Flood Prone Analysis Using GIS and Remote Sensing Data; Case Study in Semarang, Central Java

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Abstract. Flood is a natural disaster that occurs when water accumulates excessively to cover the land. Semarang is the capital in and largest city of Central Java that often experiences flooding causing casualties and damage. A disaster mitigation strategy is required to minimize losses in the future. One of the mitigation strategies that can be done is analysing prone areas to flooding in Semarang. The purpose of this study is to determine the level of prone area to flood disaster in Semarang by integrating the Geographic Information System (GIS) and remote sensing data including soil type, slope, rainfall data from the imaging satellite Himawari 8, land cover using Landsat 8 OLI, and observation data of catastrophic events in the last five years. The results obtained showed the prone area in Semarang was 44.25% and 8.18% in conditions of very prone, and 47.54% were in the condition of not prone to quite prone. Flood management through environmental adaptation of the community, design and construction of flood-resistant infrastructure by development codes can help to deal with the impact of flood damage.

1. Introduction
Flood occurs when the surface water overflow (runoff) exceeds drainage and water bodies [1]. Frequent flooding in recent years is a result of global climate change and recurring extreme events [2]. Semarang is located in the north coast of Central Java, Indonesia, which has a topography consisting of hills, lowlands, and coastal areas. Semarang is one of the cities in Indonesia that is directly affected by tide seawater thereover landslide [3], which causes flooding. This condition causes severe flooding in Semarang, significantly when high and tidal waves increase [4]. Floods are also caused by the physical conditions of cities and hinterlands that influence geological and hydrological crises and urban water resources management systems [5].

According to the Regional Disaster Management Agency (BPBD), flood in Semarang occured every year. In 2020, there were 23 incidents, while in early 2021 the floods inundated up to a height of 90 cm. This condition caused damage to property losses and causalities. The City Government has made various efforts to reduce the risk of flooding. These efforts were in the form of structural and non-structural methods [3]. Construction efforts have been carried out by building an east flood canal and a west flood canal in the 19th century [6]. Several research results stated that the main factors of flooding were rainfall, landform, physical properties, and land cover [1,2,7]. Various methods have also been carried out to...
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determine flood-prone zones. This study integration would be carried out between geographic information and remote sensing satellite data to process, analysis, and make decisions. The use of satellite imagery with a high temporal resolution is required in flood disaster mitigation efforts. Himawari-8 Satellite Imagery is an MTSAT satellite product with a sensor equipment in the form of an Advanced Himawari Imager (AHI) with better temporal, spectral, and spatial resolution than the previous one. Himawari-8 has 16 channels consisting of three visible channels, three Near Infrared Channels (NIR), and ten infrared channels [8].

The resolution per pixel of Himawari-8 is 0.5 km and 1 km in visible light, 2 km in the infrared channel, then 1 km and 2 km in the infrared channel, and 4 km for cloud data. Himawari-8 can record every 10 minutes globally and 2.5 minutes for custom observations. This satellite image is used to detect potential rainfall [9] as one of the parameters used in this study. Landsat-8 imagery is a satellite launched in February 11, 2013, belonging to America. Landsat-8 has two sensors, namely the onboard Operational Land Imager (OLI) sensor and the Thermal InfraRed Sensor (TIRS), with a total of 11 bands. The OLI sensor produces the effects of tension on objects on earth using visible, Near InfraRed (NIR), and Short Wave InfraRed (SWIR) waves.

In contrast, the TIRS sensor records the effects of radiation emitted by objects on earth. This image data can be used to interpret the physical conditions of the research area as one of the parameters of flooding and other natural phenomena. In this study, the researchers used GIS techniques as parameters and data accuracy was tested using secondary data, namely flood safety area data. This study aimed to determine the level of flood susceptibility in Semarang by integrating remote sensing data and GIS data.

2. Methodology

2.1. Study Area

Semarang, the capital city of Central Java, became the setting of the research. Semarang is one of the metropolitan cities in Indonesia which is located between 6° 50' - 7° 10' South latitude and 109° 35' - 110° 50' East longitude bordering Java Sea in the north, Demak regency in the east, Semarang regency in the south, and Kendal regency in the west. Semarang is at 2 meters below sea level to 340 meters above sea level with slopes ranging from 0% - 45% with topographic conditions in the form of a narrow lowland area and hilly areas that lie from the west to the east side of Semarang. It covers the area of 373.70 km which consists of 16 sub-districts and 117 districts.

