

Mapping of Flood-Prone Areas using GIS & AHP Methods in the Lambidaro Sub-Watershed, Palembang City

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Abstract: Flood events in Palembang City are increasing in intensity as the centre of national activities, which stimulates infrastructure development activities to support the economy and population growth, resulting in reduced green space and even the disappearance of the rivers that used to flow in most of Palembang City. Floods also occurred severely in the study area, namely the Lambidaro Sub-watershed. This study aims to identify the dominant factors that affect flooding and map the area based on the level of its flooding vulnerability. Generally, the methods used are the Analytical Hierarchy Process combined with the analysis of a Geographical Information System using primary and secondary data from valid sources. The results of AHP analysis found five types of parameters were used in making flood-prone maps in the Lambidaro Sub-watershed, namely rainfall with an influence value of 45%, elevation with a value of 11%, slope with a value of 22%, soil type and land use with each value of 5% and 11%. The results of the mapping of flood-prone areas obtained shallow class, which reached 52,19 hectares, then low reached 1136.25 hectares, moderate flood-prone level 2251.74 hectares, high flood-prone level 884,30 hectares and very high reached 599,03 hectares.

Keywords: Flood Disaster; Analytical Hierarchy Process; Geographic Information System

1. Introduction

The development of Palembang City into a city with rapid infrastructure growth is a perfect thing to support the community's activities and other economic activities. Related to that, it is also in line with the policy direction and development strategy from the document of the Ministry of National Development Planning [1], which makes the Provincial Capital a national activity centre. However, infrastructure growth in line with population growth which unfortunately not accompanied by more attention to the importance of flood disaster management by the related stakeholders, this causes flood disasters in Palembang City to occur more frequently.

Floods in Palembang City cannot be separated because Palembang is a lowland area with a vast swamp area. According to one study [2], the number of swamps in Palembang City is only 5834 hectares, divided into three main types of swamps. The total area of the swamp compared to the total area of Palembang City reaches up to 14.56%, making swamps have a vital role in storing water. The swamps are decreasing due to massive land use conversion activities [3]. Other studies mention the low topography area in Palembang City, approximately 1,6 meters above sea level to 36 meters above sea level [4]. The problems continue because

there are many cases of people who throw garbage carelessly, for example in the river in many places of Palembang City [5].

Various efforts can be made in flood disaster mitigation activities. However, these activities are generally divided into three stages, namely the pre-disaster, during-the-disaster, and post-disaster stages [6]. This research will focus on the pre-disaster stage by making a flood-prone map in the Lambidaro Sub-watershed, Palembang City. Disaster mitigation activities, especially in the pre-disaster section in Palembang City, have been carried out. Based on investigations by various mass media, it is known that the government has provided counselling to people in disaster-prone areas regarding the risk of flooding. The government is also active in revitalizing the river and expanding green areas within the city.

Regarding the making of a flood-prone map in Palembang City, it has been carried out by the local government. However, it updates infrequently, and the scope of the study area is broader than the research area, so it does not produce more detailed results. Furthermore, the method used to produce the flood-prone map is unknown because it was never mentioned before. The choice of the Lambidaro Sub-watershed as a research area is inseparable from the occurrence of several flood events that hit this area. Many researchers discuss flood events in the

Lambidaro Sub-watershed area. One of them discusses the high level of vulnerability to flooding and the existence of several inundation points, such as Jalan Hulubalang, Lorong Damai, and Lorong Dahlia [7]. In other studies, it is also stated that in the Lambidaro Sub-watershed, flood inundation often occurs, so research is needed with a focus on mitigation actions in that area [8].

As previously mentioned, the output of this study is in the form of a thematic map containing information on the distribution of areas in the Lambidaro Sub-watershed in Palembang City based on their level of flood-prone. The selection of the output results in the form of thematic maps aims to facilitate understanding for the broader community

regarding the information on areas that have a high level of flood vulnerability, besides there a study [9] explained that it is appropriate to describe flood-prone areas in the form of a thematic map, another example that there is a research which also uses this GIS in order to determine the flood-prone areas but the study area took place in Kabupaten Kampar [10]. This study aims to identify the dominant factors that influence the level of flood vulnerability in the Lambidaro Sub-watershed, Palembang City, and to determine the distribution of areas based on the level of flood vulnerability in the Lambidaro Sub-watershed, Palembang City. An overview of the research area can be seen in Figure 1 below.

