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ISSN: 2354-5844(Print)
ISSN: 2477-5223 (Online)

# Spatial Modeling of Flood-Risk Areas in Palembang City, South Sumatera

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## ABSTRACT

Flooding in the city of Palembang is a serious problem for the government because it causes large property losses and continues to spread. Spatial analysis to identify flood-risk areas is very necessary to provide information as a first step in future flood disaster mitigation efforts. This research aims to identify factors that influence flood levels in Palembang City and create a spatial model of flood-risk areas in Palembang City. This research uses two approaches, namely Analytical Hierarchy Process (AHP) and Geographic Information System (GIS). The results show that, the parameter that has the highest influence is land use at 37 %, then the rainfall parameter at 21 %, the slope parameter at 17 %, drainage density parameter at 12 %, elevation parameter at 7 % and soil type parameter at 6 %. Based on the GIS method, it is known that the flood-risk very low level covering an area of 1,141.69 hectares (3.17 %), the low flood-risk level covering an area of 4,889.44 hectares (13.58 %). The moderate flood-risk level area (the most extensive level) is 12,125.47 hectares (33.67 %), the high flood-risk level is 9,183.52 hectares (25.50 %) and the very high flood-risk level area is 8.656,54 hectares (24.09 %).

**Keywords:** Analytical Hierarchy Process, Floods, Geographic Information Systems

## INTRODUCTION

The city of Palembang has an average height of 8 meters above sea level which geomorphologically is considered lowland, mostly consisting of swamps and rivers (Kamil *et al*., 2023). Teristiandi, (2020) stated that in Palembang City, a swamp was found which was then filled in to become a residential area, or shophouse.

The development activities carried out are generally dilema related to the environment (Harahap and Anisyah, 2021), so as the development of residential areas in Palembang City which mainly as a result of the increase in population (Amalia, *et al*., 2022). In line with this, it has led to an increase in the number of people fulfilling housing needs as residential areas. Land conversion the increase in surface water run off coefficient that occurs in water cathchment areas causes water that should seep into the ground to decrease, resulting in an increase in the run off coefficient of surface water (Imanudin *et al*., 2013). In run offprevention and control, policy makers must have adequate data and information regarding influencing factors (Wildayana, 2015).

The city of Palembang has a water area which is divided into 21 sub-watershed areas, among which 19 sub-watershed areas directly flow into the Musi River (Edison & Syarifudin, 2022). Direct flow into the Musi River causes runoff, which if there is a tide in sea level will cause water to overflow from the river onto land accompanied by high rainfall intensity (Marlina & Andayani, 2018). An event when water caused by rain occurs for a long time so that it inundates an area because it exceeds capacity is called a flood (Hengkelare *et al*., 2021). Floods have become a natural disaster that often hits the city of Palembang.

The moderate to heavy rain categories that falls on Palembang City, even within 3 hours, can cause puddles along highways and even submerge residential areas (Syarifudin & Destania, 2019). The problem of flooding in the city of Palembang is a serious problem for the government because it causes large property losses and continues to spread. Spatial analysis to identify flood-risk areas is very necessary to provide information as a first step in future flood disaster mitigation efforts.

Analytical Hierarchy Process (AHP) which is a weighting method that compares criteria or parameters of each pairwise comparison matrix where the value of one other criterion is determined is used in many researches. This method is used to calculate the most influential factors in causing flooding. According to

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ISSN: 2354-5844(Print)
ISSN: 2477-5223 (Online)

Bansal *et al*., (2022) GIS is effective and efficient in efforts to map flood-Risk areas using the overlay or overlay method of flood-causing variables. According to Rakuasa & Latue, (2023), GIS can strengthen people capacity to deal with future floods.

By combining AHP and GIS, the distribution of floods can be determined through spatial modeling of flood-risk areas by analyzing aspects that influence their height and distribution. Apart from that, the spatial model of flood-risk areas also has an important role which can be used as a basis for determining policies in controlling floods in Palembang.

## METHODOLOGY

### Location and Time

This research was carried out from August 2023 to January 2024. This research activity was carried out in the River Watershed area of Palembang City, that flow directly into the Musi River. The area of the research area was 36,084.74 hectares with the largest watershed being the Borang watershed (7,011.68 hectares) and the smallest area being the Kidul watershed (279.97 hectares).

