Assessing Tidal Flooding Vulnerability in the Coastal Region of Central Java Using Remote Sensing Approach

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Abstract. The coastal area is vulnerable to various disasters, both natural and human induced. Tidal flooding is one of the coastal disasters with high frequency and the most significant impact on the environment. BNPB recorded a 46% increase in tidal flooding incidents from 2020 to 2022. These tidal flooding events had an impact on most of the northern coastal areas of Central Java. This is further exacerbated by land subsidence and sea-level rise phenomena. Assessing the vulnerability of tidal flooding in Central Java is crucial for future decision-making and mitigation plans. This study will use remote sensing approach to assess tidal flooding vulnerability with land subsidence and sea level parameters. The results indicate that most of the coastal areas in Northern Central Java have very high land subsidence and moderate sea level rise. The study results can be utilized for decision-making and future tidal flood disaster mitigation planning.

Keywords: Central Java, land subsidence, remote sensing, sea-level rise, tidal flooding.

1 Introduction

Coastal areas are susceptible to exposure to various disasters, whether caused by natural events or human interventions [1]. Coastal flood is one of the most frequently occurring coastal disasters, with the most significant impact on the environment [2]. In 2020, data from the World Population indicated that approximately 2.15 billion individuals lived in the vicinity of coastlines [3]. The occurrence of tidal floods is significant due to the high population concentration in coastal areas, posing threats to economic, infrastructural, environmental, and community settlement aspects [4]. The region of Central Java in Indonesia faces a susceptibility to river and coastal inundation because of both climate variations and geological influences [5]. To mitigate the rising risk of coastal flooding, strategic measures are required, such as vulnerability assessments in coastal areas for informed decision-making [6] [7].

Several previous studies have already examined the assessment of costal flood vulnerability. First previous study aims to evaluate the socioeconomic vulnerability of coastal communities in facing floods in Mataram [8]. This research employs various research

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methods, including surveys, interviews, and secondary data analysis, to assess the socioeconomic vulnerability of coastal communities to floods. The study results indicate that the spatial approach can elucidate the interactions between the environment and the socioeconomic conditions of the coastal areas in Mataram and underscore the importance of mitigating the risks of coastal flood disasters. Second, the previous study presents a study that uses GIS and remote sensing techniques to evaluate the vulnerability of coastal areas due to storm surges and flooding [9]. The parameters used include sea level rise scenarios to calculate flood inundation, as well as the building height to determine whether there is a potential for submergence or not. Third, the study focuses on utilizing remote sensing data and advanced modeling to evaluate the susceptibility of coastal areas to flooding [10]. To obtain vulnerability values, the parameters used include sea level rise, geomorphology, slope, elevation, and wave. Based on several previous studies, there has been no study that combined land subsidence and sea level rise data to assess coastal flood vulnerability. Land subsidence and sea level rise are two primary factors that have the potential to increase the occurrence of coastal floods [11].

In this research, the vulnerability of the coastal areas of Central Java will be assessed concerning two primary parameters, sea level rise and land subsidence projections. By combining both sets of data, the vulnerability in the future can be assessed. The main objective of this study is to identify the areas along the coast of Central Java that are susceptible to tidal flooding caused by these factors. The method to be implemented in this research is a bivariate analysis approach, which enables researchers to analyze the relationship between two key variables sea level rise and land subsidence.

2 Methodology

2.1 Study Area

Central Java is situated in the middle of the Java Island, with geographical coordinates ranging from approximately 6°S to 8°S and 108°E to 111°E. The province shares its borders with other provinces, such as West Java to the west, Yogyakarta Special Region (DIY) and East Java to the east, West Java and the Indian Ocean to the south, and the Java Sea to the north. This area was chosen because according to occurrence history, the flood in the area did not only happen on that date, but it happened every day [12]. Another reason is that the vulnerability to tidal flooding in the Central Java coastal areas is exacerbated by the population projection, reaching 60.8% from 2010 [13]. This research will focus on the North coastal areas in Central Java province. A 20 km buffer area is established from the coast based on tidal flood occurrence points that occur within 0-20 km from the coastline [13].