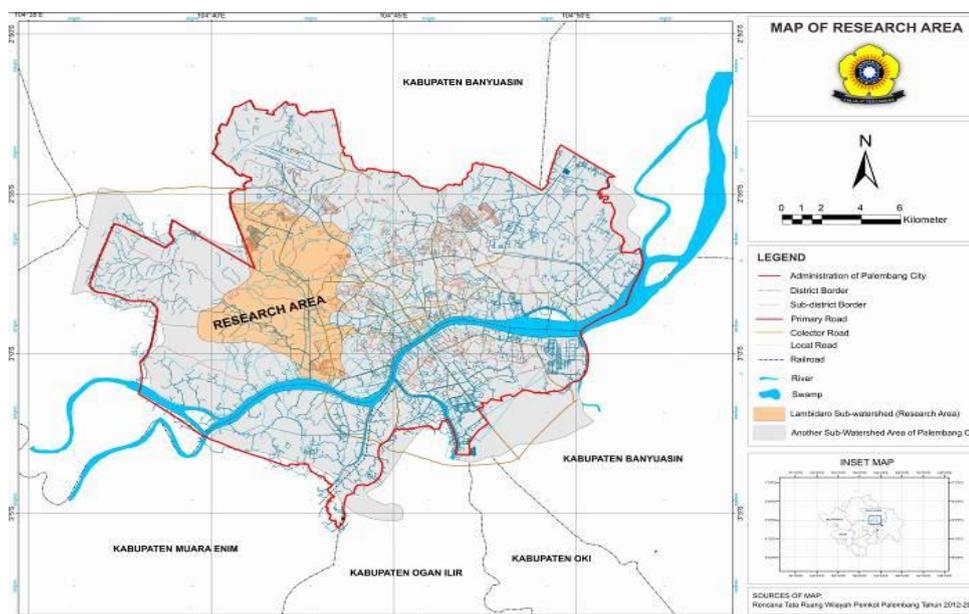


Figure 1. Map of Research Area

2. Material and Methods

2.1. The Use of Data

This study uses several data that play a vital role in the outcome of the research on mapping flood-prone areas in the Lambidaro Sub-watershed, Palembang City. The data used must come from a trusted source so that the output results can be valid. In general, two types of data are used in this study, including spatial and non-spatial data. These two data types will then be entered and processed using the Analytical Hierarchy Process (AHP) and Geographic Information Systems (GIS) methods which will be explained in more detail in the next sub-chapter.

Spatial data consists of several data, including land use, soil type, slope, and elevation, while non-spatial data only consists of one type of data, namely rainfall data. Regarding the source of the data obtained by carrying out data acquisition activities, from this activity, it was found that the source of the data used included primary data and secondary data. Primary

data was carried out by direct observation, precisely during acquiring respondent data by the experts for determining the weight level of AHP and collecting soil infiltration data in the research area.

Secondary data is carried out through research by exploring several things related to various data needs. This activity is carried out to obtain a valid and credible source for the results. For example, land use data can be found on the official page of the Palembang City government, namely geoportal.palembang.go.id. The web page shows that the related institution or service that produces the data is the Dinas Pekerjaan Umum dan Penataan Ruang of Palembang City.

2.2. Classification of Flood Vulnerability Levels

As previously mentioned, this study uses several parameters to determine flood-prone areas in the study area. Each parameter has its classification for the distribution of its vulnerability level. The types of this classification are determined by taking several

references with similarities with the research area, such as the area's characteristics so that more efficient results will be obtained. The following will explain in detail the flood-prone classification for each of these parameters in the following paragraphs.

Classification for parameters of land use and slope uses classification from the same source [11] land use is divided into five types of land use with the lowest score for settlements/industry/offices area with a value of 1 while the highest score is for swamp/lake/bush area with a value of 5, while for the slope is divided into five levels of slope with the lowest value at the degree of slope > 40% and the highest with a degree of slope of 0-2% which accordance with the rule that water will flow faster as the higher of the level.

In the classification for elevation parameters using a reference that divides the elevation level into five classes, the higher the elevation of the research area, the level of flood-prone will be lower and the lower the area, the higher the level of flood-prone [12]. Furthermore, the classification for rainfall also divides into 5 class levels, with the lowest score level having a value of <1500 mm and the highest score having a value of > 3000 mm [13]. Finally, the classification of soil types uses its classification, which is obtained from the processing of primary data, namely the process of calculating soil infiltration, which explains that the puddles will not form in areas that have a low infiltration rate because in those areas the water tends to flow so the puddles will not have time to form, this classification places settlements in areas that have the lowest vulnerability class.

2.3. Analytical Method

2.3.1. The Analysis of AHP

AHP (Analytical Hierarchy Process) is a weighting method by comparing the values between criteria from each pairwise comparison matrix and determining the value of each criterion popularized by Thomas L Saaty. The function of the AHP method can help create the most appropriate decision by forming a hierarchical structure on the considered parameters [14]. Another example comes from another research which discusses the ability of AHP methods in order to acquire the best route for evacuation units [15].

