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Evaluation Mangrove Density on the North Coast as a Means of Mitigation Danger Tidal Flood: Case Study of Demak Regency

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ABSTRACT: This study focuses on assessing the density of mangrove forests on the north coast of Demak Regency as an independent mitigation effort against tidal flooding. The impact of tidal flooding can be observed directly, such as damaged ponds and agricultural land, inundated road infrastructure, submerged houses, and disruption of livelihoods. This study is crucial because it provides data and spatial analysis to understand the current level of mangrove density, identify vulnerable areas and inform appropriate mitigation actions before the impact of tidal flooding. The study's novelty is that it focuses on specific density and vulnerability levels and uses significant short-term cover change analysis. Using spatial analysis methods through Geographic Information Systems (GIS) and satellite imagery from 2018-2023, several areas along the coast have mangrove densities varying from 1200-3400 trees per hectare. There was a 27.3% reduction in mangrove cover mainly due to changes in land use to ponds. Overlay analysis combining mangrove density with flood hazard maps and geographic information also maps how different mangrove areas are strongly related to tidal flooding. Areas with mangrove density <2000 trees per hectare are much more vulnerable to tidal flooding, which is worse at lower and better at higher ranges. The findings suggest that coastal engineering using soft hybrids, which integrate breakwater structures and mangrove rehabilitation, will be more effective in achieving long-term coastal resilience than using hard engineering techniques alone, support the integration of mangrove density thresholds into coastal infrastructure planning to enhance resilience against tidal flooding. As an effective policy for coastal management, a minimum standard of 3,000 mangrove trees per hectare is needed, and Demak Spatial Planning is needed to focus more on mangrove conservation within the Demak policy framework.

Keywords: *Mangrove Density; Tidal Flooding; Coastal Management; Spatial Analysis*

I. INTRODUCTION

Poor urban and regional planning has not solved the flood problem in Demak Regency. Historically, cities on the north coast of Java, including Demak, were built without considering hydrogeology. Since the time of the Javanese kingdoms, people have built settlements in this area simply because it is close to sea trade routes and because of its fertile soil, without considering the dangers that will come. The urban planning method from the Dutch colonial era prioritized economics and ease of transportation over disaster mitigation, creating the problems we face today [1].

The ineffective implementation of the Regional Spatial Plan (RTRW) is a problem for Demak Regency in contemporary regional and city planning. Although planning documents have indicated areas vulnerable to flooding, economic and political factors often hampered direct implementation. The complexity of the problem increases due to rapid urbanization without adequate infrastructure. The city's drainage system is not developed proportionally, creating a significant capacity gap. On the contrary, the rapid growth of built-up areas reduces the green base coefficient and water catchment areas [2].

This condition worsens because the sectoral planning approach often ignores the relationship between systems. Water management, settlements, and transportation often run independently without sufficient integration. In addition, conflicts of interest between sectors such as agriculture, fisheries, and urban development lead to suboptimal planning. For example, building embankments to protect urban areas but not considering the impact of water flow in other areas creates new problems. [3] Another challenge is the lack of a regional approach to watershed management. Demak Regency is located downstream of several important watersheds, but coordination between administrative areas in watershed management is still weak. Upstream activities such as land conversion and deforestation directly impact

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and increase the volume of surface runoff, which eventually flows into Demak. This phenomenon reflects weaknesses in cross-regional governance, an important aspect of regional planning. [4]

From the climate change adaptation perspective, regional and city planning in Demak has not fully integrated long-term climate change impact projections. Existing planning instruments tend to be reactive rather than anticipatory to increasingly extreme climate change scenarios. In fact, as a coastal area, Demak is one of the areas most vulnerable to climate change impacts, such as sea level rise and intensification of extreme weather that will worsen flooding in the future if not anticipated in regional planning. In infrastructure development, "hard engineering" approaches such as constructing embankments and concrete drainage are often prioritized, while more sustainable nature-based solutions receive less attention. Restoration of mangrove ecosystems, which have been proven effective as natural buffers against tidal and tidal waves, has not been an integral part of spatial planning. Integrating mangrove belts in coastal zoning could be a more sustainable adaptation strategy than expensive hard infrastructure that is vulnerable to land subsidence because it can reduce the load on hard structures such as sea walls and extend the service life of infrastructure. Therefore, it is necessary to analyze and identify changes in mangrove density against flood hazards and land use to carry out the right land use planning process. [5]

