EARLY WARNING SYSTEM BASED ON HISTORICAL COASTAL FLOOD EVENTS IN SEMARANG CITY, INDONESIA

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ABSTRACT:
Semarang is the capital city of Central Java located in the Northern Coastal Area of Java which floods have occurred quite often. Apart from the natural causes, the rapid development in the area resulted in worsened land subsidence leading to exacerbation of the flood's occurrence. During the last 10 years, there have been at least 15 flood events occurred in the area that was recorded by National Disaster Management Authority but early warning about these incidents is not given much. By using event data from the last 10 years, floods will then be analyzed to determine the characteristics based on three parameters, which are meteorological parameters (rainfall and wind), oceanographic (tidal wave and waves), and land subsidence in the area to create a threshold for early warning system based on these parameters. The results show that each parameter has significant influence on the occurrence of coastal flooding. Ten occurrences of coastal flood in Semarang happened on rainy season and the others on dry season. In rainy season, tidal height for each occurrence varied from 16.58 – 47.12 cm from Mean Sea Level (MSL) accompanied by heavy-extreme rainfall during or the previous day of the flooding. Rain that occurs at higher plains also affects the incidence of flooding in the coastal area of Semarang. While in dry season, tidal waves have greater influence with 80% of the occurrences have high tides above 45 cm from MSL. Wind direction and mean wave direction comes from Northwest for 46.67% and 80% of the cases. These results can be used as the preliminary threshold to increase level of alert before issuing an early warning. The average of rate of displacement for land subsidence in Semarang City is 8.9 cm/year in 2020, which indicates that if this condition occurs continuously, the potential for coastal flooding will increase regardless of season and tidal height happen in the Semarang area.

Key-words: *Coastal flood, Meteorology, Oceanography, Land subsidence, Early warning system.*

1. INTRODUCTION

Floods are one of the most frequent natural disasters which can have a significant impact on humans' activities (Nadeem, et al., 2014; Gigovic, et al., 2017; Udin, et al., 2018 in Batista, 2018). Coastal areas are not an exception, in fact most of the major flooding happen in coastal areas (Batista, 2018). Coastal flooding can result from a variety of different causes, such as tidal waves due to tidal activity, high waves due to the influence of strong local winds, incoming swell waves from distant offshore storms (Hoeke, et al., 2013; Smith and Juria, 2019), the rising of sea levels accompanied by high river currents, accelerated sea level rise due to global warming (Marfai & King, 2008), storm surges, and heavy rains (Batista, 2018). Areas that suffer from land subsidence increases the likelihood of coastal flooding and also can experience more severe impact of coastal flooding. The coastal area itself is characterized as an area that has a very diverse ecosystem that is a habitat for various species and also supports various economic activities, which causes high population growth in the area (Bijlsma et al., 1995). The city of Semarang is the capital of the province of Central Java, which is located in the North Coast of Java (Pantura). The Pantura region

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is also one of the coastal areas that has the potential for rapid development, especially in the transportation sector. This caused the Government in the 2020-2024 National Medium-Term Development Planning document to budget 50.8 trillion to provide security in the North Coast of Java due to the vulnerability of this area to the risk of land loss caused by various factors. The priority areas in this development include five large urban areas, namely Jakarta, Semarang, Pekalongan, Demak and Cirebon. In general, coastal security in these five areas aims to overcome the tidal flooding disaster. Semarang as one of the cities located in the Pantura region also has a dense population. Based on data from the Central Bureau of Statistics (Badan Pusat Statistik) in 2020, Semarang City has a population of 1.67 million people with a total area of 373.7 km^2 with a density of 4,854.54 people/km^2. Therefore, it is necessary for the vulnerable population to obtain comprehensive early warning information in this region so that losses can be minimized.