In the AHP method, several principles must be applied so that the most appropriate decision-making can be formed, including the following first is decomposition (arranging a hierarchy), then comparative judgment (comparison of assessment criteria), then synthesis of priority (setting priorities) and the latter is the logical consistency (level of logical consistency). In applying these principles, several steps can be taken [16], including creating the hierarchy, giving criteria weights which in this case is done by the experts, then creating a pairwise comparison matrix, setting synthesis priorities, and finally determining the CI (Consistency Index) and CR (Consistency Ratio) numbers. Calculations from AHP

can be declared valid if the calculated consistency ratio value is ≤ 0.1 . So, if a value exceeding 0.1 is obtained, a recalculation is needed on the comparison matrix.

In processing data using the AHP method, especially in filling the pairwise comparison matrix, respondent data is needed from experts with more expertise and understanding regarding the flood events that hit Palembang City. In this case, the number of respondent data must be more than one or at least two individuals to form a valid calculation [17]. Related to the discussion of these respondents will be discussed in more detail in the results and discussion section.

2.3.2. The Analysis of GIS

At this stage, the parameters considered to be the causes of flooding in the research area are then represented in various maps so that later a map of the distribution of flood-prone areas in the Lambidaro Sub-watershed in Palembang City can be formed. In the analysis stage of the Geographic Information System (GIS), several stages are carried out to achieve valid and accountable output results. The following is the explanation in the next paragraph.

The first step is to process information data input for each parameter using the attribute table features found in various GIS software. The entire GIS software was used in this study, namely QGIS 3.20. After providing information data for each parameter, the next step is to overlap each map layer, which is carried out using the intersect feature. The third stage that can be done is to sort the calculation results. This activity is carried out to get the maximum and minimum values needed for further calculations. After the maximum and minimum values are obtained, the score interval value is determined, which determines the distribution of flood-prone classes. Determining the value of the score interval can be calculated using the formula below:

$$S_s = \frac{S_{max} - S_{min}}{n} \quad (1)$$

Where:

- S_s = Score Interval
- S_{max} = Highest Score
- S_{min} = Lowest Score
- n = number of categories

After the value of the score interval was obtained, a classification of the potential for flooding was carried out into five classes. The determination of the potential for flooding into five classes has been seen in the formula for determining the score value above, precisely on variable n , the number of categories. The determination of flood-prone categories into these five classes is based on research which also applies the AHP and GIS method in determining the flood-prone levels of an area [9]; these five classes are to determine the level of flood-proneness of an area in the research area which is determined by using the

terms very low, low, medium, high, and very high according to the level of its flood-prone.

3. Results and Discussion

3.1. The Analysis of AHP

Based on the data processing activities and methods that have been carried out previously, two types of activities use primary data. Therefore data collection process is carried out directly. The two types of activities are the need for respondent data regarding the AHP method aimed at experts and soil infiltration rate data for each type of soil in the study area. This sub-chapter will discuss related respondent data; this respondent data is carried out using questionnaires addressed to experts with experience and responsibility who are even directly involved in flood control efforts in Palembang City. Based on the respondent criteria, the most suitable sampling method is purposive [20]. The respondents selected are from 2 related institutions in the Palembang City Government, and three other respondents come from the field of academician. All three other respondents come from the Department of Civil Engineering of Sriwijaya University.

After the questionnaire data was processed, the research continued by calculating the combination of five questionnaire data obtained by filling the pairwise comparison matrix by the experts. The calculation result is then input into the value criteria matrix, which then carries out further calculations of weight normalization. The value criteria matrix and weight normalization calculation can be seen in the table below. For information, in the table are the terms CH, which means rainfall, KL, which means slope, EL is elevation, JT stands for soil type, and PL is land use.

Table 1. Criteria Value Matrix

| Criteria | CH | KL | EL | JT | PL |
|----------|------|------|-------|-------|------|
| CH | 1 | 4,23 | 5,40 | 5,80 | 1,89 |
| KL | 0,24 | 1 | 3,04 | 2,91 | 2,48 |
| EL | 0,19 | 0,33 | 1 | 3,43 | 0,78 |
| JT | 0,17 | 0,34 | 0,29 | 1 | 0,19 |
| PL | 0,53 | 0,40 | 1,28 | 5,26 | 1 |
| Amount | 2,12 | 6,31 | 11,01 | 18,40 | 6,34 |

