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# Improved Performance of Geospatial Model to Access the Tidal Flood Impact on Land Use by Evaluating Sea Level Rise and Land Subsidence Parameters

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**ABSTRACT**

In the 20th century, climate change caused an increase in temperature that accelerated the rate of sea level. Sea level rise and land subsidence threaten densely populated coastal areas as well as lowlands because they cause tidal flooding. Tidal floods occur every year due to an increase in sea level rise and land subsidence. The lack of information on this phenomenon causes delays in disaster mitigation, leading to serious problems. This study was conducted to predict the area of tidal flood inundation on land use in 2020 to 2035. This research was performed in Pekalongan Regency, as one of the areas experiencing large land subsidence and sea level rise. The research data to be used were tides and the value of soil subsidence, as well as sea level rise. Digital Terrain Model (DTM) was obtained through a topographic survey. Modeling was used for DTM reconstruction based on land subsidence and sea level rise every year. The sea level rise value uses the satellite altimetry data from 1993–2018. A field survey was conducted to validate the inundation model that has been created. Land subsidence was processed using Sentinel-1 Synthetic Aperture Radar (SAR) image data with Single Band Algorithm (SBA) differential interferometry. This study proved that tidal flooding has increased every year where in 2020 it was 783.99 hectares, but with the embankment there was a reduction in inundation area of 1.68 hectares. The predicted area of tidal flood inundation in 2025, 2030 and 2035 without the embankment is 3388.98 hectares, 6523.19 hectares, 7578.94 hectares, while with the embankment in 2035 is 1686.62 hectares. The research results showed that the use of embankments is a solution for coastal mitigation as well as regional planning.

**Keywords**: geospatial model, tidal flood, land use, sea level rise, land subsidence.

## INTRODUCTION

Climate change is the most important threat to humans in the twenty-first century (Toan, 2014). This extreme event causes an increase in temperature which leads to an acceleration of sea level rise (Seenath et al., 2016). Tidal flooding is a disaster that often occurs in cities or coastal areas, such as in Pekalongan Regency (Ramadhan et al., 2019). Pekalongan Regency is an area affected by tidal flooding due to the direct impact of climate change (Sauda et al., 2019). Sea level rise and land subsidence will expand and deepen tidal inundation. In order to reduce tidal flooding, sea dikes and safety buildings were built on the North Coast of Java Island, including the coast of

Pekalongan Regency (Bappenas, 2019), so the question to be answered from this research was "How wide the distribution of the tidal flood inundation area on coastal land use in Indonesia?" (in the Pekalongan Regency area). By using the geospatial method, paying attention to land subsidence and sea level rise will produce a prediction map of the inundation that will occur and its impact on land use in Pekalongan Regency. The problem to be solved in this study was to find the area and distribution of tidal inundation areas on coastal land use using a spatial modeling approach.

Desalegn and Mulu (2021) conducted an assessment of flood inundation areas in the Fetam River area, Ethiopia. This research used the flood data that previously occurred and topographic data which was then used to create flood prediction maps using ArcGIS and HEC – RAS Model. In this study, the flood inundation areas that occurred in the Fetam River area, Ethiopia were 27.31, 24.85, 20.47, 17.34, and 13.78 km$^2$ for repeated periods of 100, 50, 25, 10, and 5 years. Suroso and Firman (2018) conducted the research on the role of spatial planning in reducing the exposure to the impacts of sea level rise that occurred on the North Coast of Java, Indonesia. This research used the coastal hazard level data of 2010 by modeling the inundation area for 2030 using a geospatial model of inundation prediction. This research shows that a total of 55,220 hectares of inundated land and spatial planning can increase the risk of climate-related hazards and cause higher economic losses. Bott et al. (2021) conducted an assessment of land subsidence in the Jakarta and Semarang Bay areas. This research used the data from radar altimetry, tidal data and InSAR mapping to characterize regional and relative SLRs in Jakarta and Semarang, Indonesia. This research showed that the land subsidence in Semarang has a steady downward trend of up to 10 cm/year, for Jakarta it is 6 cm/year. Maharlika et al. (2020) conducted an assessment of tidal flooding and coastal adaptation responses in Pekalongan City, Indonesia. This research used reference data and documentation such as journal books, articles, and other reading materials that are relevant to the descriptive analysis method. This research showed that tidal flooding in the coastal area of Pekalongan City is not only due to sea level rise and the topography of the area is sloping with low elevation; this condition is also exacerbated by the phenomenon of land subsidence reaching -30 to -50 cm/year. Yastika et al. (2019) conducted a long-term land subsidence study from 2003 to 2017 in the coastal area of Semarang, Indonesia. This research used the data from Envisat-ASAR, ALOS-PALSAR, and Sentinel-1A SAR with the Hyperbolic method and DInSAR Small Baseline Subset (SBAS) analysis. This research showed that the transition to subsidence varies depending on the location, and the rate of subsidence continues to increase in the northern and northeastern coastal areas. Irawan et al. (2021) conducted a study on the comparison of mean and local subsidence measurements for coastal flood projections in 2050 in Semarang, Indonesia. This research used the data on sea level, tides, and extreme water levels in Semarang with raster-based modeling (LISFLOOD-FP). This research showed that the research area in 2050 indicated the highest flood volume with an increase of 1,483,251 m$^3$ and the flood area increased to 1.5 km$^2$ (6.8%). Husnayaen et al. (2018) conducted an assessment of coastal vulnerability under increased land subsidence in Semarang, Indonesia. This research used multisensor satellite data (including Advanced Land Observing Satellite (ALOS), Phased Array type L-band SAR (PALSAR), Landsat TM, IKONOS, and TOPEX/Poseidon) to assess coastal vulnerability under increased subsidence using the CVI method. (Coastal Vulnerability Index).