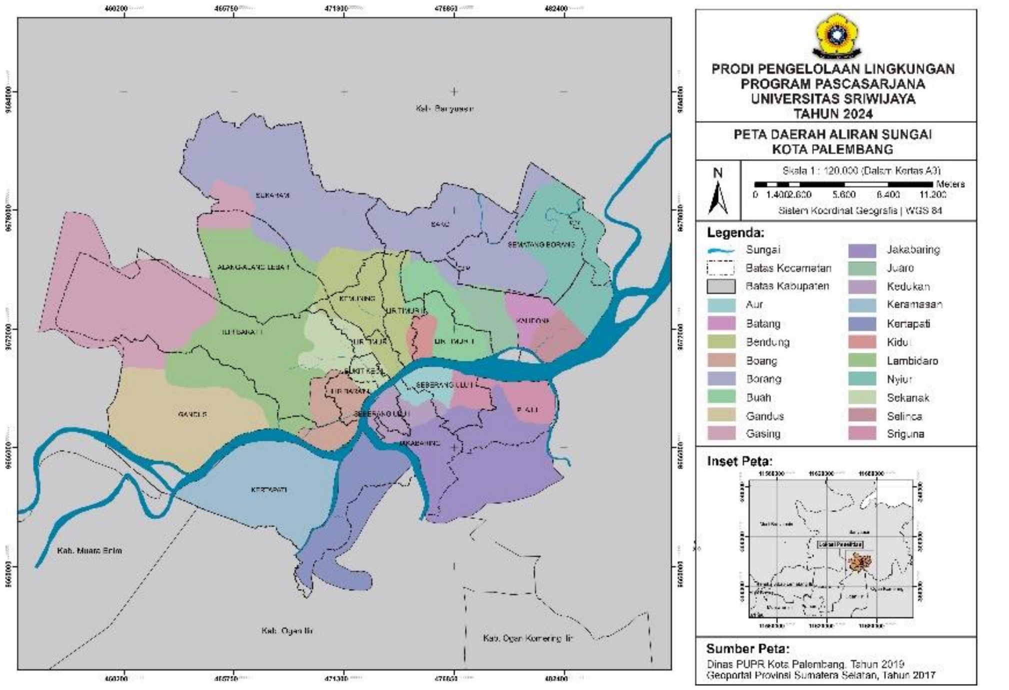


Figure 1. The research location

### Methods

The first stage of this research was data collection. Data were obtained from downloads on websites or based on archive data from relevant agencies. Meanwhile, primary data collection was carried out using field observation and interview methods. Data processing was carried out using Analytical Hierarchy Process (AHP) as well as Geographic Information System (GIS) to produce output in the form of a spatial model of flood-risk areas. There are four basic stages in AHP, namely decomposition (arranging a hierarchy), comparative judgment (comparing criteria assessments), synthesis of priority (determining priorities) and finally logical consistency (level of logical consistency) (Ardiansyah, *et al.*, 2023). The results obtained were then be used to determine the Consistency Index (CI) (formula 1) and Consistency Ratio (CR) (formula 2) numbers as a validation test of the respondent data. The consistency ratio value with a value $\leq$ 0.1 was be declared as valid.

$$CI = (\lambda \text{ maks} - n) / (n - 1) \quad \ldots(1)$$

$$CR = CI / RI \quad \ldots(2)$$

The stages in the Geographic Information System



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(GIS) carried out in this research are the overlay of maps for each parameter along with information data resulting from the AHP method using ArcGIS software. The overlay process is carried out to produce a classification of flood-risk areas with the help of score intervals (formula 3).

$$S_s = \frac{S_{max} - S_{min}}{n} \quad \ldots(3)$$

The final stage was model testing as model validation from the results obtained. This was by comparing data from field observations with spatial models. At this stage produceds an overall accuracy (formula 4) value as a validation value for the spatial model of flood-risk areas.

$$Overall\ Accuracy = \frac{A + D}{A + B + C + D} \times 100\ \% \ldots(4)$$

### Weighting and Scoring

The weighting and scoring stages are carried out for determining areas risk to flooding based on processed AHP results. The classification used in this research uses references from several previous studies which have the same characteristics of the research area as the Palembang City area.

Slope parameters, in this parameter a classification with 5 classes is obtained (table 1). Based on the classification, it is known that the higher the slope level, then the risk of flooding will be lower.

Table 1. Slope classification for flood risk areas (Wismarini and Sukur, 2015)

| No. | Slope Class (%) | Score |
|---|---|---|
| 1. | 0 - 2 | 5 |
| 2. | > 2 – 15 | 4 |
| 3. | > 15 – 25 | 3 |
| 4. | > 25 – 40 | 2 |
| 5. | > 40 | 1 |

Land use parameters, in this parameter a classification is obtained with 5 classes (table 2). Based on the classification, it is known that land use can affect water absorption capacity.

Table 2. Land use classification for flood risk areas (Wismarini and Sukur, 2015)

| No. | Land Use Class | Score |
|---|---|---|
| 1. | Residential / Industrial / Office | 5 |
| 2. | Infrastructure Facilities | 4 |
| 3. | Open Field | 3 |
| 4. | Swamp / Lake / Thicket | 2 |
| 5. | Forest | 1 |

Bulk Parameters, this parameter provides a classification with 5 classes (table 3). Based on the classification, it is known that the higher the rainfall in an area, the higher the level of flood risk, and vice versa, the lower it is, the lower the level of flood risk.

