# Classification of Flood-Prone Areas in Tomohon Using Landsat 8 OLI Satellite Imagery

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[Received: 23 June 2023, Revised: 12 September 2023]
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**ABSTRACT** — Natural disasters often occur unexpectedly, resulting in both material and nonmaterial losses. Floods are among natural disasters that often occurs in several regions in Indonesia, one of which is Tomohon. Tomohon is a city located in the highlands, so it is expected to have a low flood risk level. Nevertheless, in reality, flood still occurs in Tomohon, which then causes material and nonmaterial losses. The data used in this research were the satellite imagery of the Landsat 8 onboard operational land imager (OLI) accessed through the United States Geographical Survey (USGS). The land covers in Tomohon were classified using the supervised classification method with the minimum distance classification (MDC) algorithm. This method provided the advantage of classifying land covers by utilizing training data in Tomohon, achieving an accuracy rate of 99.56%. In addition, the calculations of normalized difference vegetation index (NDVI), normalized difference water index (NDWI), and soil adjusted vegetation index (SAVI) were also utilized to determine the level of vegetation and surface soil moisture in Tomohon using the Quantum GIS (QGIS) application. Upon examining the land covers and calculating the index, weighting was once more performed in accordance with criteria. It was done to facilitate the classification of the area into three flood risk classifications: high, medium, and low. The results showed that green spaces in Tomohon are still greater than residential areas. However, NDVI, NDWI, and SAVI calculations indicated that some densely populated areas are susceptible to flood. These areas include Tomohon Selatan and Tomohon Tengah Subdistricts, which have a high level of flood risk and the Tomohon Timur Subdistrict, which has a medium level of flood risk.

**KEYWORDS** — Supervised Classification, NDVI, NDWI, SAVI.

## I. INTRODUCTION

Natural disasters can occur unexpectedly. Public awareness plays an essential role in preventing these natural disasters. One of the natural disasters that often occurs is floods. This natural disaster can have disruptive impacts on societies as it can cause damage, loss, and even death [1]. Development aimed at promoting the welfare of society may increase the risk of disasters such as floods if it is conducted without due consideration for the impact on the environment or vegetation [2]. Therefore, the community and the government must be aware of the flood risk level in their area.

Tomohon is located at 1°15' North and 124°50' East, covers an area of 147.2178 km$^2$ or 14,721.78 ha, and is situated at an altitude of 900–1,100 meters above sea level (masl) [3], indicating that this city is in the highlands. There are few rivers close to residential areas, so the likelihood of flooding is supposed to be low. Nevertheless, over the last six years, floods have occurred in several subdistricts in Tomohon, resulting in the damage of local buildings [4], [5]. The worst flooding occurred in Tomohon Selatan and Tomohon Timur Subdistricts in 2017, resulting in the closure of the intercity roads. In 2020, floods reoccurred in the Tomohon Selatan Subdistrict, which then caused damage to the local churches. Furthermore, in 2022, flooding occurred in the Tomohon Tengah Subdistrict, leading to casualties [6].

The occurrence of this disaster raises the awareness of the community and the government regarding flood disasters that can occur in Tomohon. Flood-prone areas in Tomohon must be mapped using existing data so that these areas can be classified immediately. The geographic information systems (GIS) can be utilized for mapping these flood-prone areas [7]. The mapping of areas that have a risk of being affected by flooding is expected to help faster and more targeted management so that material and nonmaterial losses can be minimized.

Landsat imagery has been widely used to study flood-prone areas. Apart from flooding, Landsat imagery can also be used for other purposes. Landsat 8 onboard operational land imager (OLI) satellite is extensively used to examine land covers because it provides band types and wavelengths with their own functions so that these wavelengths can be calculated as a reference. Previous research employed Landsat imagery to analyze flood-prone areas in the Tuntang Subdistrict watershed [8]. The results indicated that the Tuntang Subdistrict was not susceptible to floods.

In addition to its implementation to analyze floods, Landsat imagery is widely used to analyze and classify land covers [9]. Classification based on interpretation using Landsat imagery yielded an accuracy rate of 85%, allowing land covers such as forests, mangroves, and buildings to be classified.

