Analysis of Distribution and Impact of Inundation on Land Use in Surabaya City

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Abstract
Coastal area is lowland which is same height as the height of sea tide (and means sea level). The method used in this study uses a remote sensing method with Digital Elevation Model (DEM) data. The final results of study are expected to provide information on the distribution of flood inundation in Surabaya to manage coastal and marine areas in context of developing Coastal areas, and can be used as an effort to mitigate the City Government against flood inundation which increases sea water utilization that occurs in coastal areas of Surabaya. The largest area that holds inundation or tidal floods is Sukolilo District with an area of 15,266 Km^2 and Benowo District with an area of 9,017 Km^2. The largest land cover area affected by flood inundation or tidal flood, namely housing class with area of 13,418 Km^2, followed by pond class with area of 11,056 Km^2.

1. Introduction

1.1 Background

Coastal zone is the narrow transition areas which connect terrestrial and marine environments (Crossland et al., 2005) and it is a place where rivers run out so that this area is vulnerable to sea-level rise (Imaduddina and Widodo, 2017). Sea level rise is originally a series of tidal processes, it is expected to aggravate coastal erosion, extreme marine flooding, or saltwater intrusion in coastal aquifers (Nicholls and Tol, 2006, Nicholls et al., 2007, Nicholls and Cazenave, 2010 and Cazenaane and Cozanet, 2014). The height of sea water that exceeds the topography on land causes the rising sea water to the plains, this event is known as the natural flood events due to tides or also known as tidal floods. Sea level rise is one form of short-term and periodic sea level rise. The coastal region is also a very dynamic area both in terms of physical processes and human activities.

Surabaya City is one of the coastal cities in East Java Province that has low topographic characteristics so that the range of tidal floods about 3-6 meters above sea level Except on the south region, the elevation is up to 25 - 50 m above the sea level (Statistic of Surabaya Municipality, 2019). Based on Tanjung Perak Maritime BMKG estimates, each year the Surabaya Coastal Region experiences tidal flooding and in one year there is about 4 to 5 times the danger of flooding with a maximum height of 150-170 centimeters above the mean sea level (mean sea level). Some sub-districts in Surabaya classified as coastal districts are Gunung Anyar, Rungkut, Mulyorejo, Sukolilo, Bulak, Kenjeran, Cendahean Customs, Semampir, Krembangan, Asemrowo, and Benowo. These districts have the risk of being affected by floods due to sea level rise.

Tidal floodwater or better known as tidal flooding is an environmental problem as a result of physical processes that occur in coastal areas. The tidal flood can be said to be a flood that occurs due to rising sea levels and inundation of the land when the tides experience high tides. Tidal floods will occur due to rising sea levels to a certain extent, which is a critical limit that exceeds the height of land or the surface conditions of coastal areas (Marfai, 2003).

Sea level rise has an impact on the emergence of tidal flood disasters in the Surabaya City Coastal Region. The height of the tidal flood which increases every year has an impact on the increase in the extent of inundation caused and increased economic losses of people who work in vulnerable sectors (Prawira and Pamungkas, 2014). Tidal flood is a pool of sea water in the coastal mainland that occurs due to high tides, floods driven by tidal process in coastal area as it increase continuously in term of frequency and intensity (Ni'mah et al., 2013). The existence of ups and downs and tides will affect the inundation conditions that occur. The phenomenon of flooding due to tides, some experts / experts said that flooding due to tides (tides) has had a negative impact on coastal areas.

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The impact of flood inundation due to tides has changed the physical environment and put pressure on the people, buildings, and infrastructure in the area. Flood due to sea water tides will also have an impact on the destruction of environmental facilities and infrastructure (clean water, solid waste, drainage, sanitation) as well as environmental degradation marked by a decline in the quality of public health.