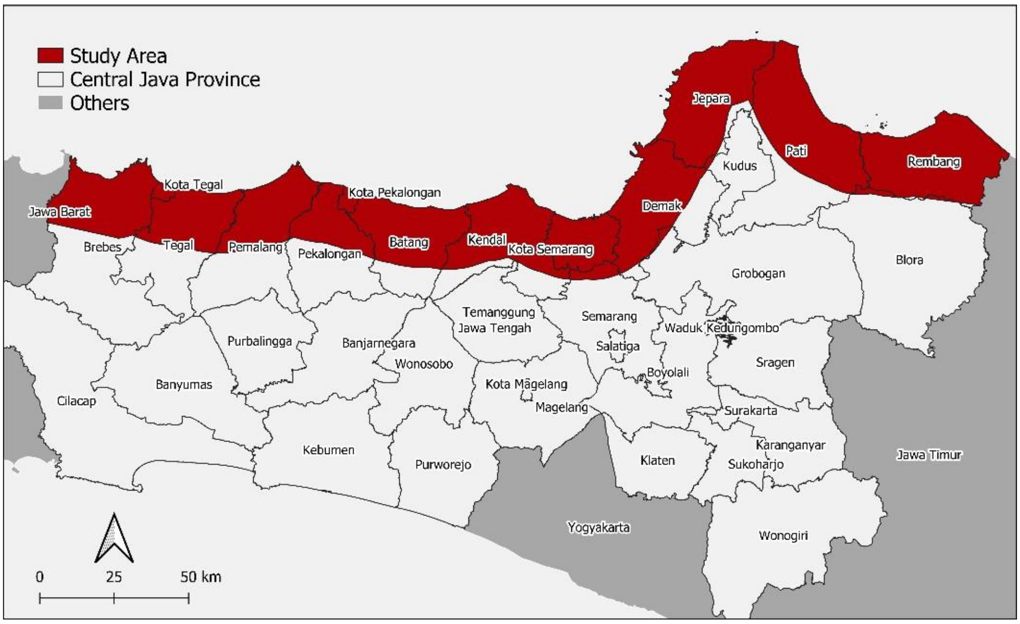

Fig. 1. Study Area.

2.2 Material

In conducting this research, various data were used such as sea level model and global land subsidence projection to assess vulnerability of coastal floods. Land subsidence and sea level rise are major factor that influence coastal flood [14] [15]. Table 1 presents the data used along with the sources and data types.

Table 1: Data used and data format.

No	Data	Product	Temporal	Type-Resolution
1	Sea-level Model	TOPEX/ Poseidon,Jason-1, OSTM/Jason-2, dan Jason-3	1993 - 2020	Raster-200m
2	Global Land Subsidence	LASII UNESCO-Global Maps of LandSubsidence susceptibility	Projection2040	Raster-900m
3	AdministrationData	Database of Global Administrative Areas	-	Vector
4	Flood Points Occurences	Central Java DisasterInformation System	2021-2022	Vector

The data for land subsidence projections is obtained from research that models land subsidence based on factors such as groundwater extraction and urbanization and assesses the associated risks to infrastructure and the environment [16]. Land subsidence projections provide valuable insights into the potential sinking or lowering of land surfaces over time. These projections are characterized by classified probability levels using a six-level equal interval scale, ranging from "very low" to "very high." These classifications help us understand the likelihood of land subsidence occurring in specific areas, with "very low" indicating minimal risk and "very high" signifying a significant likelihood of land sinking or subsiding.

The sea level model is constructed from a combination of data from several altimetry satellite missions, including TOPEX/Poseidon, Jason-1, OSTM/Jason-2, and Jason-3, spanning the years from 1993 to 2020.