Indonesian Agency for Meteorological, Climatological and Geophysics (Badan Meteorologi, Klimatologi, dan Geofisika or simply BMKG) is the official agency in charge of providing early warning to institutions related to disasters caused by meteorological, climatological, and geophysical phenomena. Based on the UN Sendai Framework for Disaster Risk Reduction 2015-2030, the World Meteorological Organization (WMO) issues specific guidelines for providing early warning information based on the impact of meteorological phenomena that occur. This then resulted in a change in the provision of early warning information which was previously only limited to hydrometeorological phenomena that occurred, into providing early warning information based on impacts. Based on the information listed on the website of the Maritime Meteorology Center of the BMKG, it explains that the Standard Operating Procedure (SOP) in providing information on coastal flooding is to use wave and swell data obtained from numerical modeling of SWAN Ina-Forecast Map of Shallow Wave Waters and based on real time data and tidal height forecast in coordination with the Indonesian Navy Hydrography and Oceanography Center as well as Geospatial Information Agency.

Research on flooding in coastal areas has been carried out quite often, including in the Semarang area. Several recent studies regarding flooding in the Semarang area, among others, were carried out by Irawan et al., (2021) who examined the projection of flood events in the coastal area of Semarang until 2050 using the LISFLOOD-FP numerical model in terms of sea level rise and land surface subsidence. Another study was conducted by Widada et al., (2020) which modeled the possible location of tidal inundation in Semarang based on the subsidence factor using the Geographic Information System (GIS) in the area. Unfortunately, the application of these models is still very limited due to the difficulty of data access and limited resources. Therefore, this research will focus on the use of data that can be easily accessed by both disaster-related agencies and the public so that early warning information about coastal flooding can reach various levels of society more easily.

2. STUDY AREA

Semarang City is the capital city of Central Java Province (**Fig. 1**) which located in the North Coast of Java. Lowland and coastal areas in Semarang City are very dynamic and versatile, where it is being used as residential areas, recreation, industrial area, fishing activities and pond areas (Marfai & King, 2008). The morphology of Semarang City is lowlands and hills that have various heights, which are between 0.75 - 348 m above sea level, with a topography consisting of coastal/coastal areas, plains and hills with land slopes ranging from 0% ‑ 45% (Afifah, 2014). The city of Semarang is also traversed by at least 16 rivers which are under the authority of the Semarang Department of Public Works and 22 rivers with non-status authority. The research area will be limited to the coastal area of Semarang City which is determined based on the Law of the Republic of Indonesia No. 1 of 2014 concerning Management of Coastal Areas and Small Islands, where in Article 2 of the Law explains that the scope of the coastal area includes transitional areas between land ecosystem and sea which are affected by changes in land and sea, landward covers the administrative area of the sub-district and towards the sea as far as 12 nautical miles measured from the coastline. During the last decade, from the National Disaster Management Authority report, at least 15 flooding events occurred in the coastal areas of Semarang as shown in **Table 1**. However, there is also a possibility that there were events that were not recorded by the authorities because historical data collection can be a problem (Smith & Juria, 2019). These 15 flooding occurences will be used as the sample in this research as coastal flood in the coastal area of Semarang frequently happened and the occurences are increasing every year.

