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Spatial Modeling of Flood Vulnerability Using Google Earth Engine (Case Study: *Pasar Minggu*, Pancoran and Tebet Districts)

Pemodelan Ruang Kerendahan Banjir Menggunakan Enjin Google Earth (Kajian Kes: Pasar Minggu, Pancoran dan Daerah Tebet)

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ABSTRACT

Flooding is a common problem in some parts of Indonesia, especially in urban areas with high population density. South Jakarta, especially in Pasar Minggu, Pancoran and Tebet Districts, has become one of the flood-prone areas. The main contributing factors include high rainfall, residential areas near rivers, lack of water absorption zones, and littering practices. To identify areas with the highest flood vulnerability, remote sensing using Google Earth Engine (GEE) has been implemented. This technique allows mapping flood-prone areas through satellite image analysis. Based on research, Tebet Regency has an average high level of flood vulnerability, while Pasar Minggu and Pancoran are included in the medium category. The accuracy of the analysis obtained is quite good, with a Kappa Accuracy of 83%, an Overall Accuracy of 91%, and an AUC of 0.732. This research contributes to developing a WebGIS-based flood vulnerability mapping system with direct integration of spatial modelling results from Google Earth Engine (GEE), which is still rarely applied applicatively in dense urban areas such as South Jakarta. The study also proposes a combination of new spatial weights with rigorous accuracy validation using Kappa and AUC values.

Keywords: Google Earth Engine; Flood, WebGIS; South Jakarta; Remote Sensing.

INTRODUCTION

Flooding is a common problem in several areas in Indonesia, especially in densely populated urban areas. Flood disasters in Indonesia that occur every year have been proven to have an impact on human life and the environment, especially in terms of loss of life and material damage. The flood phenomenon is an issue that often arises in several regions of Indonesia, especially in urban areas with high population density (Putra et al, 2017). Every year, more than 300 flood incidents occur in Indonesia, with impacts spanning more than 150,000 hectares of land and affecting about 1,000,000 people (Hernoza, et al. 2020). DKI Jakarta, which is the capital of Indonesia, was also not spared from the disaster. Based on the 2020 Indonesian Disaster Risk Index (IRBI), DKI Jakarta Province has a risk index of 64.02 (medium). In other words.

GEE offers a lot of convenience in data processing, both from a hardware and software perspective. This algorithm is often used to separate water bodies from land (Prayogo, 2021). Based on the research conducted by A. G. Ramadhan et al. entitled Analysis of Flood-prone Map Weighting Method and Flood Inundation Map NDWI Flood Incident Method (Case Study: Sidoarjo Regency), from the results of NDWI analysis, it was found that the flood inundation area is 5.56% of the total area of Sidoarjo Regency and most of it is in the eastern part of Sidoarjo Regency (Ramadhan, Handayani, Darmianto, 2022). This technique uses one of the cloud-based GIS processing platforms for analysis and decision-making. The analysis was then carried out to evaluate flood-prone areas using flood hazard maps, so that the distribution of flood vulnerability can be identified based on the area in each vulnerability class. However, a number of previous studies have not fully integrated remote sensing results into spatial information systems directly as a basis for flood disaster mitigation decision-making.

PROBLEM STATEMENT

Based on information from BNPB, DKI Jakarta faces the threat of earthquakes, floods, landslides, drought, extreme weather, and extreme waves/abrasion. (BNPB, 2021). One of the areas in DKI Jakarta that often experiences flooding is in the South Jakarta City area, especially in Pasar Minggu, Pancoran, and Tebet Districts (Triana, El-Mahmudi & Bekti, 2022). The main factors causing flooding in the area include several things. Starting from the position of settlements close to the river. High rainfall also has the potential to cause flooding. Littering can also increase the risk of flooding because it blocks drainage systems. The lack of water absorption areas that can absorb high rainwater content is also a factor that affects the occurrence of floods (Anggraeni, Marpaung & Hartuti, 2018).

