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Research article

Discerning geomorphological aspects of tsunami risk in Pangandaran, West Java, Indonesia

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ABSTRACT

The geomorphological understanding of earth dynamics, including the relationship between landforms and their processes, was one of the earliest and most specific contributions to disaster prevention. Disaster geomorphology is one of the approaches in disaster studies, which includes aspects of landforms, processes, and results of physical processes that have the potential and can cause disasters. The landform is of risk factors that can turn natural hazards into natural disasters and determines the damage that disasters can cause to human activities. Following the 2006 South Java Tsunami, infrastructural development occurred massively in the 2006 South Java Tsunami inundation areas. Several tsunami risk mitigation efforts were conducted but solely based on the 2006 tsunami scenario and ignored the existence of more considerable tsunami hazards from the Sunda Megathrust. This consideration may lead to an increasing risk of future tsunamis. We evaluate and appraise favorable and unfavorable geomorphological features to reduce the risk of future tsunamis. Pangandaran has a unique landform compared to other areas on the south coast of Java, and this landform has the potential to reduce future tsunami risk. Typical landforms studied include coastal plains, alluvial plains, Tombolo, tied islands, and structural hills. The results show that the morphological features of the Tombolo and the coastal plain area are categorized as high risk when a tsunami occurs. The tied island is categorized as a favorable morphology where these morphological units have the advantage of elevation and efficient distance to the tsunami risk zone. Evacuation facilities are also needed, especially in the coastal plain and Tombolo areas (with a height of >20 meters), to reduce disaster risk, particularly mortality caused by tsunami events.

INTRODUCTION

Coastal areas have diverse resources and are dynamic areas with diverse land uses. The diversity of land uses coastal tourism destinations, settlements, industry, agricultural activities, and conservation. However, the threat of disasters in coastal areas is also very high, including earthquakes, tsunamis, floods, tidal floods, storms, land subsidence, and coastal erosion, so planning for integrated management of coastal areas, including considering disaster aspects, absolute thing to do. The geomorphological approach can contribute to the management of coastal areas in an integrated manner.

The geomorphological understanding of earth dynamics, including the relationship between landforms and their processes, was one of the earliest and most specific contributions to disaster prevention (Alcántara-Ayala, 2002). Along with the development of science and technology, the methodologies and techniques used in geomorphological studies have also experienced significant progress (Alcántara-Ayala, 2010). Goudie (2004) and Panizza (1996) revealed that geomorphological studies could be grouped into two sub-subjects: geomorphological studies for resource analysis and geomorphological studies for disasters. Disaster geomorphology is one of the approaches in disaster studies, which includes aspects of landforms, processes, and results of physical processes that have the potential and can cause disasters. The landform is a risk factor that can turn natural hazards into natural disasters and determines the damage disasters can cause to human activities (Sakurai et al., 2021).

In the case of the tsunami disaster, the March 11th, 2011, the Tohoku tsunami took many lives from the Okawa Elementary School near the Kitakami River in Kamaya, Ishinomaki City, Japan. The Kitakami River has facilitated the extension of tsunami wave inundation to reach the school areas, although it was located about 4.5 km away from the coastal line (Koshimura, 2012; Suppasri et al., 2013; Tsuji et al., 2014; Koshimura and Shuto, 2015). A tsunami due to the July 17th, 2006, M 7.7 South Java earthquake has caused 664 fatalities (Fritz et al., 2007; Kongko et al., 2010). Many victims were farmers working in their farmlands in swells behind the coastal ridges, and this morphology hindered their sight of the incoming tsunami wave. They also did not feel the earthquake's ground shaking and were unaware of the incoming tsunami wave (Cousins et al., 2006; Lavigne et al., 2007).

However, particular landforms may also provide advantages for disaster risk reduction. During the December 24th, 2004 earthquake and tsunami on Simeulue Island, close high grounds from the coastal plain allowed villagers to quickly escape from incoming tsunami waves (Gadeng et al., 2019; Rahman et al., 2018). There was no casualty from the October 25th, 2010 Mentawai tsunami in Malakopa hamlet as all houses had been relocated to a ~40 m high ground nearby the coastal plain several years before the tsunami occurrence (Syamsidik et al., 2011; Syamsidik and Istiyanto, 2013; Yulianto et al., 2023). High coastal ridges saved lives during the 2006 South Java Tsunami. During the 2006 South Java Tsunami event, several survivors climbed onto the coconut trees on those coastal ridges (Yulianto et al., 2010). Furthermore, in the case of the 2006 South Java Tsunami, the swells also canalized the tsunami wave to flow back to the sea and hindered further inundation (Esteban et al., 2013). Those tsunami events provide evidence and lesson-learns regarding the significance of geomorphological aspects in identifying tsunami risk factors.