Table 2. Weight Normalization

| Criteria | CH | KL | EL | JT | PL | Sum |
|----------|------|------|------|------|------|------|
| CH | 0,47 | 0,67 | 0,49 | 0,31 | 0,30 | 2,24 |
| KL | 0,11 | 0,16 | 0,28 | 0,16 | 0,39 | 1,09 |
| EL | 0,09 | 0,05 | 0,09 | 0,19 | 0,12 | 0,54 |
| JT | 0,08 | 0,05 | 0,03 | 0,05 | 0,03 | 0,25 |
| PL | 0,24 | 0,06 | 0,11 | 0,28 | 0,16 | 0,87 |
| Sum | 1 | 1 | 1 | 1 | 1 | |

After performing calculations using a criteria value matrix and then weight normalization, the next step was weighting synthesis. This step is done to obtain the weight value of each parameter used in this research. In order to get the synthesis value of each parameter, there is a calculation which needs to be

done by taking the value of the total sum of each row in every parameter used in Table 2 above so the weight value of each parameter is obtained, which can be seen on Table 3 below.

Table 3. Weight value of each parameter

| No | Criteria | Weight |
|----|-----------|--------|
| 1 | Rainfall | 0,45 |
| 2 | Slope | 0,22 |
| 3 | Elevation | 0,11 |
| 4 | Soil Type | 0,05 |
| 5 | Land Use | 0,17 |

The next step was calculating the value to determine the eigenvalue. The eigenvalue calculation is done by performing matrix multiplication between the result of calculation from the criteria value matrix table before with the weight value of each parameter. From the calculation obtained, the eigenvalue of each parameter can be seen in Table 4 below.

Table 4. Eigenvalue of each parameter

| No | Criteria | Eigenvalue |
|----|-----------|------------|
| 1 | Rainfall | 5,732726 |
| 2 | Slope | 5,614665 |
| 3 | Elevation | 5,267433 |
| 4 | Soil Type | 5,409032 |
| 5 | Land Use | 5,143832 |

After having the eigenvalue of each parameter, the next step was performing the calculation to obtain the eigenvalue maximum, and the calculation can be done by averaging each eigenvalue already obtained. From the calculation which has been performed, the eigenvalue maximum is 5,433538. This value is essential in calculating the Consistency Index (CI) and Consistency Ratio (CR). The calculation is done using the second formula shown in the next column.

$$CI = ((\lambda \text{ max} - n) / (n - 1)) \dots \dots \dots (2)$$

Where

CI: Consistency Index
n: number of categories

Below the calculation of CI value in detail

$$\text{Consistency Index} = ((5,433538 - 5) / (5 - 1))$$

$$\text{Consistency Index} = (0,433538) / (4)$$

$$\text{Consistency Index} = 0,108385$$

After the CI value is obtained, the next step is calculating the Consistency Ratio value by dividing the Consistency Index value by the Index Random Consistency value. The value of the Consistency Index is already obtained, as shown above, and the Index Random Consistency is obtained based on the matrix table, which can be seen in Table 5 below [18].

Table 5. List of Random Consistency Index Values

| Matrix Size | IR Value |
|-------------|----------|
| 1, 2 | 0,00 |
| 3 | 0,58 |
| 4 | 1,90 |
| 5 | 1,12 |
| 6 | 1,24 |
| 7 | 1,32 |
| 8 | 1,41 |
| 9 | 1,45 |
| 10 | 1,49 |
| 11 | 1,51 |
| 12 | 1,48 |
| 13 | 1,56 |
| 14 | 1,57 |
| 15 | 1,59 |

Based on the table above, the size of the matrix in this study is included in size 5 because it refers to the number of criteria, for the calculation of CR value can be seen below.

Consistency Ratio = 0,108385 / 1,12
Consistency Ratio = 0,096772

This value fulfils the requirements; namely, the CR value must be <0.1 to indicate that the consistency ratio of the calculations that have been done before is acceptable so that research can continue with the results obtained.

3.2. Soil Infiltration Measurement

This soil infiltration measurement activity is one of the field's direct (primary) data collection activities. This activity was carried out to obtain infiltration rate data from each type of soil found in the Lambidaro Sub-watershed in Palembang City. This infiltration rate data will then become a reference in determining which soil type has a greater level of flood vulnerability than other soil types in the study area. It requires a location representing the conditions of various soil types in the study area to support this. Figure 2 below shows several divisions of soil types found in Palembang City.