Therefore, it is very important to know which areas have the highest level of flood susceptibility. One way to do this is to map flood-prone areas using remote sensing. One of the remote sensing methods is to use the Google Earth Engine (GEE) platform. Google Earth Engine is a cloud computing platform designed to store and process large data sets (at petabyte scale) for analysis and final decision-making. The accessible and user-friendly front-end provides a convenient access environment for the development of interactive data and algorithms. Users can also add and curate their own data and collections, while using Google Cloud resources to handle all processing.

LITERATURE REVIEWS

Table 1: Literature reviews

No.	Author Name, Journal Title, Journal Name and Year	Result	Conclusion
1.	"Analysis of Flood-prone Maps with Weighting Method and Flood Inundation Maps with NDWI Method on Flood Events (Case Study: Sidoarjo Regency)"	The results of this study reveal the method of the analysis results NDWI It is known that the area of flood inundation is 5.56% from area Sidoarjo Regency and dominant in part East of Sidoarjo Regency.	This study explains the method of flood-prone points using the weighting method and the NDWI method.

No.	Author Name, Journal Title, Journal Name and Year	Result	Conclusion
2.	"Mapping Flood-prone Areas Using remote sensing with the methods of Normal Difference Vegetation Index, Normal Difference Water Index, and Simple Additive Weighting (Case Study: Bengkulu City)"	This research produced sub-districts that are very prone to flood disasters, namely Kampung Melayu, Muara Bangkahulu and Selebar Districts. The sub-district that is prone to flooding is Sungai Serut. And the sub-districts that have a safe level are the sub-districts of Singaranpati, Teluk Segara, Ratu Agung, Ratu Samban and Gading Cempaka.	This study explains the flood-prone point method using NDVI, NDWI and SAW methods.
3.	"Detection of inundation flood vulnerability using Topographic Wet Index"	The magnitude of the TWI value is associated with high flood susceptibility. Based on the calculation of the TWI value, flood-prone areas.	This study explains the method of flood-prone points using Topography
4.	"Mapping Flood-prone Areas in Ambon City Using Geographic Information Systems"	Kebumen Regency includes Adimulyo District, Mirit District, Ambal District, Sruwu District, Rorowokele District and Buayan District.	Wet Index (TWI).
		The results of the study show that Teluk Ambon District has the largest area in each class of flood swamps in Ambon City compared to other sub-districts, this is because the sub-district is the largest in Ambon City. Meanwhile, the area of residential land spread across high-vulnerability class areas has the largest percentage of area, which is 2,222.06 ha. A total of 2,214.67 ha of medium-vulnerable class settlements spread across five sub-districts in Ambon City.	This study explains the mapping of flood-prone areas using the Geographic Information System.