II. THEORETICAL BASIS

Land use changes are caused or triggered by various factors that interact with each other. Factors or triggers of land use changes are often called driving forces. Each land use will get a different type of driving force. [6]. The dynamics of existing land changes are greatly influenced by human and physical factors such as topography in the area [7]. Land use changes result in significant environmental consequences such as erosion, soil degradation, and barrenness [8]. Damage and fragmentation of natural habitats due to land changes threaten biodiversity [9]. Urbanization and industry are activities associated with land use changes that can result in pollution and degradation of water and water quality.

Geographic Information System (GIS) is a special information system used to collect, maintain, store, analyze, output and distribute spatial data and have information about space [10]. In simple terms, there are two types of spatial data: raster data and vector data. Satellite or aerial photos usually represent raster data with pixel values, while vector data has value attributes. Spatial analysis generally uses vector data used in overlay analysis.

Sea level rise is caused by several things, such as increasing earth temperature and causing seawater to warm and increase [11]. The melting of polar ice, such as glaciers and icebergs, causes additional water to the ocean [12]. Other factors can be caused by reclamation projects, coastal erosion, river sediment discharge and groundwater use [13]. Historically, sea level has been estimated to have risen by 250 mm since 1850, with acceleration observed in the last decade. Observing the rise of sea level uses waves and satellites [14]. In the future, projections estimate that sea level rise will increase from 0.2 to 1.9 meters at the end of the century, with an estimate of around 1 meter in 2100 [15]. The impact of rising sea levels on coastal areas is the presence of inundation or tidal flooding, erosion of coastal areas, and land loss [16]. Sea level rise can also impact salination, affecting groundwater sources and ecosystems [17]. Economic costs include property damage, increased spending on coastal protection and impacts on social capital [18]. Areas with low topography, such as islands or coastal cities, will be particularly vulnerable. [19]. Strategies that can be used for adaptation and mitigation by building coastal defences include building sea walls, appropriate land use planning, and increasing natural buffers such as mangroves and other vegetation.

Urban development is a dynamic system that can be affected by the physical environment, such as climate [20]. Coastal cities are vulnerable to natural hazards such as typhoons, tsunamis, and tidal floods [21]. Massive urbanization and large-scale exploitation of coastal areas cause environmental degradation, decreased resilience, and increased vulnerability to the effects of climate change [22]. Other problems in coastal cities are socio-economic challenges, including unplanned urban development, which can encourage barriers to development and land ownership [23].

A breakwater is a natural or artificial structure that protects coastal areas, ports and other marine environments from the effects of waves. Breakwaters have many purposes and functions, including reducing shoreline erosion, making the water calmer so that ships can easily anchor and protecting port

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facilities [24]. Breakwaters are divided into 2: natural and man-made; natural breakwaters consist of marine ecosystems such as coral reefs, rocks, and mangroves. Natural breakwaters effectively handle energy from waves and protect coastal areas. However, these natural breakwaters are vulnerable to environmental changes and human activities that can degrade their structure and function [25]. Artificial breakwaters are structures built to protect coastal areas and ports. It can be constructed using various materials and designs, such as rock pile breakwaters, caisson breakwaters, and floating breakwaters [26]. Even in terms of design, it can use various environmentally friendly, economical but quality materials to support environmental conservation [27]