This research aims to present a map of flood-prone areas in Tomohon, which is currently still unavailable. The process was carried out by utilizing Landsat 8 OLI satellite imagery, which were processed to assess land covers. Subsequently, the land surface vegetation index of Tomohon was calculated. The surface vegetation index affects the categorization of land covers, which can indicate the presence of green spaces and the moisture level in Tomohon. The map presented from this research shows the classification of flood-prone areas by subdistricts. The classification is done based on subdistricts in order to simplify the classification process, allowing for more targeted prevention and more appropriate emergency management towards areas identified as having a high risk of flooding.

Similar research utilizing Landsat has been done before. Prior research has successfully classified flood zone areas in

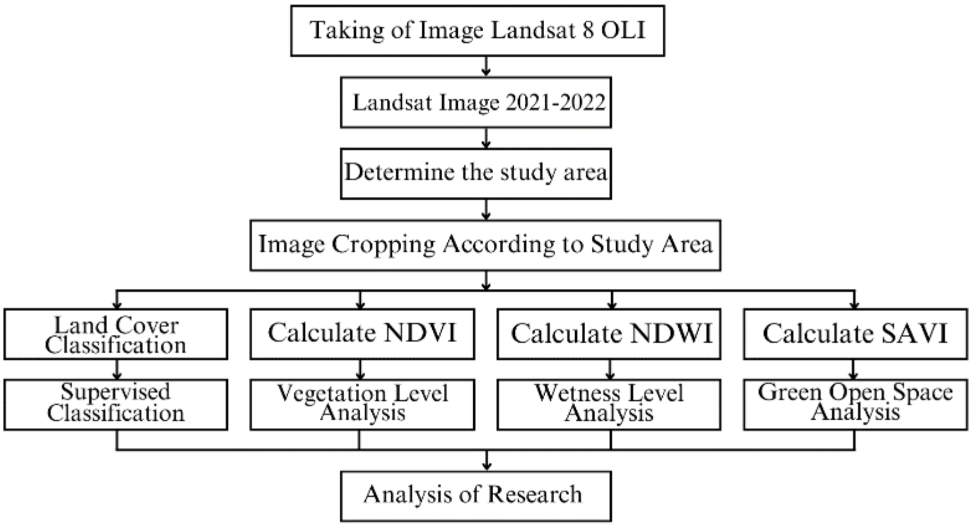



**Figure 1.** Research flow of the classifications.

Manado by subdistricts and assigned each subdistrict to one of three flood risk classifications: high, medium, and low [10]. Based on the research conducted, it is known that most subdistricts in Manado have a high flood risk. Meanwhile, there is only one subdistrict classified as medium and one subdistrict classified as low. This research was conducted using the standardized precipitation index (SPI), normalized difference vegetation index (NDVI), normalized difference water index (NDWI), soil adjusted vegetation index (SAVI), and inverse distance weighted (IDW) of Manado.

Another research has mapped flood-prone areas in Bengkulu [11]. This research was conducted by considering the NDVI and NDWI of Bengkulu based on Landsat 8 satellite imagery sensing and succeeded in mapping flood-prone areas into three categories: safe, prone, and very prone. The results have shown that three subdistricts in Bengkulu fall into the flood-prone category, and five other subdistricts are in the safe category.

Further research was conducted in Bawen and Tuntang Subdistricts and involved 25 villages [8]. This study aims to identify areas in the two subdistricts that are susceptible to floods, considering that both subdistricts are located in watersheds. Data were images obtained using Landsat 8 satellite. These images were then classified using NDVI, NDWI, and SAVI. Furthermore, the ranking of the mean values was compared with the interpolated data. The results of this study suggest that both subdistricts are classified as safe areas or not prone to flooding.

Subsequent research used NDVI to determine flood-prone areas in the East Kupang Subdistrict [12]. Classifications were divided into three where results have showed that Tanah Putih, Oefafi, Oesaso, and some parts of Tuatuka villages are flood-prone areas.

Research utilizing GIS has also been conducted by analyzing rainfall, land use, and slope level of Kepanjen City [13]. From the existing data, it is known that the flood-prone areas during the study and the prediction of flood-prone areas that will occur in the future. Areas categorized as very prone to flooding increased by 2.39%.