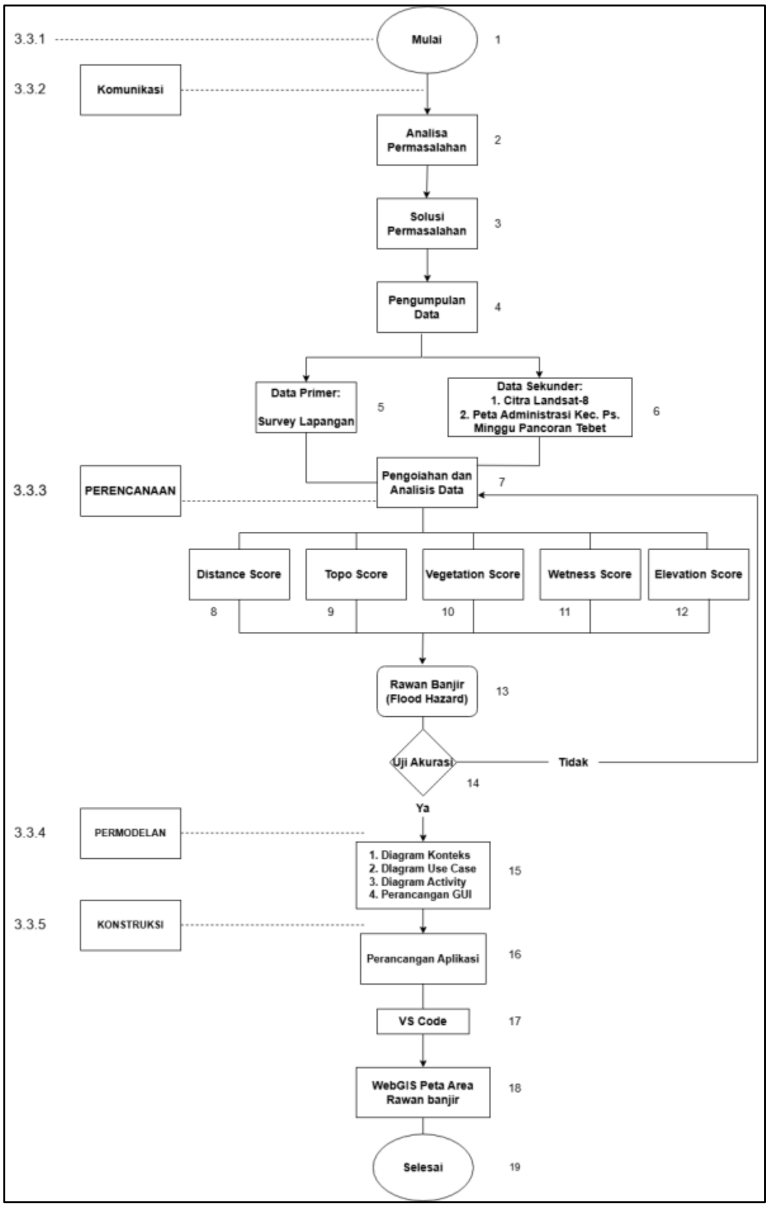
No.	Author Name, Journal Title, Journal Name and Year	Result	Conclusion
5.	"Modeling Rob Flood in the North Jakarta Region Using Geographic Information Systems"	Using a model of inundation height between 0.4 and 1.96 m, the study predicts that four out of six sub-districts in North Jakarta will be affected by flash floods. The research used secondary data, and there were Recommendations for field surveys or interferometry radar imagery to obtain more precise initial data on inundation height.	This study explains the modeling of flash flood prone in the North Jakarta area using the Geographic Information System method.

Previous studies generally only used NDWI or SAW without strong spatial validation or integration into WebGIS systems. In addition, there has not been any multi-year monitoring as was done in this study.

METHODOLOGY

The stages of this research method can be seen in Figure 1 below.

Figure 1: Frame of mind



Communication

This stage includes data collection and problem analysis to facilitate the analysis process of flood disaster identification in Pasar Minggu, Pancoran, and Tebet Districts, South Jakarta.

Planning

At this planning stage, data collection is carried out, which involves collecting information needed for research, analysis, or decision-making purposes. Data collection is a systematic step that must be followed to ensure that the data obtained meets the purpose of the research or analysis being conducted. In this study, there are secondary data and primary data.

In this study, the weighting process of scores for each environmental parameter was also carried out using a raster approach based on Google Earth Engine (GEE). The parameters used include NDWI (Normalized Difference Water Index), NDVI (Normalized Difference Vegetation Index), and Elevation (DEM – Digital Elevation Model). The weighting algorithm follows these steps:

1. Retrieve satellite imagery data from Landsat 8.
2. Calculate the value of NDWI and NDVI.
3. Extracts elevation values from DEM.
4. Classify these values into five classes of vulnerabilities using the Jenks Natural Breaks method.
5. Assign a score for each class (1–5) according to the risk level.
6. Calculates the final score of the vulnerability based on the weight of each parameter.

The logical flow diagram of this process can be visualized in the form of a flowchart consisting of data input blocks, index processing (NDWI, NDVI, DEM), classification, weighting, and the final result in the form of a flood vulnerability map.