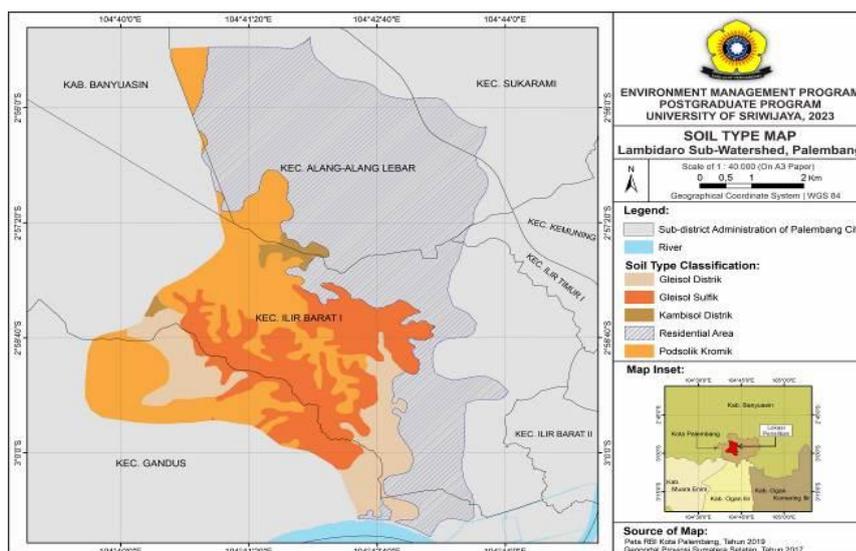


Figure 2. Soil Type Map of Lambidaro Sub-watershed

Measurement of soil infiltration data in the study area was carried out using a double-ring infiltrometer; for technical measurements such as selecting the location for infiltration data collection, they were carried out using the simple random sampling (SRS) method; and for technical calculations and data processing, used previous references [19]. Based on the research results, there were four types of soil found in the study area, namely Gleisol Distrik, Kambisol Distrik, Gleisol Sulfik, and lastly Podsolik Kromik, of the four types of soil, it was found that Gleisol Distrik soil had the highest level of infiltration ability with an infiltration rate of 66.00 cm/hour, then the second Gleisol Sulfik with an infiltration rate of 24.00 cm/hour, then Podsolik Kromik soil type with an infiltration rate of 6,00 cm/hour and finally the Kambisol Distrik with a shallow infiltration rate of 0

cm/hour.

The conclusion that can be drawn from the measurement of infiltration data is that Gleisol Distrik soil has the best infiltration rate, so when it is associated with flood disasters, this soil type has the highest level of flood hazard because the water above the land tends to stagnate first. After that, it begins to drain. Meanwhile, the soil type with the lowest infiltration rate, Kambisol Distrik, can stream the water quickly so that the flood puddle does not have time to form.

3.3. The Analysis of GIS

Further research activities were carried out at this stage by representing the various parameters used as a thematic map containing information related to the scores and weighting values calculated using the

previous AHP analysis method. The first parameter to be discussed is the rainfall parameter. The rainfall parameter significantly influences the incidence of flooding in Palembang City; based on expert judgment among the other five parameters, this parameter has the highest score. Making a rainfall map in the study area using the IDW method with the help of QGIS 3.20 software, data collection is sourced

from the BMKG using data for the last ten years from 2012 to 2021. It is known that in the study area, two areas fall under the rainfall classification [10]. It can be seen in Figure 3 below, one of which has a moderate classification with rainfall ranging from 1.500-2.000 mm/year and other areas having rainfall ranging from 2.000-2.500 mm/year.

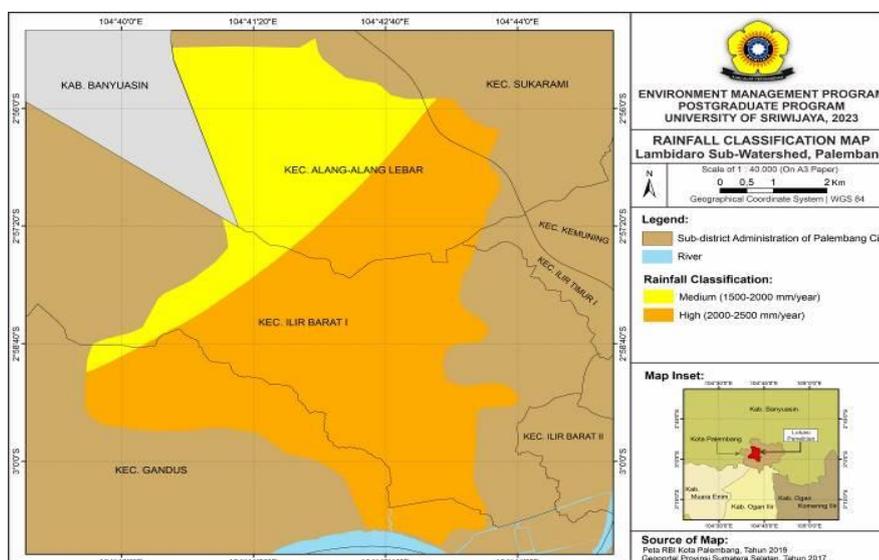


Figure 3. Rainfall Classification Map of Lambidaro Sub-watershed, Palembang City

The following parameter is elevation; we know that water always follows gravity, which means that the lower an area is, the higher the level of flooding. Of course, this parameter is closely related to the parameter we will discuss next: the slope. For the

classification of this elevation, only two areas are included in the research area. However, both have a very high and high influence because Palembang City has a shallow elevation level. More details can be seen in Figure 4, which has been attached.