The existence of much research on flood-prone areas makes this research important for Tomohon because there has yet to be a classification of flood-prone areas of this city. Most studies also take data in a specific period only. This research is eminent since the satellite imagery was taken for a whole year to identify which areas have excessive standing water that is likely to be flooding. This study attempted to combine the calculation of index and land cover of Tomohon, while other studies used only one.

## II. METHODOLOGY

This research was conducted qualitatively and started with data collection of Landsat 8 OLI satellite imagery provided by the United States Geographical Survey (USGS). The data were then processed using the combination of supervised classification methods to analyze land cover and the NDVI, NDWI, and SAVI to calculate the land surface based on vegetation and surface moisture level, which was then managed using Quantum GIS (QGIS) tools. The research stages can be seen in Figure 1.

Research was done in Tomohon, North Sulawesi. This city is divided into five subdistricts, namely Tomohon Barat, Tomohon Tengah, Tomohon Selatan, Tomohon Timur, and Tomohon Utara [3].

### A. *LANDSAT 8 OLI SATELLITE*

The National Aeronautics Space Administration (NASA) cooperates with USGS to provide the Landsat 8 OLI satellite. This satellite is equipped with an OLI sensor and thermal infrared sensor (TIRS) consisting of eleven bands. The bands are divided into two groups: bands 1 until 9 are OLI and bands 10 and 11 are TIRS [8].

Each band has its wavelength and has different uses in the mapping process. Band 1 is used for coastal and aerosol studies. Widely employed in bathymetric mapping, band 2, or blue, can distinguish soil from vegetation and coniferous species. Band 3, or green, serves to emphasize the tops of vegetation used to assess plant vigor. Band 4, or red, is used to distinguish vegetation slopes in mapping. Band 5 is used to emphasize biomass content and coastlines. This band is also commonly referred to as near-infrared (NIR). Band 6, or short-wave infrared (SWIR) 1, is utilized to distinguish soil moisture content and vegetation that can penetrate thin clouds. Band 7, or short-wave infrared (SWIR) 2, is used to enhance soil and plant moisture content that can penetrate thin clouds. Band 8, or panchromatic, is utilized for capturing image with a resolution of 15 m, which can provide clearer images. Band 9, or cirrus, as the name suggests, is commonly used for enhanced detection of cirrus cloud contamination. Bands 10 and 11 have the same function for capturing image with a resolution of 100 m and are used for thermal mapping and soil moisture estimation. However, band 11 is better than band 10 because of its longer wavelength.

### B. SUPERVISED CLASSIFICATION

Supervised classification is an intensive analysis that shows the classification process by identifying objects in the image using training areas. Therefore, sampling should be conducted by taking into account the spectral pattern of each specific wavelength to acquire a good reference region that represents an object [14].

Supervised classification offers the advantages of controlling the data used as samples so that classification accuracy can be maximized [15]. This research employed supervised classification with the minimum distance classification (MDC) algorithm. MDC has advantages in using simple concepts to determine the average value of each class [16].

The initial step in the classification process using the MDC method was to calculate the distance from the center of each class and then input the index of the nearest class image. Mathematically, finding the average value of a class feature can be done using the following equation [17]:

$$m_j = \frac{1}{N} \sum_{x \epsilon m j} x \quad (1)$$

where $j = 1, 2, 3 \ldots M$, $N$ denotes the number of pixels, and $x$ denotes data object.

If a new object with characteristic x is found, the calculation of the closest distance with Euclidean distance is as follows:

$$d_j(x) = \left| x - m_j \right| \quad (2)$$

where $j = 1, 2, 3 \ldots M$, $d$ denotes the Euclidean distance, and $x$ denotes data object.

In this case, supervised classification methods require sample data to be used as training areas, commonly referred to as regions of interest (ROI), in performing supervised classification. The process of visual image interpretation involved the utilization of Google Earth.

### C. NORMALIZED DIFFERENCE VEGETATION INDEX (NDVI)

NDVI is a greenness index used to assess vegetation on the earth's surface, allowing to show greenness level of certain areas for vegetation division [18].

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (3)$$

where $NIR$ is a near-infrared reflectance (band 5) and $RED$ is the red band reflectance values (band 4).

The classification process employing NDVI shows the value range of NDVI 0–1, where value of less than 0.2 is water bodies or rocks so that they are not classified as vegetation. Meanwhile, value of 0.4 or greater indicates the presence of high vegetation or dense forest.