Pangandaran is a beach resort in the South Java coastal area severely impacted by the July 17th, 2006, South Java Tsunami (Lavigne et al., 2007). After the tsunami, development took place rapidly in the 2006 tsunami inundation areas. The acceleration of infrastructure development was mainly triggered by the change in administrative status of Pangandaran from originally a district to a regency on October 25th, 2012 (Law 21, 2012). Land use has rapidly changed from agricultural land to residential, lodging, government offices, and supporting facilities for a beach tourism destination. Most of the construction occurred in the inundation area of the 2006 tsunami. As a result, the risk level for a tsunami disaster increased significantly, primarily due to the tsunami threat triggered by a magnitude nine earthquake off the subduction zone in southern Java (Widiyantoro et al., 2020). Therefore, more systemic tsunami risk reduction is imperative in this region (Rezaldi et al., 2021). In this study, we discern favorable and unfavorable geomorphological aspects concerning tsunami disaster risk reduction in Pangandaran Beach.

STUDY AREA

Physiographically, the Pangandaran area is included in the Southern Mountain Zone (Bemmelen, 1949). The Oligocene Jampang Formation covers this area along the Middle-Late Miocene Kalipucang and Pamutuan Formation. The Quaternary marine and alluvial deposits (Simandjuntak and Surono, 1992) (Figure 1). The Jampang Formation is composed of volcanogenic breccias, tuff with lava lenses intercalated with lithic sandstone, mudstone, marl, and conglomerate pebbly sandstone, and diamictite intercalation. The Kalipucang Formation is composed of Coralline limestone. The Pamutuan Formation is composed at the bottom of a Marly tuff Member consisting of marly tuffs intercalated with lithic sandstone, mudstone, and limestone. At the top, it comprises a calcarenite Member consisting of calcarenite and clastic limestone intercalated with marl. Quaternary deposits are composed of alluvium resulting from flood deposits and river deposits.

The rocks of these formations have different physical properties, such as hardness, that control erosion factors in the Pangandaran area. The difference in hardness and magnitude of erosion are the main factors controlling morphology. The hilly morphology with steep slopes develops in the area covered by the Jampang Formation. The hilly morphology with gentle slopes develops in the area covered by carbonate rocks and carbonates of the Kalipucang Formation and the Pamutuan Formation. Isolated hills and caves develop in areas covered by coral reef limestones of the Kalipucang Formation. Plain morphology develops in areas covered by alluvial deposits (Simandjuntak and Surono, 1992).

The southern area, Panenjoan Hill, comprises the Jampang Formation breccia on the south and Kalipucang Formation limestone on the north. The Indian Ocean surrounds the hill on the south side, Parigi Bay on the West-Northwest side, and Pangandaran Bay on the East-Northeast side (Figure 1). On the limestones of Kalipucang Formation, karst morphology has developed as isolated hills and caves with stalactites and stalagmites. Narrow sandy coastal plains develop on some of the Northeast, North, and Northwest sides of Panenjoan Hills. Above it, thin silt clay soil has formed with a thickness of 13-172 cm (Kurniawan and Parikesit, 2008). The west, south, and east sides of Panenjoan Hill are steep and high cliffs. Meanwhile, on the north side, there are swells and ridges along the coastal plain.

MATERIALS AND METHOD

This research applied a spatial overview to analyze the geomorphological aspects in establishing disaster risk factors. Geomorphological aspects were obtained from spatial data processing of each cell of the earth's surface in a digital format containing location point information, and field observation was performed to determine morphological aspects as well as the advantages and disadvantages of morphological features within Pangandaran Beach against future risk tsunami. The research required certain materials and tools. The research materials used are presented in Table 1. Quantum GIS (QGIS) Desktop 3.22 software is the primary tool to analyze geomorphological aspects, i.e., morphogenetic, morphometry, and morphography based on Digital Elevation Model (DEM) provided by DEMNAS.