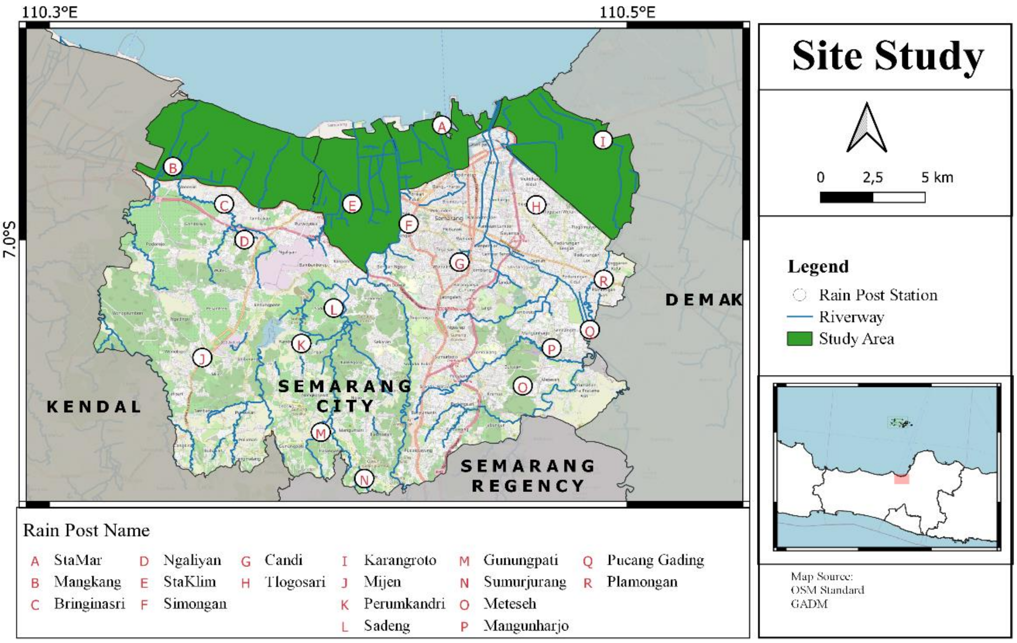

Fig. 1. Map of Semarang City and its sub-districts (green), from left to right, Tugu, West Semarang, North Semarang and Genuk.

Table 1.

Flood events in the coastal areas of Semarang from 2011-2020 recorded by National Disaster Management Authority

Affected district	Date of event
Genuk	October 31, 2020
Semarang Barat	May 2, 2020
Tugu	March 21, 2020
Genuk	March 7, 2020
Tugu	February 6, 2020
Semarang Utara	May 13, 2019
Tugu	April 4, 2019
Genuk	December 14, 2018
Genuk	December 6, 2018
Tugu	March 25, 2018
Semarang Barat	December 13, 2017
Semarang Utara	July 18, 2017
Genuk	February 15, 2017
Genuk	June 18, 2016
Semarang Utara	January 23, 2014
Genuk	January 23, 2014

3. DATA AND METHODS

3.1. Meteorological Parameters

Meteorological parameters used in this study include daily rainfall data (before incident (D-1), on the day of the incident (D-0), and the day after the incident (D+1)) and daily average wind direction and speed at the time of the incident. Both data are obtained from Indonesian Agency for Meteorological, Climatological and Geophysics (BMKG) Semarang in the form of daily total rainfall data from the nearest rain post to the affected area and hourly-observed wind speed and direction data. The result of this data can be seen on **Table 2**.

Table 2.
Analysis of rainfall conditions and wind condition at the time of flooding based on the season.

Affected District	Date of Event	Rainfall intensity (mm/day)			Wind Direction	Wind Speed (m/s)
		D-1	D-0	D+1		
Rainy Season						
Tugu	March 21, 2020	0	31	0	North – North East	1.75
Genuk	March 7, 2020	17	5	6	North West	2.30
Tugu	February 6, 2020	12	5	29	North West - North	2.75
Tugu	April 4, 2019	109	4	0	North East	1.50
Genuk	December 14, 2018	5	67	2	East – South East	1.78
Genuk	December 6, 2018	4	0	45	South East	2.03
Tugu	March 25, 2018	15	69	0	South East	1.91
Semarang Barat	December 13, 2017	0.3	14.5	7.5	North West - North	1.73
Genuk	February 15, 2017	0	14	0	North	2.29
Semarang Utara	January 23, 2014	120.5	36.9	92.8	South West – North West	5.05
Genuk		135	35	87	South West – North West	5.05
Dry Season						
Genuk	October 31, 2020	0	56	8	North	2.0
Semarang Barat	May 2, 2020	72	0	0	South East	1.61
Semarang Utara	May 13, 2019	0	0	0	North East - East	2.06
Semarang Utara	July 18, 2017	0	0	9	South East	3.52
Tugu	June 18, 2016	0	43	0	North East – South East	2.85
Genuk		4	13	1	North East – South East	2.85

3.2. Oceanographic Parameters

Oceanographic parameters analyzed in this study are tidal conditions and wave conditions (direction, significant height, maximum wave height and mean wave period). Tidal data was obtained from the Geospatial Information Agency (BIG). Tidal data will be adjusted to its Mean Sea Level (MSL) condition and also corrected with the detrend analysis to remove any trend from the data, which then will be analyzed based on the maximum tide height at the time of flooding in the coastal area of Semarang. The MSL height is obtained from the processing of the tidal harmonic components which are processed using the Least Square method. Wave conditions were analyzed using InaWAVES High Resolution hindcast data which obtain from BMKG with a horizontal resolution of $0.0625^o \times 0.0625^o$ (6 km × 6 km). This hindcast data was then processed using GrADS to determine the significant wave height, maximum wave height, wave direction, and mean wave period at the time of the incident.