Remote sensing method with Digital Elevation Model (DEM) data can be a solution for researching the problem of identifying flood inundation in coastal and marine areas, because this method is more efficient and effective in large-scale research. The final results of the study are expected to provide information on the distribution of flood inundation in coastal waters of the city of Surabaya generated by rising sea levels and identify the impact of flood inundation on the environment around coastal and marine areas in order to optimize the results of research can be useful for the management of coastal and marine areas in the framework of developing sustainable and integrated coastal areas, and can be used as an effort to mitigate the city government against flood inundation due to the influence of rising sea levels that occur in the coastal waters of the city of Surabaya.

2. The Methods

2.1 Study Area

The location of this research is the coastal area of the city of Surabaya. Geographically, it lies at 112°36' -112°21' East Longitude and 7°12' - 7°21' South Latitude. The total area of Surabaya is 34,465 Ha, which consist of 31 districts with 163 sub-district. Historically, the low-lying city of Surabaya originated from the formation of sediments in the sea area. The coastal region stretches from western city border to the port of Tanjung Perak and eastern region of the Sidoarjo Regency border. The coastal area covers 9 districts and 17 sub-districts. Generally, coastline is located in the East and North and the western part of Surabaya. The study area is presented in the following Figure 1.

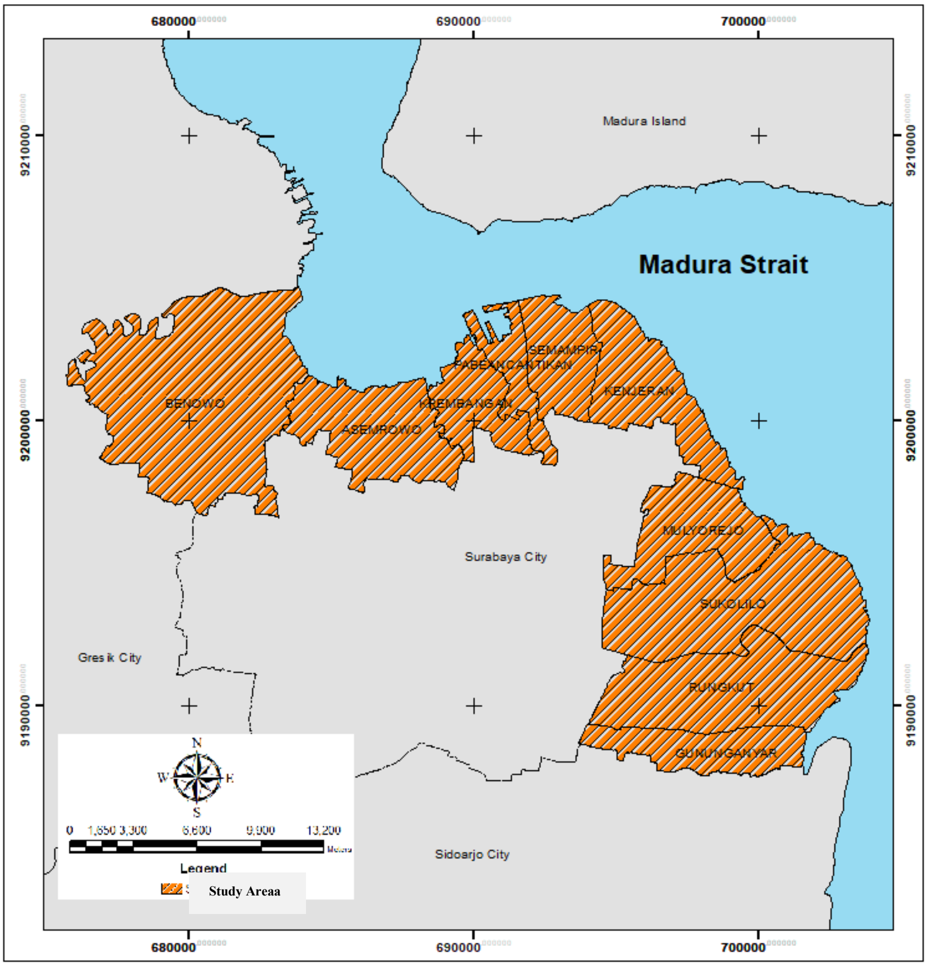

Figure 1: The study area

2.2 Data Acquisition

The data used in this study are Landsat-8 satellite image data path / row: 118/065 in 2017. Data in 201 was used to determine the physical condition of coastal area. Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) imagery year of 2018 as a reference data for ground level which has spatial resolution of 30 meters. Digital elevation model (DEM) is an important spatial input for automatic extraction of topographic parameters for the soil and water assessment tool (Buakhao and Kangang, 2016). Tidal high values used to make flood mode.

