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RESEARCH ARTICLE

Flood Risk Evacuation System in Tanjung Mas, Semarang City

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Abstract. Rapid urbanization has significantly contributed to environmental degradation, particularly in coastal cities. In Semarang's Tanjung Mas Village, frequent coastal flooding is a pressing issue, driven by rising sea levels, land subsidence, and inadequate drainage infrastructure. Therefore, this study aims to identify coastal flood hazards in Tanjung Mas and evaluate the efficiency of evacuation routes to improve disaster response strategies. Using GIS-based spatial analysis, flood modeling, and network analysis, high-risk zones, and proposed optimized evacuation pathways are identified. In line with these results, the northern and central sections of Tanjung Mas are the most vulnerable, with densely populated residential and industrial areas at the highest risk. A comparison with Seocho and Gangnam District, South Korea, and Mueang Nakhon Si Thammarat District, Thailand, highlights key differences and similarities. In South Korea and Thailand, the proposed evacuation routes have not adequately considered human behavioral factors. In contrast, a GIS-based specifically tailored to Tanjung Mas, integrating real-time flood updates and optimized route mapping to improve evacuation strategies is proposed. By drawing insights from international case studies, this study contributes to developing adaptive flood evacuation systems applicable to other coastal cities facing similar challenges. These results emphasize the importance of integrating real-time data and community-based planning to enhance disaster resilience and response strategies in urban coastal environments. The approach delivers a novel approach to combining disaster preparedness analysis and flood modeling in the results of a proposed evacuation route in the industrial coastal area.

1. Introduction

Floods are among the most devastating natural disasters affecting various aspects of society, including the economy, transportation, and social structures. In the worst-case scenario, this form of natural disaster can result in fatalities. One specific type, coastal flooding (Lee, 2020), predominantly affects coastal regions and poses significant environmental challenges for cities worldwide. Rapid urbanization, land subsidence, and climate change have intensified flood risks, increasing disaster vulnerability in low-lying areas. In particular, coastal urban settlements with high population densities often struggle with ineffective flood evacuation planning. While previous studies have examined road networks in flood-prone areas to improve evacuation, there is a gap in an investigation integrating community preparedness assessments with flood modeling in evacuation planning. Addressing this gap is important for improving disaster resilience and response strategies in vulnerable coastal regions.

Previous studies carried out in the Seocho and Gangnam Districts used network analysis to examine evacuation routes (Lee et al., 2020). The study solely focused on flood depth and spatial extent, without considering human behavioral factors. Furthermore, investigations on evacuation route development integrated with green infrastructure have been conducted in coastal South Korea, specifically in the Haeundae District of Busan (Jeong et al., 2021). Several other studies have been conducted that involve road network analysis and are related to flood disasters in various parts of coastal areas in the world (M.N. et al., 2023; Mitchell et al., 2023; Suwanno et al., 2023). These previous investigations did not consider community preparedness while developing evacuation routes. Therefore, this study aims to fill the gap and proposes an enhanced GIS-based flood evacuation system that integrates historical flood event analysis. Additionally, this study incorporates community preparedness assessment to ensure that evacuation plans are not only technically sound but also feasible for the community affected, taking into account their awareness, mobility, and social dynamics. Historical data is introduced as a crucial component, allowing for adaptive evacuation route adjustments based on the latest flood conditions. The primary question is: How can GIS-based modeling improve flood evacuation strategies in densely populated coastal areas? Unlike previous investigations, this study aims to develop an evacuation system for coastal flood hazards using GIS-based modeling, incorporating network analysis, while also taking into account community preparedness considerations and coastal flood modeling.

There is a need to integrate the elements that consist of flood modeling and community preparedness. Therefore, this study ensures that evacuation routes are not only technically optimal but also realistically implementable, as these factors consider human behavior, risk perception, and dynamic flood conditions. This approach is expected to enhance evacuation planning at the sub-district level, offering a scalable and adaptable framework for flood-prone coastal regions worldwide. This investigation applies to coastal areas worldwide that face coastal flooding issues, particularly diverse land uses, such as industrial, residential, and transportation zones, and the high-activity areas are specifically vulnerable to flood hazards. Many regions globally experience similar challenges, which are further intensified by rising sea levels and climate change, making this a universal issue. These results are in line with the UNDRR's recommendation measures for responding to intense disasters due to climate change (UNDRR, 2021). This study proposes the development of a GIS-based flood evacuation system by considering historical flood events, community preparedness for flood risk, and optimal evacuation routes. The results are expected to improve evacuation planning at the sub-district level, providing valuable information on the evolution of evacuation systems in flood-prone coastal regions.

2. Methods

Materials/Data

The materials used in this study were obtained from multiple official databases to ensure comprehensive coverage and accuracy in data collection. The selection of data was based on literature reviews that have been conducted previously (Park & Lee, 2020; Park et al., 2023; Rong et al., 2020; Trinh & Molkenthin, 2021; Wang et al., 2018). Several materials were used such as numeric data on rainfall and sea level changes from the Regional Meteorology and Climatology Bureau of Semarang, NASA POWER project (Monika et al., 2022; Ngurah et al., 2022), and Global Sea Level Observing System (GLOSS) respectively (Pratama, 2019). Subsequently, Geospatial data on topography was acquired from the Geospatial Information Bureau and Regional Planning Agency; while the land use data was derived from satellite imagery analysis, and community vulnerability data was collected through field surveys, ensuring firsthand information on local conditions and perceptions.

Sample Preparation

The study area is Tanjung Mas Village, the coastal region where its northern boundary meets the sea. The village is home to Tanjung Mas Port and Tawang Station, making it a central hub for economic, transportation, and shipping activities. As a result, the data collection was segmented based on various criteria to ensure detailed analysis. Spatial data (land use, topography, and road networks) was segmented by administrative boundaries within Tanjung Mas Village. In line with these results, numeric and textual data regarding flood occurrences and sea levels were classified from 2017 to 2022 to track temporal changes. Social data was categorized based on demographic statistics and economic conditions to analyze community vulnerability.

Experimental Set-Up

In this study, complex modeling and simulations were carried out consisting of two phases of experimental setup. Subsequently, the flood model used digital elevation models, land use, sea level, and maximum rainfall data to stimulate coastal flood under two different year scenarios, and network analysis was conducted. This analysis was used to determine potential evacuation routes based on the spatial configuration derived from the shortest and fastest path within the road network.