This research showed that land subsidence has a significant effect on coastal vulnerability in Semarang where very high vulnerability increases by 7% with the addition of land subsidence, and very high vulnerability areas are determined at 20% of the total coastline or 9.7 km from a total of 48, 7 km coastline. Jia et al. (2021) conducted a study on the dynamic variation of the deep groundwater table and the spatiotemporal evolutionary characteristics of subsidence in Dezhou city which were systematically analyzed based on a large amount of monitoring data on groundwater level and subsidence. This research was conducted based on the stratigraphic structure as well as physical and mechanical parameters in the Dezhou area. This study showed that the soil is always homogeneous and each aquifer is a hydrogeological unit the pores of which are interconnected, where the soil shows different settlement characteristics when pumping groundwater from different aquifer pressures. Malik and Abdalla (2016), conducted a study on sea level rise in coastal areas in Richmond, British Columbia, Canada. This study used a digital elevation model (DEM) which was processed in ArcGIS and analyzed using GIS and geospatial analysis tools. This study showed that the worst-case scenario estimate of a sea level rise of 4 m or 46 percent of the total surface area will be affected. Hinderer et al. (2020), conducted the research on land subsidence and water depletion in Iran. This research used gravity data, GNSS, InSAR and precise leveling data. It showed that the average annual water depletion is 1 cm while the land subsidence is approaching 4 cm/year with an increase in gravity of 13 μGal/year which results in a gravity/height ratio of 3.2 μGal/cm.

Suroso and Firman (2017) conducted a study on flood inundation prediction, but they did not use the Farthest Rob Flood Inundation Boundary Method as this research was conducted. With the determination of the limit of the farthest tidal flood inundation, it is possible to obtain information for research with face-to-face questions and answers between interviewers and informants, or without using interview guidelines (Boyce and Neale., 2006). In addition, in the research conducted by Marfai et al. (2015), the variable rate of land subsidence and sea level rise were not used. In the study of Sauda et al. (2019) the sea level rise variable was not used either. If these variables are not used, the accuracy of the modeling results will be less significant.

In order to overcome the shortcomings of previous research, this study aimed to examine the area of tidal inundation and its impact on land use using geospatial modeling in 2020 and its predictions until 2035. This research used the variables of sea level rise, land level elevation, and rate of subsidence land. The benefits of this research are expected to contribute to the development of methods for tidal flood studies. The results of this study are also expected to be a source of data and information regarding tidal flooding and its impact on use for researchers, environmentalists and local governments to support mitigation and management of tidal floods in Pekalongan Regency.

## METHOD

### Study area

Pekalongan Regency is one of the regencies in the north of Java Island which is located at 6° to 7°23’ south latitude and 109° to 109°78’ east longitude (Figure 1). Pekalongan Regency has an area of 836.15 km$^2$ with a population of 886,197 people and a population density of 1,060 people/km$^2$.

### Tide data

Geospatial Information Agency measurement data in the form of tides in November 2020 at Pekalongan station. According to Mousavian et al. (2012), the analysis of the data used for tides should involve harmonic analysis with the least squares method (Least Square), where tidal analysis is to decompose tidal waves into harmonic components and the water level is caused by waves. Tidal wave

