Spatial distribution of tidal flooding in the coastal areas of Demak Regency, Central Java

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Abstract: The melting of polar ice caps due to climate change has resulted in sea level rise that threatens coastal areas, such as the Demak Regency. The impact of tidal flooding is, exacerbated by land subsidence. This study aimed to map and predict the distribution of tidal flooding in coastal Demak and its impact on land use. The methods used included Differential Interferometry Synthetic Aperture Radar (DInSAR) for Land Subsidence (LS), supervised classification for land use, admiralty for tides, data visualization for elevation, linear regression analysis for SLR, meteorological data analysis for wind and rainfall, and spatial analysis for tidal flood inundation mapping. The results showed an LS rate of 2,74 cm/year, highest tide height of 61,93 cm, average elevation of 1,893 m above sea level, SLR rate of 0,435 cm/year, wind speed of 0,5-5,7 m/s blowing from the northwest, and average daily rainfall of 7,476 mm. The tidal flood inundation area in 2023 reached 8.954,6 hectares and is predicted to reach 11.394,5 hectares in 2031. Tidal flooding affects mangroves (523,6 hectares), ponds (3.857,9 hectares), settlements (1.095,4 hectares), industries (3.453,00 hectares), and rice fields (24,7 hectares).

1 Introduction

Global warming is a global challenge with widespread impacts, including shifting climate patterns and rising global temperatures that contribute to sea-level rise (SLR). If this trend continues, significant land areas may be inundated[1]. Changes in ocean currents and density further drive SLR, affecting coastal regions globally owing to increased sea temperatures[2]. The current global SLR rate is 3.25 mm/year, with projections indicating acceleration this century, although unevenly distributed[3][4][5]. SLR has intensified coastal disasters, making flooding the costliest issue in these areas[5][6].

Coastal regions, which account for 44% of the global population within 150 km of shorelines, are crucial to the world economy, but face challenges such as tidal flooding[7]. In Indonesia, tidal flooding results from high tides in low-lying coastal areas and is exacerbated by factors such as land subsidence, wind, waves, and rainfall[8][9]. One of the areas that was significantly affected was the Demak Regency.

The Demak Regency in Central Java, neighboring Semarang City, faces worsening tidal flooding due to land subsidence caused by groundwater exploitation and urban development, along with coastal erosion and SLR[10][11]. Although studies have examined tidal flood

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distribution in Demak, the impact of land subsidence on flooding and land use remains underexplored[12][13]. Spatial analysis is essential for mapping inundation, assessing land-use impact, and informing mitigation planning for tidal flood disasters in this region. This study aims to map the distribution and extent of tidal flood inundation in 2023, predict its occurrence in 2031, and analyze its impact on land use in the coastal area of Demak Regency, Central Java, using spatial analysis.

1.1 Study site

This study was conducted on the coast of Demak Regency, Central Java, focusing on the four affected sub-districts. These sub-districts are Sayung, Karangtengah, Bonang, and Wedung (Figure 1). These four sub-districts were chosen because they are directly adjacent to the sea and often experience tidal floods.

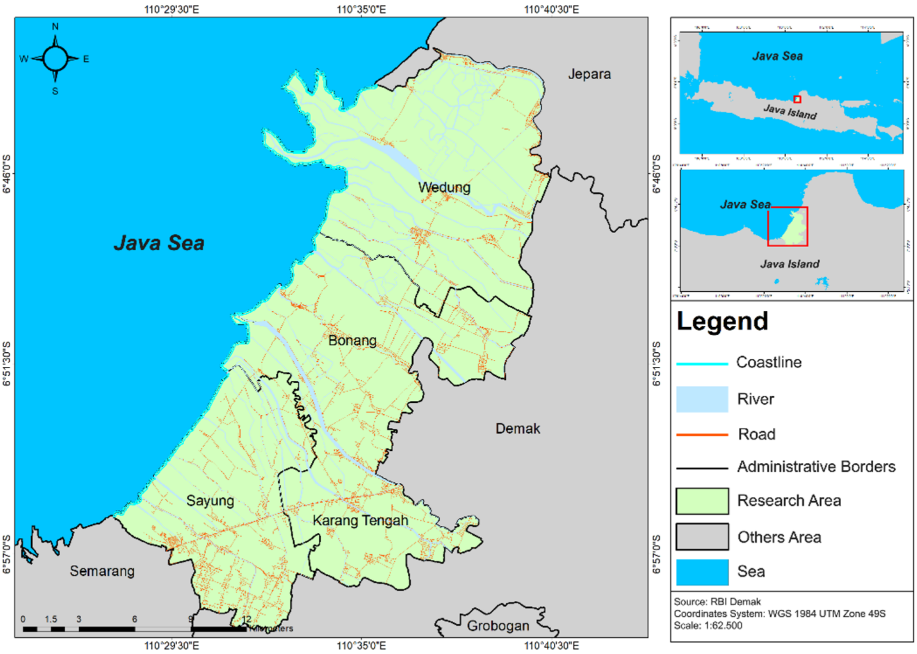

Fig. 1. Study site

2 Materials and Methods

The equipment used in this study included an Asus Zenbook 14 laptop with an AMD Ryzen 5 5500u processor, 8GB RAM, and an Nvidia MX450 graphics card equipped with software such as ArcMap 10.8, QGIS 3.23.3, ENVI 5.3, SNAP, JupyterLab, Microsoft Excel, and Microsoft Word. The materials used in this study included Sentinel-2A Level 1C imagery (dataspace.copernicus.eu), Sentinel-1A Single Look Complex (SLC) data (asf.alaska.edu), daily Sea Level Anomaly (SLA) data (cds.climate.copernicus.eu), duration and height of tidal inundation data (field data), hourly tidal data (srgi.big.go.id), National Digital Elevation Model (DEMNAS) data (tanahair.indonesia.go.id), wind data (climate.copernicus.eu), rainfall data (bmkg.go.id), and the Indonesian Rupabumi Map (RBI) of Demak Regency (tanahair.indonesia.go.id).