Mangroves are forest vegetation that grows between the tidal seawater lines in coastal areas and river estuaries. This ecosystem has special adaptations to environments with high salt content, muddy substrates, and tidal conditions. Several plant genera dominate mangroves, such as Rhizophora, Avicennia, Bruguiera, and Sonneratia. Ecologically, mangrove forests have many important functions. Mangroves act as wave and wind barriers, prevent coastal erosion, and protect the land from seawater intrusion. The complex root system of mangroves is also a spawning ground and habitat for various fish, crustaceans, and molluscs. Mangrove forests also act as effective carbon sinks. The ability of mangroves to store carbon is even five times higher than mainland tropical forests, making them important in mitigating climate change. Despite their high ecological value, mangrove ecosystems are seriously threatened by land conversion for ponds, settlements, and coastal infrastructure. Mangrove degradation has reached alarming levels in many tropical countries, including Indonesia, which has around 23% of the world's mangrove area. Mangrove conservation efforts are now increasingly integrated into coastal management and climate change adaptation policies at the global level [28].

Planning for tidal flood areas requires a multi-sectoral approach and various elements such as resource assessment, spatial planning, environmental considerations and stakeholder collaboration. Resource assessment is used to validate models and ensure the precision of resource accuracy. Spatial planning to harmonize marine activities and protect the marine environment includes identifying areas suitable for conservation and breakwater development [29].

III. METHODS

This study uses a spatial approach to see the relationship between land use, mangroves, and tidal flood hazards. Spatial data from mangroves were obtained from Google Earth Engine (GEE), which can be obtained from the internet; flood hazard data was obtained from the BNPB website, namely INARISK, while land use data was obtained from the Demak Regency Spatial Plan. The type of data taken to see the density of mangrove vegetation is raster data sourced from sentinel imagery with NDVI analysis, sentinel-2 spatial resolution (10 meters for red and NIR bands) using coding in Google Earth Engine. The data is downloaded, converted from raster to vector, and processed with a Geographic Information System (GIS) using overlay tools. The overlay stage uses union tools, which can be used to combine two or more polygon features. All features and their attribute data are used in new features, both in overlapping and non-overlapping parts, as illustrated in **Figure 1**. After overlay, quantitative and qualitative comparisons are carried out to obtain similarities and differences and recommendations for improvements to the area that can be made.

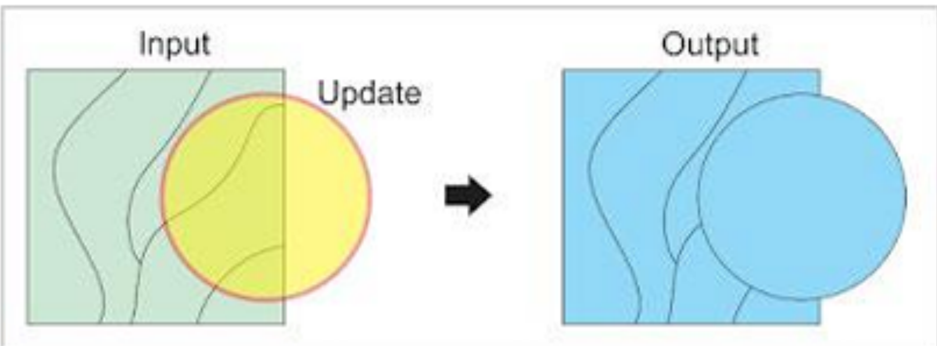

Figure 1. Union Overlay Illustration
Source: Arcmap Data Management

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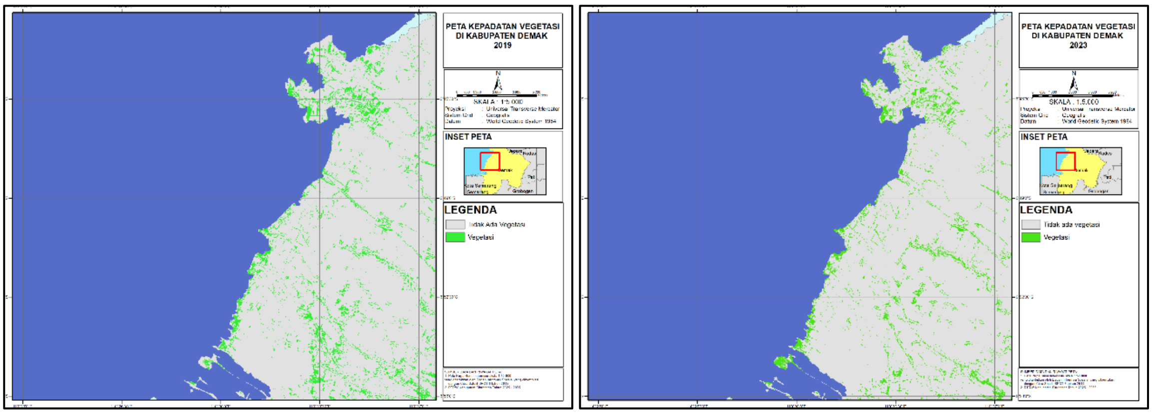
IV. DISCUSSION