Table 3. Rainfall classification for flood risk areas (Primayuda, 2006)

| No. | Rainfall Class (mm/year) | Score |
|---|---|---|
| 1. | > 3000 | 5 |
| 2. | 2501 – 3000 | 4 |
| 3. | 2001 – 2500 | 3 |
| 4. | 1501 – 2000 | 2 |
| 5. | < 1500 | 1 |

The elevation and drainage density parameter uses classification from direct results which is an adaptation



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ISSN: 2354-5844(Print)
ISSN: 2477-5223 (Online)

of previous research. This is because based on searches related to this classification, no classification was found that was appropriate to the research area. The same thing with soil type parameters, because direct analysis was carried out regarding soil characteristics and texture, it did not use references like previous research, thus forming its own classification. The classification of soil types is carried out based on the National Soil Classification Technical Guidelines by the Agricultural Research and Development Agency in 2016 with descriptions of soil characteristics such as parent material, horizon characteristics, hydromorphic characteristics and soil texture so that the water absorption and water passing capacity analysis is then carried out.

## RESULTS AND DISCUSSION

### Analytical Hierarchy Process

The first step taken was to create a hierarchy, determining the parameters used in analyzing flood-risk areas. The parameters were chosen based on references in previous research, which were then adjusted to the conditions in Palembang City to produce 6 parameters, namely rainfall (CH), slope (KM), elevation (KT), soil type (JT), land use (PL) and drainage density (DD).

The second stage was comparative judgment (comparison of assessment criteria) by experts in the field of flood control in Palembang City. The selection of respondents was based on those holding responsibility in the relevant agencies, and having experience and even being directly involved in flood control activities. Based on the requirements of the AHP method, more than two people and an odd number were selected. Data from the questionnaire results were obtained from a combined calculation of all questionnaires which were then processed into a matrix of criteria values (Table 4) and normalized weights (Table 5).

Table 4. Criteria value matrix

| **Criteria** | **CH** | **KM** | **KT** | **J.T** | **PL** | **DD** | **Description** |
|---|---|---|---|---|---|---|---|
| **CH** | 1 | 2.46 | 4.43 | 3.07 | 0.36 | 1.31 | Rainfall |
| **KM** | 0.41 | 1 | 4.62 | 2.68 | 0.32 | 2.31 | Slope |
| **KT** | 0.23 | 0.22 | 1 | 2.10 | 0.29 | 0.34 | Elevation |
| **J.T** | 0.33 | 0.37 | 0.48 | 1 | 0.18 | 0.94 | Type of soil |
| **PL** | 2.78 | 3.13 | 3.45 | 5.56 | 1 | 2.80 | Land Use |
| **DD** | 0.76 | 0.43 | 2.94 | 1.06 | 0.36 | 1 | Drainage Density |
| **Sum** | **5.50** | **7.61** | **16.92** | **15.47** | **2.51** | **8.70** | |

Table 5. Normalization of weights

| **Criteria** | **CH** | **KM** | **KT** | **J.T** | **PL** | **DD** | **Sum** |
|---|---|---|---|---|---|---|---|
| **CH** | 0.18184 | 0.32336 | 0.26188 | 0.19845 | 0.14358 | 0.15057 | 1.25972 |
| **KM** | 0.07392 | 0.13144 | 0.27311 | 0.17324 | 0.12763 | 0.26551 | 1.04488 |
| **KT** | 0.04104 | 0.02845 | 0.05911 | 0.13575 | 0.11566 | 0.03908 | 0.41912 |
| **J.T** | 0.05923 | 0.04904 | 0.02815 | 0.06464 | 0.07179 | 0.10804 | 0.38091 |
| **PL** | 0.50513 | 0.41077 | 0.20385 | 0.35913 | 0.39886 | 0.32183 | 2,19959 |
| **DD** | 0.13881 | 0.05690 | 0.17387 | 0.06877 | 0.14245 | 0.11494 | 0.69575 |
| **Sum** | **1** | **1** | **1** | **1** | **1** | **1** | |

The next stage was synthesis of priorities (determining priorities). This stage was carried out to produce a weight value (Table 6) for each parameter or to order the priority level of each cause of flooding (by adding up each parameter based on the data in the criterion value matrix table that previously obtained).