The weights of each parameter are determined based on the Analytical Hierarchy Process (AHP) approach and refer to previous literature studies and consultation with urban disaster experts. The assessment is carried out by paying attention to the relative influence of each parameter on the occurrence of flooding. NDWI is given a higher weight because of its proximity to surface water features, followed by elevation which affects water flow, and NDVI as an indicator of vegetation cover that plays a role in water absorption. The determination of this weight refers to Ramadhan et al. (2022) and the results of discussions with local hydrologists, so that the initial weights were obtained as follows: $w_1 = 0.4$ (NDWI), $w_2 = 0.3$ (Elevation), and $w_3 = 0.3$ (NDVI). This score can be adjusted to a different advanced study or area of study.

Modelling

The data collected, both primary and secondary, will be processed and analyzed. At this stage, several parameters are used, namely:

Distance Score: Measures the distance from a specific point.

1. Topo Score: Measures the distance from a specific point. Assess the topographic condition or altitude of the area.
2. Vegetation Score: Assesses the level of vegetation in the area.
3. Wet Score: Assesses the level of vegetation in the area. Assess soil moisture or moisture content.
4. Altitude Score: Measures the height of a place above sea level.

Construction

At this stage of construction, the system design is carried out using the QGISWEB platform. The languages used by this system are JavaScript (JS), Hypertext Preprocessor (PHP), and Cascading Style Sheets (CSS). The system can be run using an offline server.

FINDINGS AND DISCUSSION

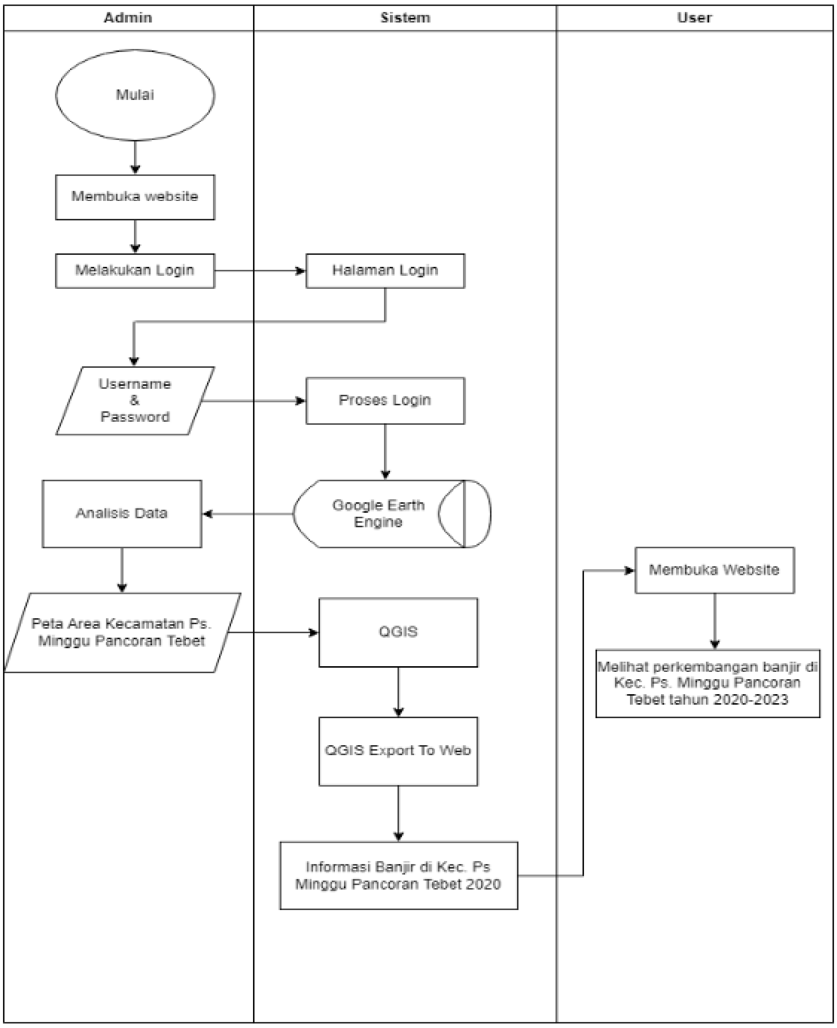
Identify the Problem

The analysis of the problem shows that flood disasters occurred in 3 sub-districts in South Jakarta in January 2020, resulting in material and non-material losses. The main factors causing flooding are high rainfall and geographical conditions close to tributaries. Currently, there is no information system that contains information about flood disasters in Pasar Minggu, Pancoran, and Tebet Districts.