Results

Demak Regency is one of the regencies in Central Java, located approximately 25 km from Semarang City. Demak is a strategic area passed by National Route 1, connecting Jakarta-Semarang-Surabaya-Banyuwangi. The area of Demak Regency is ± 1,149 km2, which is divided into land of ± 897 km2 and sea of ± 252 km2. With an area bordering the sea, Demak Regency has a coast of ± 34 km2, stretching through 13 villages and along the coast of Demak is overgrown with mangrove vegetation of approximately 476 Ha. More details can be seen in **Figure 2**.

Figure 2 explains a change in mangrove vegetation from 2019 to 2023. A change in vegetation was recorded by satellite imagery. In the coastal area, vegetation is reduced based on the results of satellite image processing. An overlay analysis was carried out using the union tool to obtain results and discussions in the studied area. The input used for the union analysis consists of 3: land use in Demak Regency, Mangrove Density, and Flood Hazard (rob) for coastal areas. For illustrations, see **Figure 3**.



(a). Mangrove vegetation in 2019 (b). Mangrove vegetation in 2023

Figure 2. Changes in mangrove vegetation from 2019 to 2023

Figure 3. Overlay Analysis

The existence of Demak Regency in the coastal area certainly has great potential for flooding. The hazard variable used is to see the natural potential if a flood occurs, not using risk because it ignores the vulnerability variable. This study purely evaluates the existence of mangrove density against flooding hazards and its influence on land use; for more details, see **Figure 4**.