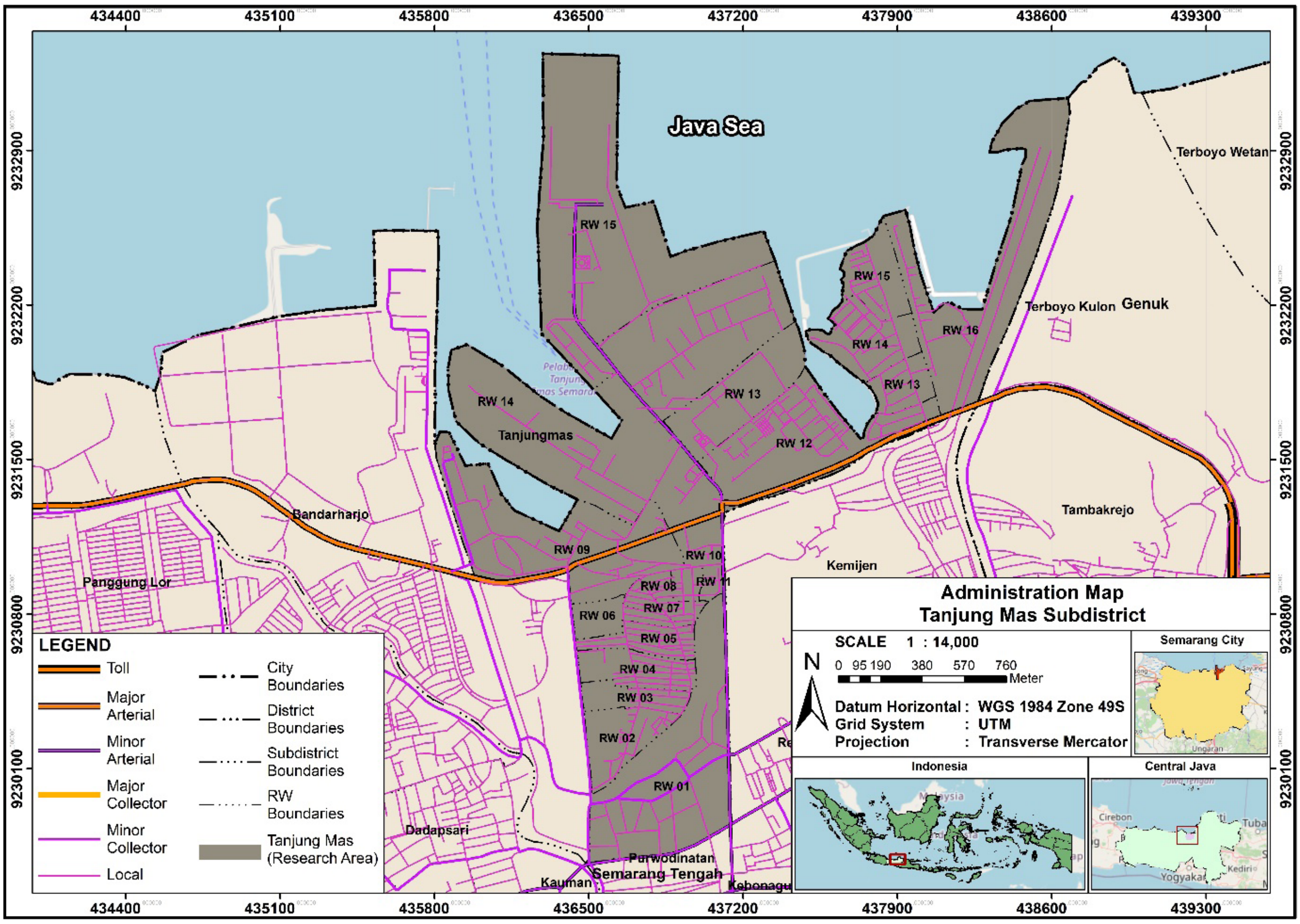

Figure 1. Administration Map of Tanjung Mas

Parameters

This study uses measured key parameters including two different types of parameters. Rainfall intensity, sea level, topographical elevations, and surface roughness obtained from land use, are considered as physical parameters. On the other hand, social parameters consist of population density, economic activities, and infrastructure vulnerabilities, and the assessment of social parameters was used to determine community risk levels.

Statistical Methods

To assist in analyzing data, various statistical and computational methods were required in this study. To provide basic information about variables such as mean, median, mode, and standard deviation descriptive statistics was used. Furthermore, to identify flood level areas, geospatial analysis was conducted and involved the use of GIS software to overlay different data layers (e.g., flood maps with land use maps). Evacuation efficiency analysis was carried out by using ArcGIS software to model different evacuation scenarios and identify the most effective routes in emergency situations.

3. Result and Discussion

Coastal Characteristics of Study Area

Topography

Tanjung Mas District is located in the northernmost part of Semarang City, a coastal region characterized by predominantly lowland topography. These geographical features, combined with its coastal nature, contribute to issues such as land subsidence and frequent coastal flooding in the area. The land subsidence in the lowlands creates more vulnerable conditions to coastal floods.

Climatology In this study the rainfall data used were obtained from two primary sources. Data from 2017 to 2022 were sourced from the Semarang Meteorology, Climatology, and Geophysics Agency (BMKG), while data from 2004 to 2016 were obtained from the NASA POWER project. Additionally, sea level data were obtained from the Global Sea Level Observing System (GLOSS) (BMKG Tanjung Mas, 2022; GLOSS, 2022; POWER NASA, 2022). The climate characteristics of Tanjung Mas District during 2017-2020 in terms of maximum rainfall rate is 46.68 mm/day. According to classification, the Meteorological, Climatological, and Geophysical Agency of Indonesia (BMKG), Tanjung Mas District is classified as medium rainfall. In 2021, the rainfall in the Tanjung Mas District recorded its highest at 155 mm/day, and this situation increases the classifications from medium to heavy rainfall. Subsequently, 2022 had the highest maximum rainfall occurrence, which occurred in five of the twelve months, specifically in May, June, July, October, and December 2022.