2.1 Satellite Image Data Processing

This study employs a multidisciplinary approach using geospatial and statistical methods to analyze land subsidence, sea level rise, tidal flooding, and their impact on coastal regions. Sentinel-1A SAR data (2018 and 2023) were processed using Differential Interferometry Synthetic Aperture Radar (DInSAR) in SNAP software with SNAPHU extensions[14][15]. Key steps included the coregistration of master (2018) and slave (2023) images, coherence estimation[16], topographic phase removal, and phase unwrapping. The DEMNAS data (2018) were integrated to update elevation maps with high geometric accuracy[17].

The land use classification used Sentinel-2A Level-1C imagery (2023), preprocessed with atmospheric correction using the Dark Object Subtraction (DOS) method, and geometric correction with 70 Ground Control Points[18]. The maximum Likelihood classification produced six land use categories—mangrove, agriculture, aquaculture, settlements, industry, and rice fields—validated using accuracy metrics including overall accuracy, user accuracy, producer accuracy, and kappa coefficients[19][20].

Hourly tidal data (September 2023 – February 2024) were analyzed for harmonic components to derive the tidal types, mean sea level (MSL), and highest high-water levels (HHWL)[21]. Historical sea-level anomaly (SLA) data (1993–2023) were analyzed via linear regression to identify sea-level rise (SLR) trends[22]. Field surveys and interviews provided data on the duration and depth of tidal flooding, which was validated by on-site documentation.

Rainfall data (November 2023) from the BMKG were processed to calculate daily and decadal averages, while wind data (November 2023) were classified using a modified Beaufort Scale and visualized with windrose diagrams[23]. The spatial analysis integrated elevation, land use, subsidence, and SLR trends to map tidal flooding for 2023 and predict scenarios for 2031, assuming linear trends in subsidence and SLR. Predictions were generated using ArcMap's Raster Calculator by applying conditional logic[24]. This comprehensive geospatial analysis highlights tidal flood risks and offers actionable insights into sustainable coastal management in the Demak Regency.

3 Result and Discussion

3.1 Land Subsidence

DInSAR processing results show that the Demak coastal area has a land subsidence rate ranging from +2 cm/year (indicating uplift or land rising) to -7.5 cm/year (indicating subsidence or land sinking). On average, the area experiences a land subsidence rate of 2.74 cm/year, as shown in Figure 2. Areas closer to the coast, industrial areas, and settlements experienced higher land subsidence rates than other areas (Figure 3). This is because the soil layer continues to compress closer to the coast, resulting in a greater land subsidence rate [25]. In industrial and residential areas, excessive groundwater withdrawal increases the land subsidence rate because the soil that was originally filled with water becomes empty and compact [26]. Building loads also affect the land subsidence rate, although not as much as the effect of massive groundwater withdrawal[27].

According to research conducted by Lumban-Gaol et al. (2024), the land subsidence pattern from DInSAR processing using Sentinel-1A SAR images is similar to direct measurements; therefore, it can be used as the main data. Land subsidence is one of the primary causes of tidal flooding. When the land surface drops, it becomes lower than sea level. As a result, it is easier for seawater to enter the land. This process causes tidal flooding, as seawater at the coastal boundary eventually overflows and floods in lower areas[28].