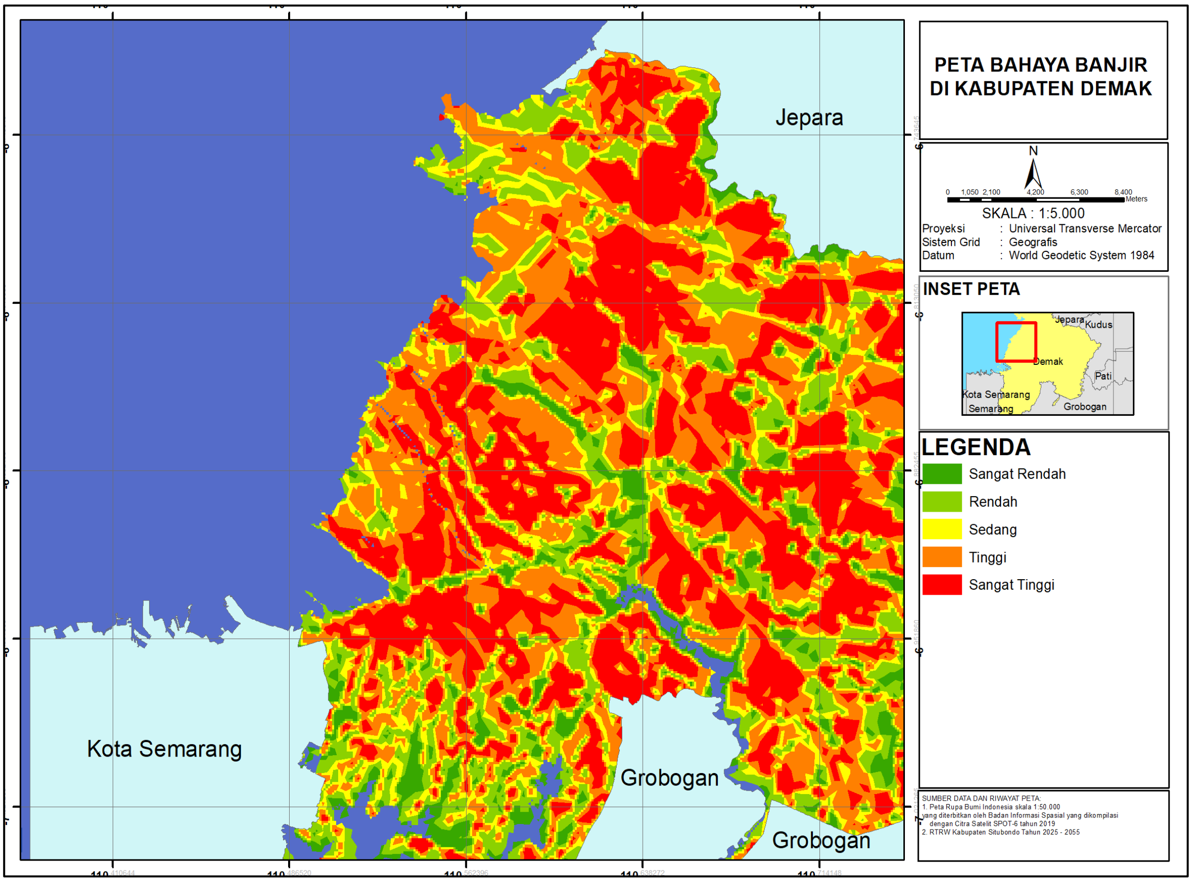


Figure 4. Flood Hazard Map

Figure 4 shows that the potential for flood hazards in several coastal sub-districts varies but is dominated by the high and very high categories. In Sayung Sub-district, the total area with high and very high flood hazard potential is 44 km2. In the Bonang Sub-district, the area has a very high flood hazard potential of 64 km2. Meanwhile, in the Wedung Sub-district, the potential for flood hazards in a low category is 19 km2, and in a very high category is 47 km2. As can be seen in **Table 1**.

Table 1 Potential Flood Hazards in the Subdistricts Closest to the Ocean

Danger Category	Subdistrict	Area (Km^2)
1	Bonang	3.50
1	Karangtengah	2.22
1	Sayung	1.81
1	Wedung	1.90
2	Bonang	9.04
2	Karangtengah	4.43
2	Sayung	8.69
2	Wedung	19.84
3	Bonang	9.93
3	Karangtengah	6.37
3	Sayung	9.30
3	Wedung	16.90
4	Bonang	32.14
4	Karangtengah	19.95

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Danger Category	Subdistrict	Area (Km^2)
4	Sayung	22.04
4	Wedung	41.11
5	Bonang	32.20
5	Karangtengah	23.59
5	Sayung	22.20
5	Wedung	47.37

Land Use in Demak Regency can be described as follows: Horticultural Area in Guntur District (0.26), Permanent Production Forest Area in Mranggen District (6.51), Aquaculture Area in Mijen District (0.27), and Urban Settlement Area in Gajah District (0.49). In addition, there is an industrial designation area in Sayung District, a wetland agriculture area in Karangawen District, a water absorption area in Karangtengah District, and a tourism area in Bonang District. The distribution of other objects includes the Community Forest Area in the Demak District, the Food Crop Agriculture Area in the Wedung District, the Mining Area in the Kebonagung District, and the Conservation Area in the Dempet District. Other recorded districts include Wonosalam with the Trade and Service Area, Karanganyar District with the Livestock Area, and Mranggen District with the Housing Area. Each area has different characteristics and areas, ranging from 0.0000144 to 38.19, which reflects spatial planning based on Regional Regulation No. 01 of 2020. The diversity of object names and sub-district distribution shows the complexity of spatial planning in Central Java Province, which considers economic, social, and environmental aspects. To better understand the distribution of land use in Demak Regency, it can be seen in **Figure 5**, which shows land use in Demak Regency.