Figure 1. Semarang city area
2.2. Method
This method used in this research was a quantitative method using several rainfall parameters such as slope, elevation, soil type, land cover, and historical flood events. Each parameter has its score according to the existing reference. Then each parameter was given a weight based on the calculation of the total score of all parameters that affected flooding. The level of flood susceptibility of an area would be determined based on the total calculated obtained score. A high calculation score indicated that the area was flood-prone.

2.2.1. Rainfall. Rainfall data were extracted from Himawari-8 Satellite data in 2020 with a spatial resolution was 4 km. Rainfall data every 10 minutes were then accumulated into the following days to become 2020 data. Furthermore, the calculation of the weighting of the rainfall was determined based on the rainfall depth (millimeter per year) of the area. Areas with high rainfall will have more influence on flood [10]. The greater the value of rainfall in an area, the greater the weighting score of the region (Table 1). It means that the region has higher potential for flooding.

| Rainfall depth (mm/year) | Class    | Score |
|-------------------------|----------|-------|
| <2.000                  | low      | 1     |
| 2.000 – 3.000           | moderate | 2     |
| >3000                   | high     | 3     |

Sources : [7]

2.2.2. Land cover. Land cover was obtained by extracting Landsat-8 OLI image data in 2021, which had been radiometric and geometric corrected. It is classified into five classes: forest/vegetation, water bodies, open land, rice fields, and settlements [1] using the maximum likelihood method. Each land cover was given a score. Land cover describes the condition of an area's ability to absorb water which then affects the potential for flood disasters. The less vegetation in an area, the smaller the absorption capacity of an area in controlling water runoff. As a result, the risk of flooding is higher than that with more vegetations. Based on the land cover classification, the weighting of land cover is presented in Table 2.

| Land cover            | Score |
|-----------------------|-------|
| Vegetation/Forest     | 1     |
| Water Body            | 2     |
| Open field            | 3     |
| Agriculture           | 4     |
| Settlement            | 5     |

Sources : [1]

2.2.3. Soil analysis. Soil type can affect the infiltration rate of the area. Generally, soil with fine texture has a low infiltration rate which can trigger runoff and vice versa. This study was divided into five soil types: alluvial, andosol, latosol, litosol, regosol [22]. Soil type scores for infiltration properties are presented in Table 3.
Table 3. Soil type score

| Soil type                  | Infiltration   | Score |
|----------------------------|----------------|-------|
| Litosol, Organosol, Rezina | very rapid     | 1     |
| Andosol, Inceptisol, Entisol| rapid          | 2     |
| Regosol, Alfisol           | moderate       | 3     |
| Latosol                    | moderately slow| 4     |
| Aluvial, Planosol, Hidromorf kelabu | slow    | 5     |

Sources: [7]

2.2.4. Slope analysis. The result showed that it was potential for flood disasters [7], where conditions in high areas would channel water quickly in low areas. Digital Elevation Model (DEM) data from the National Digital Elevation Model (DEMNAS) were extracted into slopes and then scored on the slope degree map. The weighing slope is presented in Table 4.

Table 4. Slope score

| Slope (%) | Score |
|-----------|-------|
| 0 – 8     | 5     |
| 8 – 15    | 4     |
| 15 – 25   | 3     |
| 25 – 45   | 2     |
| >45       | 1     |

Sources: [7]

2.2.5. Flood events analysis. A flood occurrence recap is a recording of flood in a certain period. A recap of flood disaster events was carried out over the last five years obtained from Semarang City disaster management (BPBD). The higher the frequency of flooding, the more likely the incident will happen again. According to the sub-district administration, the distribution of this flood recap was limited, which could later affect the final calculation in the weighting. This flood recap itself is also a validation score in the weighting method to obtain a more accurate score.

Table 5. Flood event score

| Flood event | Score |
|-------------|-------|
| 0 – 1       | 1     |
| 2           | 2     |
| ≥3          | 3     |

2.2.6. Flood prone analysis. After determining the weighting score of each parameter, the classification of the flood susceptibility level of each area was determined based on the parameters used. The formula used can be seen in equation 1 and the score of the flood-prone is presented in Table 6.

\[
\text{Flood prone} = 5 \times (R) + 4 \times (Lc) + 3 \times (S) + 2 \times (Sl) + 1 \times (F)
\]

(1)

Note: R is a rainfall depth, Lc is land cover, S is soil type, Sl is a slope, and F is flood event.

