Application of GIS for the mapping of landslide-vulnerable areas by through android-based Analytical Hierarchy Process (AHP) method in Bantul Regency

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Abstract. Landslide is a general term that covers a wide variety of soil forms and processes involving earth, rock, or debris movements falling on the lower slopes below due to the influence of gravity. This disaster occurs in many parts of Indonesia, including in Bantul Regency due to its relatively unstable land and vulnerability to land movement. In addition, a landslide disaster can lead to casualties and considerable material losses. This study aims to build an Android-based GIS application that can map landslide-vulnerable areas by dividing the vulnerability into three categories, namely low, medium, and high, using the Analytical Hierarchy Process (AHP) method. This research is expected to be useful for the community and the Government in order to be alert and responsive to handle landslide disasters in areas that have been declared vulnerable to landslide disasters. The results of research by using the GIS application produced showed that from 17 districts in Bantul Regency, 6 are districts that have a high vulnerability level of landslide disasters. The six districts are Pleret, Imogiri, Kretek, Sanden, Srandakan, and Bambanglipuro.

1. Introduction

Natural disasters as one type of natural phenomena can occur anywhere and anytime, thus causing material and immaterial losses to the community [1]. One of the natural disasters that often occur and create uneasiness in communities across the country is landslide. A landslide event, known as the motion of soil, rocks, or a combination of masses, often occur on natural slopes or non-natural slopes and is actually a natural phenomenon, that is when nature seeks a new equilibrium due to a disturbance or factors that affect and cause a reduction of the shear strength, as well as the increase of soil shear stress [2].

The risk of landslide also can be caused by several things, namely the condition of the constituent rock and soil, geological structure, precipitation, and land use. Landslides generally occur during the rainy season with high precipitation. Coarse soil is more at risk of landslides because the soil has a low soil aggregate cohesion [3]. To be able to monitor and observe the phenomenon of landslide in an area, it is necessary to employ a system of identification and mapping of landslide-vulnerable areas that can give descriptions of existing area conditions based on factors causing landslide [4].

Basically, most areas in Indonesia are hilly or mountainous, which make up slopes. Slopes, or lands which slope exceeds 20 degrees (40%), generally have the potential to move or form landslides.
[5]. Therefore, the issues raised in this article is about mapping landslide-vulnerable areas in one area in Indonesia, specifically in Bantul Regency. Bantul Regency has relatively unstable land and is vulnerable to the hazards of land movement, such as landslides. This is because Bantul Regency itself is located on a highland area with hilly terrain. In addition, according to the research, Bantul Regency is located on the cliff foothills (graben), so it is vulnerable to earthquakes, which can eventually also trigger landslides. Given the great extent of this area, then the mapping effort of landslide-vulnerable areas should be attempted. This is based on the fact that landslide disasters in the regency are frequent, which threaten large populations. This study aims to create a GIS application that can map landslide-vulnerable areas in Bantul Regency so that people in the area can be alert and cautious of the threat of landslides. The local government is also expected to be assisted by this research, because with it the Government can conduct landslide disaster prevention efforts in the area in a precise manner and additionally conduct proper self-rescue education programs against the threat of landslide disasters in the vulnerable areas.

This research was focused on determining the hazard level of landslide-vulnerability using the Analytical Hierarchy Process (AHP) method with Bantul Regency as case study through the Android platform. The vulnerability to landslides is divided into three categories, namely low, medium, and high.

2. Research Methods
2.1. Identification of needs
Identification of needs was done to obtain data and information related to the criteria of what causes the occurrence of landslides. In addition, it is also necessary to search data on Bantul district as a case study of this research, ranging from natural conditions, geographical location, to the history of landslide disasters in this region.

2.2. Data processing
The data processing stage in this research was done in accordance with AHP method to determine areas in Bantul Regency that are landslide-vulnerable based on predetermined categories. Stages of data processing are as follows:
1. Determining the types of criteria/indicators that affect the factors causing landslides and arranging the indicators in the form of matrix in pairs.
2. Summing up any existing columns in the paired matrix that has been created.
3. Determining the value of the column element of the criterion by the formula: each cell of the paired matrix was divided by the respective number of columns in the paired matrix.
4. Determining the indicator rank (normalized vector eigenvalues) on each row in by the formula: the number of rows divided by the number of criteria.
5. Measuring consistency, which is testing consistency on the paired matrix.
6. Calculating the Lambda max (α max), CI, and CR on each criterion used in this study. The criteria in question are the factors causing the occurrence of landslide disasters.
7. Calculating the rank value of 17 districts in Bantul Regency based on the vulnerability to landslide disaster that was adjusted to a specified weight and based on the natural condition in each district.