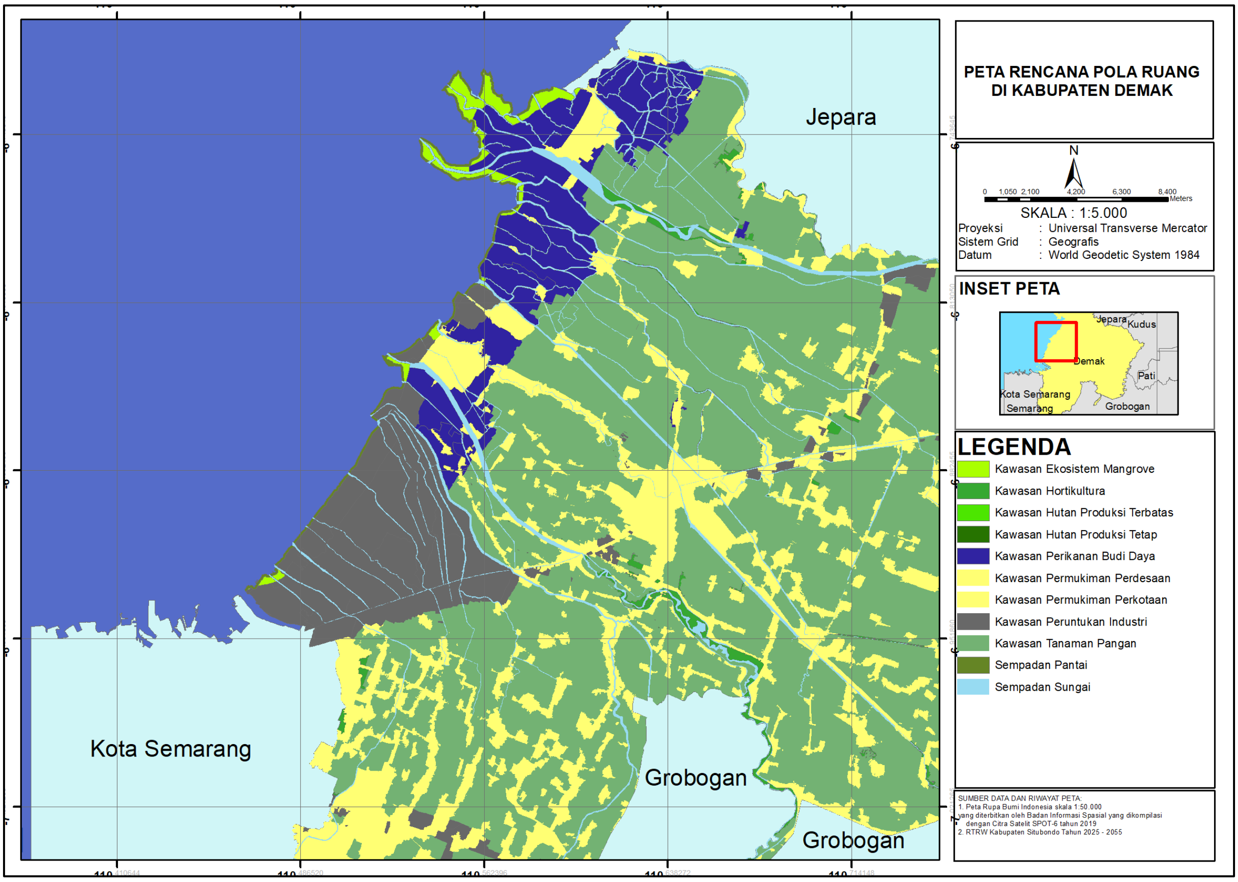

Figure 5. Land Use Map in Demak Regency 2020

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Discussion

Several findings were obtained from the research conducted on mangrove density on the north coast of Demak Regency. GIS processing shows that mangrove density in the coastal area of Demak experiences quite high variations, with a range of 1,200-3,400 trees/hectare. The Sayung coastal area has the highest density (3,400 trees/hectare), while the Kedung area has the lowest density (1,200 trees/hectare. Areas with mangrove density below 2,000 trees/hectare are predicted to increase the potential for tidal flooding yearly. In comparison, areas with a density above 3,000 trees/hectare are predicted to experience less tidal flooding per year. It proves the effectiveness of mangroves as a natural barrier against seawater intrusion. Areas with low mangrove density have the potential to experience tidal flooding more often. Corrosive seawater contains salt and other materials that can accelerate the damage to road construction materials such as asphalt, concrete, and aggregates. Repeated wet-dry cycles due to tidal flooding and receding can also cause road structures, causing cracks, holes and subsidence of the road surface. Tidal flooding can carry sediment and garbage that clogs the road drainage system; prolonged waterlogging can seep into the road foundation layer, reducing its bearing capacity and accelerating structural damage.

Meanwhile, residential areas adjacent to the coastline that are not protected by adequate mangroves will be very vulnerable to abrasion and the direct impact of tidal flood waves. Abrasion can erode the soil around the building foundation, making it unstable and at risk of collapse. Tidal water entering the building can damage building materials such as walls, floors, and electrical installations, as well as cause corrosion to metal components.