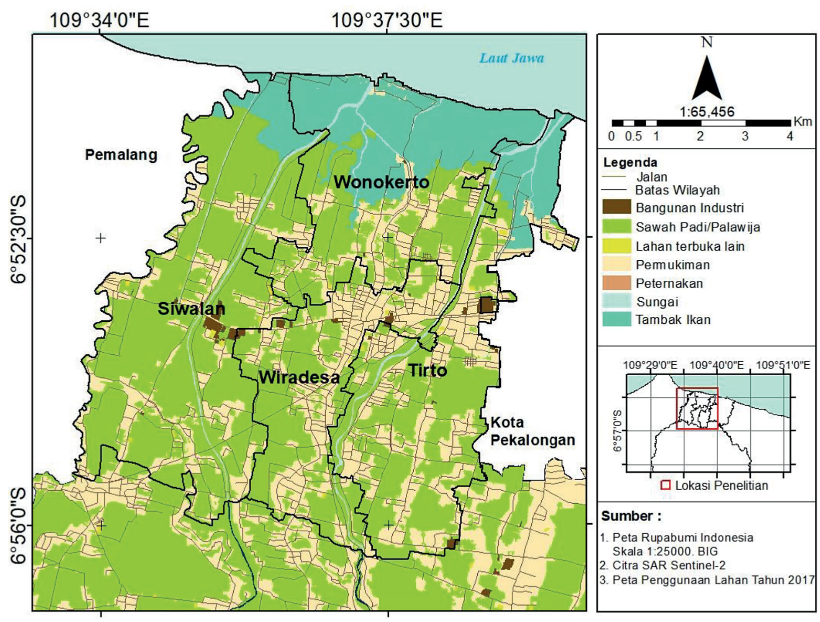


**Figure 1.** Research location

is the sum of the components of the tidal generating force. The Least Square method used consists of ERGTIDE, ERGRAM, ERGELV.

### Sea level rise

Processing of sea level rise was performed using the ROMS method. IndoSLR-V1.2 is a script to download and correct the sea level value of the RCP4.5 projection. The processing data was downloaded from InaROMS (tides.big.go.id) and CMEMS (https://marine.copernicus.eu/). This script will intercept the RCP45 InaROMS projection data and correct it with satellite observation data.After the sea level rise value is obtained, it will be calculated using linear trend analysis conducted by means of the Microsoft Excel 2013 software. Linear trend analysis is used to obtain the sea level rise rate.

### Land subsidence mapping

The data used are the images taken on 17th February 2017 and 7th July 2020. SAR images that will be processed interferometrically, especially from satellites are often referred to as complex images or SLC (Single Look Complex), in which each pixel is composed of amplitude information ($a$) and phase ($\phi$). Furthermore, Interferometry SAR Processing is performed to form a pair of interferogram images. This process is directly related to the topography of the study area, but there are still elements of noise, deformation and atmosphere. Then, there is the Differential Interferometry SAR (DInSAR) Processing process. DinSAR can be used to determine regular land subsidence in a short time and the data has high spatial resolution.

### Digital terrain model

The Sentinel-1 DSM data that was processed using the InSAR (Interferometric Synthetic Aperture Radar) method will be validated with the 2019 field survey DTM high point by extracting it using extract values to point and then interpolating with the Topo to Raster method. Interpolation process was carried out with Inverse Distance Weighting (IDW) algorithm.

### Geospatial model of flood inundation rob

Geospatial mapping uses the difference between HHWL and MSL numbers and then Reclassifies with ground elevation data. Tidal flood inundation mapping was used to determine the extent of tidal inundation. Prediction of tidal flood inundation was performed with the assumption that land subsidence and sea level rise occur linearly. The prediction of tidal flooding was done by using the reconstruction DTM which is added with the SLR according to the specified year. Validation was carried out using the results of geospatial modeling in 2020 with the farthest tidal flood from mapping in the field.

## RESULTS AND DISCUSSION

Tidal components in November 2020 are shown in Table 1. The analysis of tidal component data was conducted using the Least square method, which produced a Formzahl value of 0.82.

It indicated the type of tide in the study area is mixed, skewed to double daily, where there are two high tides and two low tides with different periods. This tidal type shows the potential for tidal flood events in a day is twice.

The sea level elevation in Table 2, consists of HHWL, MSL and LLWL of the results of tidal data calculations obtained using the least square

**Table 1.** Tidal components

| Constituent | Amplitude (cm) | Phase difference (°) |
|---|---|---|
| $M_2$ | 12.56 | -63.21 |
| $S_2$ | 8.71 | -53.67 |
| $N_2$ | 5.66 | 247.65 |
| $K_2$ | 3.62 | -23.09 |
| $K_1$ | 13.8 | 193.65 |
| $O_1$ | 3.9 | 53.61 |
| $P_1$ | 4.94 | 21.02 |
| $M_4$ | 0.67 | 223.1 |
| $MS_4$ | 1.01 | 249.8 |
| $S_O$ | 161.24 | 180 |

**Table 2.** Sea level elevation

| Sea level elevation type | Elevation (cm) | Frequency |
|---|---|---|
| Highest water spring (HWS) | 42.11 | 1 |
| Mean high water spring (MHWS) | 39.91 | 2 |
| Mean high water level (MHWL) | 16.55 | 55 |
| Mean sea level (MSL) | 0 | 720 |
| Mean low water level (MLWL) | -16.55 | 55 |
| Mean low water spring (MLWS) | -34.52 | 2 |
| Lowest water spring (LWS) | 35.21 | 1 |

method. It shows the value of HHWL as the highest value of sea level elevation during tidal flooding, which is 0.42 meters above the average sea level. This sea level elevation value can cause a large tidal inundation area, because the study area has a low topographic elevation of 0 to 7.22 meters above the average sea level. The results of the trend of sea level rise are shown in Figure 2.