### D. NORMALIZED DIFFERENCE WATER INDEX (NDWI)

NDWI is a frequently used method to compare moisture levels in the satellite images using band 5 and band 8 [19].

$$NDWI = \frac{NIR - SWIR}{NIR + SWIR} \quad (4)$$

TABLE I
SCORE WEIGHTING

| Parameter | Information | Level | Score |
|---|---|---|---|
| Land cover | Green space (forest, GOS, plantation, rice field) | > 60 % | 1 |
| | | 50 % - 59 % | 2 |
| | | 40 % - 49 % | 3 |
| | | 31 % - 39 % | 4 |
| | | < 30 % | 5 |
| NDVI | Vegetation | High greenness | 1 |
| | | Moderate greenness | 3 |
| | | Low greenness | 4 |
| | | Non-GOS | 5 |
| NDWI | Water content | Non-water body | 1 |
| | | Moderate water content | 3 |
| | | High water content | 5 |
| SAVI | Density | High | 1 |
| | | Moderate | 3 |
| | | Low | 5 |

TABLE II
FLOOD RISK CRITERIA

| Risk Level | Score |
|---|---|
| High | 3 < Risk score < 5 |
| Medium | 2 < Risk score < 3 |
| Low | 1 < Risk score < 2 |

where NIR is a near-infrared reflectance (band 5) and *SWIR* short-wave infrared reflectance (band 8).

Classification employing the NDWI calculation is divided into three classes. Class 1 is on the value range of -1 until 0, where the moisture level is not on the water body. Class 2 is in the value range of 0 to 0.33, with a medium moisture level. Class 3 is in the value range of 0.33 to 1, with a high moisture level. The closer the value to 1, the higher the level of surface moisture of an area.

### E. SOIL ADJUSTED VEGETATION INDEX (SAVI)

SAVI is a development of NDVI used in ground vegetation that emphasizes the ground pixels at the canopy brightness level [18]. Equation (5) is used to calculate SAVI.

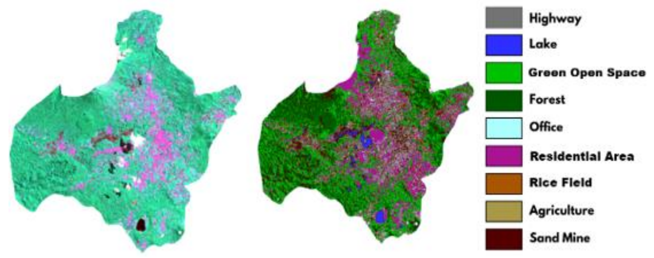
$$SAVI = (1 + L)\ x\ \frac{NIR - RED}{NIR + RED} \quad (5)$$

where $NIR$ is a near-infrared reflectance (band 5), $RED$ is the red band reflectance values (band 4), and $L$ is a soil brightness correction factor (0.5).

The SAVI-based classification process is divided into five classes. Class 1 (-0.3667 to 0.0187) with non-green open space (GOS) density is water bodies such as rivers. Class 2 (0.0187 to 0.1041), which has very low density, is a residential area in the form of open land covered with asphalt or paver blocks or paved roads. Class 3 (0.1041 to 0.3667), characterized by its low density, is areas that remain covered with soil like dirt roads or empty fields devoid of asphalt or paver blocks. Class 4 (0.3667 to 0.5214), with a medium density level, is covered vegetation areas in the form of plantations, grass, golf courses, and reeds. Class 5 (0.5214 to 0.7895), characterized by its a high-density level, is vegetation areas in the form of forest.

### F. WEIGHTING CRITERIA

Table I shows the calculation of weights used to determine whether an area is susceptible to flood. This table outlines the levels and scores given to facilitate the assessment of the




(a) (b)

