Potential distribution of water in Malang city based on Multitemporal Sentinel 2A image data

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Abstract. Malang City is one of the cities in East Java with the status of a second-level city, with Surabaya City as the first-level city. Malang City also has various advantages that can attract many people outside the city to live in Malang City. As time goes by, Malang City experiences an increase in built-up land area, which is considered to be the cause of increased flooding in Malang City. This study attempted to identify the areas vulnerable to potential inundation (flooding) using several influencing variables, consisting of data on land cover, slope, land altitude, intensity of rainfall, and NDWI. This study employed the SMCE (Spatial Multi-Criteria Evaluation) method to obtain data on the distribution of potential areas for rainwater puddles (floods) in Malang City. Based on the analysis results, most of Malang City in 2019 is dominated by areas categorized as vulnerable with a percentage of 71% or an area of 7,827.21 hectares. At the same time, the remaining 29%, or an area of 3,130.10 hectares, is an area included in the safe category from potential puddles. The percentage of this vulnerable area, when compared to 2014, increased by 6%.

1. Introduction
Malang City is one of the cities in East Java with the status of a second-level city, with Surabaya City as the first-level city. This is indicated by the number of infrastructures and facilities provided in comparison to the other cities around it. Based on the advantages possessed by the city of Malang, it will undoubtedly attract many people outside the city of Malang to plan on living in Malang. For several years, the number of people who came to live in Malang City has been increasing, which is indicated by the expansion of residential land around the outskirts of Malang City [1].

The building density has been getting wider—albeit not by spatial planning standards—which will have a serious impact on the environment, one of which is the difficulty of water seeping into the ground (infiltration) during the rainy season [2]. It will cause puddles or flooding in several areas in Malang City. Based on data from BPBD Malang City [3], several areas in Malang City always experience serious flooding every year, even though their location is close to the nearby river. This certainly raises speculation that the existing drainage system is not working correctly.

A study was then needed to determine the most influential factors on flood vulnerability in Malang City. Several variables suspected to be the triggering factors were selected and analyzed to determine the strength of their influence values. The data used was the statistical spatial database obtained using specific technology, which is remote-sensing technology. The primary data source to be processed was the digital number value in a satellite image from satellite recording. Statistical spatial data was then analyzed using Spatial Multi-Criteria Evaluation analysis. The result of the coefficient value will determine the strength of the influence of each variable in the form of a model. It is hoped that the
resulting model can be used as the basis for making development policies in the City of Malang to overcome the problem of flooding that occurs every year.

2. Method
The location of this research is Malang City. Geographically, it is located in the southern part of East Java and has an area of 145.28 km² at an altitude between 440–667 meters above sea level. Malang City is in the middle of Malang Regency, which is astronomically located 112.06°-112.07° east longitude and 7.06°-8.02° south latitude, with the following regional boundaries:

- North side: Singosari and Karangploso Districts, Malang Regency
- East side: Pakis and Tumpang Districts, Malang Regency
- South side: Tajinan and Pakisaji Districts, Malang Regency
- West side: Tajinan and Pakisaji Districts, Malang Regency

| Table 1. Research variables |
|-----------------------------|
| Variables | Required Data |
| Land Cover [4] | |
| 1. Percentage of built-up land cover | 1. Raster Image of Sentinel 2A on 02/12/2019 |
| 2. Percentage of open land cover | 2. Raster Image of Sentinel 2A on 17/09/2014 |
| 3. Percentage of land cover area in the form of trees | |
| 4. Percentage of paddy field land cover | |
| 5. Percentage of river land cover | |
| 6. Percentage of road land cover | |
| Land slope (degree unit) [5] | Malang City DEM Raster Image Data |
| The altitude of the plains of Malang City [6] | Malang City DEM Image Raster Data |
| NDWI [7] | |
| 1. Raster Image of Sentinel 2A on 02/12/2019 | |
| 2. Raster Image of Sentinel 2A on 17/09/2014 | |
| Rainfall Intensity [6] | 1. Website of Malang City BMKG |

Sources: [4] [5] [6] and [7] with modifications

The data was used to identify the factors of land cover type obtained by conducting a primary survey. The primary survey was conducted to obtain information directly by conducting field observation and remote-sensing techniques. The primary data obtained was derived from basic data processing with more detailed accuracy, namely Sentinel 2A satellite image data with the acquisition date after the flood disaster, 01/03/2019, and before the flood incident, 01/01/2019. The tools used were a set of computers equipped with ArcGIS, SPSS, Ms. Office, and ENVI software programs.