Table 6. Weight values

| **No.** | **Criteria** | **Weight** |
|---|---|---|
| 1. | Rainfall | 0.21 |
| 2. | Slope | 0.17 |
| 3. | Elevation | 0.07 |
| 4. | Type of soil | 0.06 |
| 5. | Land Use | 0.37 |
| 6. | Drainage Density | 0.12 |



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ISSN: 2354-5844(Print)
ISSN: 2477-5223 (Online)

After obtaining the weight value, the eigenvalue (lambda value) was calculated. The results of the eigenvalue calculation (lambda value) (Table 7) are obtained from the results of matrix multiplication, namely between the calculation results from the criterion value matrix with the weight value of each parameter. This was then be used in the final data processing for determining flood-risk areas in Palembang City.

CI = (6.50276 - 6) / (6 - 1)
= (0.50276) / (5)
= (0.10055)
CR = CI / RI
= (0.10055) / (1.24)
= (0.08)

The calculation results that have been obtained are then carried out by calculating the average of each parameter to produce a maximum eigenvalue (lambda value) of 6.50276.

The final stage of AHP is logical consistency (level logical consistency). This stage was carried out using the equation Consistency Index (CI) and Consistency Ratio (CR) values. IR value (i.e., 1.24) was based on value determination *index random consistency* (Handayani *et al*., 2023).

The CR value obtained in this research was 0.08, identifying that the data assessment by the selected judgment is declared consistent and acceptable.

Table 7. Eigenvalue

| No. | Criteria | *Eigenvalues* |
|---|---|---|
| 1. | Rainfall | 6.79480 |
| 2. | Slope | 6.53201 |
| 3. | Elevation | 6.21304 |
| 4. | Type of soil | 6.38104 |
| 5. | Land Use | 6.58015 |
| 6. | Drainage Density | 6.51553 |

## Geographic Information Systems

The stages in the geographic information system carried out in this research are the overlay of maps for each parameter along with information data resulting from the AHP method. Estimating a value at locations that were not sampled was also racked out know the distribution of the secondary data that has been obtained. The overlay process was carried out to produce a classification of flood-risk areas.

The results of the combined weight calculations, was obtained and sorted in terms of data size from the smallest value to the data with the largest value to make it easier to determine the score interval. This stage last stage was carried out by presenting the 6 parameters used in the form of a thematic map based on each classification, where the map provides information related to weighting and scoring which has been calculated using AHP analysis. Final results were in the level form as very low flood-risk level, low flood-risk level, moderate flood-risk level, high flood-risk level and very high flood-risk level.

ISSN: 2354-5844(Print)
ISSN: 2477-5223 (Online)

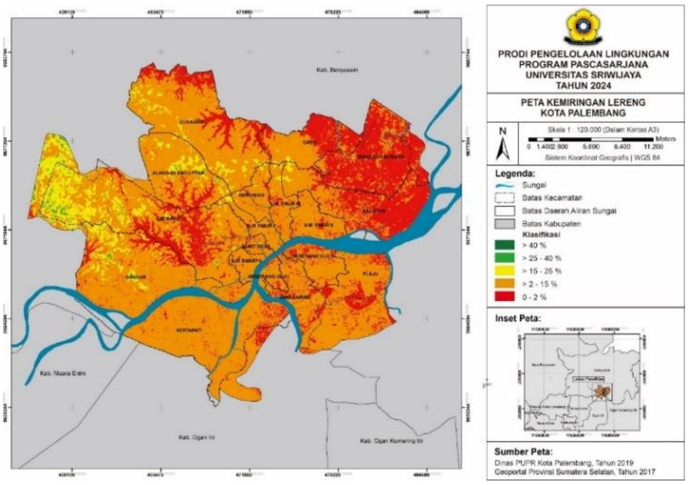


Figure 2. Slope map of Palembang city
Source: Palembang city DEM data (2019)

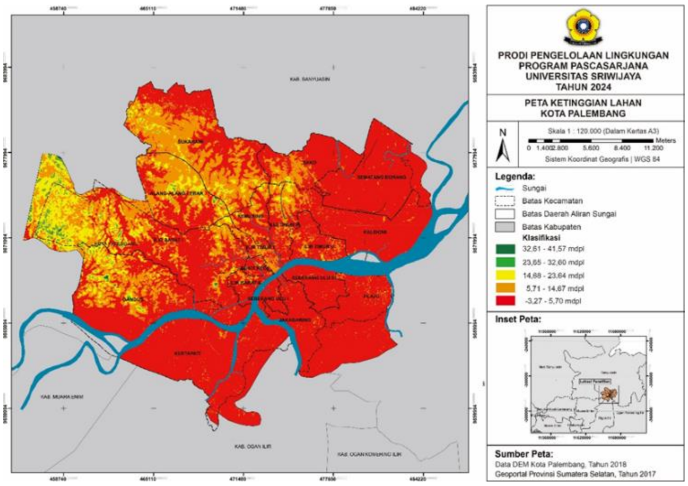


Figure 3. Land elevation map of Palembang city
Source: Palembang city DEM data (2019)