**Figure 2.** Resulting images of (a) method combination and (b) supervised classification.

TABLE III
METHOD COMPARISON

| Parameter | Combination of Two Methods (Land Cover and Index Calculation) | Use of One Method (Land Cover or Index Calculation) |
|---|---|---|
| Natural factors | These combination enables the observation of land cover, land area, slope, existing vegetation, and the moisture level. | This method can only assess the land use or natural factors such as vegetation and moisture levels. |
| Human factors | The land cover area utilized by the surrounding community can be known, so that it does not only look at the land cover index. | The consideration of land use is neglected while just focusing on the calculation of the index, and conversely. |
| Flood area classification | Densely populated areas and green spaces can be clearly identified, and pixel can be calculated based on the waveform. | It can only calculate the index or can only identify the land cover. |
| Results | There are two subdistricts classified as flood-prone areas. | There is only one subdistrict classified as a flood-prone area. |

criteria. This weighting process was done in collaboration with the Regional Agency for Disaster Management (BPBD) of Tomohon, which also provided data on flooding in Tomohon. Meanwhile, land cover observations were conducted using visual aids from Google Earth. Next, the flood-prone area criteria were categorized into three risk levels based on the conducted weighting, as presented in Table II.

## III. RESULT AND DISCUSSION

The present study utilized Landsat image data acquired between 1 January 2021 and 1 January 2022 to identify the potential flood-prone areas in Tomohon. The results derived from the use of the supervised classification methods for satellite image classification indicate that Tomohon still has many forest areas, as visually depicted in Figure 2. Meanwhile, other green spaces are used as community agricultural land. Densely populated areas can be seen in Tomohon Tengah, Tomohon Timur, and Tomohon Barat Subdistricts.

### *A. ANALYSIS METHOD*

There are various methods for identifying flood risk areas, ranging from classifications based on land cover to calculations

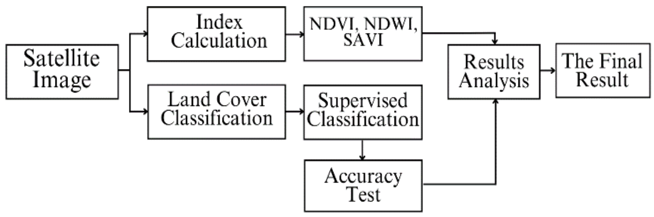



**Figure 3.** Flow model of method combination.

TABLE IV
LAND COVER AREA

| No. | Land Cover | Area (ha) |
|---|---|---|
| 1 | Lake | 214 |
| 2 | Forest | 3,704 |
| 3 | Highway | 631 |
| 4 | GOS | 4,397 |
| 5 | Office | 347 |
| 6 | Agriculture | 344 |
| 7 | Residential area | 3,266 |
| 8 | Rice field | 464 |
| 9 | Sand mine | 1,354 |
| | Total | 14,721 |

based on natural factors, such as vegetation index and rainfall. Given the unique phenomena in Tomohon, two methods were used to identify flood-prone areas. The two methods include land cover observation and index calculation. The land cover has impact on the function of land utilization. In other words, the denser an area is, the fewer trees there are. The consequence of this phenomenon is the occurrence of flooding. Meanwhile, the index calculation is used to measure in pixels based on the wavelengths on the satellite, allowing the identification of a green space or a water body within a given area. There has been limited research that has utilized the combination of these two methods. Prior research only focused on calculating the vegetation index [10] and only utilized the supervised classification method [20].

The comparative method was then employed to assess the advantages of combining the two methods in contrast to using one method alone. Table III shows the results of the comparative study.

The combined model of the two methods is presented in Figure 3. The data, which were satellite imagery, were classified based on the land cover. Furthermore, interpretation was conducted prior to the accuracy test. If the interpretation result exceeds 90%, then the land cover interpretation has good accuracy. Once the land cover was identified, the vegetation index and moisture level were calculated. This calculation aims to determine the exact level of ground surface vegetation, moisture level, and slope level that are influential in the classification process of flood-prone areas. Following the completion of the calculations, the results of these calculations were analyzed so as to produce a final result that could serve as a reference for the classification of flood-prone areas.

### *B. LAND COVER ANALYSIS*

The Landsat 8 OLI satellite imagery from the USGS is accessible to everyone at no cost. Satellite images were taken by inputting the coordinates of Tomohon City. Furthermore, the satellite images were processed using the QGIS tool. The satellite images provided were in TIFF format.