Spatial mapping using satellite imagery for 2018-2023 shows a decrease in mangrove area of 27.3% in Demak Regency, mainly due to land conversion into ponds. This reduction is related to the area's increased frequency and intensity of tidal flooding. From a socio-ecological perspective, a hybrid engineering approach combining breakwater structures with mangrove rehabilitation has proven more effective in the long term. The involvement of local communities in monitoring and maintaining mangrove areas also contributes significantly to the sustainability of the ecosystem.

The existence of settlements too close to the coastline often violates the provisions regarding coastal boundaries stipulated in spatial planning regulations. Violation of coastal boundaries increases the risk of exposure to abrasion and tidal flooding. Determining KDB and KLB with land areas that do not consider disaster risks can worsen vulnerability in vulnerable coastal areas. Overly dense and high development in tidal flood-prone zones can increase the number of residents and assets exposed to risk. Increasing mangrove density to a minimum of 3,000 trees/hectare needs to be a priority for coastal management policies in Demak Regency to mitigate sustainable and ecosystem-based tidal flooding. In addition, the existence of residential land use that is very close to the coastline deserves to be considered as a solution because the people who live there will be very vulnerable to the dangers of tidal flooding, including solutions for fisheries areas that are close to the coast and have a high potential for flooding can be included in economic vulnerability if they are affected and losses occur. An illustration can be seen in **Figure 6**.