2.3. System Implementation
The system implementation phase constituted the application of data processing using the analytical hierarchy process (AHP) into Arcview and Android-based GIS application. This GIS application were configured with a digital map from Google Maps, so the locations on the application are made accurate with a more appealing look.

3. Results and Discussion
The location of this research was Bantul Regency. The district of Bantul lies between 07°44'04"08°00'27" Latitude and 110°12'34" - 110°31'08" Longitude. It borders Gunungkidul Regency in the
east, Yogyakarta City and Sleman Regency in the north, Kulonprogo Regency in the west, and the Indonesian Ocean in the south.

The results of needs identification are the results of collecting alternative and criteria data. Alternative data in this research are the data of 17 districts in Bantul Regency. The data used in the 17 districts are dummy data, which can be seen in table 1 below.

**Table 1.** Alternative data (17 districts)

| District       | Precipitation | Geology          | Soil Texture | Slope   | Land Use                          |
|----------------|---------------|------------------|--------------|---------|-----------------------------------|
| Kretek         | > 3000        | Alluvial Material| Fine         | > 45%   | Bush and Annual Plants            |
| Bambanglipuro  | > 3000        | Alluvial Material| Moderate     | 25-45%  | Mixed Annual Plants and Settlements |
| Pleret         | > 3000        | Alluvial Material| Fine         | 8-15%   | Rainfed Rife Fields, Rice Fields, and Grass |
| Imogiri        | > 3000        | Sediment Material-1| Coarse    | 25-45%  | Bush and Annual Plants            |
| Sandakan       | > 3000        | Sediment Material-2| Coarse    | 15-25%  | Mixed Annual Plants and Settlements |
| Pandak         | > 3000        | Sediment Material-2| Coarse    | > 45%   | Rainfed Rife Fields, Rice Fields, and Grass |
| Jetis          | > 3000        | Volcanic Material-1| Somewhat   | 15      | Rainfed Rife Fields, Rice Fields, and Grass |
| Sandan         | > 3000        | Volcanic Material-1| Coarse    |        | Mixed Annual Plants and Settlements |
| Sedayu         | 2500-3000     | Alluvial Material| Fine         | 15      | Mixed Annual Plants and Settlements |
| Pajangan       | 2000-2500     | Sediment Material-1| Fine       | > 45%   | Bush and Annual Plants            |
| Piyungan       | 2500-3000     | Sediment Material-1| Fine       | < 8%    | Mixed Annual Plants and Settlements |
| Pandong        | 2000-2500     | Alluvial Material| Somewhat Fine|        | Rainfed Rife Fields, Rice Fields, and Grass |
| Bantul         | 2500-3000     | Volcanic Material-1| Fine      | 15-25%  | Bush and Annual Plants            |
| Kasihan        | 2000-2500     | Alluvial Material| Coarse      | 8-15%   | Bush and Annual Plants            |
| Sewon          | 2000-2500     | Sediment Material-2| Somewhat   | 8-15%   | Mixed Annual Plants and Settlements |
| Banguntapan    | 2000-2500     | Volcanic Material-2| Coarse   | 8-15%   | Bush and Annual Plants            |

The criteria data for the occurrences of landslide disasters, along with their sub-criteria, can be seen in table 2. These criteria data were determined on the basis of the theories discussed in the previous chapter, as well as the journal articles listed in the references. Meanwhile, a description of the importance or weight of each criterion or sub-criterion used in this study can be seen in table 3.

**Table 2.** Criteria and Sub-criteria Data

| Criteria       | Sub-criteria | Weight |
|----------------|--------------|--------|
| Precipitation  | 2000-2500    | 1      |
|                | 2500-3000    | 2      |
|                | > 3000       | 3      |
| Geology        | Volcanic Material-2| 1      |
|                | Volcanic Material-1| 2      |
|                | Sediment Material-2| 3      |
|                | Sediment Material-1| 4      |
|                | Alluvial Material| 5      |
| Soil Texture   | Coarse       | 1      |
|                | Somewhat Coarse| 2      |
|                | Moderate     | 3      |
|                | Somewhat Fine| 4      |
|                | Fine         | 5      |

Slope 0-8% 1
The data processing is done in accordance with AHP method using 5 criteria of the occurrence of landslide disasters, namely precipitation, geology, soil texture, slope, and land use.