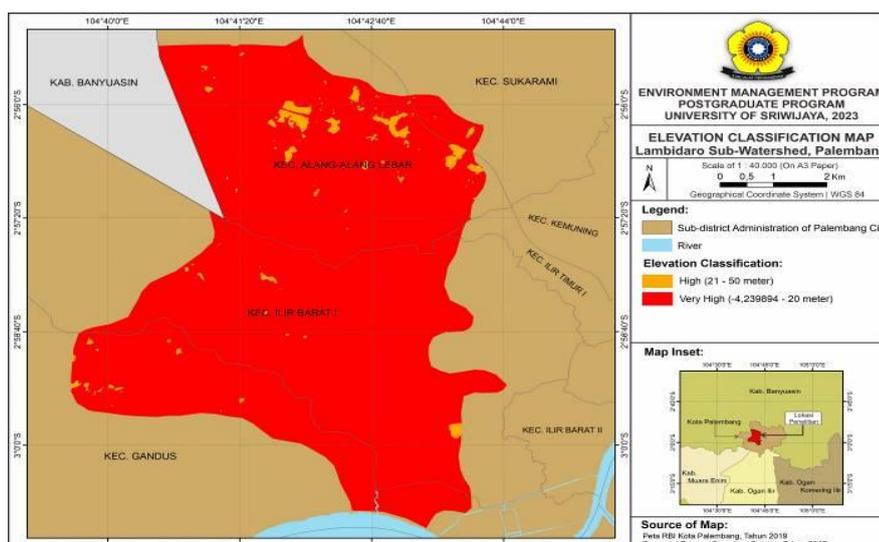


Figure 4. Elevation Classification Map of Lambidaro Sub-watershed, Palembang City

The following parameter after elevation is the slope. This parameter still has continuity with the elevation discussed previously. When it is associated with flood events, the flatter the area when flooded, the longer the flood will settle, and the level of flood-

prone will also increase, as seen in Figure 5 below. The majority of areas in the Lambidaro Sub-watershed are included in areas with flat terrain with a slope below 15% so that if there is inundation, the inundation will last quite a long time.

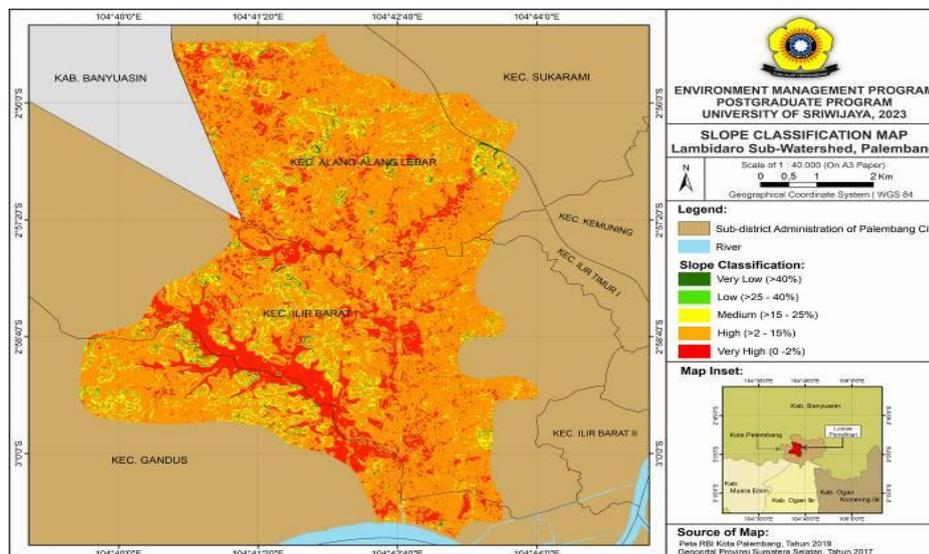


Figure 5. Slope Classification Map of Lambidaro Sub-watershed, Palembang City

The soil type parameter does not use a specific reference in dividing its level of vulnerability, as is the case with other parameters. However, it uses its classification, obtained from soil infiltration measurements described in the previous sub-chapter. In the research area, the classification of soil types is divided into five classes, with residential areas

included in the class with a shallow level of flood proneness and Gleisol Distrik soil types with a very high level of flood proneness. This soil type parameter is included in the fifth order based on the weight value calculation. More details can be seen in Figure 6 below.