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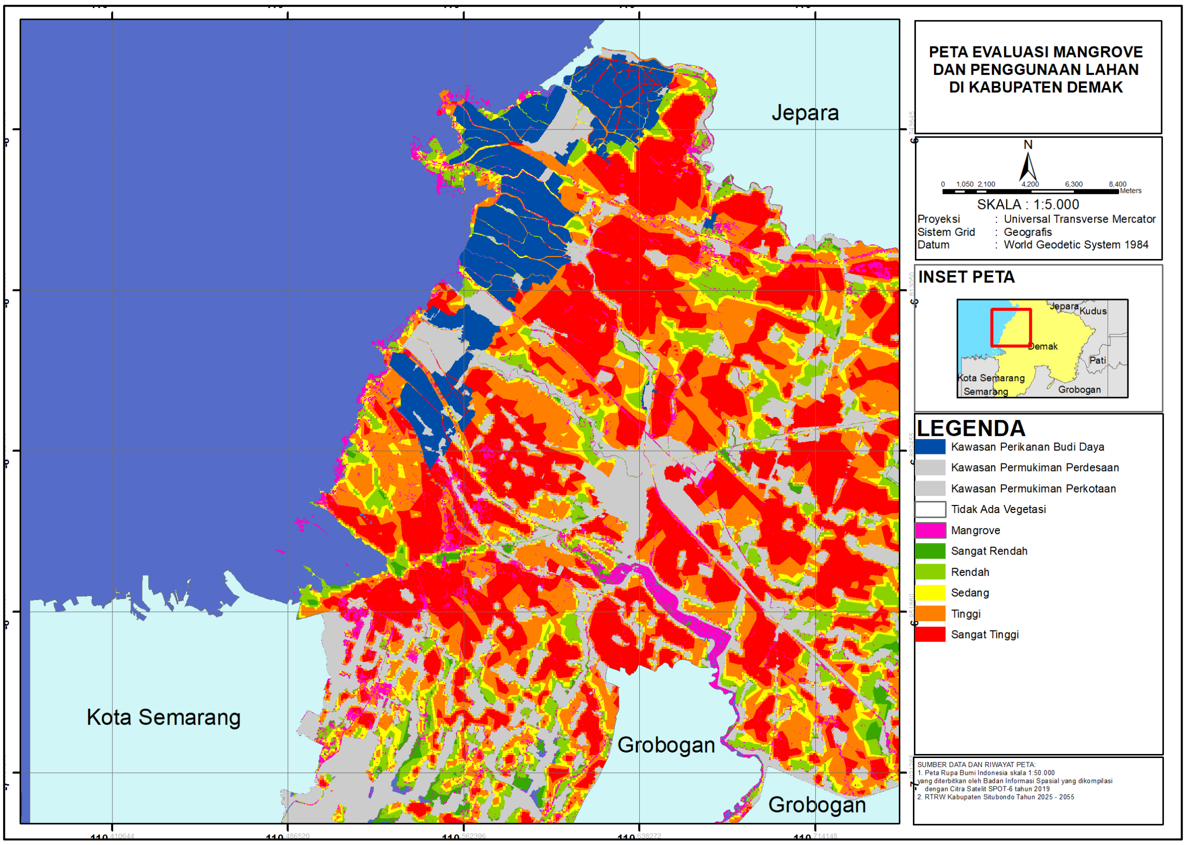

Figure 6. Results of Overlay Analysis of 3 variables

V. CONCLUSION

Several important points can be concluded based on research on the evaluation of mangrove density on the north coast of Demak Regency as a means of mitigating the dangers of tidal flooding. This study shows significant variations in mangrove density in the coastal area of Demak, with a range of 1,200-3,400 trees/hectare. The Sayung area has the highest density (3,400 trees/hectare), while the Kedung area has the lowest density (1,200 trees/hectare). The spatial analysis results using satellite imagery for 2018-2023 revealed a decrease in mangrove area of 27.3% in Demak Regency, mainly due to land conversion into ponds. This decrease is correlated with the increase in the frequency and intensity of tidal flooding in the area. The research findings show that areas with mangrove densities below 2,000 trees/hectare have a higher potential for tidal flooding, while areas with densities above 3,000 trees/hectare experience fewer tidal flooding events. It proves the effectiveness of mangroves as a natural barrier against seawater intrusion.

An overlay analysis integrating three main variables—mangrove density, flood hazard, and land use—shows spatial correlations that must be considered in coastal area planning. Residential and fishery areas very close to the coastline are at very high levels of tidal flood hazard, thus requiring comprehensive mitigation solutions. Therefore, increasing mangrove density to a minimum of 3,000 trees/hectare needs to be a priority for coastal management policies in Demak Regency to mitigate sustainable and ecosystem-based tidal flooding. Particular integration between flood hazard data and vegetation cover needs to be the basis for determining technical zones for developing coastal infrastructure resistant to tidal flooding. A deep understanding of the level of flood hazard in various mangrove density conditions will enable the planning and construction of infrastructure such as roads, drainage, and buildings that are more resilient to the impacts of tidal flooding. Zones with high mangrove density can be considered areas with lower risk but still require adaptive infrastructure design. Conversely, zones with low mangrove density and high flood hazard levels require more careful technical considerations, including selecting corrosion-resistant materials, adequate surface elevation, and effective drainage systems. In addition, there needs to

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be a review of land use planning in coastal areas, especially for residential and fisheries areas located in zones with high tidal flood hazard potential. Integrating mangrove density factors into the Demak Regency Spatial Plan (RTRW) is a strategic step that can strengthen coastal resilience to tidal flood hazards in the future.

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