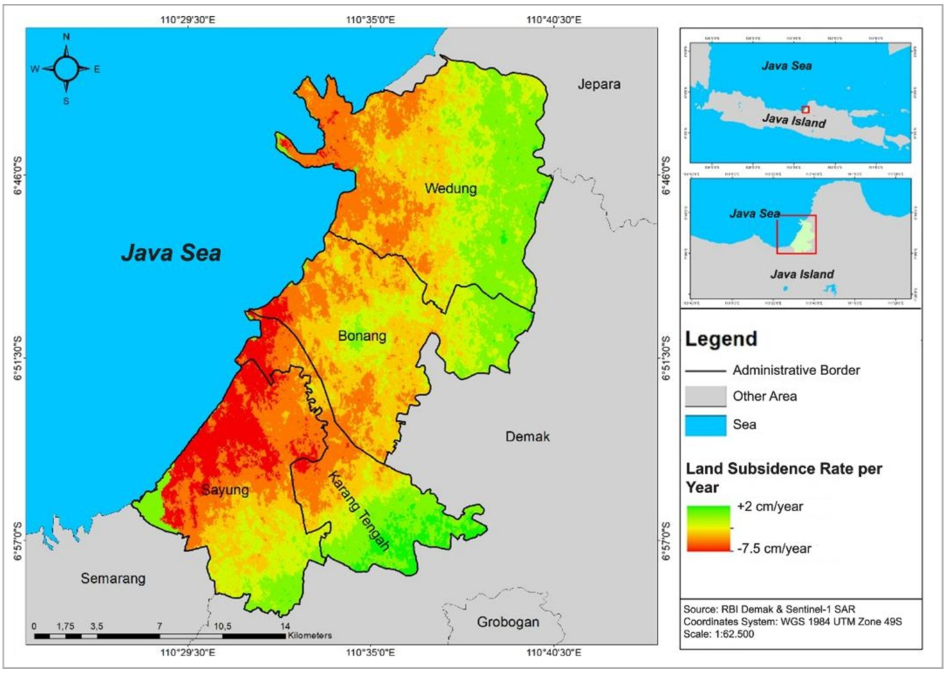

Fig. 2. Map of subsidence rate in Demak coastal area

3.2 Land Use

The results of land use processing using the maximum likelihood (MLH)-guided classification method resulted in six classes: mangroves, plantations, ponds, settlements, industries, and rice fields. These six classes are in accordance with the land cover classification standards issued by the National Standardization Agency (BSN)[29]. Land use data were used to map land use affected by tidal flood inundation. A land-use map is shown in Figure 3.

Sorted from the largest, the classes were rice fields (15,127 ha), industry (6,720 ha), settlements (6,167 ha), ponds (6,037 ha), mangroves (700 ha), and plantations (343 ha). An accuracy test was conducted by comparing the results of land-use classification from image processing with field validation data of 95 sample points. Based on the accuracy test, the results of land use classification using the maximum likelihood method are quite accurate, with the OA reaching 88% and KC value reaching 0.86.

Land use in the Sayung Sub-district is dominated by industrial and residential areas. According to the community and local officials, as a result of land subsidence and sea level rise, ponds have been damaged and no longer function; therefore, they are considered to be industrial areas, following the function of the surrounding area. In other sub-districts, in areas closer to the coast, the dominant classes were ponds and settlements. According to several studies, land subsidence has caused many changes in mangrove areas, settlements and rice fields to become ponds due to the increasing intensity of tidal surges each year[30][32].

Changes in land use further increase the risk of tidal flooding[33]. Land conversion in mangrove areas causes coastal areas to be prone to erosion. Rice fields used to be a pathway for water to enter the soil change function in ponds that are impermeable or cannot be passed by water. Residential areas that move and occupy the new area will result in land subsidence, such that the tidal inundation boundary becomes further inland.

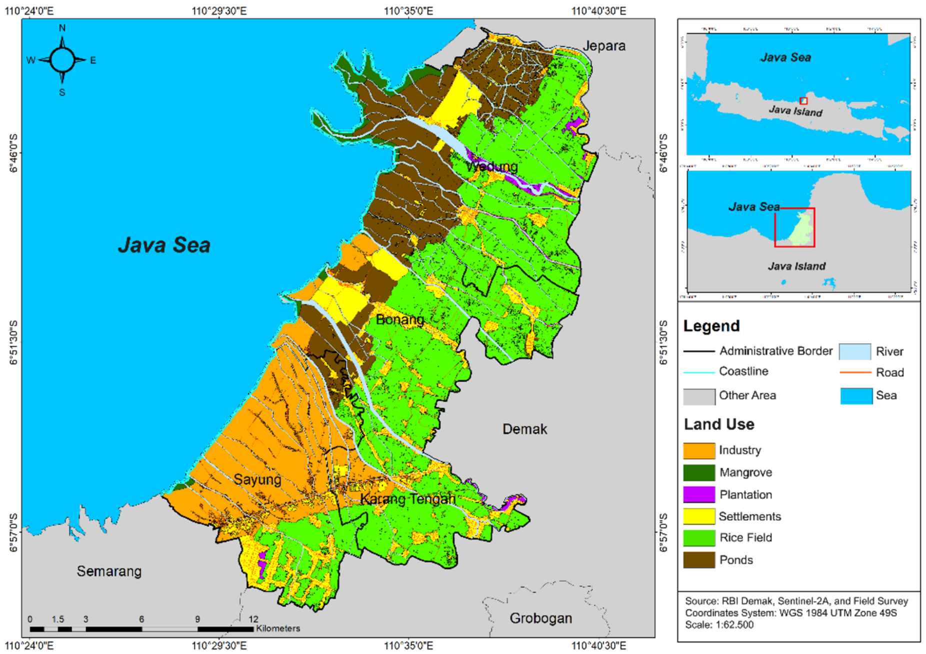

Fig. 3. Map of land use in Demak coastal area

3.3 Tides

Based on the research results, in the coastal waters of Demak Regency, the largest tide occurred on November 20, 2023 at 20.00 WIB with a height of 0.541 m, whereas the largest low tide occurred on November 22, 2023 at 05.00 WIB with a height of -0.535 meters. The Formzahl number was 1.502, and the difference between HHWL and MSL was 61.93 cm. The results of tidal data processing using the admiralty method are shown in Figure 4.