The QGIS tool was used to interpret the Landsat 8 OLI satellite imagery by merging bands 4, 5, and 6. In addition, the

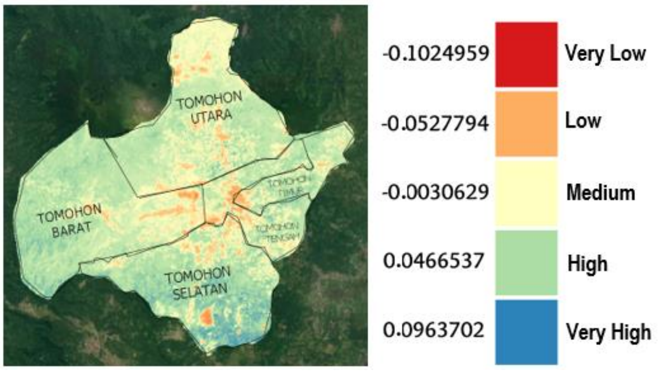



Figure 4. NDVI of Tomohon.

TABLE V
CONFUSION MATRIX

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 7 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 8 |
| 2 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| 3 | 0 | 0 | 900 | 5 | 0 | 0 | 0 | 0 | 0 | 905 |
| 4 | 0 | 0 | 0 | 873 | 0 | 0 | 0 | 0 | 2 | 875 |
| 5 | 0 | 0 | 0 | 0 | 17 | 3 | 0 | 0 | 0 | 20 |
| 6 | 0 | 0 | 0 | 0 | 0 | 870 | 0 | 0 | 0 | 870 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 13 | 0 | 0 | 13 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 25 | 0 | 26 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 14 |
| Total | 7 | 3 | 900 | 878 | 17 | 874 | 14 | 25 | 16 | 2734 |

RGB color of the merged result was modified to 3-2-1. This interpretation was achieved through the utilization of Google Earth, which provided clearer images of the present land cover. Using the training data that were interpreted previously, nine land covers were found, namely lakes, forests, roads, GOS, offices, farms, residential areas, rice fields, and sand mines, as illustrated in Figure 2. Each object was found using ten training data which were taken randomly and assisted by satellite imagery to determine whether the object was a forest, lake, highway, etc.

The training areas for green spaces were divided into two, namely forests and GOS, with the provision that forests exhibit a darker shade of green in comparison to GOS. This distinction is made because forests have a high-density satellite view.

Table IV presents the land cover in Tomohon, obtained from calculations using QGIS tools based on the supervised classification process. It can be seen that, in Tomohon, forest and GOS are more prevalent than residential areas. The forest spans a total area of 3,704 ha, the GOS is 4,397 ha, while the residential area is only 3,266 ha. In other words, the proportion of green space (forest and open space) amounts to 55%. On the other hand, residential uses only 22% of the land in Tomohon. These three are the largest areas of land in Tomohon, followed by sand mines which encompass an area of 1,356 ha. Upon examining the coverage area, Tomohon is a city with many green areas, which should have contributed to mitigate the risk of flooding.

Subsequently, an accuracy test was conducted to evaluate the level of accuracy of the employed interpretation, as depicted in Table V. After that, the accuracy level was calculated based on user accuracy, producer accuracy, and overall accuracy.

The calculation of user accuracy is done as follows:

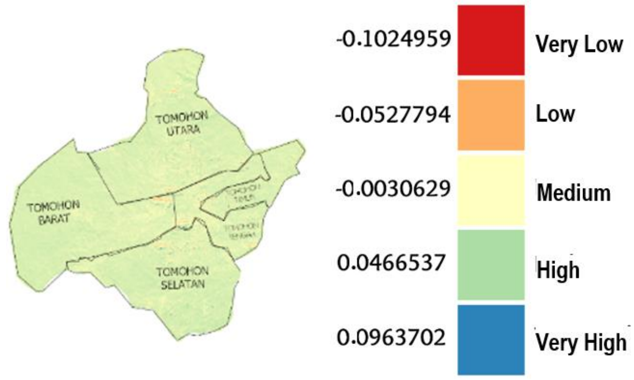



Figure 5. NDWI of Tomohon.