3.3. Land Subsidence

Land subsidence data processing was carried out using the DInSAR method by processing Sentinel-I SAR satellite data to identify spatial changes in an area by utilizing coherence in interferometric phase measurements from the same surface (Francis, et al., 1996).

Processing with the DInSAR method was carried out on the SNAP and SNAPHU applications. After obtaining the land subsidence map from the SNAP application, further analysis was carried out on the GIS mapping application to determine the rate of land subsidence in each sub-district on the coast of Semarang. The results obtained from processing with this GIS application include the minimum, maximum, average, and standard deviation rates of land subsidence in each sub-district in the research area.

4. RESULT AND DISCUSSION

4.1. Results on Meteorological Parameters

The results of processing rain data obtained from the Indonesian Agency for Meteorological and Geophysical (BMKG) daily rain post were analyzed according to the criteria specified in the KBMKG Regulation No. 009 of 2010 concerning Standard Operating Procedures for Implementation of Early Warning, Reporting and Socialization of Extreme Weather with the following criteria.

Table 3.

Rainfall Intensity Categories.

Rain Classification	Description
Light	1 – 5 mm/hour or 5 - 20 mm/day
Moderate	5 – 10 mm/hour or 20 – 50 mm/day
Heavy	10 – 20 mm/hour or 50 – 100 mm/day
Extreme	>50 mm/hour or >100 mm/day

Source: Perka KBMKG (2010)

Rainfall conditions of the previous, during and following day of the occurences also daily average wind data values can be seen in **Table 3**. According to Setiawan (2018), Semarang city is still included in the seasonal zone which is influenced by the monsoon where the rainy season and dry season has clear distinction. Rainy season in monsoon zone active on November until April and dry season active on May until October (Aldrian & Susanto, 2013; Setiawan, 2018). Based on this, the result shows that 10 cases of the flooding happened in rainy season and 5 others in dry season.

In rainy season, 2 cases have heavy rainfall on the day of the incident, 2 cases on the previous day has extreme rainfall and 6 cases with light-moderate rainfall on the day or the previous day of the incident. Due to the condition of the Semarang city area which is close to the highlands and traversed by many rivers, it is very possible that the flooding that occurred in this coastal area was caused by rain that occurred in the highland area which then resulted in increased river water discharge reaching the coastal area. Therefore, for the occurrence in the rainy season, rain post data was added for the higher plains area which is close to the river flow that flows into the coastal area of the flood incident. The rain post location and the riverway across Semarang city can be seen in **Fig 1** and the additional rain post data can be seen in **Table 4.** In dry season, there are 5 occurences of coastal flood in Semarang area, 1 cases in in October 31, 2020 has heavy rain occured on the day of the incident, 1 cases in May 2, 2020 has heavy rain occured on the previous day of the incident and 3 cases with rainfall 0 – 13 mm/day.

Based on the result in **Table 4**, it shows that in rainy season, although the flood-affected areas did not experience any heavy rains, the areas with higher elevations experienced heavy rains. It is assumed that this will result in an increase in river discharge that reaches the coastal area and causes flooding in the coastal area. From 6 cases with light – moderate rain on the location of the flooding area, 4 events indicate that flooding that occurs in coastal areas is indeed influenced by the occurrence of heavy rain that occurs in higher plains.

Table 4.
Rainfall data from rain post station located in higher plains of the flood-affected areas (Flood cases during rainy season).