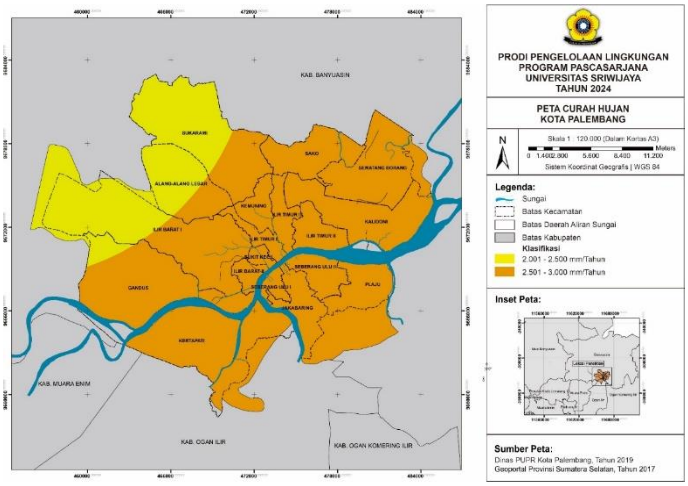


Figure 4. Palembang city rainfall map
Source: South Sumatra Class I Climatology Station (2013-2022)

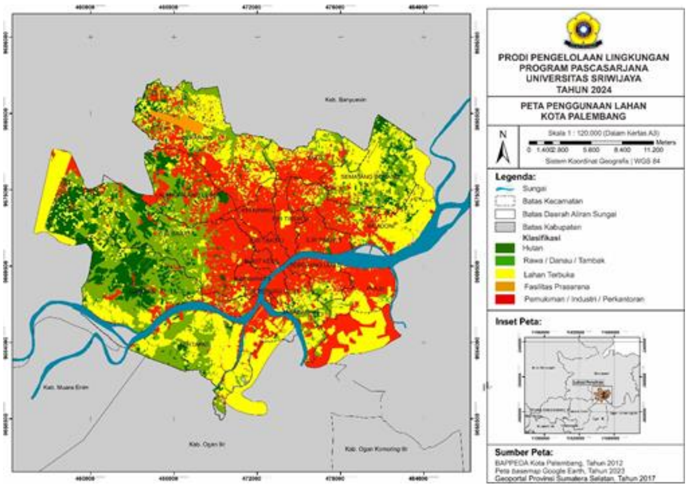


Figure 5. Palembang city land use map
Source: Palembang City BAPPEDA (2012), Google Earth basemap (2023)

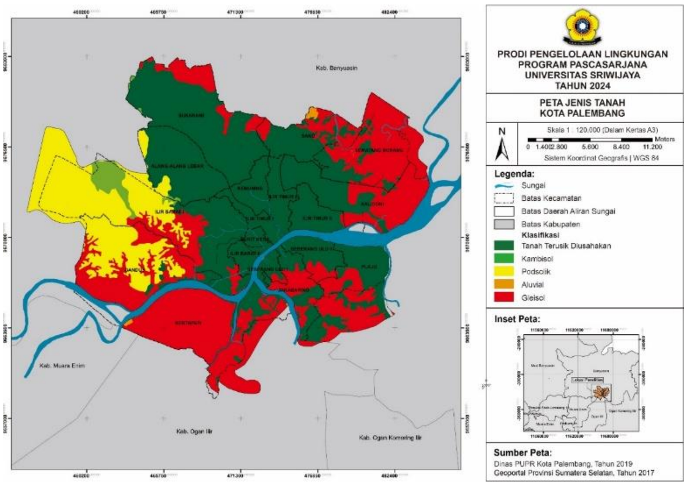


Figure 6. Soil Type Map of Palembang city
Source: Palembang City BBSDLP (2017)

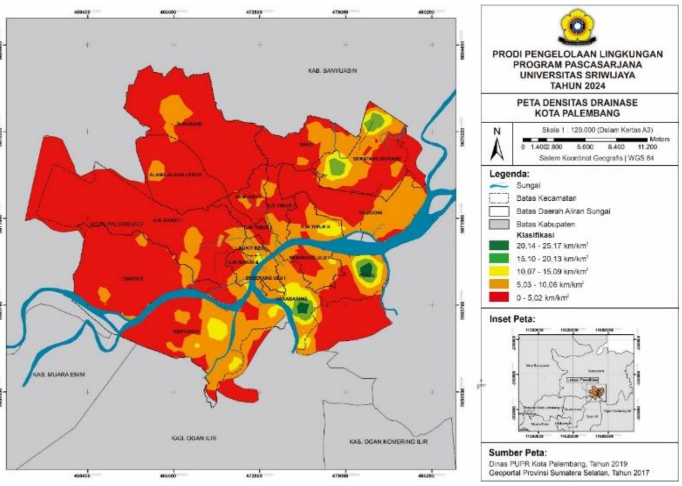


Figure 7. Palembang city density map
Source: Palembang City PUPR (2019)



