GIS-BASED ASSESSMENT OF COASTAL VULNERABILITY IN THE JATABEK (JAKARTA, TANGERANG, AND BEKASI) REGION, INDONESIA

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ABSTRACT:

JATABEK (Jakarta, Tangerang, and Bekasi) is a significant area where massive developments are concentrated in the coastal region, becoming the center of industry. Due to the vulnerable coastal area, threats of hazards and disasters are undoubtedly avoided. Therefore, assessing coastal vulnerability is crucial to identifying the potency of coastal damages throughout the JATABEK coastal zone. This study examines six primary parameters (geomorphology, elevation and slope, land use, rigid structure, and coastline changes) to determine the coastal vulnerability in the study area using GIS-based and scoring assessments. The coastline change is quantified based on Modified Normalized Difference Water Index (MNDWI). The scored parameters are then analyzed using Coastal Vulnerability Index (CVI) to gain the distribution of vulnerability levels in the study area. Of particular concern, 42.27% of the JATABEK coastline is categorized as a less vulnerable area. In contrast, 31.59% and 11.45% of the coastal area are categorized as high and very high vulnerability, concentrated in the Bekasi Regency and a little part of Tangerang. The remnant categories are moderate (9.56%), and very low (1.73%) vulnerability observed in the Tangerang and eastern part of Jakarta Bay. The presence of permanent artificial structures, land elevation and slope, and land use changes are the most impactful factors determining coastal vulnerability in the study area. Therefore, mitigation efforts are crucial to stabilize the overwhelming abrasion and deal with tidal flooding events in the vulnerable areas.

Key-words: *Coastal vulnerability, JATABEK, scoring assessment, coastal hazards*

1. INTRODUCTION

Jakarta is Indonesia's most significant capital city, with a considerable population (more than 9.6 million people registered in 2010) and a total area of 662 km^2 (Takagi *et al.*, 2016). Skyrocketed developments in the Jakarta coastal area result in various problems. Aside from environmental impacts, it induces coastal damages and vulnerability. Even though the development could enhance the physical growth in the neighboring areas, many coastal issues are reported in the surrounding cities (Tangerang and Bekasi) (Azwar *et al.*, 2013). Furthermore, the urban development is dominated by informal sectors altering the land use in Jakarta and its surroundings.

Due to climate change issues and anthropogenic pressures, Jakarta's coastal area and surroundings are prone to hazards and disasters, such as coastal flooding, sea-level rise, and land subsidence (Takagi *et al.*, 2021). Many solutions, management systems, and environmental-based assessments have been established comprehensively to surmount the impact of rapid urban development (Hakim *et al.*, 2020; Rudianto & Tantu, 2014; Yoo *et al.*, 2014). However, these efforts only encompass several significant areas on the Jakarta coast and did not apply to the surrounding cities. As a result, overwhelming coastal degradation is expected to occur in the Tangerang and Bekasi

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Regency. Therefore, a coastal vulnerability assessment is essential to determine the vulnerable areas in the JATABEK (Jakarta, Tangerang, and Bekasi) region (Oloyede *et al.*, 2022).

Coastal management in JATABEK should be regenerated to achieve optimal sustainable development considering environmental awareness (Zacarias *et al.*, 2011). As a preliminary stage, coastal vulnerability assessment in JATABEK needs to be initiated to solicit coastal issues due to urban development in these areas. Several previous studies have proven the overwhelming coastal erosion occurrence in the Jakarta coastal area and its surroundings (Fatimatuzzahroh *et al.*, 2018; Latif, 2022; Prabawa *et al.*, 2021), where sedimentation instability and marine pollution worsen coastal conditions (Breckwoldt *et al.*, 2016; Sindern *et al.*, 2016).

Since earlier studies just analyzed one or two vulnerability factors and did not consider related factors triggering coastal vulnerability (Ningsih *et al.*, 2011; Varrani & Nones, 2018), an integrated assessment of the JATABEK coastal area is crucial to be conducted. Because of many factors that possibly trigger the coastal vulnerability, this study focuses on examining geological and oceanographical aspects using the coastal vulnerability index. A few studies have reported the influence of geo-oceanographical factors on inducing coastal vulnerability (Fatimatuzzahroh *et al.*, 2018; Latif, 2022; Ningsih *et al.*, 2011; Prabawa *et al.*, 2021; Varrani & Nones, 2018), and these aspects should be investigated and re-reviewed. Moreover, the standard scores to assess every parameter are modified and adapted to the natural condition of the study area. Therefore, this study aims to identify and assess the coastal vulnerability in the JATABEK area. This study is expected to be a basis for future decision-making related to coastal management and hazard mitigation in the JATABEK coastal area.