Coastal conditions of Tanjung Mas District showed an annual increase from 2017 to 2022, according to the Meteorological, Climatological, and Geophysical Agency of Indonesia (BMKG), and the area is classified as meso-tidal. The highest rise was recorded in May 2022 reaching 210 cm significantly higher than the six years average of 1.52 meters. The climatology characteristics of Tanjung Mas District, which include medium rainfall and meso-tidal, contribute to the risk of potential coastal flood disasters. Combined with its lowland characteristics, these factors cause floods in the area to persist for extended periods.

Land Subsidence

Another characteristic that the study area had is the occurrence of Land Subsidence, which occurred over 100 years ago (Andreas et al., 2019). The main factor of this condition is the alluvial soil sedimentation (Abidin et al., 2013). This situation is further intensified by the ongoing exploitation of groundwater, along with the expansion of built-up areas for industrial and warehouse activities in coastal regions (Bott et al., 2021). The pace of land subsidence in the study area ranges from the slowest pace at 3 cm and the highest at 7 cm and is projected to reach 7.7 cm by 2031 (Andreas et al., 2019; Istiqomah et al., 2020).

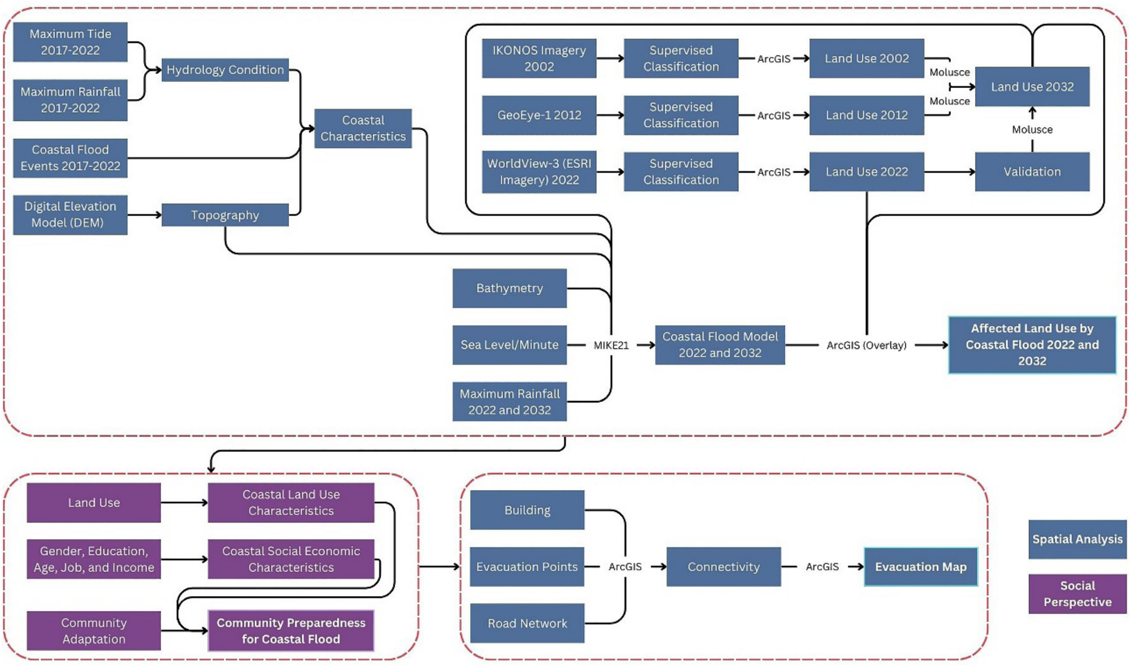

Figure 2. Analysis Flowchart

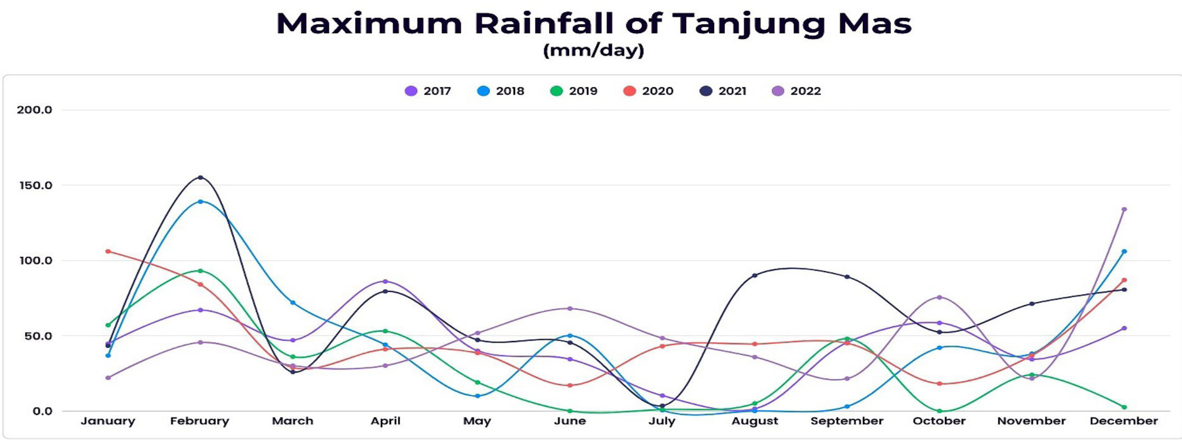

Figure 3. Maximum Rainfall of Tanjung Mas