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ISSN: 2354-5844(Print)
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Developing a map of slope and Elevation based on Palembang City DEM data obtained from the official government website, tanahair.indonesia.go.id/demnas, the DEM data is presented representing 2018. Developing a rainfall map in the research area was carried out using the Inverse Distance Weighting (IDW) with Arcgis software. Palembang City Rainfall Data for the period 2012 to 2021 was obtained from the South Sumatra Class I Climatology Station. The creation of the Palembang City land use map was sourced from Palembang City land use data obtained from BAPPEDA Palembang City, this data represents the year 2012 and then overlaid with a basemap map from Google Earth in 2023. The soil type map for Palembang City was obtained from BBSDLP Palembang City, this data represents the year 2017 which is used to present the distribution of soil types in Palembang City. Then classified according to their ability to pass water, based on analysis of the characteristics and texture of the soil. Developing a drainage density map based on River and Drainage data obtained from the PUPR Palembang City.

**Spatial Model of Flood Risk Areas in Palembang**

The final stage in creating a spatial model in this research is the overlay process based on the thematic map for each parameter that has been obtained. After analyzing each existing parameter, the results obtained show that the area prone to flooding in Palembang City is dominated by a medium level, namely 33.67% or an area of 12,125.47 hectares, with the highest distribution being in the Borang watershed area of 3,006.66 hectares, then the Lambidaro watershed area of 2,146.41 hectares and the Keramasan watershed area of 1,347.95 hectares. Based on the analysis, it is known that at very high levels of flood risk the land has a very low elevation or is a swamp area which is then filled in, housing is built but is not equipped with good drainage. Another problem which is a non-technical cause is the tidal events of the Musi River which occur because the season has a real effect on the depth of the groundwater level where the groundwater level is located near the ground surface and can be above the ground surface or inundate the ground during the rainy season (Imanudin, *et al.*, 2023). An alternative to controlling water levels by implementing subsurface drainage which can act as water retention during the rainy season so excessive flooding can be minimized (Bakri, *et al.*, 2015).

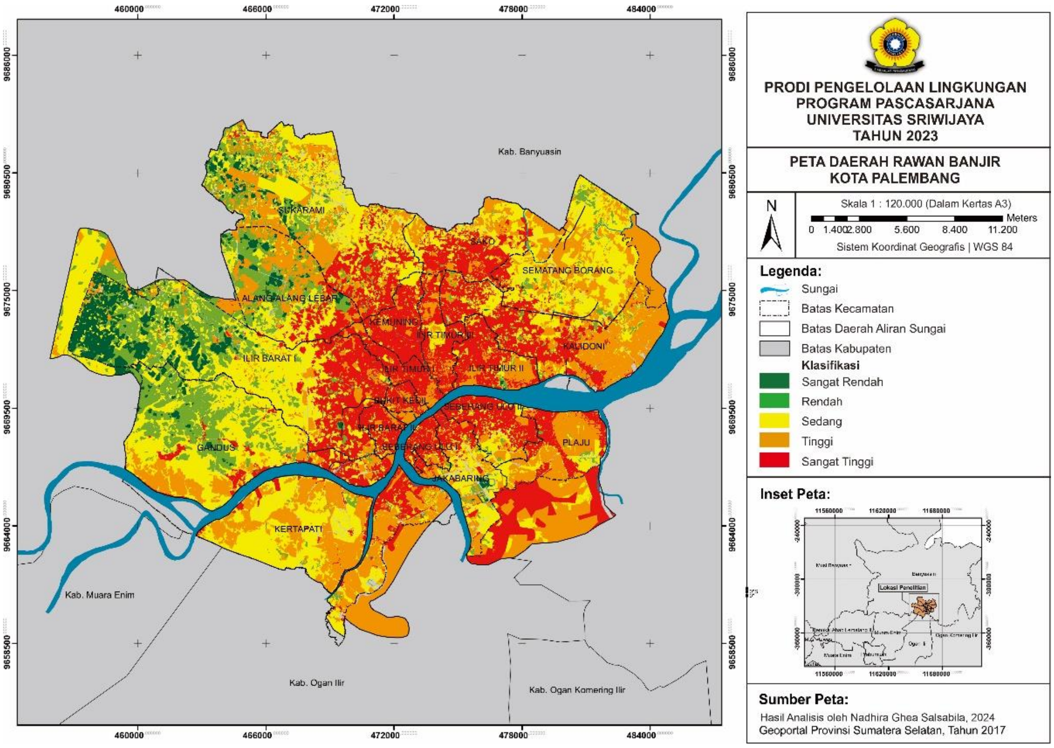


Figure 8. Spatial model of flood-risk areas in Palembang city

ISSN: 2354-5844(Print)
ISSN: 2477-5223 (Online)