3. Discussion
3.1 Land Cover
The land cover in Malang City was identified based on the interpretation generated after processing the Sentinel 2A raster. The raster used is a raster with an acquisition date of December 2, 2019, and the previous five years, which was September 17, 2014. The land cover classification was carried out on the Malang City raster processed with the scope of the Malang City area as a whole. This was done to simplify and speed up classifying raster images without processing a raster with enormous scope, i.e., Malang Regency. Image processing was carried out using a supervised classification method, which relied on training sample managers as the basis for classifying land cover.
Figure 1. Malang city land cover
Source: Image Processing Results

Based on Figure 1, it can be concluded that built-up land cover is the most pronounced land cover in Malang City in 2014. The land cover of roads is also markedly noticeable in the Malang City map. Most of the built-up land cover is in Kedungkandang District, with a total area of 1,668.84 hectares or 15.09%. Meanwhile, the least built-up land cover is found in Klojen District, with a total area of 769 hectares or a percentage of 6.96%.

3.2 Altitude and Slope
In this study, slope data was obtained from the DEM or SRTM raster image processing using several features in the ArcGIS software. This software produces a slope gradient raster output with an accuracy of pixels in degrees.
Figure 3. Map of altitude land in Malang City
Source: Image Processing Results

Based on the result of processing Malang City DEM image into Malang City slope map data in Figure 5, it can be concluded that most of the land in Malang City has a slope angle from 2% to 15%, i.e., wavy but not too steep. An area with this slope makes it easier for residents to expand the built-up land.

Based on Figures 2 and 3, it can be inferred that the altitude in Malang City is very diverse. Blimbing District has an altitude ranging from 455 m – 520 m with an area of 1,890.57 hectares. Thus, it can be said that the entire Blimbing District is located on high plain. This is different from the Kedung Kandang District, which has four types of plain height categories, where the plain category is class 455 m – 520 m with an area of 2,874.04 hectares. At the same time, the lowest altitude class in Kedungkandang District is 585 m – 650 m with an area of 266.25 hectares. Klojen District also has a similar altitude with Blimbing District, which is 455 m – 520 m, but with an area of 889.83 hectares. Lowokwaru District has four altitude classes, with most of the area (1637 hectares) belonging to the 455 m – 520 m class, while the class with the smallest area has an altitude of 650 m – 700 m with an area of 39 hectares. Sukun District has three altitude classes with the class 455 m – 520 m having the highest area of 2,039 hectares, while the class 390 m – 455 m has an area of 12.75 hectares.

3.3 Climate
Rainfall intensity data was essential as it is one of the variables that affect the level of flood vulnerability or puddles in an area. Data on the distribution of rainfall intensity in Malang City was obtained from the rainfall intensity data for Malang City in 2014 and 2019 in the Malang City BMKG (Meteorology, Climatology, and Geophysical Agency) website, adjusted to the date of acquisition of Sentinel 2A raster data. The data on the distribution of rainfall intensity in Malang City was digitized manually using the ArcGIS software, and this needed to be done considering that the website does not provide shapefile data on rainfall intensity. The digitization results of the rainfall intensity distribution in Malang City in 2014 and 2019 can be seen in Figure 4.
Figure 4. Map of rainfall intensity in Malang City
Source: Malang City BMKG

Based on the map presented in Figure 4, it can be concluded that the rainfall intensity in Malang City in 2014 and 2019 shows some differences. Differences in the distribution of rainfall intensity may be influenced by several other factors, such as climate and its sub-factors. The difference in rainfall intensity was intentionally used to measure the potential difference in areas prone to waterlogging during the rainy season in Malang City between 2014 and 2019. The rainfall intensity in Malang City in 2014 has a class of 51 mm – 200 mm. In 2019, Malang City has a rainfall intensity class ranging from 21 mm - 100 mm.

3.4 Normalized Difference Water Index
The advantage of using this NDWI value is that we may know the potential distribution of rainwater in an area without including other factors that might affect it and having to identify it in detail. The results of processing the Sentinel 2A images from 2014 to 2019 to produce NDWI distribution data can be seen in Figure 5.

Figure 5. Map of NDWI in Malang City
Source: Image Processing Results
3.5 SMCE
In this study, the detailed analysis used was the Spatial Multi-Criteria Evaluation (SMCE), which is used in the decision-making process where the analysis considers and evaluates various criteria spatially. Each research variable was given different weights according to the effect of these variables on the level of vulnerability. Likewise, the parameters were given different weights according to the scenario to be carried out. Each variable was then scored according to its level of influence on the potential for the distribution of puddles in Malang City. The lower the value of the sub-variable on a particular variable, the lower the score. A score is an absolute number from 1 to 10. The scoring and weighting were made directly by considering references and previous studies.