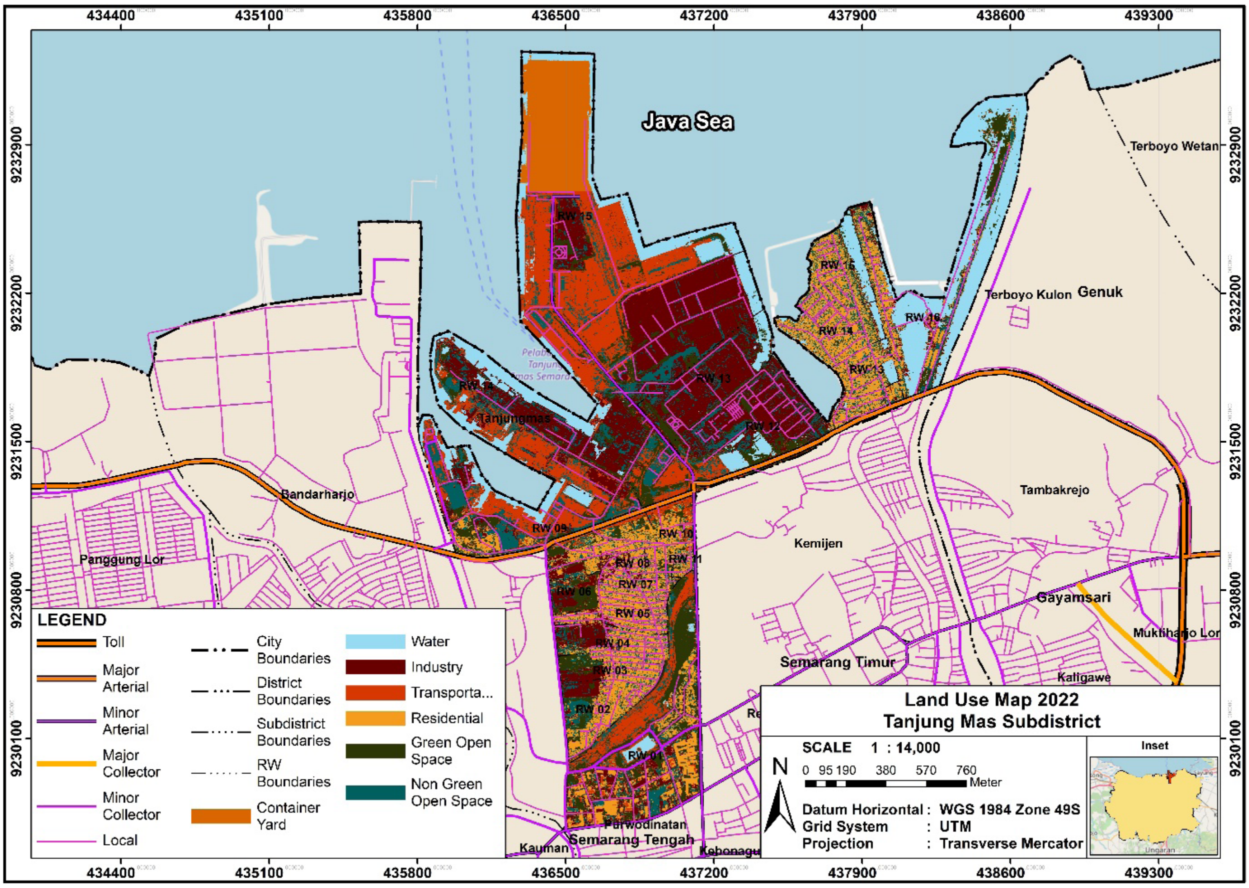

Figure 4. Land Use Map of Tanjung Mas 2022

Land Use Analysis

Built-up areas dominate the land use of the Tanjung Mas District. The Port of Tanjung Mas Semarang predominantly occurs in the northern part of this district. It operates on a national scale and is undergoing development to achieve international status. The other land use of this area consists of residential, aquaculture, and mixed-use commercial. The map of Tanjung Mas district's land use can be seen in Figure 4.

The land use analysis related to evacuation of flood risk that repeatedly occurs in the study area is required to assess the land use condition in the future. The land use condition in the future in this study uses a land use modeling method to determine the potential for land use change. This modeling analysis conducts the land use model for 2032 of the Tanjung Mas District. This land use modeling uses the Geographic Information System (GIS). The kappa coefficient of the modeling is 0.69 for the 2032 land use model. The result of the land use modeling can be seen in Figure 5.

The location used as a container yard in the northern part of the study area is not included in the land use projections that were made. The land use modeling maps for 2022 and 2032 show changes across all land use categories. Notably, the areas designated for aquaculture water bodies and non-green open spaces have decreased. On the other hand, transportation,