2.3 Data Processing

2.3.1 Slope

Making a flood tidal model requires ground level data which in this study was obtained from DEM data. According to Hajar et al., (2017), DEM is a model of the surface of the earth that is made to present the height of a digital area. The initial step is extraction of ground height values from DEM by making shapefile points at each pixel which will then be used as a medium to place ground level information on each pixel. This was done in order to get the land height value in accordance with what is needed in the study. The DEM value extraction process uses the Extract Multi Values Point tool. The height values will then be averaged based on the grid in Ms. software. Excel uses the Pivot Table menu. The final height value obtained from each grid will be used as a parameter for making a tidal flood model

2.3.2 Tides

Average tidal values that have been calculated will then be smoothed to get better tidal data results. That is also because the tidal data is still in the form of raw data so there is still a lot of noise that needs to be removed. Tidal data has been smoothed will then be processed for tidal harmonic analysis. Tidal harmonic analysis is a data processing process that aims to find the value of the amplitude of the tidal data and also to obtain the phase difference of the tidal harmonic constant (Khasanah et al., 2017). In this study the tidal harmonic analyst uses the Admiralty method. The analysis process using Admiralty method is calculated by using the table in the Ms software. Excel with several calculation schemes. This calculation phase will produce a tidal harmonic constant value. The harmonic constant value is then used to find Formzahl number as a value that will indicate the type of tides in the coastal waters of the City of Surabaya.

The formula used to calculate Formzahl numbers is:

$$F = \frac{AK1 + AO1}{AM2 + AS2}$$

Equation 1

Information:
F: Formzahl Numbers
AK1: Amplitude value of the harmonic constant K1
AO1: Amplitude value of the harmonic constant O1
AM2: Amplitude value of the harmonic constant M2
AS2: Amplitude value of the harmonic constant S2

Tidal types are classified based on Formzahl numbers as follows:

1. $F \leq 0.25$: Double daily (semi-diurnal) tides
2. $0.25 < F \leq 1.50$: Tidal mixture tends to double daily
3. $1.50 < F \leq 3.00$: Tidal mixture is biased toward a single daily
4. $F > 3.00$: Single daily tides (diurnal)

2.3.3 Map of flood inundation

The main objective of this research is to make a model of tidal flooding in coastal of Surabaya. The model will be used to identify which areas are affected by tidal floods. The method used to classify the tidal flood model is using the help of Geographic Information Systems (GIS). In this study, the scenario used to create a tidal flood model is the HHWL value. This HHWL value is used as a flood tidal scenario with the consideration that with the highest tide value ever occurring (HHWL) it can represent the impact of inundation at any high tide that has occurred on the coast of Surabaya. Another parameter used to construct the tidal flood model is the height of the land. Areas with land elevation below the highest tidal value each month, including areas that are flooded by tidal floods. The formula used to determine the inundated and high flood area according to Triana (2020), is as follows:

$$G = HHWL - T$$

Equation 2

Information:
G: high flood inundation
Q: Land height

Flood Inundation Map Data Classification: The difference between the HHWL and the height of the ground is the high value of tidal flood inundation.