Table 1. Research materials and data availability.

No	Data Types	Data Sources	Notes
1	Topographic data	Digital Indonesian Topographical Base Map (RBI) by the Geospatial Information Agency (BIG)	Scale of 1:25,000
2	Elevation data	• Digital Elevation Model National (DEMNAS) by Geospatial Information Agency (BIG) • Google Earth	Spatial resolution: 8.3 m Google Earth Pro
3	Geological data	Geological map of Pangandaran Quadrangle, Jawa, by GRDC	Scale of 1:100,000
4	Tsunami data	• Tsunami hazard zone map of Pangandaran, West Java Province by Center for Volcanology and Geological Hazard Mitigation (PVMBG) • Tsunami hazard layer by InaRisk	Scale of 1:100,000 Provided by InaRisk BNPB

Geomorphological aspects were assessed following Van Zuidam (1983), who classifies geomorphological aspects into four main aspects: morphology, morphogenesis, morpho-chronology, and morpho-association. Morphological aspects include morphometry and morphography. Morphometry includes aspects of the size and shape of the elements that make up the landform. Morphography is the arrangement of natural objects on the earth's surface. Morphogenesis is the origin, development, and processes that shape and work on the landform. The morpho-chronology describes the sequence of landforms on the earth's surface due to geomorphological processes. Meanwhile, morpho-association links one landform and another in its spatial arrangement or distribution on the earth's surface.

To determine the advantages of these geomorphological aspects related to tsunami risk, the inundation and height of the three tsunami events were used as the basis of the risk assessment, i.e., the 2004 Aceh tsunami due to Mw. 9.3 subduction zone earthquake, the 2006 South Java tsunami due to Mw. 7.6 subduction zone earthquake, and the 2011 Tohoku tsunami due to Mw. 9.0 subduction zone earthquake. Each tsunami has a maximum inundation distance of more than 5, 0.5, and 5 km and a maximum tsunami height of about 32, 20, and 40 m, respectively (Lay et al., 2005; Fritz et al., 2006; Mori et al., 2011; Abe et al., 2020).

RESULT

Geomorphological analysis within the Pangandaran beach complex is divided into three areas; 1) the western Beach, 2) the middle part of Pangandaran, and 3) the eastern Beach (Table 2). Geomorphological interpretation in the Pangandaran area was carried out based on DEM data and visual analysis in the research area. Generally, the southern area is dominated by the morphology of the Coastal Plain, Tied Island, and Tombolo. The central area is dominated by Alluvial plain, while the northern area of the study area is classified as Structural hills (Figure 1).