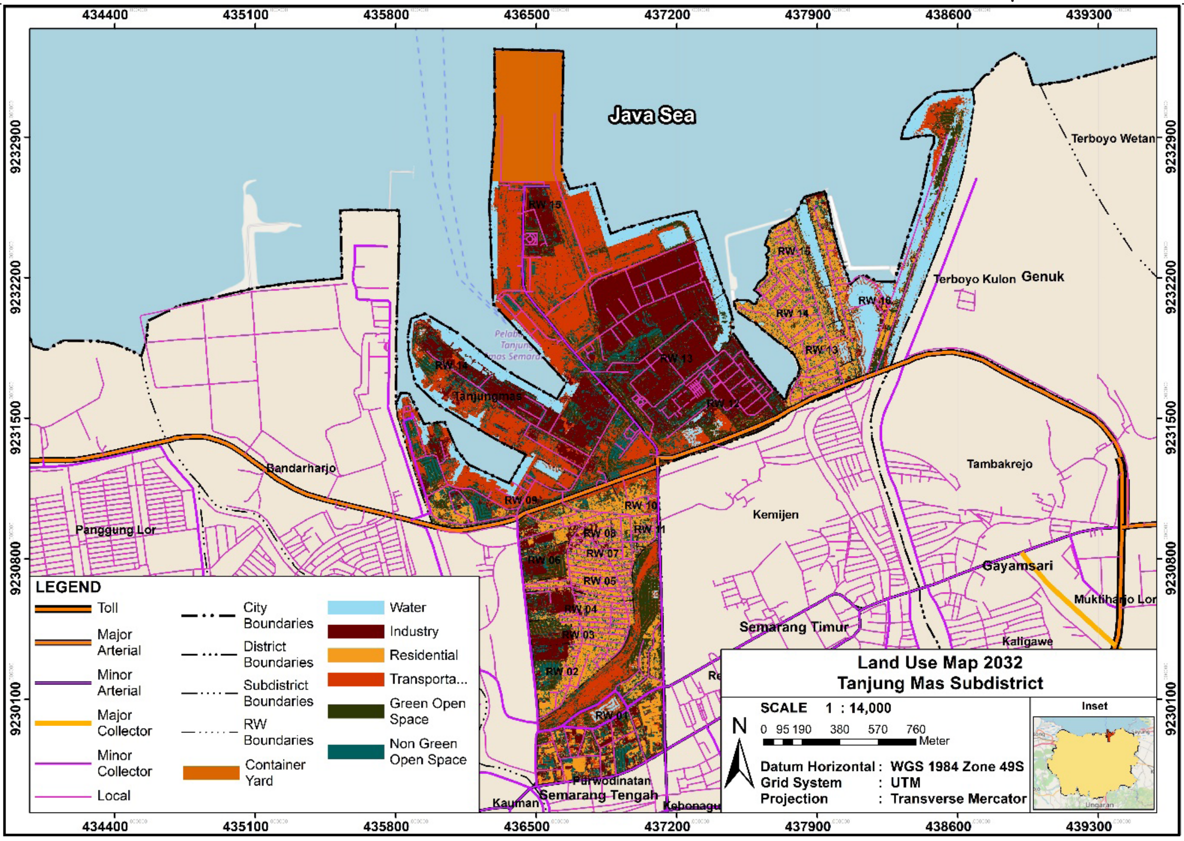

Figure 5. Land Use Map Projection of Tanjung Mas 2032

industry, residential, and green open space are 12.79 ha, 1.47 ha, 4.43 ha, and 2.28 ha of increase, respectively. This condition corresponds to the plans outlined in Semarang City Regional Regulation Number 5 of 2021 about Semarang City Regional Spatial Planning Policy. The 2032 land use model changes can be identified in the southern and northern parts of the study area. The changes in the southern area are identified as an expansion of the residential area, while transportation and industry are expanding in the northern area.

Flood Modeling

The next step is assessing flood risk in the study area which involves conducting flood modeling. This analysis relies on data from the May 24th, 2022, flood event, which recorded water levels ranging from 40 to 150 cm (Santoso, 2022). The flood model incorporates various supporting factors, including topography, bathymetry, land use, water levels, and rainfall data, to enhance accuracy in simulating flood conditions. These elements collectively contribute to a more precise understanding of flood patterns in Tanjung Mas. The resulting coastal flood map for 2022 is shown in Figures 6 and 7, providing a visual representation of affected areas and their respective flood depths.

From flood modeling 2022, half the areas of Tanjung Mas district are flooded, and the total depth of flood water in the study area varies from <0.1 meters to >2.5 meters. Most of the study area is flooded by a total water depth of 0.1-0.5 meters, the north side of the study area is mostly affected by floods. The areas of RW 09, RW 12, RW 13, RW 14, and RW 16 experienced the highest water depth. The Port of Tanjung Mas is the most severely affected area. The primary cause of the significant water depth in this region is the presence of a perforated sea wall, which allows coastal floods to rapidly intrude into the area.

Based on this phenomenon, a model for the future of flood phenomena can be projected. This projection is based on the scenario that each year the Sea Level Rises 4.4 mm, and the result of the estimation of maximum rainfall and the projected land use in the study area (Irawan et al., 2021; Zhong et al., 2014).

Affected Land Use by Coastal Flood

Further analysis of flood modeling is required to identify the areas at risk of flooding. This analysis is conducted by comparing a land use map with a flood map to identify the activities that may be impacted by flooding. It examines both the existing conditions in 2022 and the projected conditions for 2032.

The land mostly affected by flood water is the transportation land use, consisting of the Port of Tanjung Mas and the Semarang Tawang Train Station. The Port of Tanjung Mas is the most severely affected area. Floodwaters in this area range from less than 0.1 meters to over 2.5 meters deep enough to submerge an adult. This flooding will disrupt all logistics, transportation, and industrial activities in the area, leading to significant material losses. Furthermore, the residential area projected would be flooded with water depths ranging from level 0 to 6 (<0.1 m->2.5 m), placing its communities at a disadvantage.

The other highly affected area is the north side of RW 16, the flood water in this area creates fatal damage to the aquaculture activity and causes material damage to the owner. Floods also caused damage to the community's houses, and the water inundation also brought mud and sand to the community neighborhood and caused a mess in the house and the road. Therefore, the impact of the flood on the whole daily activity is terrible.