The rate of sea level rise in 1993–2018 reached 3.8 mm every year, as illustrated by Figure 2. Prediction of inundation height in 2025 obtained through the difference between HHWL and MSL plus MSL is 0.44 m. Sea level rise every year can threaten densely populated coastal areas, because they have a great potential for tidal flooding. The results of processing using the DinSAR method enabled to obtain land subsidence which is shown in Figure 3. It was found that the land subsidence in Pekalongan Regency were varies. The average land subsidence in the study area reached 20.58 cm to 23.49 cm. Wonokerto sub-district is the sub-district with the highest land subsidence in Pekalongan Regency at 23.49 cm/year. Land subsidence that continues to occur causes the area to be lower than the average sea level. On the basis of these results, it can be seen that the land subsidence increases as it approaches the sea.

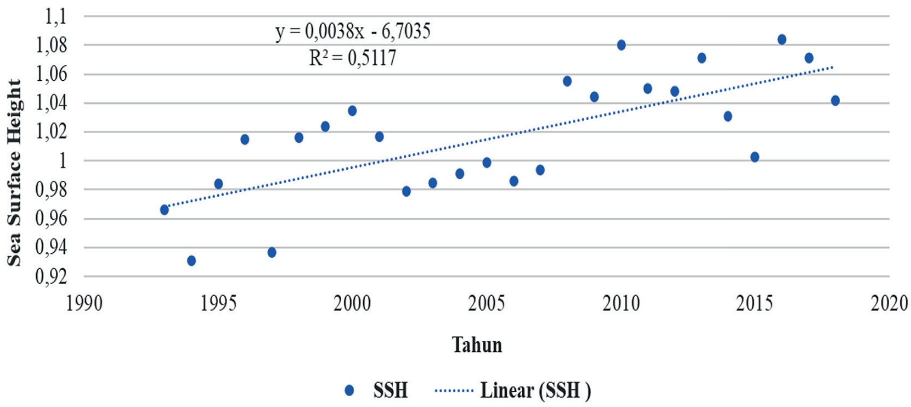


**Figure 2.** Graphic of sea level anomaly

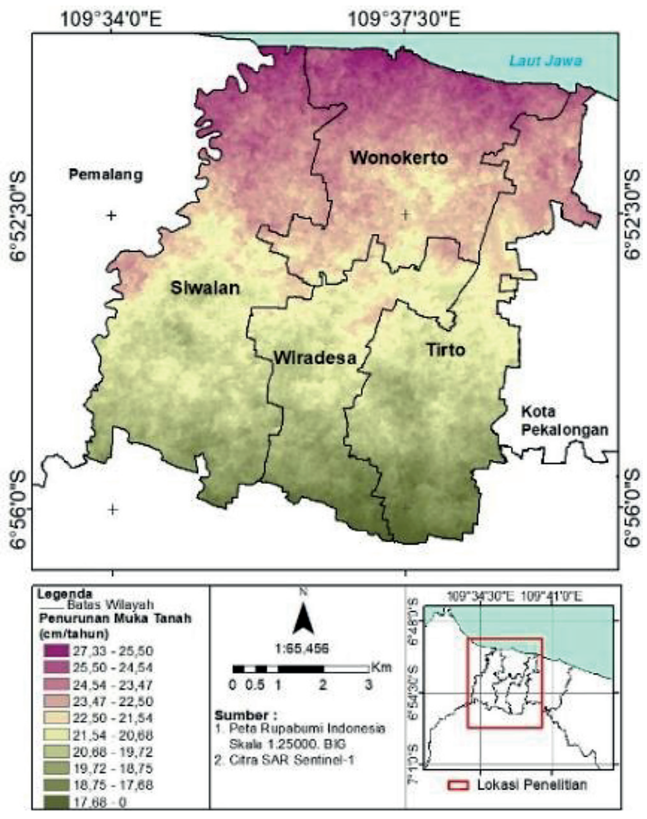


**Figure 3.** Land subsidence year 2017–2020

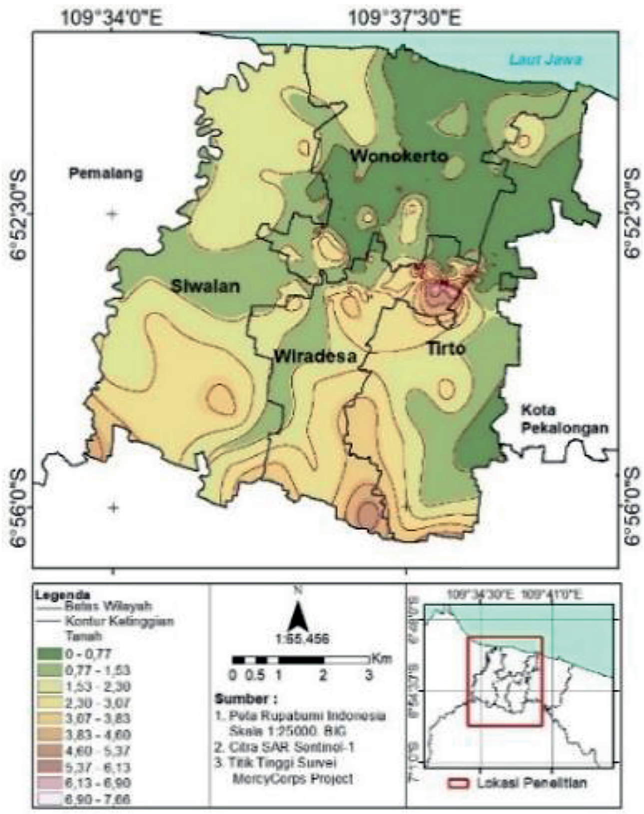


**Figure 4.** Ground elevation map generates by DEM process

The results of the ground level elevation in Figure 4 show that the elevation on the coast of Pekalongan Regency is 0.0–7.66 meters. The land level in Pekalongan Regency is included in the low category. The low ground elevation can be caused by the continuous subsidence of the land surface. This causes tidal flooding to inundate coastal areas with low ground elevations. The coordinates of the tidal flood location in 2020 are shown in Table 3.