District	Date Of Event	Rainpost Location			Rainpost Location			Rainpost Location		
		Rain data (D-1)	Rain data (D-0)	Rain data (D+1)	Rain data (D-1)	Rain data (D-0)	Rain data (D+1)	Rain data (D-1)	Rain data (D-0)	Rain data (D+1)
Tugu	March 21, 2020	Mangkang			Bringin Asri			Ngaliyan pp ex rumah dinas		
		0	31	0	1	19	0	0	0	0
Genuk	March 7, 2020	Karangroto			Tlogosari			Plamongan		
		4	15	11	8	8	14	4	15	11
		Pucang Gading			Mangunharjo			Meteseh		
		1	21	13	4	26	13	4	13	17
		Sumurjurang								
		61	76	35						
Tugu	Feb 6, 2020	Mangkang			Bringin Asri			Ngaliyan pp ex rumah dinas		
		12	5	29	3	16	56	65	15	95
Tugu	April 4, 2019	Bringin Asri			Ngaliyan pp ex rumah dinas			Mijen		
		81	48	0	109	4	0	89	14	10
Genuk	Dec 14, 2018	Karangroto			Tlogosari			Plamongan		
		5	67	2	38	75	2	21	42	1
Genuk	Dec 6, 2018	Karangroto			Tlogosari			Plamongan		
		4	0	45	3	0	27	0	0	79
Tugu	March 25, 2018	Bringin Asri			Ngaliyan pp ex rumah dinas					
		15	69	0	11	50	0			
Semarang Barat	Dec 13, 2017	Staklim			Simongan			Sadeng		
		0.3	14.5	7.5	1	126	12	0	62	17
Genuk	Feb 15, 2017	Karangroto			Tlogosari			Plamongan		
		0	14	0	1	23	1	1	39	8
		Mangunharjo			Meteseh			Sumurjurang		
		10	13	12	1	53	23	31	68	23

From the condition of the direction and speed of the wind at the time of the incident, 46.6% of the total flooding events, the wind came from the Northwest – North, 13.3% from North East – East, and the rest came from South East with wind speeds varying from 1.5 – 5.05 m/s. This wind speed condition based on the KBMKG Perka (2010) is not included in extreme conditions. The extreme wind speed conditions based on the KBMKG Perka (2010) are above 12.8 m/s.

4.2. Results on Oceanographic Parameters

Analysis of wave conditions was studied based on significant height, maximum wave height, mean wave direction and also the mean period. The analysis of significant wave heights then was categorized according to the Douglas scale as shown in **Table 5**. The tabulation results between wave conditions and sea level based on tides can be seen in **Table 6**. The significant wave height in the northern waters of Semarang varies between 0 – 1.23 meters. Based on the Douglas scale this altitude is still in the smooth to moderate category. While maximum wave height varies from 0 – 2.07 meters. In the Perka KBMKG (2010), it is stated that the condition of sea waves that need to be disseminated for early warning is significant sea waves with a height greater than or equal to 2 meters. The mean wave period also varies between 2 - 6 seconds in all cases of coastal flooding. According to Holthuijsen (2010), the mean wave period shows that the sea surface is still influenced by the wind, so the waves formed are still in the category of wind-generated waves. As for the direction of the waves, in line with the definition of wind-generated waves or waves that are still influenced by the wind, the direction of the waves at the time of the flooding incident was 80% from the Northwest. The same thing also happened to the condition of the wind direction which was dominated from the Northwest.

Table 5.

Wave Categories based on Douglas sea scale.

Wave height (m)	Description
0.1 – 0.5	Smooth
0.5 – 1.25	Slight
1.25 – 2.50	Moderate
2.50 – 4.0	Rough
4.0 – 6.0	Very Rough
6.0 – 9.0	High
9.0 – 14.0	Very High

Source: Owens E.H (1982).

Table 6.

Tabulation of wave and sea level data analysis.