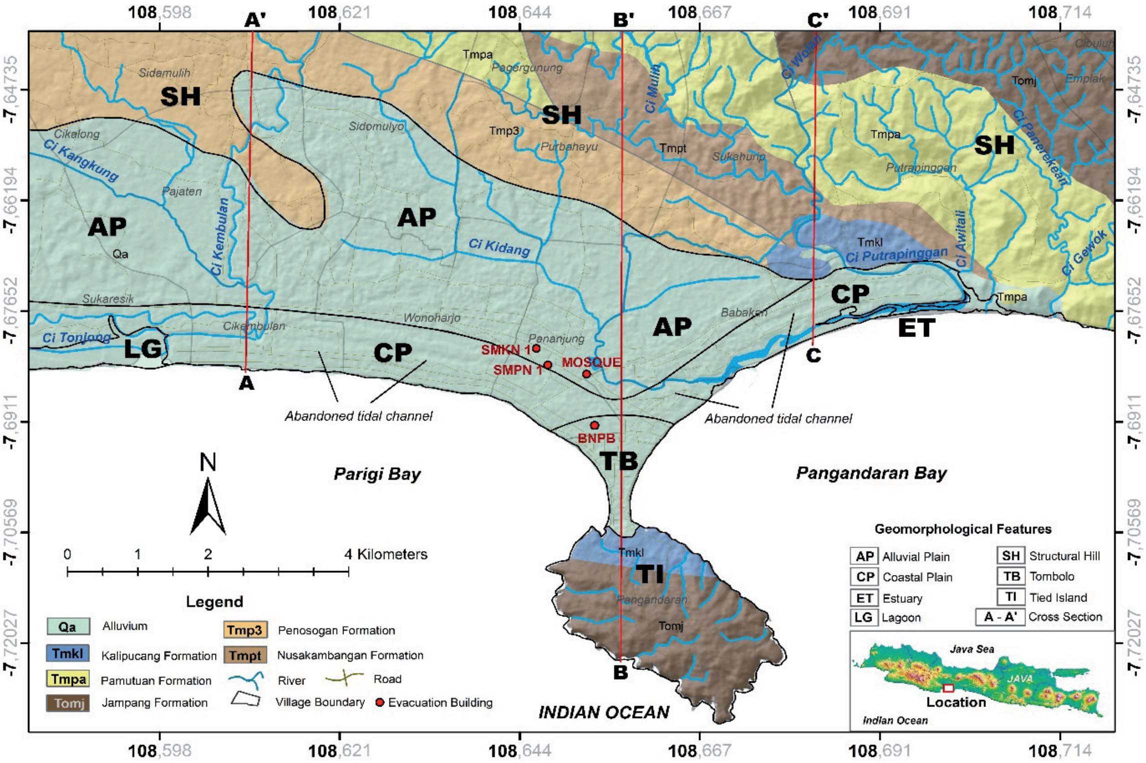

Figure 1. Map of the study area, showing geology, geomorphological features, and location of tsunami evacuation shelters.

Table 2. Geomorphological features of the Pangandaran area

Location (Villages)	**Geomorphological Aspects**				
	Morphogenetic	**Morphometry**		**Morphography**	
		Slope		**Landform**	**Elevation (m)**
		Class	**Degree**		
Cikembulan Pamugaran Wonoharjo Pananjung Pangandaran Babakan	Coastal plain	Flat	0 - 2	Sand beach	0 - 13
				Beach bund	
				Rocky beach	
				Beach flat	
				Tidal channel	
				Estuary	
				Marine terrace	~ 5
					~ 10
Pajaten Purbahayu Sukahurip	Alluvial plain	Flat	2 - 4	Alluvial plain Flood plain	2 - 38
				Marine terrace	~ 10
Sidamulih Sidomulyo Pagergunung Putrapinggan	Structural hill	Undulating	8 - 40	Hill	8 - 190
				Ridge	
Bukit Panenjoan	Tied island	Undulating	8 - 35	Karst and hill	5 - 114
				Cliff	
Pananjung-Pangandaran	Tombolo	Flat	0 - 2	Sand beach	4 - 8

Coastal Plain

The distribution of the coastal plain is in a range of less than 1 km from the coastal line. The height of the coastal plain varies between 0-13 meters above sea level, with a slope of less than 8%. The grain size of beach sand on protected beaches is finer than on open beaches controlled by waves. The coastal plain morphology on the coast is protected from waves, and the coastal slopes are generally flat to slightly wavy. Meanwhile, on the beach, which is more open to waves, the slope is slightly steeper, which shows a rhythmic beach morphology in the form of a beach cusp, where there are two parts of the beach with different characteristics, namely the horn and cusp (Figure 2). Low sand beach cliffs are often found on the cusp. The presence of coastal cliffs in the cusp section indicates that the wave energy is higher compared to the horn section (Setyawan et al., 2011). In the coastal plain, several landforms were observed, i.e., Sand beach, Beach bund, Rocky beach, Beach flat, Tidal channel, Estuary, and Marine terrace. Active and abandoned tidal channels appear as swells parallel to the coastal lines. Several active tidal channels have merged with estuaries, as observed in the Cikembulan, Cikidang, and Ciputrapinggan rivers. The swells of abandoned tidal channels have been utilized as paddy fields, as observed in Cikembulan, Wonoharjo, Pananjung, and Babakan. Two marine terrace platforms were identified in the Coastal Plain. The height of the platforms is about 5 m and 10 m.