The modeling of tidal flood inundation in 2020 resulted in the map shown in Figure 5. On the basis of spatial modeling of tidal inundation in November 2020, the area that should have experienced tidal flooding was 783.99 hectares where Wonokerto District was the area with the largest

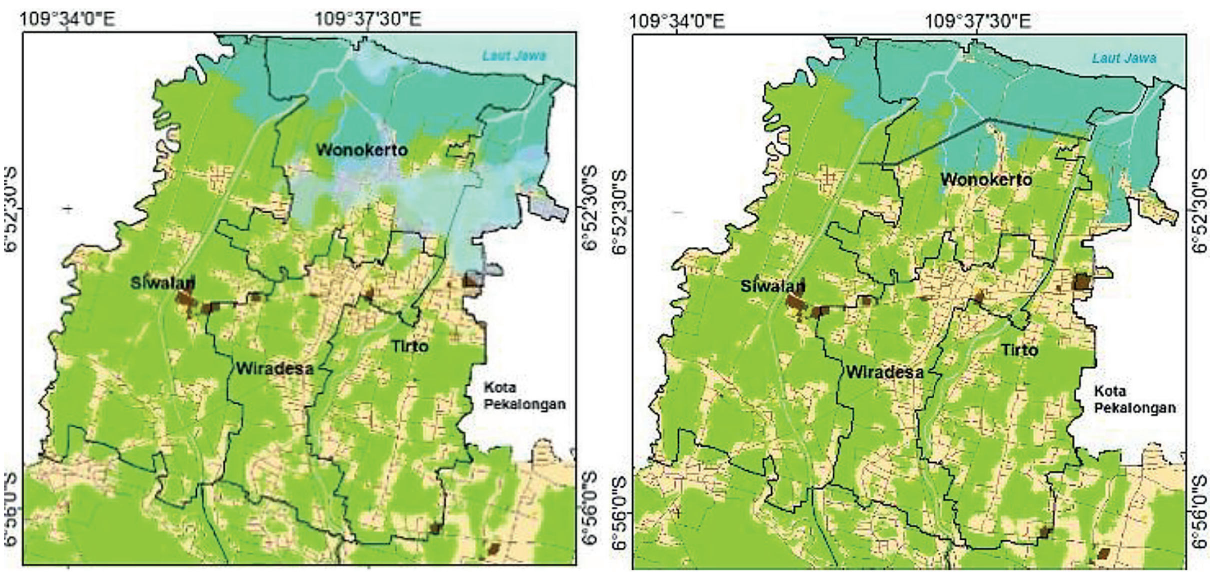


**Figure 5.** Map of tidal flood inundation in 2020 without embankment (left), with embankment (right)

**Table 3.** Coordinates of the rob flood survey

| No. | Latitude | Longitude | Kelurahan | Guna Lahan |
|---|---|---|---|---|
| 1 | -6.846514° | 109.632919° | Wonokerto Kulon | Rice fields/ Palawija |
| 2 | -6.849127° | 109.625527° | Wonokerto Kulon | Rice fields/ Palawija |
| 3 | -6.844735° | 109.623183° | Wonokerto Kulon | Rice fields/ Palawija |
| 4 | -6.842625° | 109.619308° | Semut | Rice fields/ Palawija |
| 5 | -6.843707° | 109.621192° | Semut | Rice fields/ Palawija |
| 6 | -6.843552° | 109.626015° | Wonokerto Kulon | Rice fields/ Palawija |
| 7 | -6.867393° | 109.643505° | Pecakaran | Settlement |
| 8 | -6.874252° | 109.622443° | Bebel | Settlement |
| 9 | -6.866480° | 109.638028° | Pecakaran | Settlement |
| 10 | -6.886358° | 109.640829° | Karangjompo | Settlement |
| 11 | -6.878081° | 109.6646991° | Tegaldowo | Settlement |
| 12 | -6.886213° | 109.647262° | Karangjompo | Settlement |