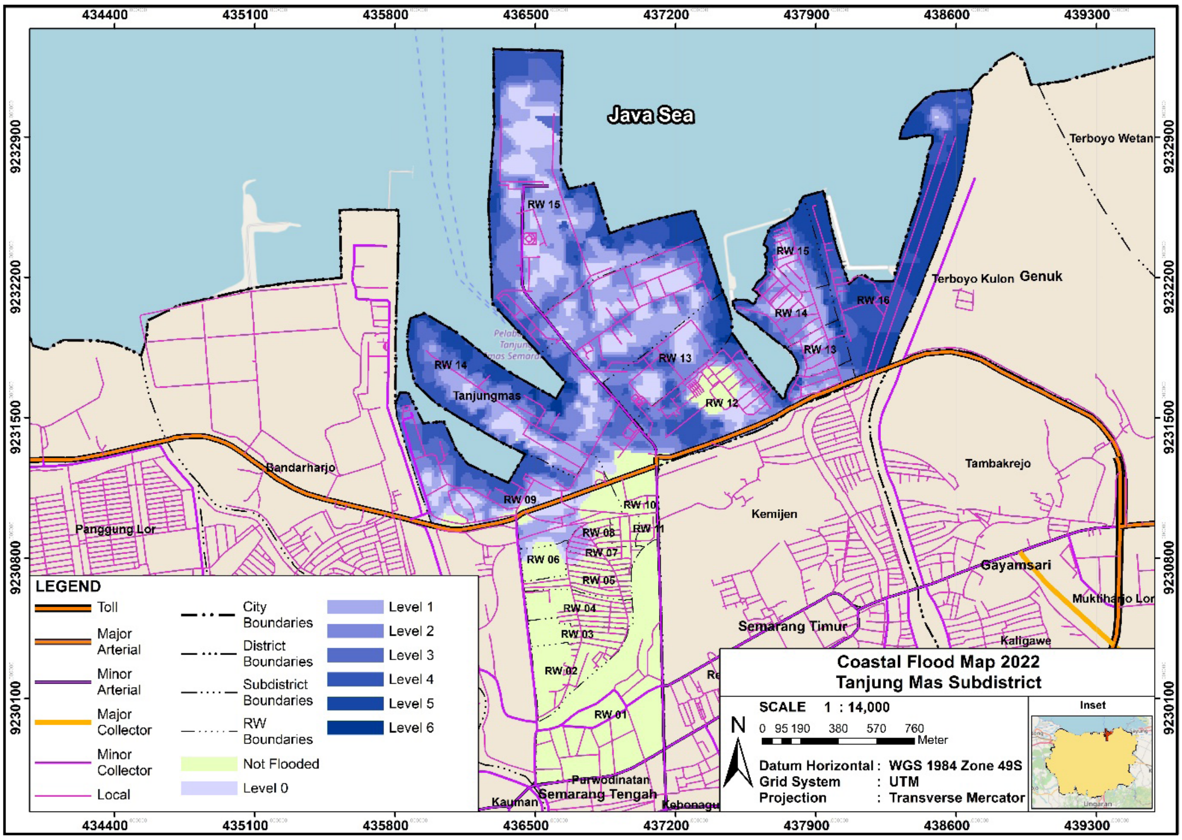

Figure 6. Coastal Flood Map of Tanjung Mas 2022

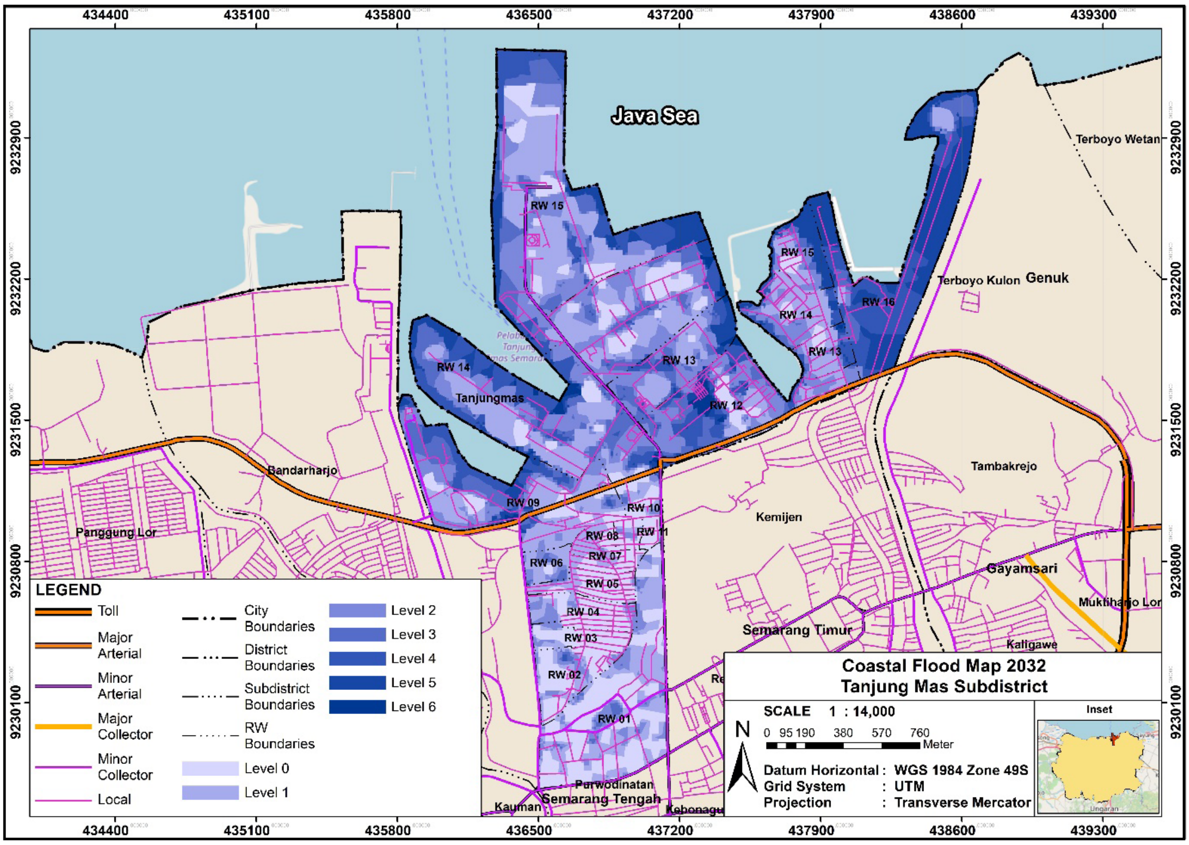

Figure 7. Coastal Flood Map of Tanjung Mas 2032

Community Preparedness

In order to completely understand flood disaster's impact on the community, it is also essential to analyze the community preparedness. This analysis is purposed to understand the communities' perception of flood disaster, this analysis examines socio-economy aspects, disaster awareness and management, and community adaptation. The result of the community vulnerability in each RW can be seen in Figure [8].