2. STUDY AREA

This study was carried out in the coastal area of JATABEK (Jakarta, Tangerang, and Bekasi), Indonesia, encompassing Bekasi Regency, Bekasi City, North Jakarta Administrative City, Tangerang City, and Tangerang Regency, with a total assessed coastline of 198.06 kilometers (**Fig. 1**). Generally, the coastal topography of the study area is a lowland formation composed of sedimentary materials developed after the Pleistocene era. According to its slope angle, coastal morphology throughout JATABEK consists of declivous beaches with mangroves and steep beaches with sand-dominated materials (Puspasari & Turni, 2017).

Physio-graphically, JATABEK coastal area is composed of alluvial deposits surrounded by highlands. It is characterized by muddy, sandy, silty sand and sandy silt beaches, commonly found in nearby estuaries (Hidayah & Apriyanti, 2020; Puspasari & Turni, 2017).

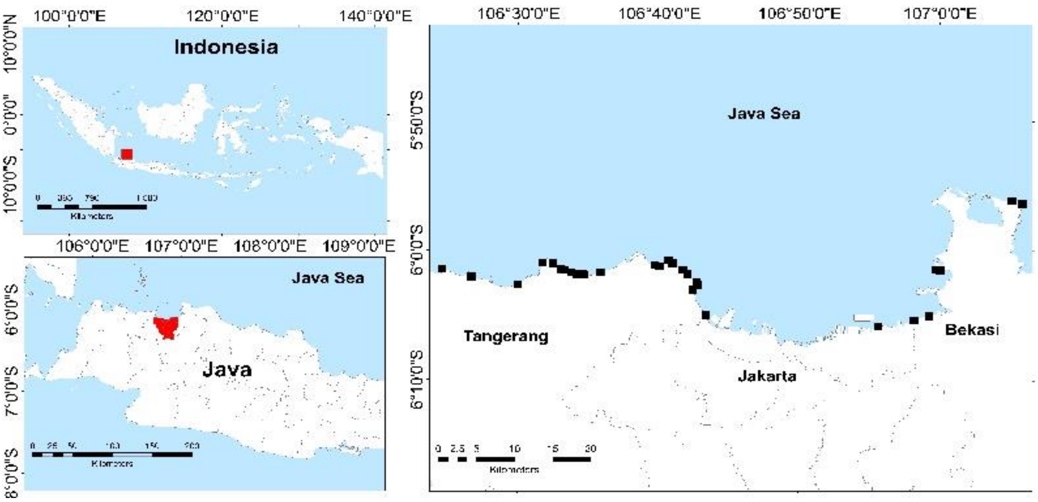

Fig. 1. Details of study area and the observation stations in the JATABEK Region.

3. DATA AND METHODS

3.1. Data Collection and Coastline Changes Identification

The primary data used in this study were collected via field surveys during May 2022 and consisted of several on-site assessments (geomorphological conditions, abrasion and accretion, and coastal structure identification). Thirty-one observation stations were chosen throughout JATABEK Region focused on the area of interest (AOI) (**Fig. 1**). Since the secondary data were remote sensing-based (**Table 1**), it was calibrated by the field measured data to increase the accuracy. The collected data were then analyzed based on the scoring category shown in **Table 1** to determine the vulnerability level of every assessed point. Rigid structures throughout the coastline of the study area were identified using high-resolution imageries (Pleiades and QuickBird) released in 2013-2015 with a spatial resolution of 0.5 meters. In contrast, the coastline change was analyzed using Landsat 8 OLI imagery during 2017 – 2021, with a resolution of 30 meters. On the other hand, the coastline's exact position was quantified from land-water area extraction by applying MNDWI (Modified Normalized Difference Water Index) formula as follows:

$$MNDWI = \frac{\rho_3 - \rho_6}{\rho_3 + \rho_6} \tag{1}$$

where:
ρ_3 = Band 3 of Landsat 8 OLI
ρ_6 = Band 6 of Landsat 8 OLI

Even though the exact coastline is difficult to detect in some cases (Pardo-Pascual *et al.*, 2012), the MNDWI technique uses bands 3 and 6 of Landsat 8 OLI to generate the coastline data (Xu, 2006). The digitized coastlines were then analyzed using DSAS (Digital Shoreline Analysis System) program developed by USGS (Thieler *et al.*, 2000). The transect point was positioned every 500 meters along the baseline, with a total transect of 754.