inundation of 439.23 hectares and Siwalan District was the least inundated area of 7.26 hectares. However, with the embankment, the area of the tidal flood inundation is greatly reduced, where the tidal flood only inundated 1.68 hectares in two sub-districts, namely Tirto District covering 1.54 hectares and Wiradesa District covering 0.13 hectares. The difference between the inundation model and the farthest tidal survey can be caused by the construction of the embankment that is already underway. The existence of the embankment reduces the tidal flood inundation significantly.

The modeling of tidal flood inundation in 2025–2030 resulted in the map shown in Figure 5 exhibited that every year the tidal flood prediction increases, the worst tidal flood inundation in the area without the embankment will occur in 2035, which is 7578.94 hectares. In 2035, tidal floods will almost inundate the entire coast of the district. Widespread inundation is caused by land subsidence that continues to occur every year. The modeling of tidal flood inundation in 2035 with and without embankments resulted in the map shown in Figure 6(e–f). In the final prediction year, 2035, the flood inundation will be reduced due to the embankment covering an area of 1686.62 hectares. The year 2035 is the year the tidal flood inundation will begin to inundate coastal areas again. This is because the inundation has exceeded the planned dike which is 3 meters high.

Table 4 showed that the area that is inundated by tidal flooding without any embankments each year. It can be seen that every year the inundation

**Table 4.** The total area inundated by the tidal flood in 2020–2035 without any embankments

| Districs | Affected land | Area (ha) | | Total (ha) | |
|---|---|---|---|---|---|
| | | 2020 | 2035 | 2020 | 2035 |
| Siwalan | Industrial buildings | | | | |
| | Other open land | | | | |
| | Rice fields / Palawija | | 23.99 | 0 | 33.09 |
| | Settlement | | 9.10 | | |
| | Fish pond | | | | |
| Tirto | Industrial buildings | | 2.42 | | |
| | Other open land | | 2.90 | | |
| | Rice fields / Palawija | 0.34 | 114.75 | 1.55 | 423.69 |
| | Settlement | 1.21 | 130.47 | | |
| | Fish pond | | 173.14 | | |
| Wiradesa | Industrial buildings | | 8.11 | | |
| | Other open land | | 0.50 | | |
| | Rice fields / Palawija | 0.01 | 30.60 | 0.13 | 63.88 |
| | Settlement | 0.12 | 24.67 | | |
| | Fish pond | | | | |
| Wonokerto | Industrial buildings | | 0.46 | | |
| | Other open land | | 1.84 | | |
| | Rice fields / Palawija | | 380.52 | | |
| | Settlement | | 211.57 | | |
| | Fish pond | | 571.58 | | |
| Total area of affected land (ha) | | | | 1.68 | 1686.62 |

