Mitigation of floodwaters inundation due to land subsidence in the coastal area of Semarang City

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Abstract. Semarang city is the capital of Central Java province, which is located on the coast. The Semarang coastal topography is flat, with slope percentage around 0-2%. Most area is almost the same as height as the sea level and in some places are lower. Environmental problems faced by Semarang related to this topography area tidal inundation, land subsidence and flooding during rainy season. The research was conducted to model locations that area vulnerable to tide inundation. The data of spot height, contour line and the rate of subsidence were analyzed by using Geographic Information System (GIS). The results showed that the Semarang coastal had a high level of vulnerability to inundated area. Tidal flood inundation area was about 2,400 ha with depths varying from 1 to 66 cm. Mitigation of tide inundation impact must be adjusted to land use and social condition of the local community. The house on stilts or lightweight houses that are easy to dismantle pairs is one of the solutions that is suitable for fisherman residential areas. Whereas the trade and service areas must be carried out by raising of the building floor and making protective buildings from sea water.

1. Introduction
Semarang City which is the capital of Central Java Province has developed very rapidly. This makes almost all of its coastal land area has been used as industrial areas, housing, shops, education centers and other sectors. As a coastal area composed by quartz deposition, it triggers a subsidence [1,2] which results in changes the coastline and widespread inundation of tidal floods [3]. This has caused many problems, such as damage to various infrastructures, loss of land and ponds on the beach, disruption of community activities and the emergence of disease vectors.

Research on tidal flood inundation in Semarang City has been widely carried out. The expansion of tidal flood inundation areas in Semarang City due to land subsidence is a serious threat to the environment [4]. Land subsidence significantly affects the increase in the area of tidal flood inundation. The relatively high subsidence rate causes the area of tidal inundation to increase from 2162.5 Ha (5.6%) to 2,834.7 Ha (7.4%) in 2016 and will increase to 3,896.3 Ha (10.1%) in 2021 to come [4]. The effect of land subsidence on the increase in flood and tidal inundation areas in the...
Tenggang and Sringin watersheds during the 2014-2031 period was 23.6% or 1.39% per year, [5]. The area of tidal flooded waters correlates very strongly with the rate of land subsidence and threatens future disasters. On the other hand, mitigation and/or adaptation are still not planned, the handling is still sporadic and individual [6].

At present monitoring and prediction of tidal inundation areas can be done quickly and cheaply using satellite imagery and tidal forecasts as well as land subsidence data which can also be predicted using image analysis. Efforts to deal with tidal flood disasters that have been made can be seen the level of success and used as a basis for further mitigation planning. This research was conducted to determine the inundation area of 2109 and evaluate the mitigation that had been carried out by the community, business people and the government.

2. Methods

Secondary data used in this study includes 2019 Google Earth imagery data, high point data, 1:25,000 scale topographic maps, tidal data and subsidence trend data. Google Earth imagery in 2019 is used to identify the land use of the research location. The elevation point was obtained from BIG Demnas data and the tidal data was obtained from the BIG Tidal Data in 2019. While the subsidence trend is assumed to be linear based on the results of the previous study [1,2]. The highest tide data is used as a basis for calculating the area affected by tidal flood inundation. Determination of the distribution of areas affected by tidal inundation is done using the formula:

$$\text{DEMt} = \text{DEM} - ((\text{Pt} - \text{MSL}) + \text{S})$$

Where:

- \(\text{DEMt}\) : DEM inundated areas
- \(\text{DEM}\) : DEM high point
- \(\text{Pt}\) : Highest tide
- \(\text{MSL}\) : Mean Sea Level
- \(\text{S}\) : Value of subsidence

In this model it is assumed that the sea level is fixed and the factors affecting the area and inundation distribution are only subsidence factors. Ground checks are carried out by tracing the area affected by tidal floods to ensure the correctness of the tidal flood distribution map based on the model and inventorying the types of mitigation that have been carried out to overcome the impact of tidal floods.

3. Result and Discussion

Based on the 2018’s tidal data processing, the Mean Sea Level (MSL) value was 155.24 cm and the Highest High Water Level (HHWL) was 215.16 cm. Land subsidence in the coastal area of Semarang City ranges from 0 - 11.2 cm/year with the distribution as listed in Figure 1. The topographical conditions of the Semarang coast are very flat with a slope of 0-2%, most of the area is almost as high as sea level even at several places under it [3]. Based on field observations, locations that appear concave are lower than the surrounding area, so that they are always flooded (Figure 2). This adds to the area of tidal flooded areas.