After determining the types of criteria, then the researchers performed the preparation of these criteria in the form of paired matrix, as well as the sum of each column. The value contained in the cell is obtained from the formula of individual opinion matrix that had been discussed earlier on the theoretical basis. Numbers 1 to 5, which are placed diagonally, are constant, and in this study the number 5 is used as the upper limit because there were 5 criteria. The number 1 is always divided by the numbers on the right row, the results of which will be placed in the column under the number 1. An example of calculations in column 1 of the paired matrix is as follows.

\[
\begin{align*}
1/2 &= 0.5 \\
1/3 &= 0.33 \\
1/5 &= 0.2 
\end{align*}
\]

So, the following paired matrix is obtained.

Paired matrix:

\[
\begin{pmatrix}
1 & 2 & 3 & 4 & 5 \\
0.5 & 1 & 2 & 3 & 4 \\
0.33 & 0.5 & 1 & 2 & 3 \\
0.25 & 0.33 & 0.5 & 1 & 2 \\
0.25 & 0.33 & 0.5 & 1 \\
\end{pmatrix}
\]

Addition of each column of paired matrix:

\[2.28 ; 4.08; 6.83 ; 10.5; 15\]
Next is the value determination of each element of the criteria columns. First of all, each cell in the paired matrix is divided by the sum of the columns corresponding to the location of the column of the cell itself. The calculation example in column 1 of normalized vector eigenvalue matrix is as follows.

\[
\begin{array}{l}
\frac{1}{2.28} = 0.44 \\
\frac{0.5}{2.28} = 0.22 \\
\frac{0.33}{2.28} = 0.15
\end{array}
\]

Thus, the new matrix obtained is as follows.

Normalized vector Eigen matrix:

\[
\begin{pmatrix}
0.44 & 0.49 & 0.44 & 0.38 & 0.33 \\
0.22 & 0.24 & 0.29 & 0.29 & 0.27 \\
0.15 & 0.12 & 0.15 & 0.19 & 0.2 \\
0.11 & 0.08 & 0.07 & 0.10 & 0.13 \\
0.09 & 0.06 & 0.05 & 0.05 & 0.07
\end{pmatrix}
\]

After obtaining the new matrix, each row is summed. The sum of each row of the above matrix is:

2.08 ; 1.30 ; 0.80 ; 0.49 ; 0.31

Then, normalized vector eigenvalues are obtained from the division of the sum of the rows by the number of criteria used. The number of criteria used in this study is 5, so the divisor is 5. From this calculation, we get the result of normalized vector eigenvalues from the above matrix as follows:

\[
\begin{array}{l}
\frac{2.08}{5} = 0.42 \\
\frac{1.30}{5} = 0.26 \\
\frac{0.80}{5} = 0.16
\end{array}
\]

The value of criteria column element is obtained from the multiplication of each normalized vector eigenvalue and the sum of the paired matrix columns. The results of these values are then summed as follows.

\[
\begin{array}{l}
0.42 \times 2.28 = 0.95 \\
0.26 \times 4.08 = 1.07 \\
0.16 \times 6.83 = 1.10 \\
0.10 \times 10.5 = 1.04 \\
0.06 \times 15 = 0.94 + \\
\text{Total } (\lambda \text{ max}) = 5.10
\end{array}
\]

Afterwards, a consistency measurement is performed. First, the consistency index calculation (CI) is done. The CI formula is:

\[(\lambda_{\text{max}} - n) / n - 1,\]

where n is 5 because n is the number of criteria, so the result is as follows.

\[\text{CI} = (5.10 - 5) / (5 - 1) = 0.02\]
The calculation result of CI value is used to find the value of CR, with the formula of \( CR = \frac{CI}{RC} \). RC values can be seen on Table 4.4 below.

**Table 4. Random Consistency (RC) Values**

| n  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
|----|----|----|----|----|----|----|----|----|----|
| RC | 0  | 0.58 | 0.99 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.51 |

The RC value used is the value in the 5th column, which is 1.12, which is chosen because it corresponds to the number of criteria \( n = 5 \). Thus, the following result is obtained.

\[ CR = \frac{0.02}{1.12} = 0.02 \]

Since the CR value is 0.02, it can be concluded that the consistent weighting preference is adjusted to the provision that if CR <0.1 the preference value is consistent.

The consistency measurement of sub-criteria for each criterion is then performed. The consistency measurement method of these sub-criteria is the same as the measurement of criteria consistency.

The measurement of consistency in the precipitation sub-criteria is adjusted to table 4.2, which shows that there are only 3 sub-criteria in precipitation. First, a paired matrix is created as follows.