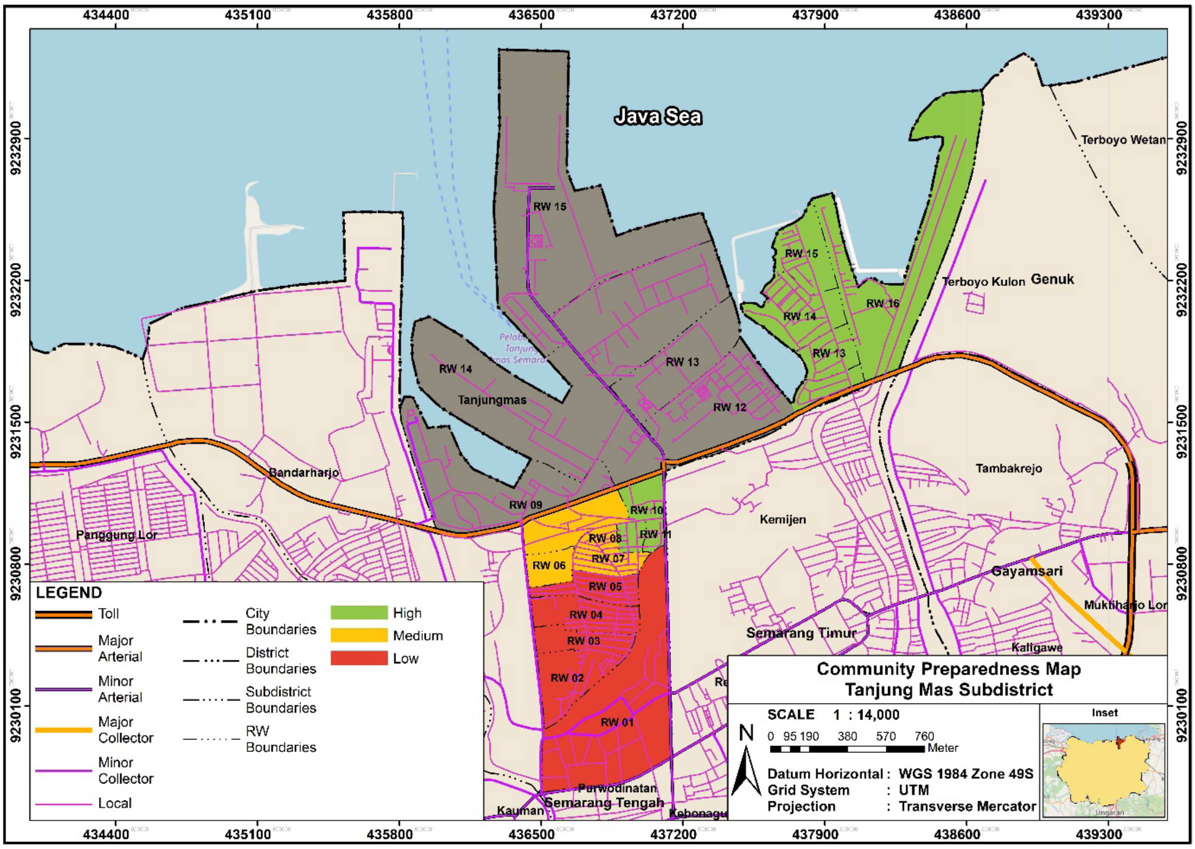

Figure 8. Community Preparedness Map 2022

The categories in the study area are classified into three classes, low, medium, and high level of preparedness. Several areas in the North of Tanjung Mas Village are not identified due to its land use, which is classified as industrial areas. A low level of preparedness is in the lower side of Tanjung Mas Village, including RW 1, 2, 3, 4, and 5. While the high level of preparedness is in the northern part of the study area and consists of RW 10, 11, 12, 13, 14, 15, and 16. The areas with a high level of preparedness are also identified with high levels of coastal flood, and most are used as residential areas. This condition is in line with this area's topography, which is considered low land but also facing the sea directly.

Communities' characteristics in a high level of preparedness are mainly influenced by their ability to adapt to coastal floods and passed from generation to generation. The communities prepared their expenditure to construct their home to make it 500 cm to 1 meter higher every five years. Additionally, as the community has experienced frequent flooding, there is a need for an awareness of when conditions are becoming dangerous. In the absence of a formal warning system, flood alerts are announced through the nearest mosque in the study area.

Despite the threat of coastal flooding, the community has chosen not to relocate, even to safer areas, and the main cause is that they did not want to lose their job as fishermen. However, based on the interviews with with communities of Tanjung Mas show that there has been no dissemination or discussion regarding coastal flooding in the area. Additionally, communities require clear guidance on evacuation routes in the event of coastal flooding.

Evacuation Route Analysis

Identifying the most efficient and effective evacuation route in the study area is essential. This route is crucial for enhancing community preparedness in pre-disaster management and facilitating safe evacuations during flood events. This analysis will be carried out based on the network analysis on the road by ArcGIS Pro, and the results analysis will be discussed below.

The assembly point on the map is determined from the location which has the highest population. This analysis does not use the number of the population of each neighborhood but uses assumptions from the building shapefile data. This assumption is also used in the literature reviewed (Parajuli et al., 2023). In addition to considering the population, the selection was carried out based on the location that has the lowest level of flooding in line with the previous analysis. Therefore, it would be easier and safer for communities to gather to evacuate.

Urban Network Analysis, particularly the Reach component is also taken into account for determining assembly point location. The Reach Index shows how many buildings can be reached by providing information on areas within 400 m based on road networks. The selection of a 400-meter distance is based on the ideal walking distance commonly referenced in various studies on transit users (Bivina et al., 2020; Eisenberg-Guyot et al., 2019; Pueboobpaphan et al., 2022). The higher index shows that the location has the highest accessibility. Locations with the highest accessibility are mostly identified as residential uses. There are several assembly point locations with a moderate reach index because these routes have already been used as evacuation points. For instance, in RW 13, 14, and 16, almost all the assembly points are not located in the highest reach index.

The evacuation route is then processed by ArcGIS Pro and considers two factors such as the shortest and fastest route to travel by walking. The result shows the best route from the assembly to evacuation points. Evacuation points