Table 6. Flood prone score

| No | Score | Class       |
|----|-------|-------------|
| 1  | ≥57   | Very Prone  |
| 2  | 41 - 51 | Prone       |
| 3  | 31 - 41 | Quite Prone |
| 4  | 22 - 31 | Slightly Prone |
3. Results and discussion

According to the Department of Public Works, flood-prone areas have a frequency of flooding that occurs once or repeatedly. The analysis of flood-prone zones in Semarang uses five parameters, namely rainfall, land cover, soil type, slopes, and flood.

Based on the analysis of rainfall from Himawari-8 imagery, it is known that most areas in Semarang had rainfall depths up to 4,600 mm/year (Figure 2a). The rainfall was relatively high compared to the annual Isohyet map of Semarang according to the Public Works Department (2017). The spatial resolution of the satellite data used, which was 4 km, was according to [21] which many factors cause satellites to have biases and errors such as sampling frequency and sensor perspective non-uniformity, and uncertainty in rainfall.

In this study, the data entered for consideration of Land cover information were Landsat data -8 years with a spatial resolution of 30 m in 2020. A clear image was selected among the available data with the assumption that there had not been much change in land cover in the research area within one year. Then it was classified using the maximum likelihood approach. There were five classes of land cover information, namely class 1 built up, class 2 agriculture, class 3 open land, class 4 water bodies, and class 5 forest. The map and table are presented in Figure 2b and Table 7 for each area based on interpretation. The training area needed the classification process as an introduction to object classes [12].

Furthermore, the training area is a reflection of the characteristics of each classified object. For built-up land, it was a mixture of groups, buildings based on color characteristics, size of texture patterns, and the location of object associations. Meanwhile, the rice field class was a mixture of rice fields, grasses, and object association characteristics. Moreover, plantations were made into one category for the forest class. According to several studies, one of which is research from [12], mentioned that land cover affected the flood hazard of an area. Meanwhile, according to [13,14], the increase in the building area would impact the hydrology of the watershed, which reduced land infiltration and might be the cause of increasing the danger of flooding.

| No. | Land cover     | %     |
|-----|---------------|-------|
| 1   | Built up area | 49.26 |
| 2   | Agriculture   | 5.10  |
| 3   | Open land     | 13.49 |
| 4   | Forest        | 31.48 |
| 5   | Water Body    | 0.75  |

Soils data were obtained from Regional Planning Agency. Soil type will affect the ability of the soil to hold air because it is closely related to how quickly the air leaves the soil. According to [15], infiltration capacity, soil moisture, organic carbon content, and weight are influenced by soil type. This ability is closely related to the occurrence of floods and the receding of floods sooner or later. Based on Figure 2c, Semarang consists of five soil types, namely alluvial in the north, Mediterranean and Grumasol in the middle, latosol, and regasol in the south. According to [16], alluvial soil is the one with a fine texture, including soil saturated with water absorbed.

According to [17], the slope is significant to know the speed of the water channel that will carry air. Watersheds with steep slopes will drain rainwater faster than those with gentle slopes. Figure 2d shows the northern part of Semarang as an area with a plain to wavy topography. The land area with a 0-8% slope included the sub-districts of Tugu, North Semarang, Mraggen, Genuk, Mijen, and some located in West Semarang. The slope of 0-8% was a low slope with the potential for flooding [18]. The hilly topography was undulating to steep, covering South Semarang, Ngaliyan, Gajahmungkur to Candisari, while the Tembalang, Banyumanik, and Gunung Pati areas were sharply cut mountains to steep mountains. This geomorphological condition was controlled by the structural geological conditions of Semarang.
For the last five years, the history of flood was obtained from the Regional Disaster Management Agency (BPBD) of Semarang. According to [2] the historical flood of an area will provide information on the characteristics of the flooding that occurred and it is necessary to be used in the future flood management. The higher the frequency of flooding, the more likely it will happen again. This flood event recap is also a validation score in the weighting method to get more accurate data. The frequency of flooding in Semarang is presented in Table 8.