2.3 Method

The study area is created from a 20 km buffer zone. The main goal is to create a coastal flood vulnerability map by integrating sea level models and land subsidence projections. To generate the vulnerability map, a data normalization process is conducted with the aim of ensuring data consistency across the entire system. The bivariate values will be used to assess the conditions of flood occurrence locations. Subsequently, bivariate visualization is employed as a data analysis and visualization approach designed to explore the concurrent connections between two variables. This visualization method is used to observe how two distinct variables are interconnected or how they mutually influence each other. To illustrate the methodology employed in this study **Figure 2** shows the flow diagram used in this research.

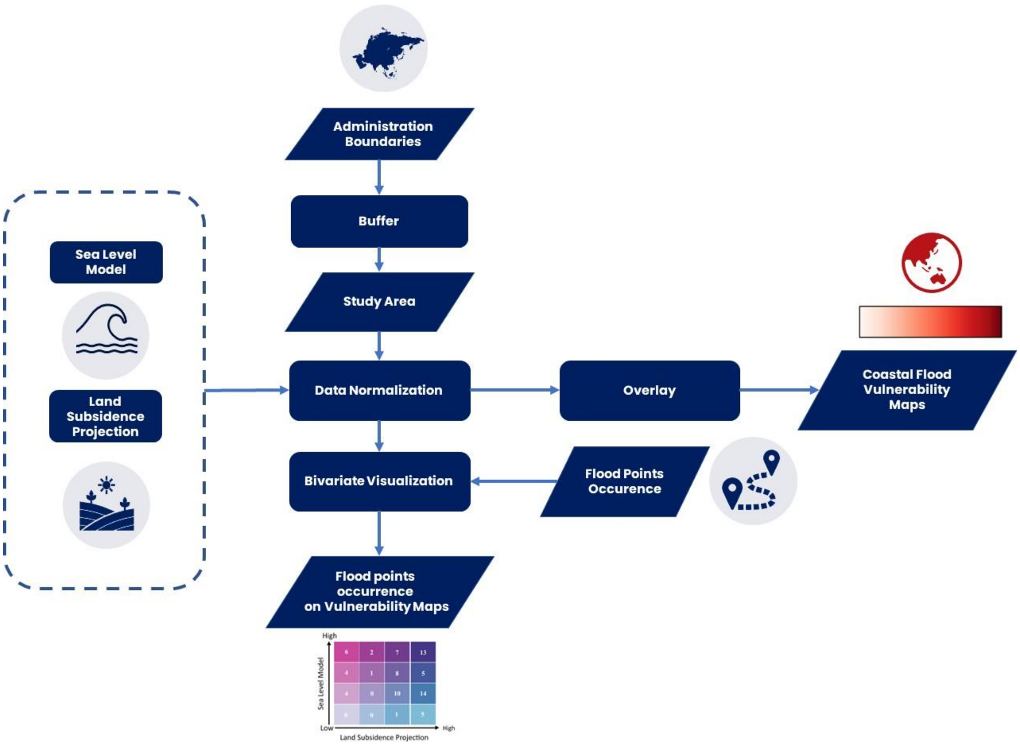

Fig. 2. Methods Flowchart.