Meanwhile, the coastline changes rate was calculated using the End Point Rate (EPR) approach (Qiao *et al.*, 2018). Coastline changes are classified as accretion if the EPR is positive and erosion if the EPR is negative. The value in each transect has a specific numbering, easing the spatial detection of coastline change. Rates of erosion and accretion were classified into five categories with values ranging from one to five.

3.2. Coastal Vulnerability Index Assessment

CVI is a calculating method to analyze coastal vulnerability by examining several threatening factors in a region (Gornitz, 1991). The basic calculation of CVI is square-rooting the multiplied parameters and divided by the amount of parameters (Pantusa *et al*., 2018; Romadhona *et al*., 2020). The CVI could be calculated using a simple formula as follows (Gornitz, 1991):

$$CVI = \frac{\sqrt{x_1 * x_2 * x_3 * x_4 * x_5 * x_6}}{6} \tag{2}$$

where:
CVI = coastal vulnerability index score
x = variable scores

Table 1 shows the scoring criteria of each parameter used in this study. The vulnerability range of geomorphological parameters was referred to a category previously established (Pantusa *et al*., 2018). While the vulnerability range of land elevation and the coastal slope was adapted from Irham *et al*. (2021), and the range of land use and coastal area with rigid structures was referred from Romadhona *et al.* (2020).

Table 1.

Vulnerability specification and scoring of each parameter.

No.	Parameter	Category				
		Very Low	**Low**	**Moderate**	**High**	**Very High**
		1	**2**	**3**	**4**	**5**
1.	Geomorphology	High cliff, rocky beach	Medium cliff, pebble beach	Low cliff, muddy land	Rocky beach, estuary, lagoon	Barrier beach, sandy beach, brackish swamp, mud, delta, mangrove, coral reefs
2.	Coastal Elevation (m)	≥30.10	20.1-30	10.1-20	5.1-10	0-5
3.	Coastal Slope (%)	>1.2	1.2-0.91	0.9-0.61	0.6-0.30	<0.3
4.	Land Use	Dry land	Farm, Bush Land	Vacant land with farm area	Sand area, mangrove, plantation area	Building, Beach, ponds degrade mangrove, swamp, and aquaculture
5.	Artificial Hard Structure-Attached Coastline	80-%-100%	60%-80%	40%-60%	20%-40%	0-20%
6.	Coastline Changes	≥2.1 Accretion	≥1 – <2 Stable	< 1 – > -1 Low Erosion	≤ -1 – > -2 Moderate Erosion	<-2.0 High Erosion

These six parameters were then divided into a specific vulnerability range, ranging from one to five representing very low, low, moderate, high, and very high vulnerability categories, respectively (**Table 2**).

Table 2.

Vulnerability classification based on CVI.

Vulnerability class	CVI	Color
Very low	0-4.47	Green
Low	4.48-8.15	Blue
Moderate	8.16-11.83	Yellow
High	11.84-15.51	Orange
Very high	15.52-22.82	Red

4. RESULTS AND DISCUSSIONS

4.1. Coastal Vulnerability Based on Coastline Changes and Coastal Protection

The highest erosion rate of -233.26 m/year was identified in the surrounding Cikeas Estuary and Babelan Coast, Bekasi Regency. This state could be caused by the recent decrease in mangrove forest areas, as reported by (Hidayah & Apriyanti, 2020). The decreased mangrove area is believed to diminish coastal function as a stabilizer from erosion (Walters *et al.*, 2009). More interestingly, the lowest erosion rate was also observed in the Bekasi Regency, with approximately -0.96 m/year concentrated in the surrounding Muara Gembong mangrove forest.