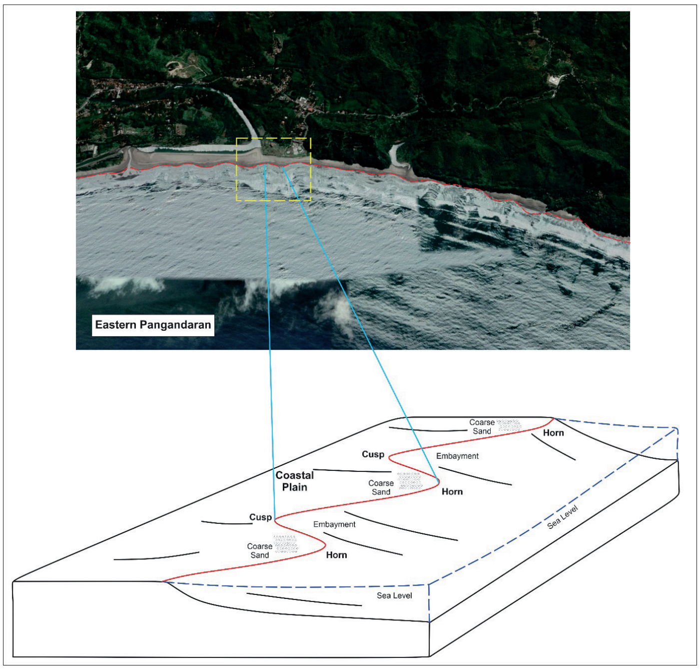

Figure 2. Rhythmic beach morphology with different characteristics of horn and cusp.

Alluvial Plain

The coastal alluvial plain's morphology can be identified well in all research areas. The maximum with of the Alluvial plain is about 2.5 km. This morphology is directly adjacent to the coastal plain and dominated by alluvial deposits of clay and sand either transported via the Cikembulan and Ciputrapinggan rivers or beach sand transported by the wind. In contrast, at elevation, the morphology of the coastal alluvial plain varies between 2-38 meters above sea level.

Tombolo

"Tombolo" comes from Italian (meaning pillow or cushion) and is a term used in geomorphology for a narrow sandy landform deposited across the sea that connects two more extensive lands (islands) (de Mahiques, 2016). Due to its narrowness, the bridge looks like a neck, and one of the connecting islands becomes its head. This small island connected by the Tombolo is called the Tied Island. The formation of the Tombolo occurs when the Tied Island blocks the impact of waves from the open ocean. As a result, the waters behind the island became calmer. If a sufficient sediment supply is available, the sedimentation process may be concentrated in the shadow area of the island.

The middle part of Pangandaran near the shoreline is called Pangandaran Tombolo (Figure 1). It is currently connecting the island of Panenjoan Hill to the main island of Java. The Tombolo feature is 300 m broad at the narrowest part, where Pangandaran Bay and Parigi Bay bound the eastern area in the western area. The elevation of the Pangandaran Tombolo is 4-8 meters, with the highest elevation in the central tombolo area. Based on lithology analysis in the Tombolo area, Pangandaran Tombolo is dominated by beach sand and clastic deposits such as sandy clay from the Ciputrapinggan River estuary.

Morphologically, the Pangandaran Tombolo is a Coastal plain with a slightly different genetic process. The Tombolo is the center of Pangandaran Beach resort which is densely populated with many buildings of hotels, lodgings, and houses. The west coast of the Tombolo, with its long and wide Sand beach, is the center of tourism activities. The east coast is mostly Beach bunds and has traditionally been a fishing port.

Tied Island

The Tied Island is an island connected with the mainland by a Tombolo. The Tied Island morphology consists of an island connected to the mainland or another island only by a Tombolo. This feature is named Bukit (Pasir) Panenjoan in the study area. Panenjoan Hill comprises the Jampang Formation breccia on the south and Kalipucang Formation limestone on the north. The Indian Ocean surrounds the hill on the south side, Parigi Bay on the west-northwest side, and Pangandaran Bay on the east-northeast side (Figure 1). In the limestones of the Kalipucang Formation, karst morphology has developed as isolated hills and caves with stalactites and stalagmites. Narrow sandy coastal plains develop on some of the northeast, north, and northwest sides of Panenjoan Hills. Above it, thin silt clay soil has formed with a 13-172 cm thickness (Kurniawan and Parikesit, 2008). The west, south, and east sides of Panenjoan Hill are steep and high cliffs with narrow rocky Coastal plains in some parts. Two main rivers flow intermittently across Panenjoan Hill, namely the Ciborok River, which empties into Cikamal Bay-Parigi Bay, and the Cirengganis River, which empties into Pangandaran Bay.