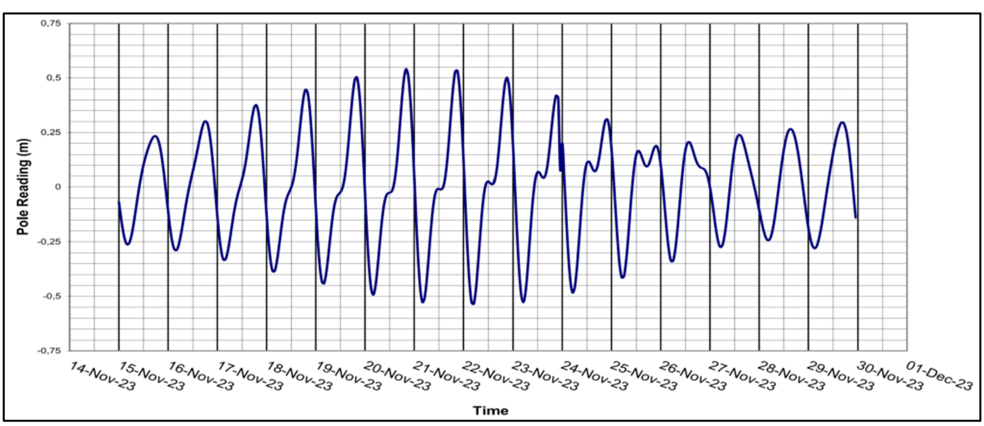

Fig. 4. Demak coastal tide chart in November 2023

The coastal waters of Demak Regency have a type of mixed tide leaning to a single day, where in one day there is one tide and ebb, but sometimes there are two tides and ebbs with different heights. This is reinforced by Sagala et al. (2024), who stated that the waters of

Demak Regency north of Java Island have a single daily tidal type[34]. High tides can cause tidal flooding because land elevation is lower than the tide. Tides in Demak waters in the west season tended to increase the intensity of tidal flooding compared to the east season. This is caused by the monsoon winds that blow from the South China Sea, carrying air masses that flow towards the Karimata Strait and Flores Sea. These winds also cross the South Coast of Kalimantan and the North Coast of Java Island, moving from west to east in accordance with the direction of the monsoon wind rotation. The influence of these monsoon winds causes higher tides[35].

3.4 Elevation

The coastal areas of the Demak Regency have elevations ranging from -3 m below sea level to 21 m above sea level, with an average of 1,893 m above sea level. Elevations were lower in areas closer to the coast owing to the influence of abrasion and land subsidence. Abrasion causes erosion of the land and reduces its elevation over time. Land subsidence can also cause a decrease in elevation in coastal areas, making them lower than areas farther from the coastline. The elevation of the study area is shown in Figure 5.

Elevation is one of the parameters that affects tidal flood inundation because the lower the elevation of an area, the higher the potential for tidal flooding[36]. Based on the research results, the coastal areas of the Demak Regency, especially those directly adjacent to the sea, have a high potential to be affected by tidal flooding because they have a lower elevation than the sea surface. In addition, the coastal areas of the Demak Regency have sloping contours, low elevation, and complex land use, making them easily affected by tides [37].

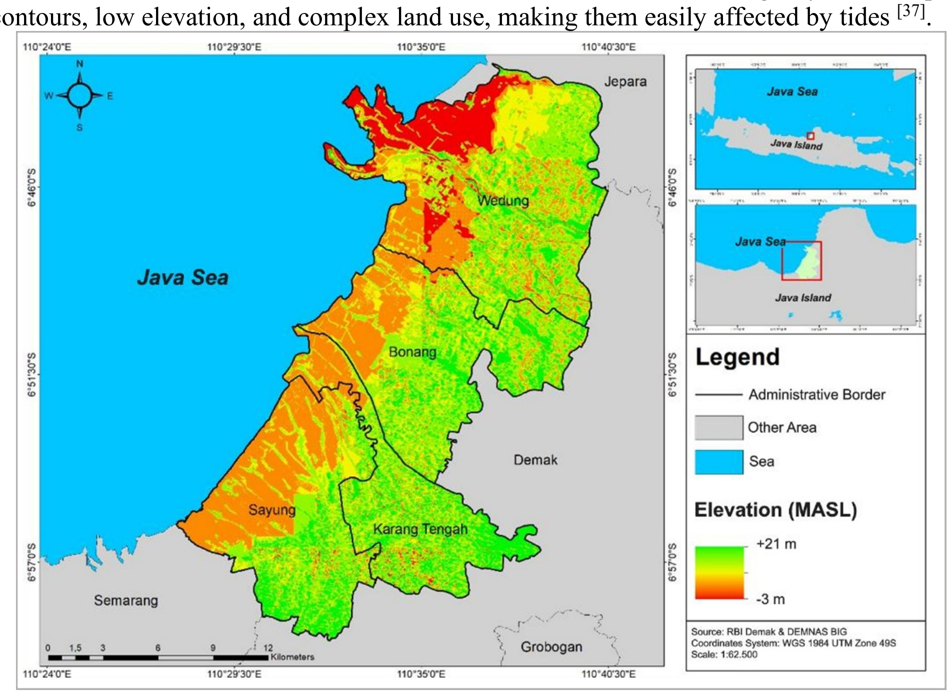

Fig. 5. Elevation of the study area

3.5 Rate of Sea Level Rise

The results of sea level anomaly data processing show that the rate of sea level rise in the coastal waters of the Demak Regency is 0.435 cm/year. This rate is higher than the global rate, which is 0.325 cm/year[38][39] and in line with the research of Lumban-Gaol et al. (2021) which states that Indonesian waters experience a sea level rise rate of 0.43 cm/year[40]. A high rate of sea-level rise can increase the risk of tidal flooding, especially during high tides. Land subsidence in this area also increases the risk of tidal flooding because every year, more land is below sea level. A graph of the rate of sea level rise is shown in Figure 6.