On the other hand, coastal accretion was detected in 175 points scattered in the study area concentrated in North Jakarta. The highest accretion rate was observed in the Pakuhaji - Tangerang Regency (188.29 m/year). The remnant categories, such as low erosion, moderate erosion, and stable, were also identified in the study area though they are not dominant (**Table 3**). Overall, most of the coastlines in the JATABEK Region are highly vulnerable, with a more than two m/year change rate and approximate cover of 56.97% of the entire study area. Moreover, the highest vulnerability level was detected in the Bekasi Regency, mainly caused by coastline changes.

Coastal vulnerability assessment based on coastline changes in the JATABEK Region is shown in **Table 3** and **Fig. 2**. 56% of the assessed coastline is highly vulnerable (coastline change rate more than two m/year). Meanwhile, Bekasi Regency is the most vulnerable area with significant erosion (24.45% vulnerable coastline). This state shows the impact of massive developments in Jakarta, worsened by sea-level rise and land subsidence issues (Abidin *et al.*, 2013).

Table 3.

Percentage of coastal vulnerability caused by coastline changes in the study area.

Location	Coastline Vulnerability					Total
	Very Low	Low	Moderate	High	Very High	
Tangerang	0.89%	5.07%	1.47%	0.97%	17.57%	25.97%
Jakarta	0.59%	8.88%	11.50%	1.20%	17.64%	39.80%
Bekasi	0.39%	10.29%	0.71%	1.08%	21.76%	34.23%
Total	1.87%	24.24%	13.68%	3.25%	56.97%	100%