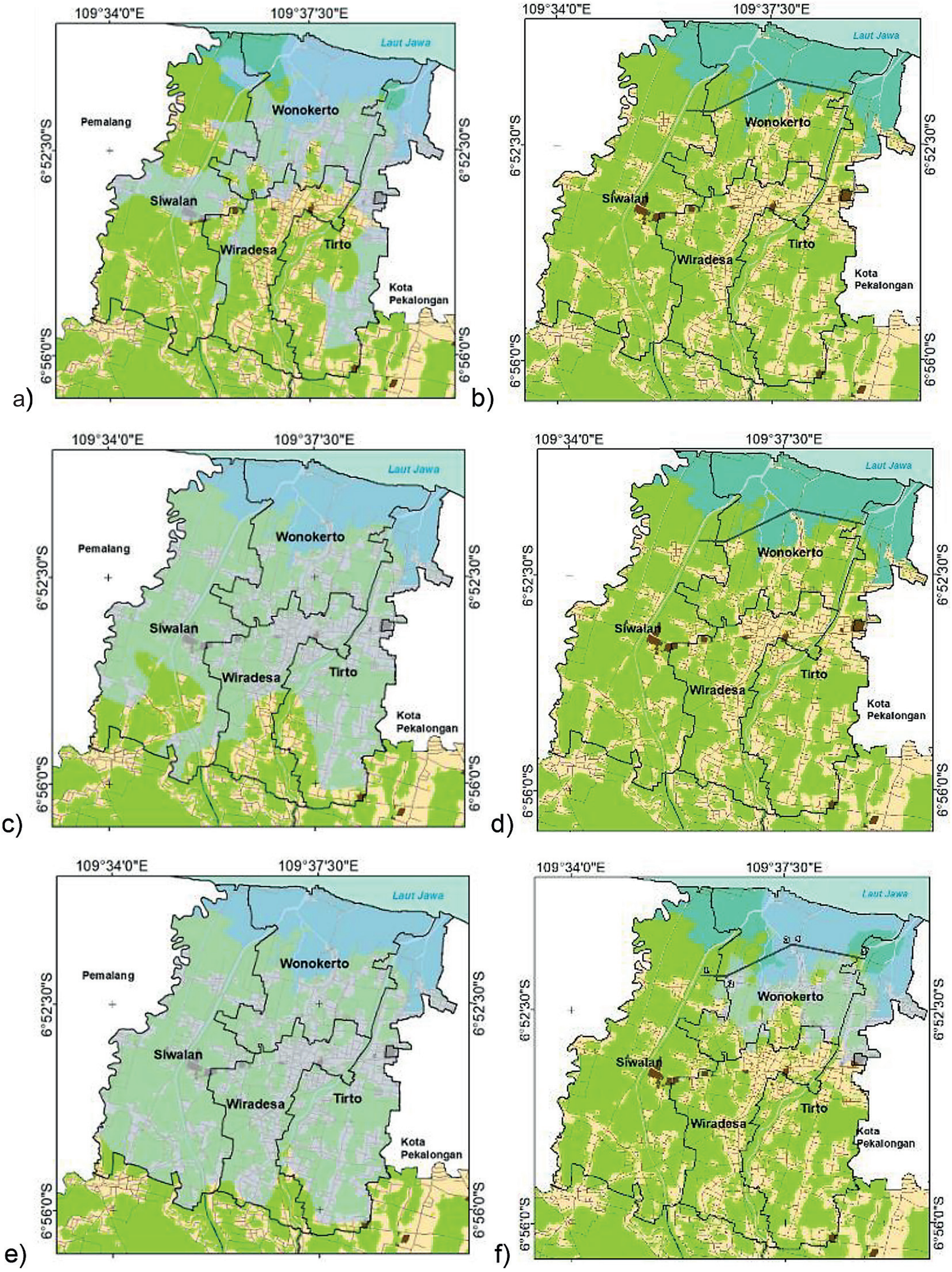


**Figure 6.** Prediction map of tidal flood inundation in 2025 without embankments (a), with embankment (b); Prediction map of tidal flood inundation in 2030 without embankments (c), with embankment (d); Prediction map of tidal flood inundation in 2035 without embankments (e), with embankments (f)

area increases and it can be seen in Figure 6 (a, c, e) that almost the coast of Pekalongan Regency is inundated by tidal flooding. Paddy / Palawija rice fields became the land that was inundated by the widest tidal flood. This is due to the location of rice fields / secondary crops in the coastal area.

It can be seen also from Table 4, that the existence of a 3 meter high planned embankment can reduce the inundation area, where inundation is only found in the survey area of 1.68 ha while in 2025 to 2030 the tidal flood will not reached the embankment so no inundation will occurred. In 2035, tidal flooding will inundate an area of 1686.62 ha. The planned embankment will be able to withstand tidal flooding for 10 years until 2035.

The results of BIG tidal data processing in November 2020 are mixed skewed to double daily. The mixed tidal type tends to double daily, where in one day there are two high tides and two low tides but with different periods. The tidal type is only used to determine the tidal type in the research area. This study has a drawback where the least square calculation only uses a time span of one month. The results obtained are the same as in the research conducted by Iskandar et al. (2020) where the mixed tidal type tends to be double daily. This type of tide can cause two high tides and two low tides for 24 hours with different periods.

The sea level rise according to BIG and Copernicus tidal data processing is 3.8 mm/year, so the sea level rise reaches 1.9 cm. There are several shortcomings in this study, where data processing only has a time span of 1993–2018, and the latest data has not been entered. According to Oppeheimer et al. (2019), sea level rise reached 3.58 mm/year in the 2006–2015 period. Knowing that sea level rise is one of the causes of tidal flooding and knowing that every year the rate of sea level rise increases, so that it can cause various kinds of coastal disasters. According to Handiani et al. (2019) there is an increase in global sea level as an effect of climate change. The sea level rise due to climate change is one of the causes of coastal disasters, one of which is tidal flooding. Sea level rise can threaten densely populated coastal areas, as well as lowlands (Khan et al., 2000; Qin and Lu, 2014). On the basis of the sea level rise data that has been obtained, the difference between HHWL and MSL for inundation heights in 2025, 2030, and 2035 is 44.01 cm, 45.91 cm, and 47.81 cm, respectively.

Wonokerto sub-district is the sub-district with the highest land subsidence, which is 23.49 cm/year. This sub-district is dominated by paddy/palawija rice fields which are located on the coast. Most of the coastal sub-districts, namely Siwalan, Tirto and Wiradesa sub-districts, experienced land subsidence of 21.63 cm/year, 20.58 cm/year, and 20.27 cm/year, respectively. Land subsidence in this study has a drawback, namely the absence of data validation. According to Marfai et al. (2008) and Takagi et al. (2016) tidal flooding will be more widespread if sea level rise and land subsidence continue to occur.