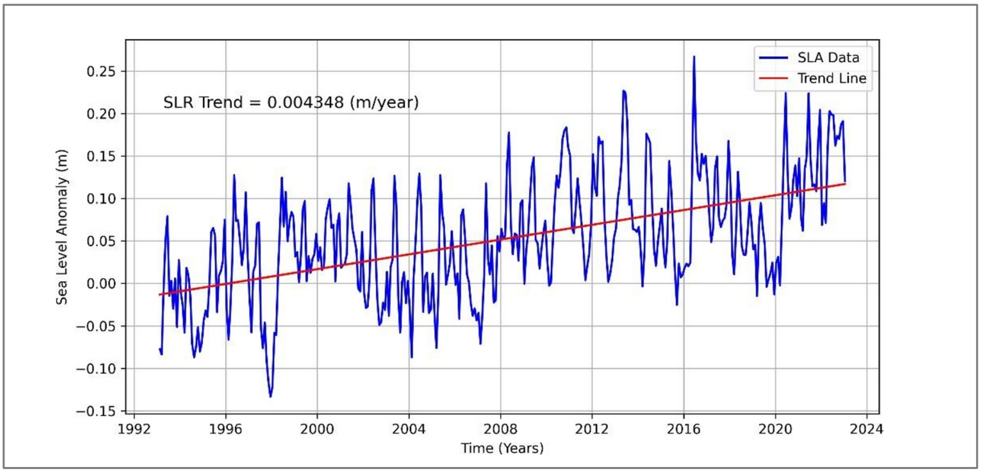

Fig. 6. Rate of sea level rise in coastal Demak

3.6 Rob Flood Inundation Height and Duration

The duration and height of the tidal flood inundation were obtained through interviews with communities in the Demak coastal area. Based on the results of interviews with residents of coastal Demak in 2024, it is known that the height of tidal flooding varies, ranging from the ankle of an adult to the calf of an adult, with a range of ± 20–30 cm. According to the local community, the worst tidal flooding occurred in the Sayung subdistrict. Tidal flooding significantly affects the social and economic lives of the coastal communities of Demak. Losses occur in the form of loss of goods, loss of income sources, damage to infrastructure, and casualties due to drifting or drowning. In addition, tidal floods disrupt transportation and the loading and unloading of goods and cause health and sanitation problems.

3.7 Wind

Seasonal wind changes greatly affect the current patterns in the coastal waters of the Demak Regency. During the western season, global current circulation is heavily influenced by changes in the monsoon winds worldwide. Winds moving from the South China Sea carry water masses, which then flow towards the Karimata Strait to the Flores Sea. These winds also cross the southern coast of Kalimantan and the northern coast of Java Island, moving from West to East. This causes current patterns in the coastal waters of the Demak Regency to be influenced by the transportation of these water masses, increasing the potential for tidal flooding[41]. The wind speed and direction measured in the coastal area of Demak Regency in November 2023 are displayed in the form of a wind rose, as shown in Figure 7. The wind rose aims to show the frequency of wind speed (m/s) and wind direction at the location and time of the study.

Winds in November 2023 on the coast of Demak Regency have a range of 0.5 m/s - 5.7 m/s with dominant wind speeds in the range of 0.5 m/s - 2.1 m/s and an average of 1.76 m/s. The dominant wind direction was from the northwest. Based on the Beaufort scale, the wind on the coast of the Demak Regency falls under the category of light breezes. According to research conducted by Fitrianti et al. (2018), light winds do not affect the distribution of tidal floods because they do not cause significant changes in tide heights, but moderate and strong winds can affect tidal floods[42]. The coastal area of Demak Regency has waters facing northwest; therefore, if there is moderate or strong wind during a tidal flood event, the tidal flood distribution will increase and exacerbate the tidal flood event.

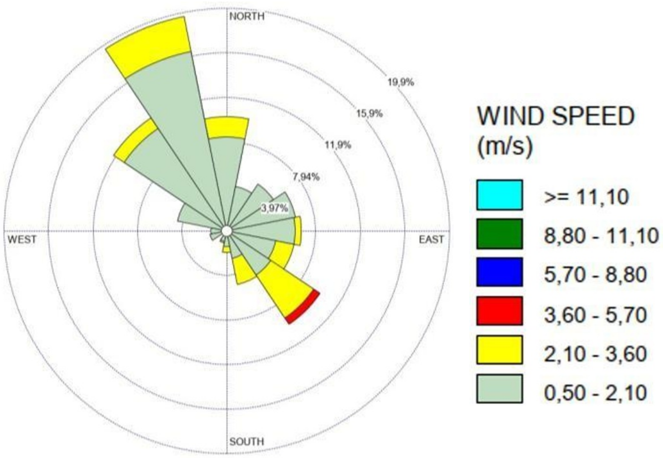

Fig. 7. Wind rose in November 2023 in coastal Demak

3.8 Rainfall

Decadal rainfall was calculated by dividing the total monthly rainfall into three periods of one month. According to the daily rainfall data, the beginning of the rainy season (AMH) occurred in mid-November. This refers to the BMKG standard; namely, if the rainfall value in three consecutive dashes is more than 50 mm, it can be said to be AMH[43]. Based on research conducted by Syafitri and Rochani (2021), the rainy season that lasts during November affects tidal flood inundation[44]. This is because rain causes soil to become saturated. Consequently, areas affected by tidal floods experience deeper inundation and take longer to recede.