3 Results

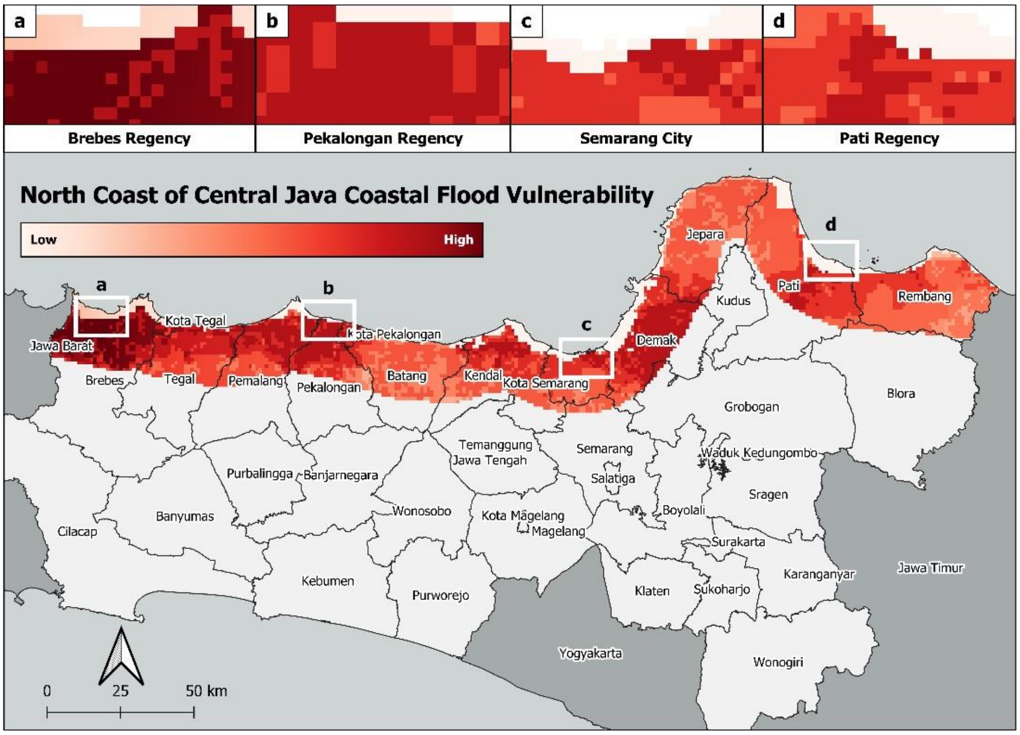

Fig. 3. North Coast of Central Java Coastal Flood Vulnerability.

The coastal flood vulnerability map for the northern coast of Central Java can be seen in **Figure 3**. To obtain vulnerability values, a data normalization process is conducted for both parameters, sea level model and land subsidence projection. The values obtained after normalization range from 0 to 1. After normalizing the data, an overlay of the two datasets is performed, resulting in values ranging from 0 to 2, indicating the vulnerability level of the area. The closer the value is to 2, the higher the vulnerability of the area due to both a high sea level rise and a high land subsidence projection.

Brebes Regency has the highest number of flood incidents compared to other regions, totaling 23 occurrence points. When reviewing the vulnerability assessment results, Brebes Regency is represented by a dark red color, indicating that it has the highest level of vulnerability compared to other areas. Brebes Regency experiences a high rate of sea-level rise and has a high land subsidence projection. Other areas such as Pekalongan, Semarang, and Pati have a total of 8, 17, and 11 consecutive incidents, and represented with values leaning towards dark red.

Areas identified as highly vulnerable are more likely to experience significant land sinking, which is the gradual lowering of the ground's surface when they undergo development. This sinking ground can have serious consequences, one of which is an increased risk of coastal flooding. When the land sinks, it gets closer to sea level, making it easier for seawater to flood into these areas, especially during high tides and storms. This poses a major threat to homes, infrastructure, and the overall safety of the people living there. To protect against this risk, it's crucial for vulnerable regions to put in place strategies to deal with coastal flooding and its potential damage.