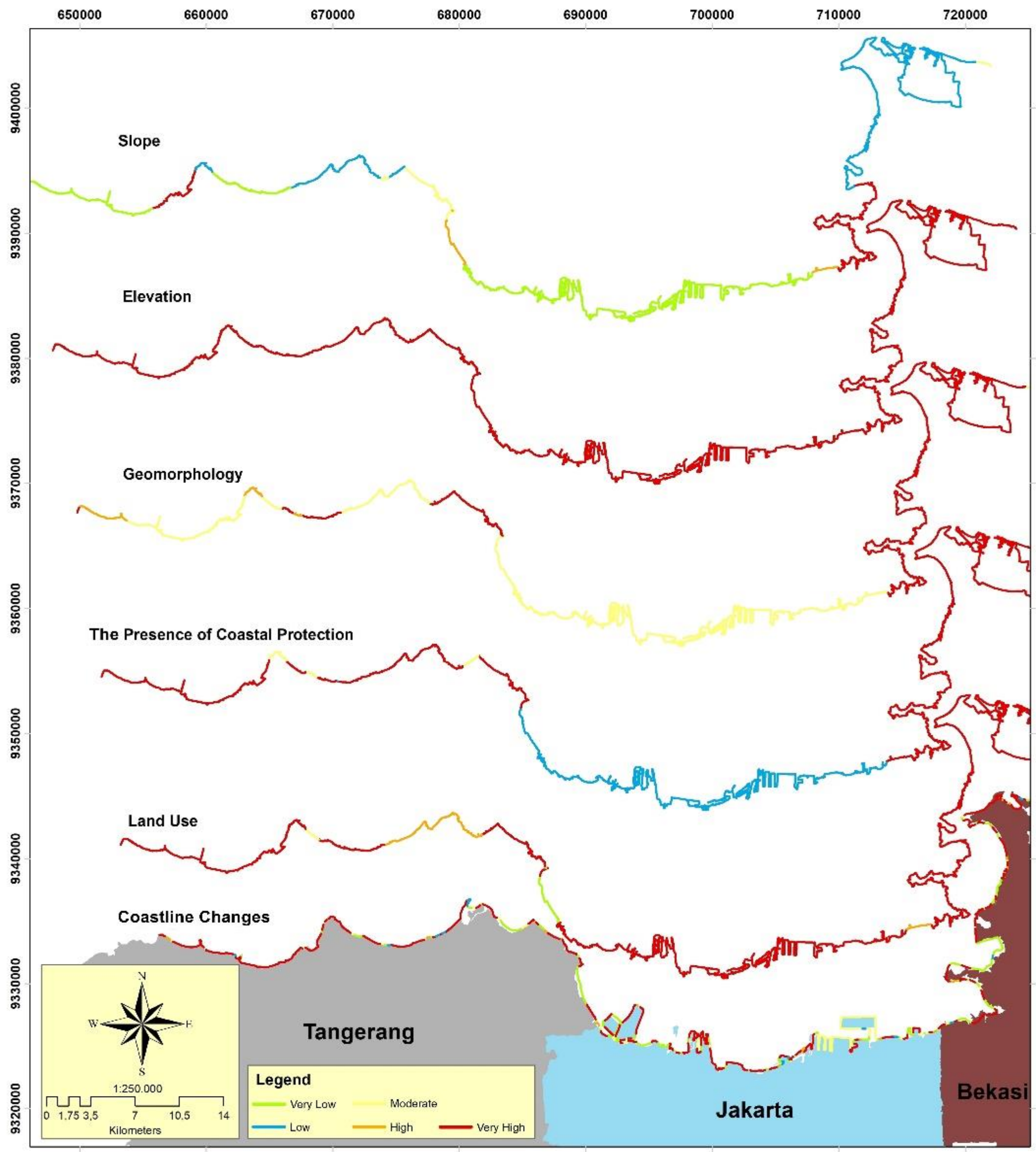

Fig. 2. Coastal vulnerability assessment result of every parameter used in this study.

In addition to coastal erosion, the evidence of erosion in the study area is shown in **Fig. 3**.

Fig. 3. Coastal erosion documented during field survey in 2022. Erosion in Tanjung Anom, Tangerang (a); erosion in Muara Gembong (b); erosion in Pulo Cangkir, Tangerang (c); and erosion in Marunda (d).

The most altered coastline is observed in the Bekasi coastal area, where the absence of coastal protection is the main factor triggering coastline changes. In contrast, Jakarta and Tangerang coastlines tended to be stable because of coastal protection, as El-Mahdy *et al.* (2022) reported that the unstable coastline due to erosion/accretion processes could be overcome using coastal structures. Therefore, coastal protections should be prioritized to protect significant areas from the threats of erosion, sea-level rise, and other coastal hazards and disasters (Hidayat, 2006).

On the other hand, coastal vulnerability assessment based on coastal structures is shown in **Fig. 2** and **Table 4**. A low vulnerability was detected throughout Jakarta coastal area with 36.20%. 80% of the Jakarta coastline is protected by reclaimed islands and coastal breakwater, seawalls, and revetments. Moreover, the local government and third parties have prepared a “Giant Sewall” master plan to protect Jakarta City from tidal flooding (van der Wulp *et al.*, 2016). In contrast, high and very high vulnerability categories were found in Bekasi and Tangerang, where the coastal area is mainly used for aquaculture and tourism. The significant deformation of mangrove forests becoming aquaculture ponds in Muara Gembong - Bekasi results in expanded erosion areas (Oktaviani *et al.*, 2019). Based on the present study analysis, Bekasi Regency experienced a very high erosion with a small area protected by coastal structures (0-20%).

Table 4.

Percentage of coastal vulnerability based on coastline changes and the presence of coastal structures.

Location	Coastal Vulnerability					Total
	Very Low	Low	Moderate	High	Very High	
Tangerang	6.69%	1.67%	1.39%	0.00%	14.15%	23.90%
Jakarta	0.00%	36.20%	0.00%	0.00%	0.00%	36.20%
Bekasi	0.00%	0.00%	0.00%	0.00%	39.90%	39.90%
Total	6.69%	37.87%	1.39%	0.00%	54.05%	100.00%

4.2. Coastal Vulnerability Assessment Based on Coastal Elevation and Slope

Coastal elevation in the study area ranged from 0 to 5 meters. Based on this parameter, the coastal area of JATABEK is highly vulnerable (**Fig. 2**). Land elevation is one indicator determining the area prone to sea-level rise and tidal flooding. A previous study (Dasanto, 2010) predicted that the sea level will rise 0.5 to 1 meter in 2050 and 2100 during flood tides. However, higher sea surface levels and wave inundation contribute to increased coastal hazard potency (Handiani, 2019).