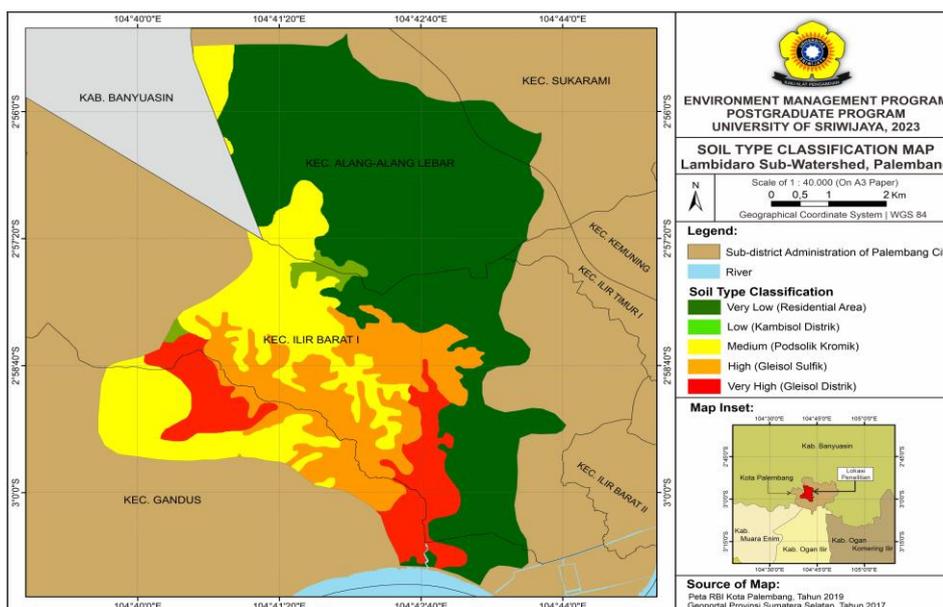


Figure 6. Soil Type Classification Map of Lambidaro Sub-watershed, Palembang City

The land use parameter is the last parameter to be discussed. This parameter uses the classification described in the previous section; based on this classification, there are five types of land use according to the classification type used, which can be seen in Figure 7 below. The research area is

dominated by residential, industrial, or office areas, which in the predetermined classification, are included in a very low classification in terms of flood proneness. In addition, in terms of weight value calculation, this land use parameter ranks third compared to the other parameters.

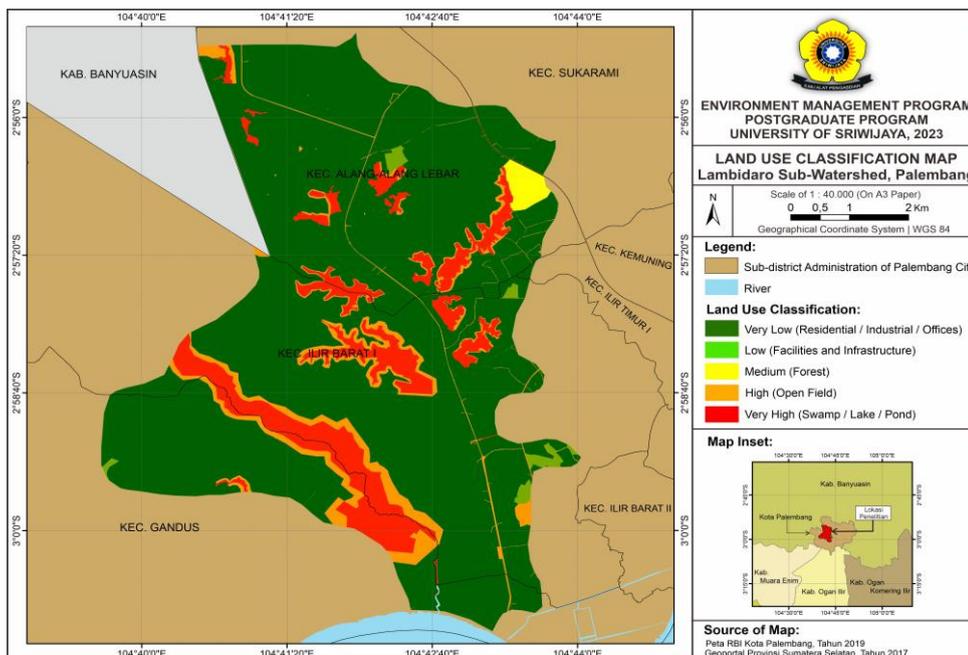


Figure 7. Land Use Classification Map of Lambidaro Sub-watershed, Palembang City

3.4. Distribution of Flood-Prone Areas in the Lambidaro Sub-watershed, Palembang City

After all the maps for each parameter have been obtained and information data has been provided, the next step is for each of these parameters to be overlapped or overlaid between one map and another so that a flood-prone class is formed, as seen in Figure 8 below. The figure states that the area with the shallow level of vulnerability only covers up to 1% of