Figure 1. Map of Semarang land subsidence based on GPS measurement methods [1].
Based on the results of the analysis, it is known that the area of tidal flood inundation is spread almost in all coastal areas of Semarang City as shown in Figure 3. Based on these images it can be seen that the most extensive area of tidal floods is Tugu District due to the number of ponds that have sunk. The extent of the tidal flood inundation area for each sub-district and the depth of the puddle is listed in Table 1. The depth of the tidal flood inundation at the highest tide also varies to a maximum of 66 cm.
Table 1. Wide area of tidal flood inundation in the coastal area of Semarang City

| Depth (cm) | Tugu   | Semarang Barat | Semarang Utara | Semarang Timur | Gayamsari | Genuk   | Total area in each depth (ha) |
|-----------|--------|----------------|----------------|---------------|-----------|--------|-----------------------------|
| 40-66     | 1,030.61 | 110.89         | 50.24          | 1.48          | 2.23      | 212.96 | 1,408.41                    |
| 20-40     | 230.14  | 70.76          | 29.06          | 0.29          | 3.06      | 132.68 | 465.99                      |
| 0-20      | 245.24  | 163.61         | 34.26          | 4.15          | 37.95     | 40.57  | 525.78                      |
| Total area in each district (ha) | 1,505.99 | 345.27         | 113.56         | 5.92          | 43.24     | 386.21 | 2,400.18                    |

The tidal flood has resulted in many houses and buildings being flooded during high tides. Land subsidence and efforts to elevate the road / floor of the building make some houses that have not been elevated are in a condition that the floor is below the ground level, so that it is flooded (Figure 4). The impact of this tidal flood is often exacerbated during heavy rains, the flow of water from upstream in the river is blocked by sea water so that it inundates the area around the river [5,8]. Because land subsidence is still ongoing and there is a tendency to increase sea level elevation [9], efforts to raise the floor of a house / building / infrastructure will always be repeated. For those who cannot afford it, they must be willing to live in a very low house (Figure 5) which of course is not a healthy home.

Figure 4. Examples of houses those are below ground level so that the floodwaters are flooded and abandoned by residents.

Figure 5. Examples of low houses even sink because the floor is raised, while the roof is not
In the industrial area, the elevation of the building floor seems to be the main choice so that its activities are not affected by tidal flooding (Figure 6.a). Seawalls and pump houses in the Terboyo Industrial Estate have shown quite encouraging results (Figure 6.b) so that the area is not flooded by tidal floods. The polder and pumping house in Tawang and Tanah Mas, also looks very helpful in reducing tidal flooding, so that the surrounding area is currently free from tidal flooding. Monitoring of tidal flood conditions must be carried out because the land subsidence is still ongoing [2,10]. Besides that groundwater pumping must also be reduced because it has an impact on the increasing rate of subsidence [11]. For residential areas near the pond or even in the former pond area adjacent to the beach, the rate of land subsidence is large enough so that the elevation of the floor of a house building is in line with the land subsidence itself, and this is not effective as a mitigation. Actually, stilt houses are an adaptive choice for land subsidence and tidal flooding, but are socially difficult to accept. Lightweight houses such as bamboo (Figure 7) that can be assembled are other alternatives that can be taken. If the floor surface of the building has been lower than the elevation of the water during a flood, the increase in the floor of the building floor can easily be followed by replacing the house on a new floor at a much lower cost than demolition of a brick walled house.

![Figure 6. a. Raising the ground floor of industrial buildings in an effort to avoid inundation of tidal floods b. river normalization and pump installation to avoid flooding](image)

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![Figure 7. Lightweight houses that can be assembled, alternative building houses in areas near the coast where the rate of land subsidence is large](image)

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4. Conclusion

The area of tidal flood in Semarang City reaches 2,400 ha with a depth of inundation ranging from 1 to 66 cm. The morphology of the sloping coastal area of Semarang City with elevation approaching MSL and the many basins make sea water easy to flow inland and inundate residential, industrial and submerged ponds near the coast. Elevation of the ground floor of the building, construction of seawalls and pump houses is an effort to prevent flooding in the industrial area. Considering the elevation of the building floor requires a large cost, the construction of houses on stilts or lightweight houses that can be dismantled is an alternative to flood mitigation for houses in areas near ponds that have a higher land subsidence rate than other regions.

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