Paired matrix:

\[
\begin{pmatrix}
1 & 3 & 5 \\
0.33 & 1 & 2 \\
0.20 & 0.50 & 1 \\
\end{pmatrix}
\]

1, 3, 5 are used because there are 3 precipitation sub-criteria and the definition of those numbers is the same as the weight description in table 4.3.

The sum of each column:

1.53; 4.50; 8

Next, the determination of sub-criteria column element value was done. Each cell in the paired matrix is divided by the sum of the columns corresponding to the location of the column of the cell itself. Normalized vector Eigen matrix:

\[
\begin{pmatrix}
0.65 & 0.67 & 0.63 \\
0.22 & 0.22 & 0.25 \\
0.13 & 0.11 & 0.13 \\
\end{pmatrix}
\]

The sum of each row:

1.94; 0.69; 0.37

Then, the normalized vector eigenvalues from the results of the division of the sum of rows by the number of precipitation sub-criteria would be obtained. The number of precipitation sub-criteria is 3, so the divisor is 3. With this, the normalized vector eigenvalues are obtained:

0.65; 0.23; 0.12
The results of the normalized vector eigenvalues are then multiplied by the sum of each column in the paired matrix, so the results become:

0.99; 1.03; 0.98

which, when added, yields a value of 3.01, which is the value of \( \lambda_{\text{max}} \).

Afterwards, the calculation of the CI values was performed using the formula: \((\lambda_{\text{max}} - n) / n - 1\), where \( n = 3 \) because there are 3 precipitation sub-criteria. Thus, the following result is obtained.

\[
\text{CI} = (3.01 - 3) / 3 - 1 = 0.003
\]

The calculation result of CI value is used to find the value of CR, with the formula \( \text{CR} = \text{CI} / \text{RC} \). The RC value used is 0.58 because \( n = 3 \). Thus, the following result is obtained.

\[
\text{CR} = 0.003 / 0.58 = 0.005
\]

Since CR value is 0.005 and CR < 0.1, it can be concluded that the weighting preference of precipitation sub-criteria is declared consistent. The way of measuring the consistency of these precipitation sub-criteria is similar to the consistency measurement of geology, soil texture, slope, and land use sub-criteria.

After all sub-criteria were calculated, it was found that all sub-criteria used in this study were declared consistent.

The last stage was the ranking each district based on the level of vulnerability to landslide disasters. The ranking began by inserting the weight or importance values for each of the criteria used. The weight value of each criterion was adjusted with alternative data and weight data on the criteria that can be seen in Table 5.

**Table 5. Criteria weighing for each district**

| District   | Precipitation | Geology | Soil Texture | Slope | Land Use |
|------------|---------------|---------|--------------|-------|----------|
| Kretek     | 3             | 5       | 5            | 5     | 2        |
| Bambanglipuro | 3         | 5       | 3            | 4     | 3        |
| Pleret     | 3             | 5       | 5            | 2     | 1        |
| Imogiri    | 3             | 4       | 1            | 4     | 2        |
| Grandakan  | 3             | 3       | 1            | 3     | 3        |
| Sanden     | 3             | 2       | 2            | 5     | 1        |
| Jeths      | 3             | 2       | 2            | 3     | 1        |
| Pandong    | 2             | 5       | 5            | 3     | 3        |
| Sedaya     | 1             | 5       | 4            | 5     | 3        |
| Pajangan   | 1             | 4       | 5            | 5     | 2        |
| Pyungan    | 2             | 3       | 3            | 5     | 2        |
| Dlingo     | 2             | 4       | 1            | 1     | 3        |
| Pandak     | 2             | 2       | 4            | 5     | 1        |
| Bantul     | 2             | 1       | 5            | 3     | 2        |
| Kasihan    | 1             | 5       | 1            | 2     | 2        |
| Sewon      | 1             | 3       | 4            | 2     | 3        |
| Banguntapan| 1             | 1       | 1            | 2     | 2        |

Further, the values of each weight were adjusted to the normalized vector eigenvalues of the sub-criteria and multiplied by the normalized vector eigenvalues of the criteria, then summed. Thus, the calculation of the values of Kretek District is as follows:

\[
\text{Kretek} = (0.65 \times 0.42) + (0.42 \times 0.26) + (0.06 \times 0.16) + (0.42 \times 0.1) + (0.26 \times 0.06)) = 0.50
\]