The results of the coastal slope assessment are shown in **Fig. 2** and **Table 5**. The coastal slope ranged from 0.1 to 3.2. The same result is also defined by Dahlia *et al.* (2019), whereby the slope of the Jakarta coastal area is less than five meters. Based on this parameter, the coastal area of JATABEK was predominated by a low vulnerability with 45.70%. The lowest slope was detected in the Bekasi Regency, and the highest slope was identified in the Jakarta coastal area. While, in the Tangerang and Bekasi coastal areas, the slope ranged from 0.1% to 0.25%, categorized as very high vulnerability covering 1.81% and 0.96% of the entire study area, respectively.

Table 5.

Percentage of coastal vulnerability based on slope in the study area.

Location	Coastal Vulnerability					Total
	Very Low	Low	Moderate	High	Very High	
Tangerang	9.50%	5.93%	2.88%	3.67%	1.81%	23.78%
Jakarta	36.23%	0.00%	0.00%	0.00%	0.00%	36.23%
Bekasi	0.00%	26.99%	11.47%	0.54%	0.99%	39.99%
Total	45.73%	32.92%	14.34%	4.20%	2.80%	100.00%

4.3 Coastal Vulnerability Assessment Based on Land Use and Geomorphology

Coastal settings and patterns could minimize the risk of sea-sourced disasters. By contrast, significant land use changes increase hazard and disaster threats in coastal areas (Adnan *et al.*, 2020). Moreover, massive coastal transformation, such as the deformed agriculture area, will cause unstable soil fertility and salinity, eventually affecting the surrounding area's existing buildings (Khan *et al.*, 2015; Lee & Brody, 2018; Rahman *et al.*, 2017). The result of land use analysis in the JATABEK coastal area is shown in **Fig. 2** and **Table 6**.

Table 6.

Percentage of coastal vulnerability based on land use in the study area.

Location	Coastal Vulnerability					Total
	Very Low	Low	Moderate	High	Very High	
Tangerang	1.85%	0.00%	0.58%	5.63%	15.84%	23.90%
Jakarta	0.00%	0.00%	0.00%	0.00%	36.20%	36.20%
Bekasi	0.00%	0.00%	0.00%	0.99%	38.91%	39.90%
Total	1.81%	0.00%	0.55%	5.62%	92.03%	100.00%

Based on land-use parameters, the JATABEK region is highly vulnerable, encompassing more than 90% of the study area. The coastal area of JATABEK is generally used for aquaculture, developed area, and barren zone. On the other hand, the spatial pattern of the JATABEK area complies with the structure and spatial patterns following the main road and highway. A previous study (Nur *et al.*, 2018) defined the increasing tendency of developed areas in the city center, and the development is directed toward the eastern region of Jakarta, including East Jakarta, Bekasi City, and Bekasi Regency. On the other hand, the reclamation area is planned in North Jakarta and Tangerang. 36.20% of the coastline in Jakarta is categorized as a very vulnerable area (**Table 6**). This region has been experiencing massive and rapid urban development in settlement, industry, open green areas, and agriculture (Mulyaningsih *et al.*, 2018).

In the Tangerang coastal area, a plethora of coastal areas are mismanaged, especially the development of illegal settlement and aquaculture that infringe the spatial regional space regulation (Hidayat, 2006). Nevertheless, a small part of the Tangerang Regency is less vulnerable, with 1.85 % empty spaces in the coastal area. In contrast, 38.91% Bekasi coastal zone is categorized as very high vulnerability with the general land use for aquaculture.

Marine-fluvial amalgamation processes generally arrange the land formation of the JATABEK coastal area. The marine process is commonly found in the northern part of the coastal zone. While the fluvial process predominantly influences the middle and the southern areas. These land formations were defined using Digital Elevation Model (DEM), validated by the field assessment. JATABEK coastal area is characterized by low elevation where this region is composed of alluvial lithology (Qa) consisting of clay, silt, sand, and pebble, and beach embankment deposits (Qbr) marked by alluvial lithology, consisting of fine-coarse sand with well-sorted sediment combined with mollusk shell fragments (Turkandi *et al.*, 1992).

Land types in the JATABEK area generally consist of alluvium beaches, beach ridges, the area between ridges, swamps, flooded land, alluvial land, alluvial fan, and riverine channels (Priyatna *et al.*, 2015). The domination of alluvium deposits in the JATABEK Region makes this area prone to puddles and the most vulnerable.