High rainfall can also affect the expansion of tidal flood areas because it will increase the volume of water in the tidal inundation if it occurs at the same time as the tidal flood event, especially if there is tidal flooding around areas where there are many rivers, because it will cause river water to overflow inland[45]. A Dasarian histogram is shown in Figure 8.

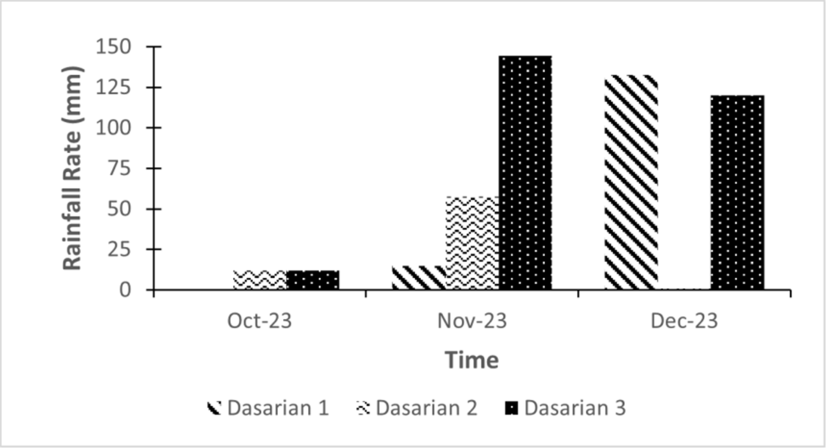

Fig. 8. Histogram of dasarian rainfall in coastal Semarang City

3.9 Distribution of Rob Flood in 2023 and its Prediction in 2031

The results of the spatial analysis of tidal flood inundation can be mapped onto the coastal land-use map of the Demak Regency, resulting in the tidal flood inundation distribution map presented in Figure 9. In 2023, all subdistricts bordering the sea in the Demak Regency experienced tidal flooding. The total inundation area reaches 8,954.6 ha or approximately 25.5% of the total area of the four sub-districts located on this coast. The most affected sub-district is Sayung and the least affected is Karang Tengah. Tidal flooding also inundates land use in this area. In the Bonang, Karang Tengah, and Wedung sub-districts, the most affected land use is ponds, causing significant losses to local communities, especially those that depend on the aquaculture sector.

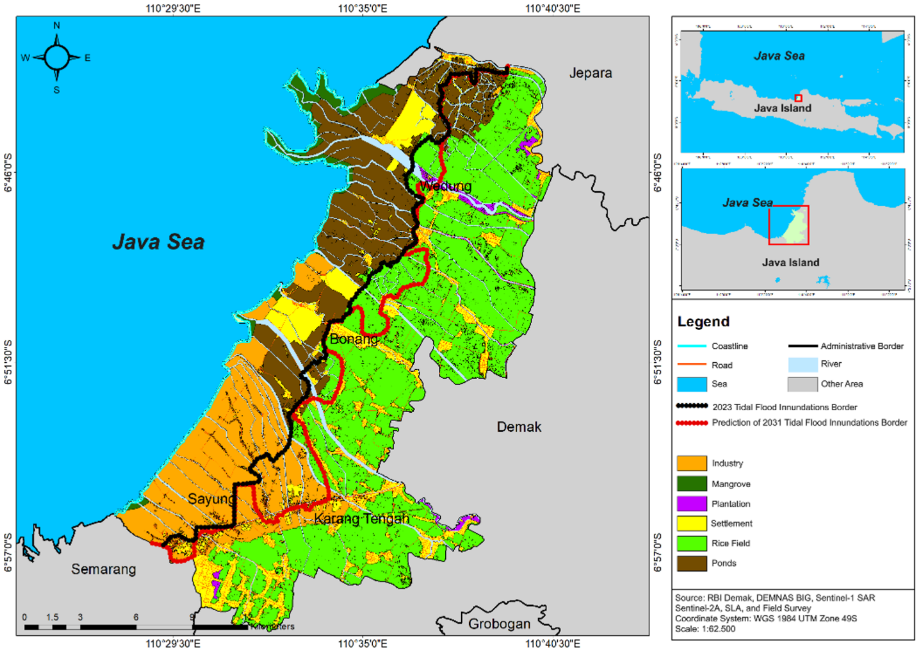

Fig. 9. Tidal flood inundation distribution map

In Bonang sub-district, affected are predicted to increase from 774.5 hectares (68.5%) in 2023 to 1,007.7 hectares (89.1%) in 2031. Settlements also increased from 527.2 hectares (27.4%) to 628.2 hectares (32.7%). Meanwhile, rice fields, which were initially only affected by 16 hectares (0.3%) in 2023, will increase significantly to 257.9 hectares (5%) in 2031. In Karang Tengah Sub-district, the affected industrial land increased from 195.3 hectares (18.5%) to 341.5 hectares (32.3%). Ponds also increased from 355.4 hectares (79.4%) to 407.5 hectares (91%). Settlements only experienced a slight increase, from 3.5 hectares (0.3%) to 5.3 hectares (0.5%).

In Sayung sub-district, the impact of tidal flood on industrial land increased significantly from 2,997.7 hectares (56.5%) to 3,765.9 hectares (71%). The number of affected ponds increased from 2,593 hectares (61.8%) to 2,978.4 hectares (70.9%). Affected paddy fields increased from 0.3 hectares (0.1%) to 34.7 hectares (2.2%). In the Wedung sub-district, the affected pond land increased from 2,593 hectares (61.8%) in 2023 to 2,978.4 hectares (70.9%) in 2031. Settlement land increased from 549.3 hectares (34.1%) to 567.5 hectares (35.2%). While paddy fields experienced a significant increase from 8.4 hectares (0.2%) to 202.8 hectares (3.7%).