Affected District	Date of Event	Mean Period (s)	Significant Wave Height (m)	Maximum Wave Height (m)	Wave Direction (from)	Tidal Height (cm)
Rainy Season						
Tugu	March 21, 2020	4	0.04 – 0 .06	0.06 – 0.08	West	34.77
Genuk	March 7, 2020	3 – 4	0.35 – 0.49	0.47 – 0.65	North West	20.04
Tugu	February 6, 2020	3 – 4	0.36 – 0.76	0.53 – 1.11	North West	16.58
Tugu	April 4, 2019	3	0.01 – 0.03	0.02 – 0.04	North West	20.34
Genuk	December 14, 2018	3 – 4	0.05 – 0.17	0.08 – 0.23	North West	47.12
Genuk	December 6, 2018	4	0	0	West – North West	28.27
Tugu	March 25, 2018	3 – 6	0.03 – 0.21	0.04 – 0.28	North West	16.95
Semarang Barat	December 13, 2017	4	0 – 0.16	0 – 0.27	West – North West	38.72
Genuk	February 15, 2017	4	0.37 – 0.47	0.62 – 0.77	West – North	35.09
Semarang Utara	January 23, 2014	4 – 5	0.93 – 1.23	1.58 – 2.07	West - North	20.38
Genuk		4 – 5	0.93 – 1.23	1.58 – 2.07	West - North	20.38
Dry Season						
Genuk	October 31, 2020	4	0.01 – 0.04	0.01 – 0.06	North West	28.58
Semarang Barat	May 2, 2020	2 – 4	0.02 – 0.40	0.02 – 0.52	South West – North West	51.00
Semarang Utara	May 13, 2019	2 – 6	0 – 0.5	0 – 0.5	North East – South East	45.61
Semarang Utara	July 18, 2017	3 – 5	0.03 – 0.07	0.07 – 0.10	South West - West	52.41
Tugu	June 18, 2016	3 – 4	0 – 0.06	0.03 – 0.09	South West - West	56.5
Genuk		3 – 4	0 – 0.06	0.03 – 0.09	South West - West	56.5

There were 4 events with a significant wave height ≥ 0.5 meters and 2 events with a maximum wave height above 1 meter. Nursamsiah, et al (2017) tried to analyze the extreme height of significant wave height in the Northern waters of Semarang area, which the result shows that extreme significant height in this area varies between 0.25 – 1.48 meters depends on the month. The highest extreme condition occurs in January, February, December and March with height 1.48 m, 1.27 m, 0.87 m, 0.80 m respectfully. This result is also seen in the results of this study where the wave height is also quite high in these months. The MSL height in Semarang waters which obtained using the Least Square method is 187.63 cm. This value is obtained from the So component of the tidal harmonic analysis. After the observation data was adjusted to the MSL height and eliminated the trend using the detrend analysis, the result can be seen in **Fig. 2.**

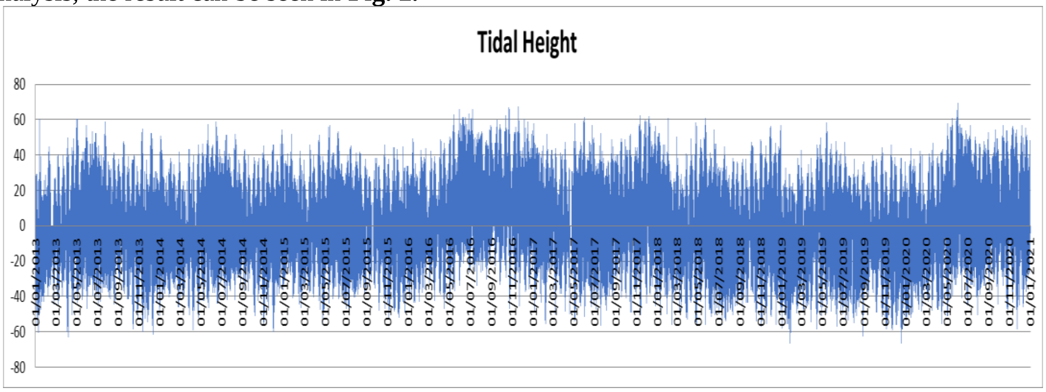

Fig. 2. Historical data of tidal waves on Semarang area in 2013–2020.