the total area. The low level of flood-prone covers up to 23%, the medium level of flood-prone covers most of the research area, up to 46% and then for the area with the high level covers up to 17,5%. In comparison, very high vulnerability covers up to 12,5% for each class level. For details of the area with the level of flood vulnerability can be seen in Table 6 below.

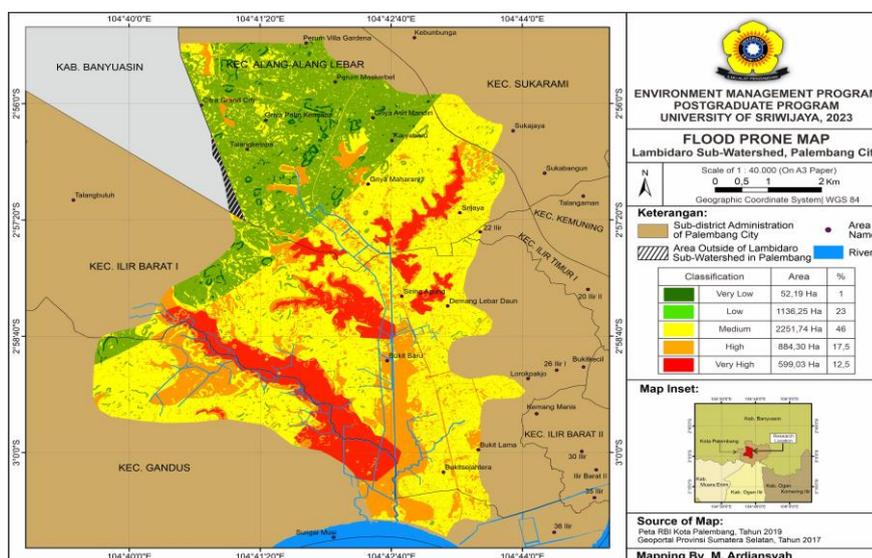


Figure 8. Flood-Prone Map of Lambidaro Sub-watershed, Palembang City

Table 6. Total Area Based on Flood-Prone Level

| No. | Flood-Prone Level | Total Area (Hectare) |
|-----|-------------------|----------------------|
| 1 | Very Low | 52,19 |
| 2 | Low | 1136,25 |
| 3 | Medium | 2251,74 |
| 4 | High | 884,30 |
| 5 | Very High | 599,03 |

Based on the flood hazard map shown in Figure 8 above, the information is obtained from a very high level of flood hazard-hitting areas with shallow elevation topography and very flat slopes. It is suspected that severe flooding can occur in the area due to conditions when rain occurs, so the area functions as a storage area for the surrounding area. Based on the explanation, more attention can be paid to areas that are in areas with low elevation and slope so that when a flood occurs, it can be appropriately handled and smoothly without causing any loss.

4. Conclusion

Based on the discussion above, the following conclusions can be drawn:

1. Five parameters are used in making flood hazard maps in the Lambidaro Sub-watershed, Palembang City, including rainfall, elevation, slope, soil type and land use. Based on the results of the analysis using the AHP method, of the five parameters, rainfall has the highest priority value with a percentage of 45%, then the slope parameter with a priority value of 22% then, the land use parameter with a priority value of 17%, in fourth place there are the elevation parameter slopes with a priority value percentage of 11%, lastly the soil type parameter with a percentage of 5%.
2. Based on the results of the zoning analysis of flood-prone levels in the Lambidaro Sub-watershed. Palembang City has five flood vulnerability levels: very low, low, medium, high and very high. Areas with a very high level of flood hazard include a research area with an area of 599,03 hectares (12,5%), then areas with a high level of flooding cover an area of 884,30 hectares (17,5%). Areas with a moderate level of flood hazard cover almost half of the research area, i.e. 2251,74 hectares (46%), then areas with a low level of flood hazard cover an area of 1136,25 hectares (23%). Finally, areas with very low levels of flood hazard only cover a tiny portion of the research area, namely only 52,19 hectares (1%) respectively.

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