The difference results are then classified to get high tidal flood distribution values. The classification stage starts with sorting flood inundation data which can then be calculated by the amount of data. The amount of data will be used as a value to determine the number of classifications based on high tidal flood inundation data. Determination of the number of classes for high tidal flood in this study using the Sturges formula, namely:

$$K = 1 + 3.33 \log N$$

Equation 3

Information:

K: number of classes to look for

N: amount of data

Class intervals are calculated using the formula which requires the number of classes, maximum and minimum values of data. Maximum and minimum values can be searched after the data is sorted. The formula from Kingma used to calculate class intervals is:

$$I = (T\text{-}R) / K$$

Equation 4

Information:

I : Class interval

T : Maximum Value

R : Minimum Value

K : Total Class

3. Result and Discussion

3.1 Tides

The results of tidal processing for 15 days on May 16 - 30 2019 produced sea level elevation values shown in Table 1. The value of Formzahl numbers on coastal of Surabaya is 0.67, which means the type of tides in the area is Tidal mixture tends to double daily, because according to the tidal type classification, the value of 0.25 <F <1.5 is the type of mixed tidal mixture to double daily. The sea level data that has been obtained has produced the highest sea level (HHWL) of 136 centimeters with an average height of 40.7 centimeters (Figure 2).

3.2 Inundation Distribution Analysis

Flood inundation is one of the problems that must be faced by Surabaya coastal community. Flood in sense here is an extension of the right and left side of the rivers that empties into the sea or close to the coast and it is often inundated at the time of high tides, while the definition of inundation is a low area where water enter it cannot flow elsewhere. Basically, flood inundation is a natural phenomenon that usually occurs during conditions of a full moon.

Table 1: Seawater surface elevation value of Surabaya city

Sea Level Elevation	Unit (centimeters)
Lower Low Water Level (LLWL)	0.4
Mean Sea Level (MSL)	40.7
Higher High Water Level (HHWL)	136

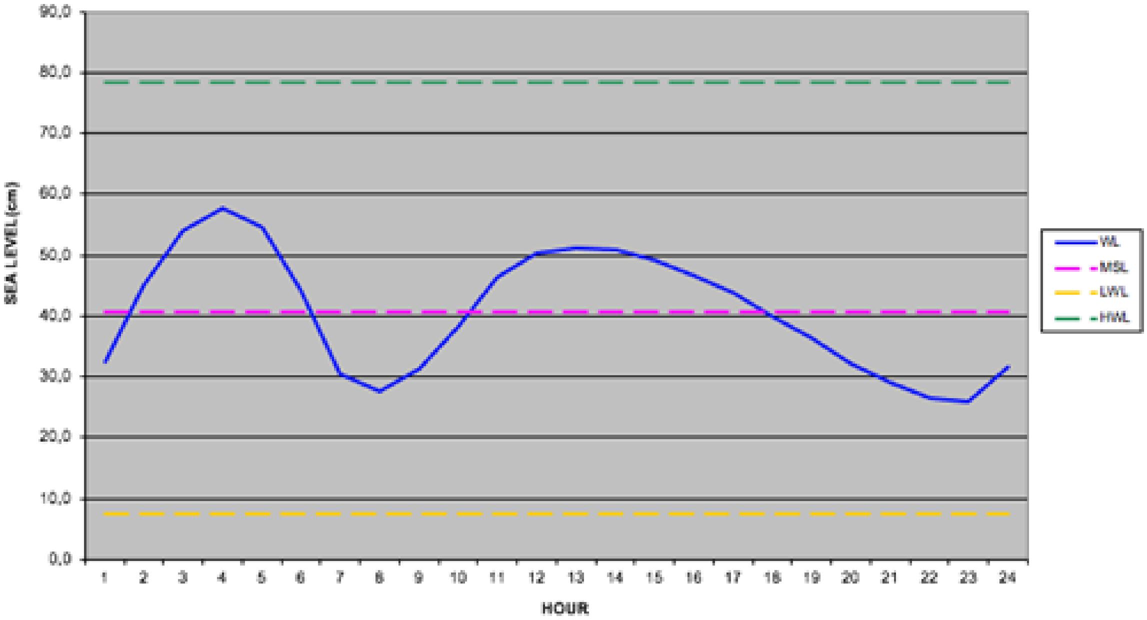

Figure 2: Surabaya Tidal Coastal Elevation Graph

At that time the gravitational force of the moon on the This type of flooding caused by tides or tides generally occurs in coastal alluvial plains which are located quite low or in the form of basins and there are many river mouths with tributaries so that if there is a tide from the sea then the water.