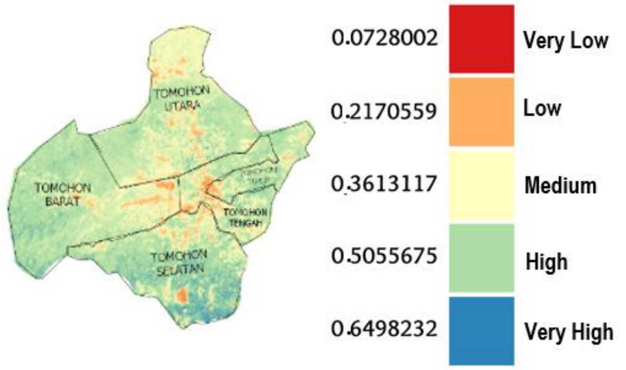



Figure 6. SAVI of Tomohon.

$$\text{Highway} = \frac{7}{8} \times 100\% = 87.5\%$$
$$\text{Lake} = \frac{3}{3} \times 100\% = 100\%$$
$$\text{GOS} = \frac{900}{905} \times 100\% = 99.4\%$$
$$\text{Forest} = \frac{873}{875} \times 100\% = 99.7\%$$
$$\text{Office} = \frac{17}{20} \times 100\% = 85\%$$
$$\text{Residential Area} = \frac{870}{870} \times 100\% = 100\%$$
$$\text{Rice Field} = \frac{13}{13} \times 100\% = 100\%$$
$$\text{Agriculture} = \frac{25}{26} \times 100\% = 96.2\%$$
$$\text{Sand Mine} = \frac{14}{14} \times 100\% = 100\%$$

The calculation of producer accuracy is done as follows:

$$\text{Highway} = \frac{7}{7} \times 100\% = 100\%$$
$$\text{Lake} = \frac{3}{3} \times 100\% = 100\%$$
$$\text{GOS} = \frac{900}{900} \times 100\% = 100\%$$
$$\text{Forest} = \frac{873}{878} \times 100\% = 99.4\%$$
$$\text{Office} = \frac{17}{17} \times 100\% = 100\%$$
$$\text{Residential Area} = \frac{870}{874} \times 100\% = 99.5\%$$
$$\text{Rice Field} = \frac{13}{14} \times 100\% = 92.8\%$$
$$\text{Agriculture} = \frac{25}{25} \times 100\% = 100\%$$
$$\text{Sand mine} = \frac{14}{16} \times 100\% = 87.5\%$$

The calculation of overall accuracy is done as follows:

$$\text{OA} = \left(\frac{7+3+900+873+17+870+13+25+14}{2{,}734}\right) \times 100\% = 99.56\%$$

The overall accuracy calculation resulted in an accuracy higher than 90%, which was 99.56%. It indicates that the accuracy level is very good, and the interpretation is successful.

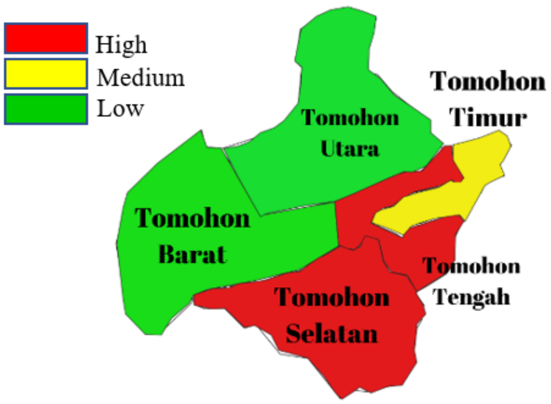



Figure 7. Flood-prone area map of Tomohon.

TABLE VI
SCORE RESULTS

| Subdistrict | Land Cover | NDVI | NDWI | SAVI | Result |
|---|---|---|---|---|---|
| Tomohon Utara | 2 | 2 | 1 | 3 | Low |
| Tomohon Selatan | 3 | 4 | 3 | 3 | High |
| Tomohon Tengah | 5 | 4 | 1 | 3 | High |
| Tomohon Timur | 4 | 2 | 2 | 2 | Medium |
| Tomohon Barat | 1 | 2 | 2 | 2 | Low |

### C. VEGETATION INDEX ANALYSIS

Supervised classification with the MDC algorithm shows densely populated areas in Tomohon. Green space, such as forests and GOS in Tomohon, remains abundant. Nevertheless, population density is already evident in certain subdistricts. Based on this, calculations using NDVI, NDWI, and SAVI algorithms were also conducted to see the vegetation and moisture levels on the land surface of Tomohon.