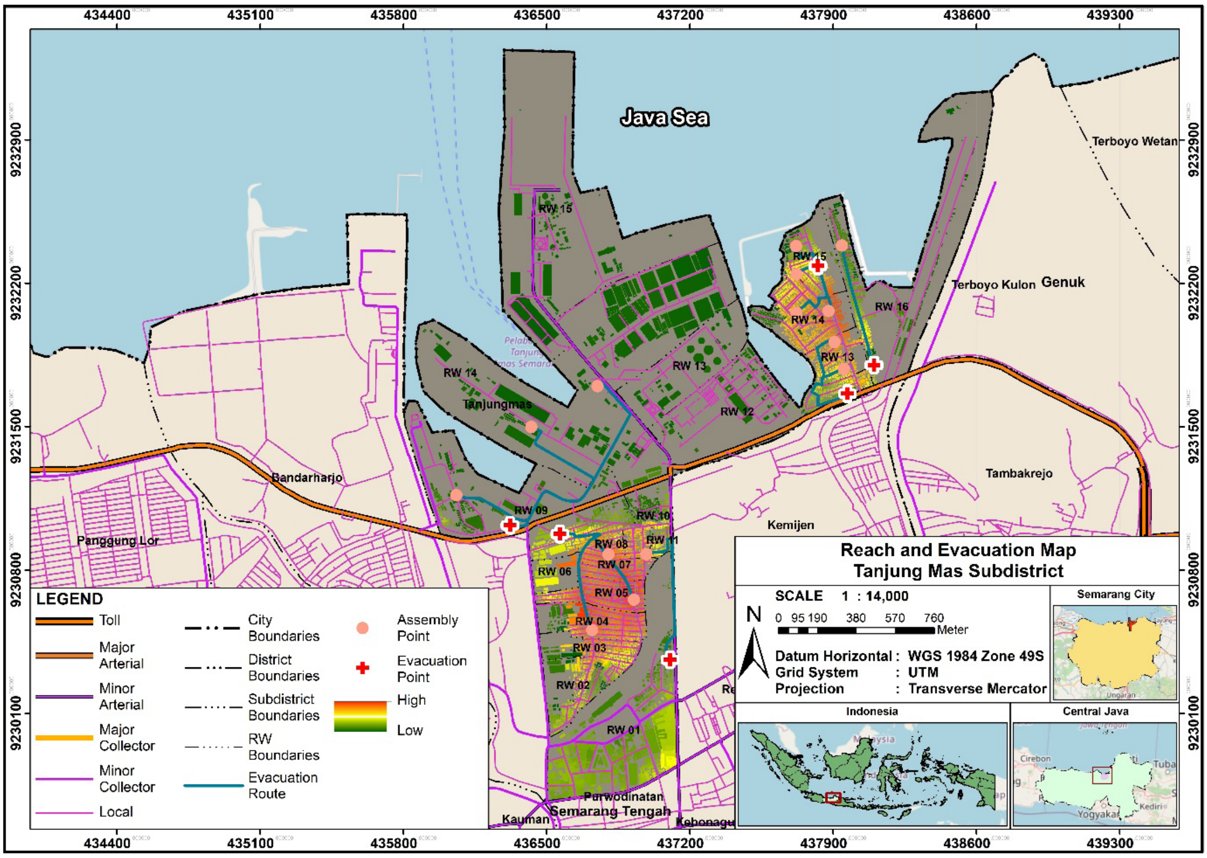

Figure 9. Evacuation Map 2022

have already been decided by the Regional Agency for Disaster Management (BPBD) Semarang City, and it has seven locations. The northeast of Tanjung Mas has the most evacuation points, and this is mainly because the level of flooding is more severe than the other parts of the village. Moreover, this location has the highest exposure to coastal floods. Considering that the southern part of the study site has low community preparedness, four gathering points have been proposed to make it easier for the community to evacuate.

Evacuation routes that use recorded data and consider community preparedness assessments for coastal flood disasters are proposed. The use of community preparedness assessment is intended to assess the level of the community's ability to deal with coastal floods in order for the community to adjust to the condition of the evacuation route generated. This study applies the same method as the investigations conducted in Malaysia, which shows the importance of community involvement in formulating planning, specifically related to disasters (Abid et al., 2024). Furthermore, the consideration of coastal floods that occur, specifically in low-lying coastal areas was considered (Lee et al., 2020; Suwanno et al., 2023)

The importance of integrating spatial analysis and community preparedness assessments in developing effective evacuation routes for coastal flood disasters is reported. By using a GIS-based approach, this study aligns with previous investigations conducted in Malaysia (Abid et al., 2024), Thailand (Suwanno et al., 2023), and South Korea (Lee et al., 2020), which emphasize the significance of localized evacuation strategies suitable for specific risk factors.

Other locations in various parts of the world have similarities with the study areas. Some results try to develop evacuation routes and consider flood depth and velocity. Although the study did not use a coastal location, in the middle of the city, precisely in Seocho and Gangnam District, the results could be applied to coastal floods (Lee et al., 2020). In line with these findings, a different approach was used and still involves flood depth compared to other investigations. In line with these results, flood depth is obtained through modeling results by using data on flood events in the study areas and other supporting data such as DEM, rainfall, sea level, and land use. In addition, this study also emphasizes consideration of the level of community preparedness and network analysis using GIS. However, flood velocity in creating evacuation routes is not included.

This study has also complemented an investigation conducted in Haeundae District, Busan, South Korea, coastal area. The results formulated evacuation routes and integrated them into green infrastructure (Jeong et al., 2021). Regarding evacuation routes, this study also considered the surface runoff index as it was also involved in another result by Jeong et al., 2021. However, the surface runoff resistance component is included in the flood modeling process, which is obtained by identifying land use and converted into manning values. Previous studies also carried out this conversion (Kaiser et al., 2011). Furthermore, in line with Jeong et al., 2021, this study also uses vector-based analysis in GIS processing. However, another difference in approach to the processing used is with Urban Network Analysis.

The study aligns with investigations in other coastal areas that have dense populations, such as those conducted in Mueang Nakhon Si Thammarat District. Heavy rainfall, elevation, and land use were considered (Suwanno et al., 2023). These three aspects have been involved in the flood modeling process. Furthermore, studies on the road network have been conducted in other locations with similar locations, namely on the coast and affected by coastal floods. These studies are in line with Ho Chi Minh (M.N et al., 2023) and Virginia (Mitchell et al., 2023). Both showed that roads are influential during floods, playing a role in evacuation. Therefore, in this study, which is located in Tanjung Mas, North Semarang, Central Java, an evacuation system through flood modeling and community preparedness assessment is attempted to be developed, resulting in a proposed evacuation route.

4. Conclusion

In conclusion, the study on flood risk evacuation in Tanjung Mas, Semarang City, has provided critical insights into the challenges facing coastal floods and the effectiveness of current evacuation routes. Important results show that Tanjung Mas is highly susceptible to coastal floods due to environmental factors such as sea-level rise, increased rainfall, and land subsidence. In line with these results, significant gaps in the current evacuation infrastructure, complicate efficient emergency responses are reported.

The collected data underline the urgent need for optimization of evacuation routes and systematical flood management strategies. The most critical insight from this study is the correlation between land use changes and increased flood risk. Residential and industrial expansions and insufficient drainage systems exacerbate flood impacts, particularly in densely populated areas such as RW 13 to RW 16. This underscores the necessity for integrating flood hazard considerations into urban planning and infrastructure development to mitigate future risks effectively.

This study shows that evacuation systems can be developed using GIS, and it is one of the effective methods relevant for coastal-industrial areas or similar environmental conditions facing coastal floods. The approach used also contributes to taking measures to respond to disaster hazards. Therefore, there is a suggestion that stakeholders can formulate evacuation plans while protecting communities, minimizing fatalities, and increasing disaster preparedness.

Future studies should focus on several key areas to build on these results. Firstly, there is a need for advanced modeling including real-time land subsidence data to improve flood predictions. Secondly, there is a need to investigate the socio-economic impacts of floods on local communities, particularly vulnerable populations, to develop targeted resilience strategies. Additionally, exploring the integration of innovative technologies such as mobile apps for real-time flood alerts and evacuation guidance could significantly enhance emergency response efficiency. Lastly, a comprehensive review of current evacuation facilities and detailed community perception studies are essential to design effective, user-friendly evacuation systems tailored to the specific needs of Tanjung Mas communities.

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