Based on the tidal flood distribution presented in Figure 3, the area of the tidal inundation is 46,763 Km^2. There are 10 districts in coastal areas of Surabaya which are affected by inundation or tidal floods such as Asemrowo District, Benowo District, Gunung Anyar District, Kenjeran District, Krembangan District, Mulyorejo District, Pabeancunggu District, Rungkut District, Semampir District, and Sukolilo District. The area of flooded area is calculated using an approach through the Geographic Information System (GIS). GIS is used to create a tidal flood inundation model with the result of a Flood Inundation Potential Map. The Flood Inundation Potential Map was created using ArcGIS software using the Conditional formula as a condition for certain conditions to occur in the Raster Calculator module (Ramadhan et al., 2015). The inundation area produced by data processing using GIS approach is limited to high point data, DEM and sea level elevation values, so that the resulting map is a flood inundation map that arises due to land elevation (topography) which is lower than the face elevation value sea water.

Tidal flood inundation models are made using the Raster Calculator tool found in the modeling software. Modeling is done by entering DEM data and water level values, the water level values used are the difference between the Highest High Water Level (HHWL) and Water Level Average (MSL). Formula for modelling can be seen in the following equation (Marfai et al., 2011):

$$WD = con\,(con\,(\,[DEM\,] \leq Elevation,\ Elevation),\ con\,(\,[DEM\,] \leq Elevation,\ Elevation\,) - [DEM],\ 0)$$

Equation 5

Information:

WD	: Depth of tidal inundation water
DEM	: Ground level data
Elevation	: HHWL – MSL