Table 8. Flood event historical

| Urban Village     | Frequency | Time                           |
|-------------------|-----------|--------------------------------|
| Bambankerep       | 1         | 3 March 2016                   |
| TawangMas         | 1         | 3 March 2016                   |
| Ngaliyan          | 1         | 4 March 2016                   |
| Rowosari          | 3         | 23 February 2020, 7 and 31 March 2020 |
| Wonsari           | 2         | 6 February 2017 and 4 February 2020 |
| Karangrejo        | 1         | 2 May 2017                     |
| Gebangsari        | 1         | 3 November 2017                |
| Mangkang Kulon    | 1         | 9 February 2018                |
| Urban Village       | Frequency | Time                                      |
|--------------------|-----------|-------------------------------------------|
| Mangkang           | 1         | 15 February 2018                          |
| Trimulyo           | 2         | 28 February 2018 and 6 Dec 2018           |
| Mangunharjo        | 2         | 25 March 2018 and 21 March 2020           |
| Tambrejo           | 3         | 2 December 2018, 18 January 2019, and 22 February 2020 |
| Kembangarum        | 1         | 3 December 2018                           |
| Kaligawe           | 1         | 8 December 2018                           |
| Muktiharjo Kidul   | 1         | 14 December 2018                          |
| Banjardowo         | 1         | 15 December 2018                          |
| Meteseh            | 2         | 25 December 2018                          |
| Sendangguwo        | 1         | 7 March 2020                              |
| Wonosari           | 2         | 19 January 2019 and 4 February 2020       |
| Manghunrajo        | 2         | 25 March 2018 and 21 March 2020           |
| Kamijen            | 1         | 21 January 2019                           |
| Panggung Lor       | 1         | 23 January 2019                           |
| Karanganyar        | 1         | 25 January 2020                           |
| Mangkang Wetan     | 1         | 4 February 2020                           |
| Jomblang           | 1         | 12 April 2020                             |
| Tlogomulyo         | 1         | 31 October 2020                           |
| Cangkiran          | 1         | 19 November 2020                          |
| Gemah              | 1         | 7 March 2020                              |

Source: [23]

Based on the analysis of the five parameters above, Semarang was in the non-prone to a very high prone zone. Based on Figure 3, in general, the areas with very high prone zones were in the northern part of Semarang. In contrast, the non-prone to moderately prone zones were distributed in the southern part of Semarang.

Figure 3. Flood prone zone map
Table 9. Area of flood-prone

| Zone        | %   | Area (Km²) |
|-------------|-----|------------|
| Not prone   | 4.89| 18.72      |
| Slightly Prone | 20.38 | 78.08      |
| Moderate prone | 22.27 | 85.25      |
| Prone       | 44.25| 169.36     |
| Very prone  | 8.18 | 31.32      |

Table 9 showed that the prone zones in Semarang dominated the existing zones, followed by the moderately prone and slightly vulnerable zones. The prone zone was located in the middle to the north and was distributed throughout the area. This percentage of prone zones was caused by several things, both from the physical and non-physical aspects of the environment. In addition to the northern part, the coast was also affected by tides and land subsidence [19]. The climate change that occurred [20] exacerbated the incidence of flooding in Semarang. Meanwhile, land covers were also an essential role in increasing the incidence of flooding where almost 50% of the research area was built-up land, causing runoff to flow directly to lower areas. Slopes in practically all areas would cause flooding in the central to the northern areas, especially if there were tidal conditions and were not supported by a good urban drainage. Viewed from this condition, it is essential to adapt holistically, starting from the community's adaptation, government, and other stakeholders. Transformation of buildings and infrastructure also needs to be undertaken and avoiding disaster-prone areas as other economic activities is necessary to reduce the impact of floods.

4. Conclusion
This study used remote sensing and GIS techniques to identify the character of areas and flood susceptibility zones in Semarang. Physical conditions significantly affected the frequency and occurrence of floods. According to several studies, the land cover classified from Landsat 8 imagery was only 30% in the form of forest and it could reduce water runoff directly to water bodies and land. The DEM data applied by DEMNAS have proven that the area geomorphologically involved was a gentle slope. The integration between remote sensing data and GIS has been able and practical to understand flood-prone zones by understanding the physical character and history of flood. This research is expected to be essential for policymakers for sustainable development and flood disaster mitigation strategies. In further research, the development of the results of this study can be improved using other parameters. Then it is recommended to implement holistic adaptations from the community, government, and stakeholders to reduce future impacts.

Credit Authorship Contribution Statement
Yosian Berkat: Writing, Formal analysis, Visualization, Writing - review & editing, Software
Hana Listi Fitriana: Conceptualization, Methodology, Formal analysis, Visualization, Writing - review & editing

Declaration of Competing Interest
The authors declare that there is no conflict of interest.

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