

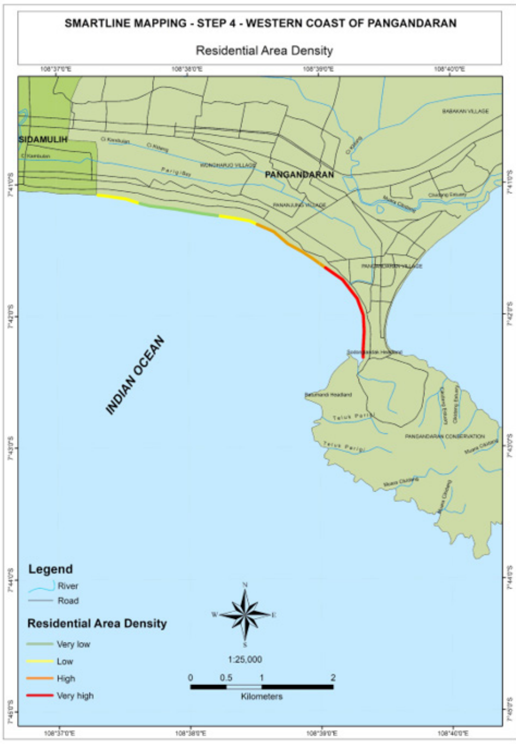

Figure 11. Residential area density.

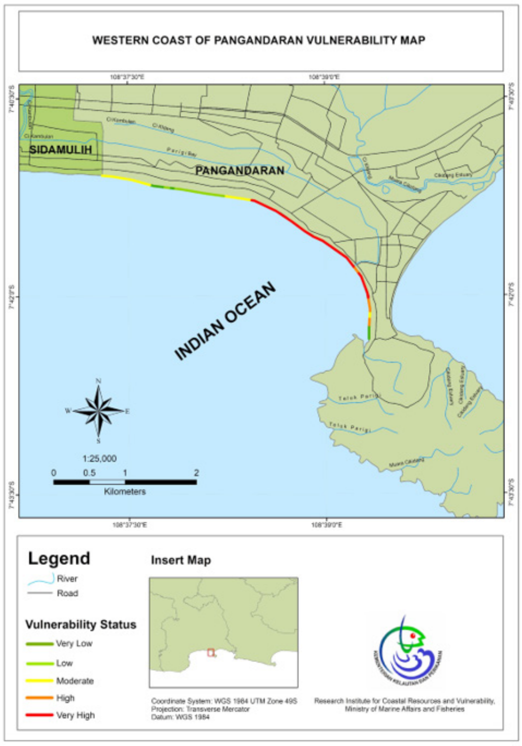

Figure 12. Coastal vulnerability map of western coast of Pangandaran.

the local government and stakeholders to establish comprehensive plan to develop sustainable tourism in the western coast of Pangandaran

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