The result of coastal vulnerability assessment based on geomorphology parameters in the JATABEK area is divided into three types of vulnerability; very high, high, and moderate (**Fig. 2**), where the predominant category was very high vulnerability (43.86%) and moderate vulnerability (52.56%) (**Table 7**). The moderately vulnerable area is arranged by silty land formation, related to the fundamental characteristic of the depositional area. In contrast, the highly vulnerable area is arranged by the barrier and sandy beaches, brackish swamp, mud, delta, and mangrove.

Table 7.

Percentage of coastal vulnerability based on the coastal geomorphology parameter.

Location	**Coastal Vulnerability**					**Total**
	Very Low	**Low**	**Moderate**	**High**	**Very High**	
Tangerang	0.00%	0.00%	14.44%	3.58%	5.88%	23.90%
Jakarta	0.00%	0.00%	36.20%	0.00%	0.00%	36.20%
Bekasi	0.00%	0.00%	1.92%	0.00%	37.98%	39.90%
Total	0.00%	0.00%	52.56%	3.58%	43.86%	100.00%

In addition to the geomorphology of the study area, the alluvium land of JATABEK is composed of uncompacted alluvial deposits. The arranging lithology in the form of younger alluvial deposits and beach embankments consists of sandstone, marl, and limestone deposits, playing a significant role in the basic structure of alluvium, reducing the river runoff (Dahlia *et al.*, 2019). Therefore, the potency of river and coastal flooding could be reduced. In contrast, coastal lithology with sandstone, marl, and limestone triggers flooding area formation. Furthermore, lateral erosion intensity in the coastal area with sand lithology is higher than in the alluvium coast. The high vulnerability of the JATABEK area is worsened by sandy beaches where the sand sediment is easily transported by currents and waves (Serafim *et al*., 2019).

On the other hand, muddy areas in the surrounding estuaries predominate the center area of study with moderate vulnerability status (**Fig. 2**). The mud (silt) sediment is more solid than the sand texture, thereby minimizing the level of vulnerability. By contrast, the highly vulnerable locations are usually composed of sand (coarse-sized) sediments (El-Mahdy *et al*., 2022).

4.4 Coastal Vulnerability Index (CVI) in the JATABEK Region

The GIS-based CVI analysis shows that 42.27% of the JATABEK coastline was categorized as lowly vulnerable, concentrated in Tangerang and North Jakarta. Artificial coastal structures could reduce the potency of coastal damages, erosion, and wave overtopping in these areas where it protects almost 80% of the North Jakarta Region. By contrast, the highest vulnerable area is observed in the Bekasi and Tangerang Regency, covering 28.45% and 3.14% of the study area, respectively. The remaining categories are 9.56% moderately vulnerable, 31.59% highly vulnerable, and 11.45% of very high vulnerability (**Table 8** and **Fig. 4**).

Table 8.

Percentage of CVI in the JATABEK Region.

Location	**Coastal Vulnerability Index**					**Total**
	Very Low	**Low**	**Moderate**	**High**	**Very High**	
Tangerang	1.73%	6.07%	9.56%	3.14%	3.39%	23.90%
Jakarta	0.00%	36.20%	0.00%	0.00%	0.00%	36.20%
Bekasi	0.00%	0.00%	0.00%	28.45%	11.45%	39.90%
Total	1.73%	42.27%	9.56%	31.59%	14.84%	100.00%

The most significant parameter in CVI determination is the land elevation, where the entire study area is characterized by less than 5 meters of elevation. The declivous slope of JATABEK is prone to sea-sourced disaster impacts where in some places, the slope state induces a sudden disaster and increases the coastal zone's vulnerability level (Michoud *et al.*, 2012).