Figure 4 shows the results of the NDVI for Tomohon, as derived from Landsat imagery. Based on Figure 4, Tomohon still possesses many vegetation areas. With a range of values from 0.0485 to 0.4322, Tomohon can still be classified as an area with a high level of green vegetation. Areas with high vegetation values indicate that the area has many green spaces, such as forests. The data indicates that the factor contributing to floods, typically attributed to insufficient green areas for water infiltration into the soil, can be mitigated by the NDVI value of Tomohon, which is still at a high vegetation level.

The NDWI was calculated to determine the moisture level in Tomohon, as shown in Figure 5. The figure illustrates a significant presence of green color. The NDWI of Tomohon was in the range of -0.1025 until 0.0964, suggesting that the moisture levels in this city remain relatively low. In an area, some places are waterlogged, which can be caused by poor drainage that result in the stagnation of water. The range of values below 1 indicates that there are wet areas in Tomohon, although the majority of this city is at a low moisture level. These wet areas could be where water is inadvertently stored, which may eventually overflow their capacity and cause flooding during periods of heavy rainfall.

Figure 6 shows the SAVI value of Tomohon. As seen in the figure, there is still much green color with SAVI values in the range of 0.0728 until 0.6498. It demonstrates that Tomohon still has many green spaces, such as grass, plantations, and forests. SAVI is a development of NDVI that analyzes surfaces such as soil, asphalt roads, paver blocks, rice fields, and green areas such as grass and reeds. Although the land cover in Tomohon is still primarily green fields, some subdistricts have dense land cover that can cause flooding, including asphalt roads without drains, large paver block areas, and dense residential areas.

### D. SCORE ANALYSIS

Table VI presents the results of land cover analysis and index calculations, which were then weighted. In addition, from the results obtained, a classification map of flood-prone areas was made, as shown in Figure 7.

Based on NDVI, NDWI, and SAVI data, some areas in Tomohon remain at risk of flooding. Since the identified land cover areas of green space and residential areas are relatively balanced, two subdistricts, namely Tomohon Barat and Tomohon Utara, has low scores of flood risk. Meanwhile, in Tomohon Selatan, there are quite a few areas of standing water that can overflow during period of intense rainfall. Tomohon Selatan and Tomohon Tengah are the subdistricts with a high potential for flooding, while Tomohon Timur is at a medium level, as shown in Figure 7, displaying a map of flood-prone areas in Tomohon.

## IV. CONCLUSION

Tomohon is situated in a geographical region that is typically not susceptible to floods; however, over the last six years, it has experienced flooding. The classification of flood-prone areas plays a vital role in early flood prevention. This research aims to generate a map of flood risk areas in Tomohon so that early flood prevention can be carried out. NDVI, NDWI, and SAVI were calculated, focusing on calculating the surface vegetation index of Tomohon. Additionally, supervised classification was employed to assess the land cover. The results showed that out of five subdistricts, there are three subdistricts that are potentially prone to flooding. Tomohon Tengah and Tomohon Selatan exhibit significant-potential flood-prone areas. At the same time, Tomohon Timur is classified as medium due to the substantial amount of green space in comparison to the number of residential areas. Meanwhile, Tomohon Utara and Tomohon Barat are still in the safe area from flooding. Losses caused by flooding can be substantially reduced through awareness of flood-prone areas. This research can be expanded in order to investigate other factors affecting flooding in Tomohon apart from the natural surroundings.

## CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in the research and writing of this article.

## AUTHOR CONTRIBUTION

Conseptualization, Gabriel Kenisa Meqfaden Baali, Kristoko Dwi Hartomo, and Sri Yulianto Joko Prasetyo; methodology, Gabriel Kenisa Meqfaden Baali; writing—original draft preparation, Gabriel Kenisa Meqfaden Baali, Kristoko Dwi Hartomo, and Sri Yulianto Joko Prasetyo; writing—review and editing, Kristoko Dwi Hartomo and Sri Yulianto Joko Prasetyo; supervision, Gabriel Kenisa Meqfaden Baali.

## ACKNOWLEDGMENT

Thanks to the authors' parents for financially supporting this research and the authors' master's degree. Thanks also to the lecturers and staff of Universitas Kristen Satya Wacana who have always supported the writing of articles. Furthermore, thanks to the Tomohon City government, specifically BPBD, for their assistance in supplying data for research purposes.

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