Morphologically, Panenjoan Hill is a Structural hill surrounded by narrow Rocky and Sand beaches. The tied island elevation is 1-150 m above mean sea level. The island's northwest side is a limestone hill as high as 15-25 m above mean sea level, extending east-west to almost reach the coast. At the southern foot of this limestone hill, the Ciborok River flows westward and empties into Muara Cikamal. A north-south cross-section of the morphology of the western part and eastern part of the Panenjoan Hill elevation profile shows that a height of >10 meters is about 50-500 meters from residential areas or crowds of tourists on both the west and east coasts. This island is a forest reserve.

Structural Hills

The morphology of the structural hill covers the north and northeast of the Pangandaran area. These hills lie 1 km from the shoreline in the eastern area of Pangandaran Bay, while in the Parigi Bay area, the structural hills are located more than 2.5 km from the shoreline. Genetically, the morphology is formed due to the activity of the geological structure. The hilly unit of the structure has an NW-SE lineament extending from Nusakambangan to the northwestern Kalijaya area of the Pangandaran area. The Breccia unit from Jampang Formation covers the northwestern region to the central area of Pangandaran. Jampang Formation has a low-medium weathering level, while the southeast area of the hill is structurally composed of limestone from the Kalipucang Formation, where the limestone units have medium-high levels of dissolution and weathering. The elevation formed on this landform varies from 8-190 meters above sea level with steep to very steep slopes.

DISCUSSION

In this discussion, the wave heights of three tsunami events are projected in three geomorphological cross-sections on the study area (Figure 3). Tsunami height projections are plotted based on the maximum height of the tsunami waves.