Table 2. Weight of variables

| No. | Indicator Variables | Variable Value/Flood Indicator | Weight |
|-----|---------------------|--------------------------------|--------|
| 1   | Land Cover          | 1 = River                      | 0.25   |
|     |                     | 2 = Trees                      |        |
|     |                     | 3 = Fields                     |        |
|     |                     | 4 = Open Land                  |        |
|     |                     | 5 = Road                       |        |
|     |                     | 6 = Built-up Area              |        |
| 2   | Land Slope          | 1 = Steep                      | 0.3    |
|     |                     | 2 = Tertiary                   |        |
|     |                     | 3 = Wavy                       |        |
|     |                     | 4 = Flat                       |        |
| 3   | Rain Intensity      | 1 = 21 mm – 50 mm              | 0.25   |
|     |                     | 2 = 51 mm – 100 mm             |        |
|     |                     | 3 = 101 mm – 150 mm            |        |
|     |                     | 4 = 151 mm – 200 mm            |        |
| 4   | NDWI                | 1 = (-0.4 - -1) Lowest         | 0.05   |
|     |                     | 2 = (-0.21 - -0.4) Low         |        |
|     |                     | 3 = (-0.2 – 0.2) Middle        |        |
|     |                     | 4 = (0.21 – 0.4) High          |        |
|     |                     | 5 = (0.41 – 1) Highest         |        |
| 5   | Land Altitude       | 1 = 390 m – 455 m              | 0.15   |
|     |                     | 2 = 456 m – 520 m              |        |
|     |                     | 3 = 521 m – 585 m              |        |
|     |                     | 4 = 686 m – 650 m              |        |
|     |                     | 5 = 650 m – 700 m              |        |

Source: Analysis, 2021

In the raster calculation process, the material used was the Sentinel 2A imagery of Malang City in 2014 and 2019 to produce the required variable data. The variable data comprised land cover distribution data, NDWI distribution data, land altitude distribution data, slope data, and Malang City rainfall data. The variable data was overlaid using the raster calculator method, in which the formula or formula overlays for producing a score for the potential level of puddles is as follows:

Score of Potential Flood Proneness = (Land Cover year t + NDWI year t + Plain Altitude + Slope + Rainfall Intensity year t) / 4 Class
Figure 6. Map of potential waterlogging in Malang City in 2014 and 2019

Based on Figure 6 it can be concluded that most areas of Malang City in 2014 has various levels of vulnerability to waterlogging. However, some parts of the area are dominated by areas prone to waterlogging or flooding. The area that exceptionally prone to flooding is Sukun District with a very vulnerable area of 536.28 hectares or 5.14%. Meanwhile, the district that has a very vulnerable area with the smallest area is Lowokwaru District, with an area of 126.71 hectares or 1.16%. This is supported by a statement by Supardjo in the Study of the Effect of Land Use Change on Surface Run-off in Manado City where the rapid development of cities with an increase in population and built-up areas indicates a decrease in water catchment areas [8]. Consequently, rainwater that falls to the surface cannot seep through and flow directly into channels leading to the river.

Based on Figure 6 it can be concluded that the condition of the level of vulnerability to puddles in Malang City in 2019 has a variety that is almost similar to that of Malang City in 2014. Areas that are categorized as very vulnerable in Malang City in 2019 are mostly located in Kedungkandang District with an area of 730.48 hectares or 6.67%. At the same time, the district that has the smallest area categorized as very vulnerable is Lowokwaru District, with an area of 242.14 hectares or 2.21%. The difference in the districts with the highest level of flood vulnerability from 2014 and 2019 is probably due to changes in land cover from undeveloped land to built-up land. In addition, other factors can also influence, such as changes in rainfall and changes in drainage conditions that are not included in this study. This is also in line with what was expressed by Fuad Halim (2014) that the level of flood vulnerability in an area is caused by changes in the function of rice fields into housing or industry, while climate change may also play a part. Some sectoral aspects, such as the system and condition of the drainage network, are also very influential.

4. Conclusion
Based on the analysis results using the SMCE method, the results are in the form of potential areas prone to puddles (floods) in Malang City in the last five years, namely 2019 and 2014. This is divided into two categories, namely the safe category and the vulnerable category. In 2019, it was dominated by areas categorized as vulnerable, with a percentage of 71% or an area of 7,827.21 hectares. At the same time, the remaining 29% or an area of 3,130.10 hectares is an area that is included in the safe category from the potential of puddles. The percentage of areas that are classified as vulnerable shows an increase of 6% when compared to 2014. Several factors that influence the increase in areas prone to waterlogging are the increasing number of built-up areas in Malang City and rainfall shifts. Several factors were not discussed in this study and may be used for further research in the future.
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