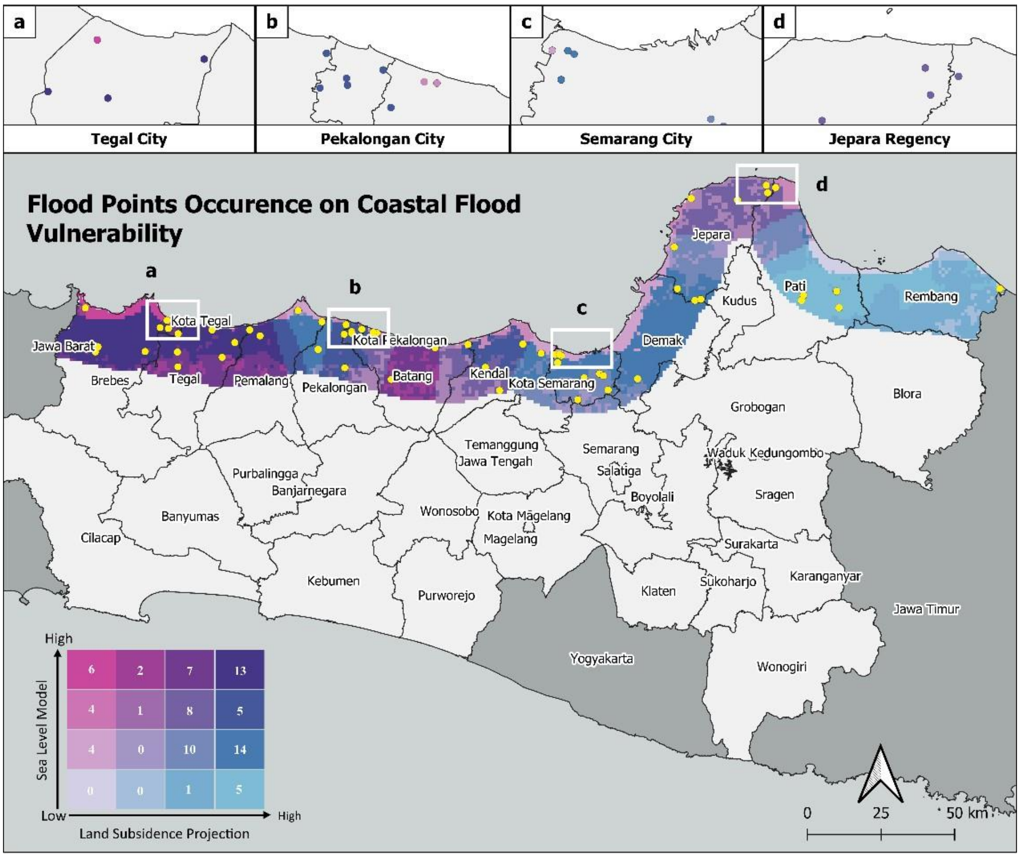

Fig. 4. Floods Points Occurence on Coastal Flood Vulnerability.

In order to obtain the results presented in **Figure 4**, a bivariate visualization was performed. Considering two parameters: the sea-level model and the land subsidence projection. After being normalized, each of these parameters was categorized into four classes, ranging from low to very high. This led to the creation of 16 distinct classes, representing different combinations of these two parameters. The intensity of the purple color in the visualization corresponds to the magnitude of both the sea-level model and land subsidence projection, with darker shades indicating higher values. Subsequently, bivariate values were extracted at flood incident points to assess the conditions at those specific locations.

When reviewing the coastal flood vulnerability area, according to **Fig *4***, the largest area falls within the category of very high land subsidence projection and moderate sea level model. The total area for this category is 14% or approximately 1107.235 km². The second largest area falls under the category of very high land subsidence and very high sea level model, covering 11% or approximately 931.562 km².

When examining the flood incident points, the majority of them fall within the same category as the largest area. There are 14 flood incident points in the very high land subsidence projection and moderate sea level model category, and 13 flood incident points in the very high land subsidence and very high sea level model category. This indicates that the assessment of coastal flood vulnerability accurately represents the real-world conditions based on flood incident points.

4 Conclusions

Based on the research findings, the areas along the northern coast of Java are classified as highly vulnerable, with 14% falling under the category of "very high land subsidence projection and moderate sea level model" and 11% falling under "very high land subsidence and very high sea level model." This conclusion is reinforced by the fact that the highest number of flood incidents also occur in these categories. Therefore, it is imperative for relevant authorities to take further action to prevent and address potential coastal flooding incidents.

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