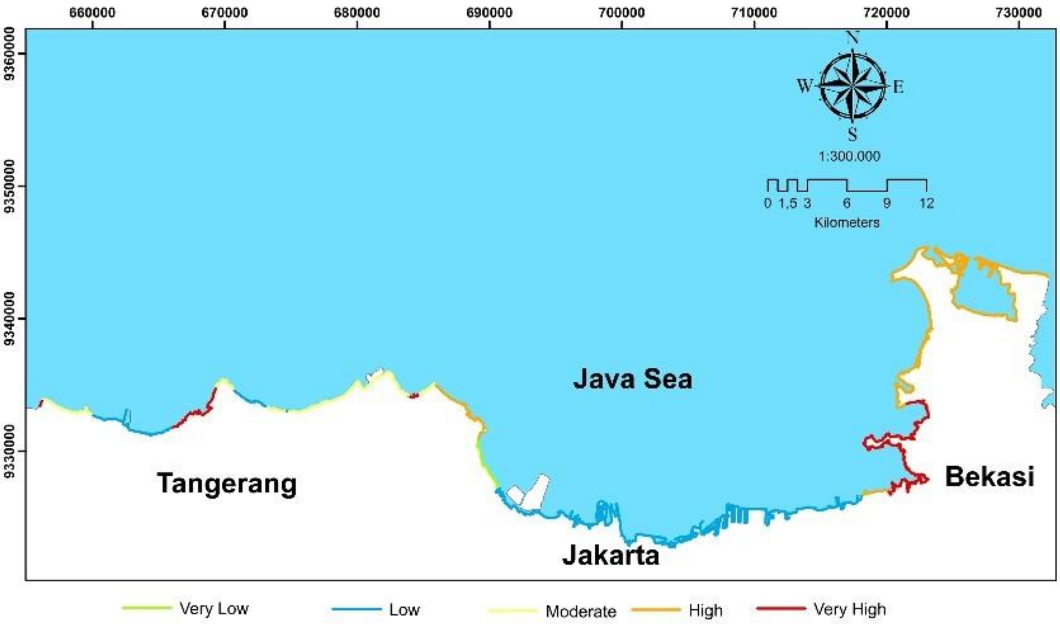

Fig. 4. Coastal vulnerability index in the JATABEK Region.

However, land use in the study area in the form of developed areas and aquaculture ponds also increases the level of vulnerability, generally observed in the Bekasi region with high (28.5%) and very high (11.45%) vulnerability. The coastal destruction in this area is less mitigated, and the massive land use transformation exacerbates the vulnerability status of the Bekasi Regency.

A large scale of coastal vulnerability is caused by the coastal disaster intensity, such as erosion, flooding, and cyclone (Hoque *et al.,* 2022). Vulnerability assessment of a coastal zone is imperative to reduce the impact of coastal hazards. Several scholars prove that many coastline cities are prone to hazards and disasters and eventually impact the socio-economic sectors (Cao *et al.,* 2022; Wang *et al.,* 2021). However, the natural condition of a coastal zone plays a significant role in triggering coastal vulnerability and could trigger other hazardous threats (Yin *et al.,* 2012).

In this study, the use of remote-sensed and field data to generate the CVI analysis complements each other. Land use, elevation, and rigid coastal structure could be remotely observed from satellite images (Elkafrawy *et al*., 2021). Moreover, satellite data could also cover the gap between field stations (Irham *et al*., 2021). Therefore, the remote sensing data are significant in determining the vulnerability level in the coastal zone, even though it should be validated using field data to enhance the accuracy of the GIS-based processing results. In addition to the accuracy, the denser field observation station will increase the fidelity of the resulting data (Jana and Bhattacharya, 2013), which is recommended for further studies to extend the observation station during the field survey.

5. CONCLUSIONS

To conclude, based on the GIS-based analyses, the coastal area of North Jakarta is categorized as a less vulnerable area where the presence of artificial coastal protections is significant to preserve this capital area from coastal hazards and disasters. Despite detecting coastal erosion and highly vulnerable areas, several parts of the Tangerang Regency are less vulnerable due to the presence of coastal structures. The most vulnerable area is found in the Bekasi Regency, with high and very high vulnerability categories.

The primary data used in this study was collected from satellite imagery which the lack of accuracy is possible due to the difference in resolution. On the other hand, the field survey could improve the result of GIS-based modeling, where the denser the observation point, the better the data obtained. We recommend regularly monitoring the coastal zone changes since rapid urban development is still happening in the JATABEK region, which may trigger further coastal alterations and increase the impact of coastal hazards and disasters. A preliminary study is crucial before applying developments in the coastal area since it is now prone to erosion issues.

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