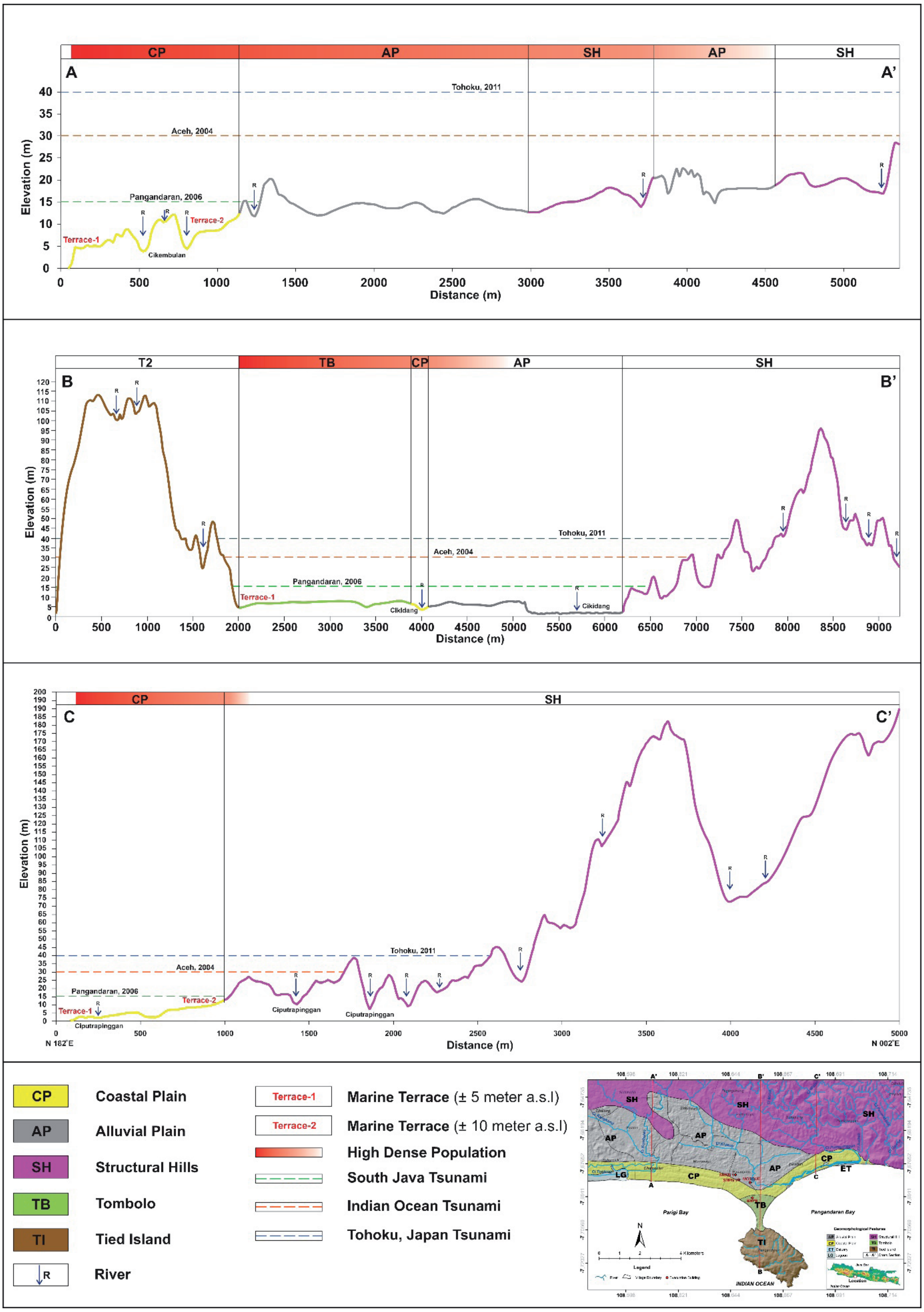

Figure 3. Three longitudinal sections of the geomorphology of the study area show the relative position and distribution of geomorphological features, and simple projection lines of the maximum heights of the 2004 Indian Ocean tsunami, the 2006 South Java tsunami, and the 2011 Tohoku tsunami.

Coastal Plain

In general, the coastal plain is a disadvantage that increases tsunami risk, mainly if the plain is several km wide before reaching a tsunami-safe height. Vast coastal plain increases tsunami risk, particularly in places with short tsunami golden time. The Coastal plains of the study area were inundated by all tsunami scenarios with different tsunami heights (see Figure 3). Meanwhile, no elevated landform can be designated as a tsunami shelter in the Coastal plain.

In the case of the 2006 South Java tsunami, the range of tsunami heights and run-up in the Coastal plain is ca. 3-8 m (Reese et al., 2007; Lavigne et al., 2007). The tsunami inundation reached the sewer channel in Cikembulan and the frontmost swell of the abandoned tidal channels in Wonoharjo before flying back to the sea through the sewer and the abandoned tidal channel. It shows that elongated depressions parallel to the coastal lines have effectively prevented the tsunami from inundating further inland. On the other hand, the elongated depressions may also be barriers to evacuation, particularly when the depressions are submerged by water, such as river flows or swamps. The depressions also potentially increase the risk of people who regularly must be in the depressions for farming. Many depressions are shallow, so the nearby beach ridge hinders people working in their farmlands from being aware of incoming tsunami waves, mainly when it is a tsunami-earthquake. In the case of the 2006 tsunami earthquake, many survivors were working in such depressions, and they did not feel the earthquake shaking and were surprised and swept by the tsunami (Yulianto et al., 2010).

The presence of river flows in the Coastal plain, such as the Ciputrapinggan River in the east and the Cikembulan River in the west of the study area, may increase the tsunami risk as the tsunami waves flow faster through the river channels. These disadvantages may destroy bridges that people use for evacuation. On the Cikidang, Ciputrapinggan, and Cikembulan rivers, there is only one bridge each, connecting the main Banjar-Pangandaran and Pangandaran-Tasikmalaya roads. Ca. 20 km and ca. 8 km of the road are in the Coastal plain of the Parigi and Pangandaran Bays, respectively, parallel to and less than 1 km from the coastline. This road will be the main route to flee from the tsunami hazard zone when people know the arrival of the tsunami wave. They may be trapped on this road due to traffic congestion, significantly if the faster tsunami wave in the river channels has damaged or swept away the bridges. A tsunami triggered by an Mw. 9 earthquakes will drown the road. The Sunda subduction zone along the south of Java is hypothetically capable of triggering an Mw. 9 earthquake (McCaffrey, 2008) that may generate a tsunami wave with a height of more than 20 meters (Widiyantoro et al., 2020).

Furthermore, the river channels may extend the tsunami inundation limit further inland which may cause more loss and damage. This kind of incident occurred near Sendai, Miyagi, where the inundation limit of the 2011 Tohoku tsunami extended more than 4 km further inland through river channels (Nakajima and Koarai, 2011).

Alluvial Plain

Vast flat alluvial plains may extend the tsunami inundation limit further inland, particularly for large-magnitude tsunamis. The 2006 South Java tsunami inundation did not reach the Alluvial plain in the study area (Maemunah et al., 2010). The projection of maximum run-up of the 2004 Indian Ocean and the 2011 Tohoku tsunamis, however, show that a tsunami triggered by M 9 earthquake from the south Java subduction zone will presumably drown the whole Alluvial plain (Figure3).