Based on the results in **Table 6**, in rainy season, the tidal height varies between 16.58 – 47.12 cm, while in dry season the tidal height varies from 28.58 – 56.5 cm. 4 out of 5 cases of flooding events happened in dry season has tidal height exceeding 45 cm, the case on October 21, 2020 is more likely being affected by the heavy rain as explained in the previous section Based on this results, it can be concluded that the floods that occur during the dry season are more influenced by high tidal waves. The flooding areas map based on the result of this and previous section can be seen in **Fig. 3.**

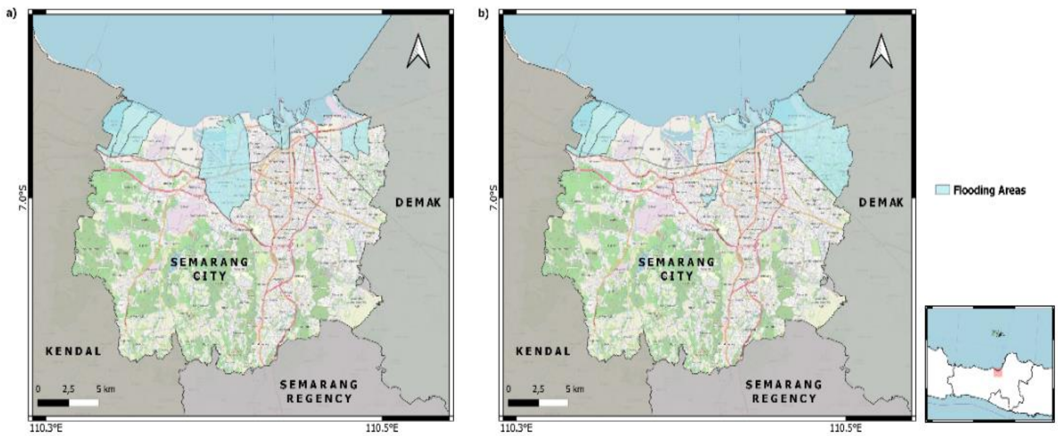

Fig. 3. (a) Flooding areas caused by tidal waves, (b) Flooding areas caused by rainfall

Flooding areas data was obtained from both BNPB and online newspaper, since not all flooding location was mentioned in BNPB records. Verification of the area that affected by the floods in Semaranng city is very difficult because there is no field data that can be used to verify it, such as satellite image data or aerial photos during a flood.

4.3. Results on Land Subsidence

Sentinel-I SAR data processing used recorded data from 2021 and 2020 so that the results of land subsidence in this study indicate the rate of land subsidence during 2020. The map of land subsidence resulting from the processing of the DInSAR method can be seen in **Fig. 4.** Processing on the GIS application was carried out to form Regions of Interest (ROIs) to obtain the maximum, minimum, average and standard deviation values for each sub-district in the coastal area of Semarang. The statistical results of ROIs can be seen in **Table 7**