Table 8. Areas at flood-risk level in Palembang city

| No. | Flood-Risk Level | Area | |
|---|---|---|---|
| | | Hectares (Ha) | Percentage (%) |
| 1. | Very low | 1.141,69 | 3.17 |
| 2. | Low | 4.889,44 | 13.58 |
| 3. | Moderate | 12.125,47 | 33.67 |
| 4. | High | 9.183,52 | 25.50 |
| 5. | Very high | 8.676,54 | 24.09 |

The results show that the flood-risk area in Palembang City is dominated by moderate flood-risk level, 33.67 % and high flood-risk level, 25.50 %. What's even more unfortunate is that the area is very low flood risk levels at only 3.17 %. The most influential parameter is land use at 37 %, Palembang City has a high population density, especially those living on the banks of the Musi River (Faturrakhman, *et al*., 2023). This should be of great concern to policy holders and the public regarding the condition of the surrounding environment. Another aspect mentioned in research by Ali & Putri (2023) is that the city of Palembang is currently still having difficulty providing adequate housing, so people are eroding swamp areas, there by risking increasing flooding problems.

## Validation of Field Conditions

Validation activities in the form of field observation and interview with residents around the incident in the research area were carried out directly. Sample selection used Simple Random Sampling (SRS) Method, that is by being selected was 2 river basin areas for each flood-risk level classification based on the spatial model of flood risk areas that had been obtained previously. The classification of flood-risk levels obtained was 5 classes so that there were 10 observation points for field validation and interviews. Apart from that, pay attention to the distance of one point from another point so that it can represent another area.

*Very Low Flood Risk Level*

Point 1 is part of the Lambidaro watershed which is the Bukit Siguntang area. This area is one of the highest areas in Palembang City with the highest peak around 29-30 meters above sea level, no puddles were found around the observation area (Figure 9a). Point 2 is part of the Gasing watershed which is in Ilir Barat I District. At the time the observation was carried out, it had rained 2 days earlier but no puddles were found, it can be seen that the water was collected in retention ponds located around the observation location so that there is runoff that inundates the road surface (Figure 9b).


(a) (b)

Figure 9. Areas with very low flood risk level
(a) observation point in Lambidaro watershed (b) observation point in Gasing watershed



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ISSN: 2354-5844(Print)
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*Low Flood Risk Level*

Point 3 is part of the watershed documents, located at the *Sri Mulyono Herlambang* Air Force Complex. When the observations were made, it had rained the previous day and flushed the area but no puddles were found (Figure 10a). Point 4 is part of the Gandus watershed, which is in the Indonesian National Army 200 Raider area. When the observations were made, the area had rained 1 day before the observations but did not leave any puddles. It can also be seen that there are still lots of trees in this area (Figure 10b).


(a) (b)

Figure 10. Areas with low flood risk level
(a) observation point in Borang watershed (b) observation point in Gandus watershed

*Moderate Flood Risk Level*

Point 5 is part of the Nyiur watershed, at the time of the observation was carried out, it had rained in the area 1 day before the observation for almost 5 hours and puddles were found that were still around the resident's houses and it was also discovered that the drainage was poorly maintained so that the water flow was blocked (Figure 11a). Point 6 is part of the Jakabaring watershed, the rain had just stopped after pouring in the area for 1 hour and there were remaining puddles, the area lacked drainage so the water was stagnant (Figure 11b).


(a) (b)

Figure 11. Areas with moderate flood risk level
(a) observation point in Nyiur watershed (b) observation point in Jakabaring watershed

*High Flood Risk Level*

Point 7 is part of Keramasan watershed in Kertapati District, Karya Jaya. At the time the observations were made, the area had not received rain for 2 days but



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ISSN: 2354-5844(Print)
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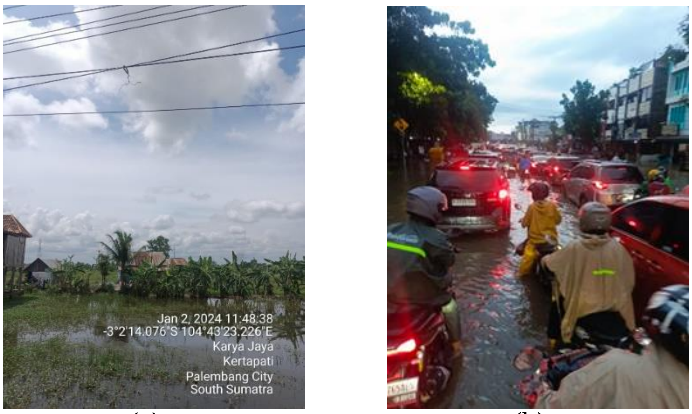
flooding still occurred around residential areas (Figure 12a). Point 8 is part of Sekanak watershed, rain was pouring down in the area and there were puddles (figure 12b). It can be seen that in this area the flood was quite high, causing several vehicles to break down.