Tombolo

Geomorphologically, the Tombolo is a Coastal plain. It is the most populated area in Pangandaran and the center of hotels, lodgings, and tourist activities. Consequently, it is the highest tsunami risk in the study area. The whole area of the Tombolo was inundated by the 2006 South Java tsunami (Mardiatno et al., 2020). The tsunami waves hit from the west, Parigi Bay, and from the east, Pangandaran Bay, with height ranges of ca. 4-8 m (Reese et al., 2007; Lavigne et al., 2007). Despite several high buildings along the west and east coasts, the Tombolo has no natural heights. A tsunami evacuation building capable of accommodating 5,100 people was built in 2016 by the Indonesian Government in the center of the Tombolo (Husa and Damayanti, 2019). Several buildings have also been designated as temporary tsunami shelters, i.e., the Pangandaran Mosque, SMPN 1 Pangandaran, and SMKN 1 Pangandaran, which can accommodate 682, 3221, and 2872 people, respectively (Husa and Damayanti, 2019). Most tsunami evacuation signs direct people toward the tsunami evacuation building, and several others direct people toward the mosque, SMPN 1, and SMKN 1 Pangandaran buildings.

Those evacuation buildings are expected to save 11,875 people in the most populated area in Pangandaran from a tsunami comparable to the 2006 tsunami (Koswara et al., 2021). However, the designated tsunami evacuation buildings of mosques and school buildings will presumably be drowned by tsunami waves if a tsunami comparable to the 2004 Indian Ocean and the 2011 Tohoku tsunami hit the area. Those buildings are two-story buildings built on the Coastal plain with ground elevations lower than 12 m asl (Husa and Damayanti, 2019). The second floor of those buildings is a height of about 15 m asl. The mosque, the SMKN 1, and SMPN 1 buildings are only about 1 km, 1 km, and 0.7 km from the coastline, where the tsunami flow depth may be 15 m or higher. Accordingly, the designation of those buildings as tsunami evacuation shelters in the Pangandaran area needs to be evaluated.

Tied Island

The Tied Island is geomorphologically Structural Hills. A narrow, isolated sandy beach northwest of the island is one of the most popular tourist destinations. According to several survivors of the 2006 South Java tsunami (pers. Comm), although the 2006 tsunami waves hit the narrow Coastal plains of the island, including the sandy Beach, the waves did not inundate the north Coastal plain of the island. Despite its publicly limited accessibility due to its use for forest reserve, the Tied Island provides natural landforms for tsunami evacuation shelters, particularly for people who are in the southern area of the Tombolo. Several tsunami evacuation signs were observed toward this forest reserve.

Structural Hills

The tsunami inundation limit may reach the area of Structural Hills only when giant tsunamis generated by the Mw 9 earthquakes occur along the subduction zone South of Java. Projection of the maximum tsunami heights and maximum inundation limits of the 2004 Indian Ocean tsunami and the 2011 Tohoku tsunami shows that the inundation limit of tsunamis with such comparable magnitudes may potentially reach the Structural Hills area (Figure 3) with relatively shallow flow depths. The vast heights in this area may be utilized as natural tsunami evacuation shelters, particularly in areas close to the river flows.

CONCLUSION

The spatial overview analysis and field observation above produce some exciting things related to geomorphological aspects in terms of tsunami risk. First, the Pangandaran area is divided into five geomorphological features, i.e., Coastal Plain, Alluvial Plain, Tombolo, Tied Island, and Structural Hills. These features have different characteristics, several features are favorable, and several others are unfavorable of tsunami risk.

Tombolo and the coastal plain are categorized as unfavorable geomorphological features regarding tsunami risk due to their lower elevation, proximity to the coastline, and dense population. Meanwhile, the geomorphology of the tied island provides natural tsunami evacuation shelters for all scenarios of tsunami due to its heights and proximity to the most populated settlement and tourist activities area of the Tombolo.

On the other hand, the designation of the Pangandaran Mosque, SMPN 1 Pangandaran, and SMKN 1 Pangandaran as tsunami evacuation shelters need to be evaluated to anticipate the tsunami risk of giant tsunamis generated by M 9 earthquakes from the subduction zone.

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