Processing of high point data from the Sentinel-1 SAR images that have been validated with the 2019 topographical survey DTM. The interpolation process obtains Pekalongan Regency Coastal DTM with an altitude range of -0.92 m to 7.66 m. In a study conducted by Fariz and Nur (2017), it was stated that the area that was flooded in 2017 was Pekalongan Regency consisting of four sub-districts, namely Tirto District, Siwalan District, Wonokerto District and Wiradesa District, which has a height between 0 m to 22 m. The difference in research results is due to the difference in coherence values in the Sentinel-1 SAR image pair in the C-band wave, which cannot reflect waves perfectly in dense vegetation areas and watery areas. There is a difference in the lowest elevation in settlements because, there is no change and causes the C-band wave to block so that the coherence value is greater (Sunu et al., 2019). The processing of high points in this study is based on the 2019 topographic DTM survey where there are shortcomings, namely that it is not carried out thoroughly in Pekalongan Regency. Point data processing is used as the basis for the DTM reconstruction for the predicted year along with subsidence data.

On the basis of spatial modeling of tidal inundation in November 2020, the area that should have experienced tidal flooding was 783.99 ha, where Wonokerto District was the area with the largest inundation of 439.23 ha and Siwalan District was the least inundated area of 7.26 ha. However, with the planned 3 m high dike, the area of the tidal flood inundation is greatly reduced, where the tidal flood only inundated 1.68 ha in two sub-districts, namely Tirto District covering 1.55 ha and Wiradesa District covering 0.13 ha. The occurrence of tidal inundation is due to the lower topography compared to the highest tide that occurs every month. Tides occur due to differences in the gravitational force where there is a change in position between the moon and the sun which is relatively at one point on the Earth's surface. According to the research, tidal flooding has an impact on society, the economy and the natural environment (Fang et al., 2020). According to the research by Fang et al. (2020) and Hsiao et al. (2021) tidal floods have a negative impact on the environment, including increased damage to buildings near the coast and disruption of population activities in residential, aquaculture and industrial areas. This study has not many coordinate points, so that the validation is not comprehensive to one district. This modeling was carried out in 2020 so that it can be used as a benchmark for the prediction year.

On the basis of geospatial modeling carried out for tidal flood prediction in Pekalongan Regency, there was a change in area in 2020 from 783.99 ha to 3388.98 ha in 2025. Meanwhile, the presence of embankments caused tidal flooding to decrease to 1.68 ha in 2020. The percentage of embankment effectiveness in 2020 will reach 99.79%. The prediction of tidal flood inundation in 2030 is 6523.19 ha with no embankments. The year 2035 is the last year of prediction of tidal inundation in this study with an area of 7578.94 ha of tidal inundation without the embankment and 1686.62 ha with the embankment. In 2035, the paddy field/palawija area will be the area that is the most inundated, reaching 52.06%, because most of the coastal areas are agricultural areas. The effectiveness of the embankment in 2035 is 77.75%. According to Marfai et al. (2013) the most extensive inundated areas in land use are settlements with an inundation area of up to 55.50% and irrigated rice fields with an inundated area of about 32.81%. The difference in flooded land is caused by the land changes that occur on the coast of Pekalongan Regency. This study has a drawback where the embankment used is a 3 meter high planed embankment so that it is not in accordance with the conditions in the field. This modeling prediction is certainly used as a reference to anticipate the occurrence of tidal flood inundation that will occur in the prediction year.

## CONCLUSIONS

This study aimed to examine the area of tidal inundation on land use based on inundation height, rate of sea level rise, land level elevation and land subsidence. The results of this study indicate that the inundation area increases every year. Tidal flooding occurs when the highest tide reaches 42.11 cm. There is an increase in sea level rise of 3.8 mm/year and a land subsidence of 15.63 cm/year to 27.33 cm/year. Thus, the increase in tidal flood inundation in 2020 reaches 783.99 ha and predictions of tidal flood inundation without embankments in 2025, 2030, and 2035 are 3388.98 ha, 6523.19 ha and 7578.19 ha, respectively. Meanwhile, the prediction of tidal flood inundation with the embankment in 2035 is 1686.62 ha. In future research, it is recommended to use field data validation to determine the rate of land subsidence with the data from a Geodetic GPS receiver linked to a Continuous Operating Receiver (CORS) to obtain the land subsidence data to millimeter (mm) accuracy and the actual embankment height data to increase the accuracy of the resulting model. The increase in SLR in Pekalongan waters will reach 3.8 mm/year for 2025, whereas sea level rise will reach 1.9 cm/year. The existing land surface elevation in the study area is between 0.0–7.66 m above MSL, where the ground elevation in Pekalongan Regency is relatively low. The existence of land subsidence that occurs every year results in a pattern of the distribution of flood inundation and changes in ground level. The increasing rate of sea level rise and land subsidence will cause an increase in tidal flooding in 2030.

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