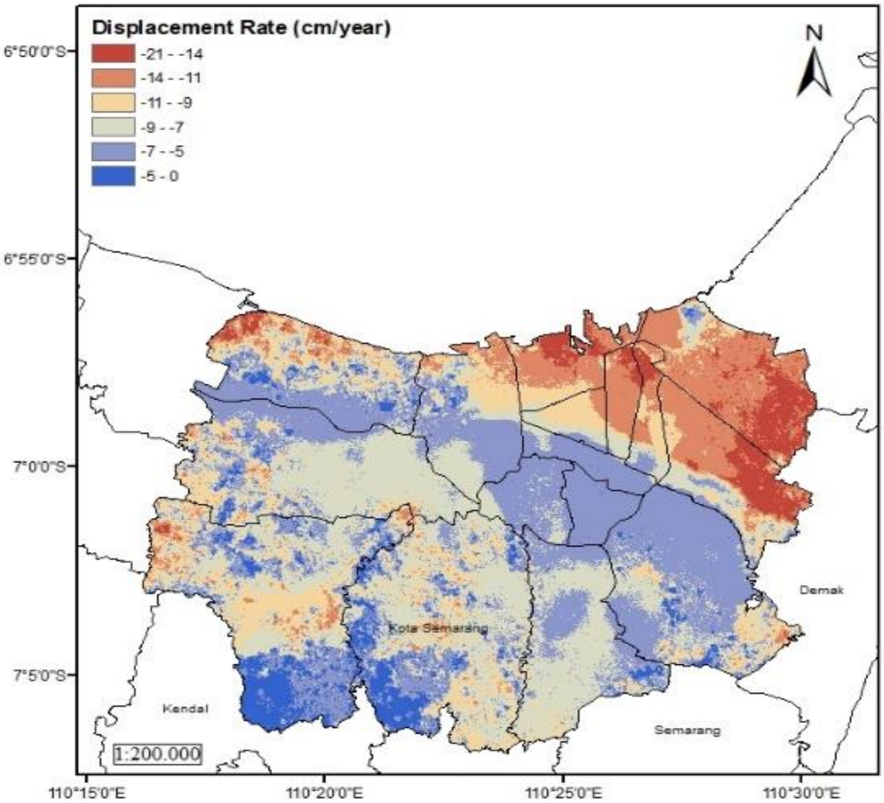

Fig. 4. Map of the land subsidence of Semarang City in 2020.

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Table 7.
The rate of land subsidence in Semarang City in 2020 using the DInSAR method.

District	**Maximum (m)**	**Minimum (m)**	**Average (m)**	**Standard Deviation**
Tugu	-0.19	-0.016	-0.089	0.024
Semarang Barat	-0.16	-0.023	-0.087	0.019
Semarang Utara	-0.21	-0.071	-0.129	0.020
Genuk	-0.21	-0.041	-0.132	0.0186
Semarang (City)	-0.21	+0.018	-0.0899	0.026

Based on the results above, the average land subsidence in the coastal area of Semarang is greatest in the Genuk District, based on a land use map in Semarang according to Agency for Regional Development (Bappeda) (2011) this area is dominated by residential and industrial areas. Research on land subsidence has often been done, with a similar method Fakhri Islam et al., (2017) researching land subsidence in the Semarang area in 2016, the results can be seen in **Table 8** below.

Table 8.
The land subsidence rate of Semarang City in 2016 used the DInSAR method.

District	Maximum (m)	Minimum (m)	Average (m)	Standard Deviation
Tugu	-0.1674	+0.0585	-0.0474	0.0238
Semarang Barat	-0.1463	+0.0113	-0.0411	0.0196
Semarang Utara	-0.1549	-0.0203	-0.0823	0.0158
Genuk	-0.1593	-0.039	-0.1035	0.0186

Source :Fakhri Islam et al., (2017)

By comparing data of land subsidence in 2020 to the result of research done in 2016, it is shown that the rate of land subsidence in all coastal areas of Semarang has increased by 50% or doubled. This condition will greatly affect the tidal conditions that occur. When coastal areas continue to subside, these areas will more easily experience tidal flooding due to sea level that is higher than the land areas that are experiencing land subsidence.

5. CONCLUSION

Based on the results of previous section, it is known that the incidence of flooding in the coastal area of Semarang can be distinguished by the causal factors based on the season. Semarang City which is still included in the monsoon zone has 2 types of seasons, namely the rainy season in November - April and the dry season in May - October. Floods that occur in the rainy season are strongly influenced by the intensity of the rain that occurs. All flood events that occured in the rainy season have heavy to extreme rain intensity with a value of > 50 mm/day either on the day or the previous day before the incident. Interestingly, in several flood events during rainy season, the incident area did not experience high intensity of rain. However, because this coastal area is also traversed by rivers and the slope of the land in the Semarang area is quite high, then when heavy rains occured in the higher plains of the Semarang area, it can cause flooding in the coastal areas of Semarang. Thus, monitoring the rain that occurs in the highlands of Semarang is also very necessary. During dry season, tidal wave conditions also need to be monitored. Four out of 5 flood cases during the dry season have high tides above 45 cm. These results of the analysis show that important parameter that can be used in making early warning information for coastal flooding in the coastal area of Semarang is the rainfall and tide wave condition. These parameters can be used to increase the level of vigilance before issuing early warning information. Land subsidence parameters also play an important role in the incidence of coastal flooding. Based on the results of the study, the difference in the rate of land subsidence in the last 5 years has increased significantly. If the condition of the worsened land subsidence is not handled properly, the potential for flooding in this coastal area will likely continue to increase.

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