Tidal flooding in the coastal Demak Regency is influenced by several factors, such as land subsidence, sea level rise, tides, and low area elevation. Land subsidence caused by groundwater exploitation and soil compaction (Novita et al. 2021), makes the already low coastal land of Demak Regency even lower. In line with previous research, wind direction, speed, and rainfall did not significantly affect the distribution of tidal flood inundation because tidal floods are not always accompanied by extreme wind and rainfall conditions[46][47].

Land subsidence lowers the land surface below sea level, making the area more vulnerable to inundation during high tides[48]. Sea-level rise leads to higher sea levels, making coastal areas more vulnerable to inundation during high tides or storms. This results in an increase in the frequency and intensity of tidal flooding, as higher seawater more easily overflows onto land[49].

Tidal flooding in the coastal areas of Demak Regency has a significant impact on land use. One of the affected areas is the mangrove forest, which plays a crucial role in mitigating tidal flooding owing to its strong roots and leaves that help reduce tidal surges[50]. Land conversion in mangrove areas has decreased protection against tidal flooding. Additionally, tidal flooding affects shrimp farming areas, disrupts production cycles, delays harvests, and damages farms with foreign materials, such as mud and sand[51]. Flooding also affects the industrial zones, settlements, plantations, and rice fields. In industrial areas, tidal flooding can disrupt operations and damage the factory infrastructure, thereby hindering production processes. In settlements, it damages homes and public facilities while also causing health issues such as skin diseases.

Flooding also disrupts planting and harvesting cycles in plantations and rice fields, forcing farmers to delay planting new crops and harvesting, directly impacting agricultural productivity, reducing crop yields, and affecting farmers' incomes. A comprehensive strategy, including the construction of flood barriers, improved drainage systems, and sustainable environmental management, is needed to address tidal flooding. Additionally, educating and empowering communities on climate adaptation and tidal flood risk mitigation are essential. The government should also collaborate with relevant stakeholders to implement mangrove reforestation as a natural barrier to erosion and flooding.

4 Conclusion

Spatial analysis of tidal flooding in the coastal areas of Demak Regency shows that in 2023, all sub-districts directly bordering the sea were affected, with a flood area of 8,954.6 ha, or approximately 25.5% of the total area of the four sub-districts. The Sayung Sub-district was the most affected, while the Karang Tengah Sub-district was the least impacted. Affected land uses included mangrove forests, shrimp ponds, settlements, industries, and rice fields. By 2031, the flood area is projected to increase to 11,394.5 ha, or approximately 32.5% of the total area of the four subdistricts, with the most severe impact still in Sayung and the least in Karang Tengah. The threat of tidal flooding has become more serious as even plantation areas, which are at higher elevations and farther from the sea, are now submerged. Factors contributing to tidal flooding in Demak include land subsidence, sea level rise, tidal surges, and the low elevation of the region. Tidal flooding has a significant impact on land use, including mangrove forests, shrimp ponds, industrial areas, settlements, plantations, and rice fields. The damage includes the disruption of industrial production, planting and harvesting cycles, destruction of infrastructure, and reduced income for local communities.

References

1. Y.T. Triana, Z. Hidayah, *Juvenil: Jurnal Ilmiah Kelautan dan Perikanan* **1**, 1 (2020)
2. [IPCC] International Panel for Climate Change. 2018, New York (US): Cambridge University Press.
3. X. Chen, X. Zhang, J.A. Church, C.S. Watson, M.A. King, D. Monselesan, B. Legresy, C. Harig, *Nature Climate Change* **7**, 7 (2017)
4. J.T. Fasullo, R.S. Nerem, *Altimeter-era emergence of the patterns of forced sea- level rise in climate models and implications for the future* in Proceedings of the National Academy of Sciences 18 Dec 2018, Toulouse, France (2018)
5. B. Fox-Kemper, H.T. Hewitt, C. Xiao, G. Aðalgeirsdóttir, S.S. Drijfhout, T.T. Edwards. 2021. *Ocean, cryosphere, and sea level change* In Climate Change, Cambridge (2021)
6. N.A. Azuga, *Jurnal Riset Kelautan Tropis* **3,** 2 (2021)
7. C. Quagliolo, P. Roebeling, F. Matos, A. Pezzoli, E. Comino, *Science of The Total Environment* **902** (2023)
8. R. Pelich, M. Chini, R. Hostache, P. Matgen, C. López-Martínez, *IEEE Geoscience and Remote Sensing Letters* **18**, 10 (2020)
9. E.S. Wulandari, R.A. Aziz, *Model prediksi dengan artificial neural network untuk kejadian banjir rob di wilayah pesisir Kota Bandar Lampung* in Prosiding Seminar Nasional Darmajaya 29 Aug 2022, Lampung, Indonesia (2022)
10. D. Kurniawan, S.Y. Prasetyo, C. Fibriani, *Indonesian Journal of Computing and Modeling* **4**, 1 (2021)
11. L.N. Istiqomah, L.M. Sabri, B. Sudarsono, *Jurnal Geodesi Undip* **9**, 2 (2020)
12. D. Wacano, A.A. Rif'an, E. Yuniastuti, R.W. Daulay, M.A. Marfai, *Seri Bunga Rampai Pengelolaan Lingkungan Zamrud Khatulistiwa* (Percetakan Kanisius, Yogyakarta 2013)
13. A. Asrofi, D.S. Hadmoko, *Jurnal Ketahanan Nasional* **23**, 2 (2017)
14. D. Nafisah, H. Setiyono, H. Hariyadi, Pemetaan sebaran genangan rob di pesisir bonang, Kabupaten Demak. *Journal of Oceanography* **6**, 3 (2017)
15. I.G. Darmawan, Z.K. Manurung, M. Nurul, W.P. Prihadita, K. Karyanto, *Jurnal Geosaintek*. **7**, 2 (2021)
16. E.D. Safitri, N. Hayati, F. Bioresita, *Jurnal Teknik ITS* **10**, 2 (2021)