Thus, the values of every district can be determined, as are listed on table 4.6, and later the results can be ranked starting from the largest value of the highest level of vulnerability to the smallest value of the lowest level of vulnerability.
Table 6. The value results of the districts

| District       | Result       |
|---------------|--------------|
| Kretek        | 0.50295029   |
| Bambanglipuro | 0.46989118   |
| Pleret        | 0.46201239   |
| Imogiri       | 0.39031633   |
| Srandakan     | 0.37727135   |
| Sanden        | 0.35901276   |
| Jetis         | 0.33386073   |
| Pandong       | 0.32704685   |
| Sedaya        | 0.28250717   |
| Pundong       | 0.24369392   |
| Piyungan      | 0.22104968   |
| Dlingo        | 0.21990837   |
| Pandak        | 0.21115992   |
| Bantul        | 0.19582433   |
| Kasihan       | 0.18439819   |
| Sewon         | 0.1031943    |
| Banguntapan   | 0.1031943    |

The system implementation in this study is the application of data processing using the analytical hierarchy process (AHP) on an Android-based GIS application, making it more flexible and easy to use and also imaged on arcview as in Figure 1, which shows the district divisions by color. Then, the areas are divided into three categories based on the level of vulnerability ranging from red (high) to green (low), which can be seen in Figure 2 below.

![Figure 1. Subdistrict division by color](image1.png)

![Figure 2. Vulnerability level category division](image2.png)

Meanwhile, the implementation on the Android-based GIS application is configured with a digital map from Google Maps using the Google Maps API. The use of Google Maps is also intended to make the location on the application accurate and flexible.

In the initial view, the application will show all districts in Bantul Regency, along with all existing categories. The vulnerability categories in each district are indicated by green balloon showing low vulnerability, yellow balloon showing moderate vulnerability, and red balloon showing high vulnerability. The balloon symbol, when touched, will show the name of the district shown by the balloon itself, as can be seen in Figure 3. However, this app can bring up areas based on each category of vulnerability that can be selected via the button on the top left corner of the screen as visible in Figure 4.
If a region with a high degree of landslide vulnerability is selected, then its appearance will change to be as shown in Figure 5. When the balloon symbol is touched, the district's data will be displayed. The same also applies to the other categories as shown in Figures 6 and 7. If the selected category is in the moderate category, areas of moderate vulnerability will appear as shown in Figure 6. If the low category is selected, areas with low vulnerability will be shown as depicted in Figure 7.

3.1. System Testing
At the test session, the app was tested using the Blackbox testing method. This method does not directly check the syntax and internal logical structure of a software, but it aims to determine the expected functions such as to ensure that the output is correctly generated from the input and that the database is accessed and updated correctly, in addition to testing whether the database will execute those functions appropriately. Blackbox testing tends to be performed in the final stages of testing. This application has been tested by assessing whether the functions to display each district, as well as the category levels, have been successful or not as indicated in Figure 8. Then, a test on whether the description in each district can appear when the balloon button is touched was also done. The output on the application must also be adjusted to the output of the manual calculations, as shown in Figure 9.
In figure 9, the output of the application has been in accordance with the manual calculations because in the figure it can be seen that Kretak District is a district with a high level of vulnerability, similar to the result of manual calculation which has been discussed in the discussion chapter.

3.2. System Evaluation
The evaluation of this system is the result of system testing that determines whether the system was made properly. In this application, each district has been successfully displayed and categorized into the three categories based on its level of vulnerability. This application has also been able to display the expected descriptions. In addition, this application has succeeded in producing output in accordance with manual calculations using the AHP method.

4. Conclusions
The conclusions obtained from this study are as follows:
1. A GIS application can be built by utilizing digital maps from Google Maps using the Google Maps API, which can assist in encoding and configuring Google Maps.
2. The Analytical Hierarchy Process (AHP) method can be used to rank districts based on the level of vulnerability to landslides with predetermined criteria and criteria weighting.
3. In the research results, using the application, the 17 sub-districts in Bantul Regency were divided into three categories (low, medium, high) based on the vulnerability to landslides using the AHP method. The district locations are indicated by red, yellow, and green balloon symbols corresponding to the level of vulnerability displayed on a digital map from Google Maps.

The suggestions from this research are as follows:
1. For further research, there should be a search and use of valid data in accordance with the actual situation. In addition, further research should also make comparisons or may also incorporate the use of other methods for the results of research to be more accurate, useful, and in accordance with the reality.
2. In this study, the alternatives used are districts. Subsequent research can narrow the alternatives further by using subdistricts or villages as alternatives, so the locations vulnerable to landslide disaster indicated by the application based on the research results can be more accurately described. If necessary, the research location can be expanded to not only Bantul Regency, so the benefits of the produced application can be enjoyed by more people.

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