(a) (b)

Figure 12. Areas with high flood risk level
(a) observation point in Keramasan watershed (b) observation point in Sekanak watershed

*Very High Flood Risk Level*

Point 9 is part of the Bendung watershed which is in front of SMA Ignatius Global School. At the time the observation was carried out, it had been raining in the area since the evening before the observation for almost 5 hours and there were still puddles around the observation point (Figure 13a). Point 10 is part of the Buah watershed which is on Jalan Sapta Marga, it was raining and water overflowed onto the road (Figure 13b) the height of the puddle was up to an adult's thighs.


(a) (b)

Figure 13. Areas with very high flood risk level
(a) observation point in Bendung watershed (b) observation point in Buah watershed



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### Model Validation

In this study, the confusion matrix method was used to carry out validation tests. Based on the calculation stages, it is obtained that the overall accuracy (level of accuracy) value is 90 %. The concept of calculating the overall accuracy value is to compare the data that is identified correctly with the overall data to obtain a percentage that shows the accuracy of the model data (Cahyaningtias, 2018).

The accuracy value is influenced by the parameters used, parameter selection is based on theory and previous research. The accuracy values obtained show that the spatial model that has been produced provides a fairly accurate illustration as a basis for providing policies in flood-risk areas in Palembang City.

Policies for anticipating flood events based on model validation tests require a Flood Control System Plan to be implemented. In its application, a retention pond with a large storage is required (Zarei *et al*., 2023) which of course must be close to the river flow area, where this system is a pumping stage which is carried out when the water is receding.

The water in the retention pond is channeled to the river basin, which then flows directly into the Musi River. Pumping is carried out as a form of Flood Control Planning System so that when the Musi River is high, the retention pond will function properly to hold water so that it does not overflow into the surrounding area and cause flooding in Palembang City.

Based on the Palembang City Planning Agency, it is stated that the ideal retention ponds in Palembang City are 103. But now, only around 50 retention ponds are available and not all of them are working optimally. This shows that there is a need for expansion to be carried out to overcome flooding events in Palembang City. However, limited land is an obstacle in carrying out this effort. In line with this, the government's policy in handling permits to build settlements on land that is not supposed to, such as filling up swamp areas, must be strictly enforced and monitored more strictly, because this greatly affects the absorption area in Palembang City.

Apart from that, adapting to flood events that occur is also a form of anticipation that can be done. In line with Sastrodihardjo (2010) in the book Overcoming Floods Comprehensively, the expression that we can apply is "We Must Learn to Live With Floods". The effort is to build a house on stilts with a structure that is elevated from the ground level. Stilt houses are typical buildings in Palembang City, especially on the banks of the Musi River, with a dominance of wooden structures and semi-permanent two-story structures, as well as specific interiors (Prima, 2022) as a form of adaptation. This policy is an alternative that is very necessary in lowland areas, considering that the city of Palembang has an average height of 8 meters above sea level and is greatly influenced by the tides of the Musi River.

## CONCLUSIONS

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

1. Based on the AHP method, the parameters have the highest influence is land use at 37 %, then the rainfall parameter at 21 %, the slope parameter at 17 %, the drainage density parameter at 12 %, the elevation at 7 % and the soil type at 6 %.
2. Based on the spatial model of flood-risk areas, it is known that there are five classes divided into very low flood-risk areas with an area of 1,141.69 hectares (3.17 %), then areas with low flood levels of 4,889.44 hectares (13.58 %). The area with a moderate flood-risk level is the largest level, namely 12,125.47 hectares (33.67 %), then the area with a high flood-risk level is 9,183.52 hectares (25.50 %) and the area with a very high level of flood risk is 8,676.54 hectares (24.09 %).

## ACKNOWLEDGMENTS

This research was part of Magister thesis of Nadhira Ghea Salsabila, S.P., under supervision of Prof. Dr. Momon Sodik Imanudin, SP, M.Sc., Dr-Ing. Listen Prima, ST, M. Planning and Dr. Ir. Bakri, M.P. Many thanks from authors to all of those who have been involved in finishing this project.

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-----Accredited by Directorate General of Higher Education Indonesia, No. 158/E/KPT/2021, Valid until July 2025----

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