17. B. Setiawan, G.D.P.N. Akbar, F.D. Suyeda, R. Permana, *Applicable Innovation of Engineering and Science Research (AVoER)* **14,** 1 (2022)
18. D.B. Susetyo, *Geodesy and Cartography* **49**, 4 (2023)
19. M. Prabandaru, *Jurnal Ilmiah Geomatika.* **2**, 1 (2022)
20. F.B. Simamora, B. Sasmito, Hani'ah, *Jurnal Geodesi Undip* **4** (2015)
21. O. Silitonga, D. Purnama, E. Nofriadiansyah, *Jurnal Enggano* **3**, 1 (2018)
22. O.S.R. Ongkosongo, Suyarso, Pasang Surut (Lembaga Ilmu Pengetahuan Indonesia, Jakarta, 1989)
23. Copernicus Climate Change Service, Sea level gridded data from satellite observations for the global ocean from 1993 to present (Copernicus Climate Change Service, Climate Data Store, 2018)
24. A. Ma'rufatin, A. Yananto, W.W. Pandoe, *Jurnal Teknologi Lingkungan* **25**, 1 (2024)
25. A. Suanda, D.M. Driptufany, D. Defwaldi, F. Fajrin, I. Armi, *Aerospace Engineering* **1**, 2 (2024)
26. B. Sasmito, *Elipsoida: Jurnal Geodesi dan Geomatika* **3**, 2 2020)
27. I. Gumilar, H.Z. Abidin, L.M. Hutasoit, D.M. Hakim, D.A. Sarsito, H. Andreas, T.P. Sidiq, *Indonesian Journal of Geospatial* **1**, 4 (2012)
28. B.D. Yuwono, H.Z. Abidin, M. Hilmi, *Analisa geospasial penyebab penurunan muka tanah di Kota Semarang* in Prosiding Sains Nasional dan Teknologi 5-11 Juli 2013 , Semarang, Indonesia (2013)
29. A.W. Syafitri, A. Rochani, *Jurnal Kajian Ruang* **1**, 1 (2021)
30. A.C. Kusuma, I. Irwani, S. Widada, *Journal of Marine Research* **2**, 3 (2013)
31. S. Munasikhah, *Journal of Indonesian History* **10**, 2 (2021)
32. M.S. Kuba, N.A. Rumata, C.A. Amal, *Journal of Green Complex Engineering* **1**, 2 (2024)
33. P.M. Sagala, R.K. Bhomia, D. Murdiyarso, *Regional Studies in Marine Science* **70** (2024)
34. S. Widada, B. Rochaddi, H. Endrawati, *Buletin Oseanografi Marina* **1**, 2 (2012)
35. A.D. Ramdhany, H.W. Wiranegara, M.N. Luru, *Jurnal Bhuwana* **1**, 2 (2021)
36. G. Bariroh, H.K. Surtikanti, *Applied Environmental Science* **1**, 2 (2024)
37. J. Lumban-Gaol, S. Vignudelli, I.W. Nurjaya, N.M.N. Natih, M.E. Sinurat, R.E. Arhatin, E.E. Kusumaningrum, *IOP Conf. Ser. Earth Environ. Sci*. **944** (2021)
38. N. Fitrianti, Y.D. Haryanto, E.V. Simamora, H.F. Bintari, A. Hartoko, S. Anggoro, M. Zainuri, *IOP Conference Series: Earth and Environmental Science* **162**, 1 (2018)
39. M.G. Novita, M. Helmi, R. Widiarati, H. Hariyadi, A. Wirasatriya, *Indonesian Journal of Oceanography* **3**, 3 (2021)
40. J. Jamalludin, K.I. Fatoni, T.M. Alam, W.S. Pranowo, *Jurnal Chart Datum* **2**, 2 (2016)
41. P.M. Kurniawan, P. Widodo, H.J. Saragih, P. Suwarno, E. Legowo, *G-Tech: Jurnal Teknologi Terapan* **7,** 2 (2023)
42. N.R. Adawiyah, T. Triyatno, *YASIN* **4**, 3, (2024)
43. A.S. Afifah, M.M. Sari, S. Suhardono, I.W. Suryawan, *Jurnal Serambi Engineering* **8,** 4 (2023)
44. R. Dewi, A.P. Ivo, S. Aninda, *Jurnal Rekayasa, Teknologi, dan Sains* **7**, 2 (2023)
45. R. Erlani, W.H. Nugrahandika, *Journal of Regional and Rural Development Planning (Jurnal Perencanaan Pembangunan Wilayah dan Perdesaan)* **3**, 1 (2019)