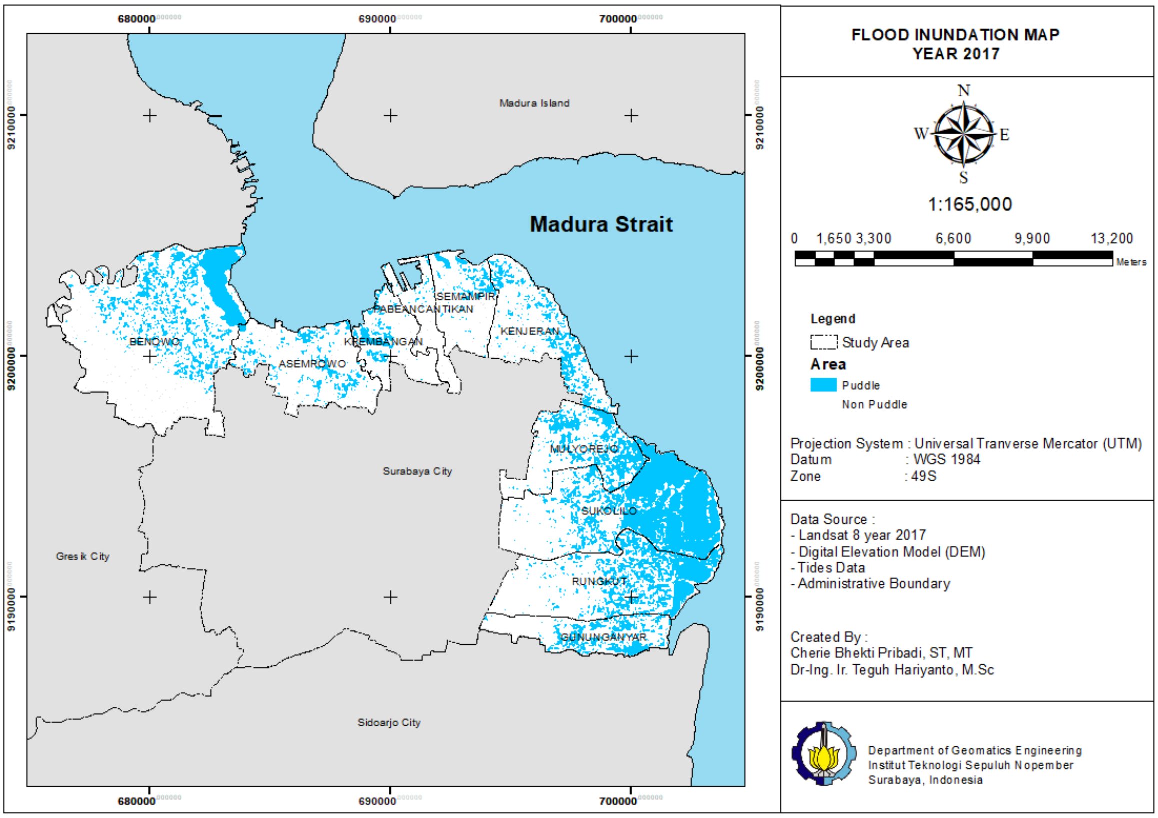

Figure: 3 Flood Inundation Map

Table 2: Extent of flood inundation for each village

District	Flooded Area (Km^2)	Unflooded Area (Km^2)	Total Area (Km^2)
Asemrowo	2,145	13,842	15,988
Benowo	9,017	34,472	43,489
Gunung Anyar	2,748	7,174	9,922
Kenjeran	3,098	11,165	14,263
Krembangan	1,308	7,033	8,342
Mulyorejo	4,316	8,844	13,161
PabeanCantikan	0,222	5,289	5,511
Rungkut	7,469	15,033	22,502
Semampir	1,173	8,088	9,261
Sukolilo	15,266	13,560	28,826
Total	46,763	124,982	171,263

Table 3: Effect of regions on land cover

Land Cover Class	Flooded Area (Km^2)	Unflooded Area (Km^2)	Total Area (Km^2)
Water Body	4,390	8,097	15,988
Road	5,151	13,868	43,489
Vacant Land	6,684	27,897	9,922
Settlement	13,418	61,357	14,263
Pond	11,056	5,022	8,342
Vegetation	5,772	7,843	13,161
Total	46,763	124,982	171,263

The tidal flood inundation model that is made is limited to DEM data and sea water elevation, meaning that inundation only arises because the height of the area is lower than the sea level. Tidal floods that occurred in Tegal City occurred during the full moon. During the full moon sea water experiences a higher tide. When the highest tides occur, the sea water overflows to the mainland and causes inundation. The area of tidal floods which occurred in each district can be seen in Table 2.

3.3 Analysis of Impact of Inundation on Land Cover

Inundation which occurs in Surabaya coastal area has a significant impact on physical condition of the surrounding land cover, the distribution of puddle gives influence to six classes of land cover in 10 coastal districts of Surabaya, including Asemrowo District, Benowo District, Gunung Anyar District, District Kenjeran, Krembangan District, Mulyorejo District, Pabeancunggu District, Rungkut District, Semampir District, and Sukolilo District. The following Table 3 describes the extent of land cover affected by inundation flood.

The land cover class which has most affected by tidal flood inundation is residential class with an area of 13,418 Km^2, followed by pond class with an area of 11,056 Km^2, vacant land with an area of 6,684 Km^2, the vegetation class with an area of 5,772 Km^2, road class with an area of 5,151 Km^2, and the lowest area affected by tidal flood inundation is the water class with an area of 4,390 Km^2. The greatest impact of inundation gives a very significant loss that is the unevenness of community mobility and material losses that must be borne by the owners of each settlement affected by tidal flooding.

4. Conclusion

There are ten subdistricts along the coast of the city of Surabaya, including those affected by inundation or tidal floods including Asemrowo District, Benowo District, Gunung Anyar District, Kenjeran District, Krembangan District, Mulyorejo District, Pabeancutut District, Rungkut District, Semampir District, and Sukolilo District. The largest area affected by inundation or tidal flooding is Sukolilo District with an area of 15,266 Km^2 and Benowo District with an area of 9,017 Km^2. The biggest land cover class affected by flood inundation or tidal flood is residential class with an area of 13,418 Km^2, followed by pond land cover class with an area of 11,056 Km^2.

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