Problem Solution

Create an information system about post-flood disasters with analysis using the GEE platform.

Figure 2: Proposed system



Data Collection

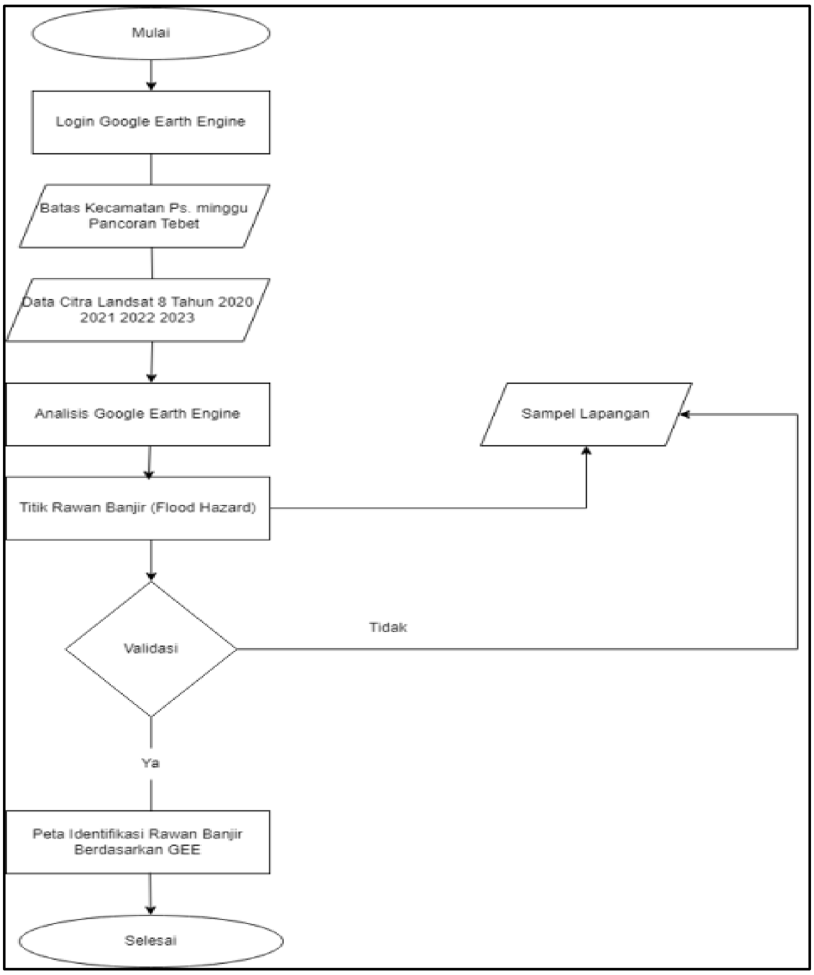
At the data collection stage, secondary and primary data are used. Secondary data was obtained from Landsat 8 imagery through the GEE platform, while primary data was obtained directly from field surveys.

Planning

Data Processing

Data management and analysis involves spatial data, including Landsat 8 imagery for flood point data and administrative boundaries of Pasar Minggu, Pancoran, and Tebet Districts, South Jakarta, Special Capital Region (DKI) Jakarta. The following is shown in Figure 3.

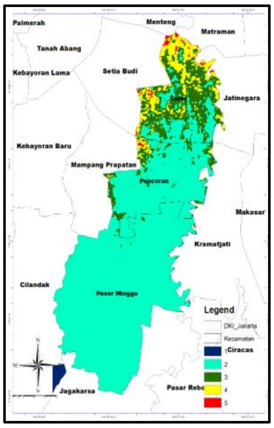
Figure 3: Data processing flow diagram



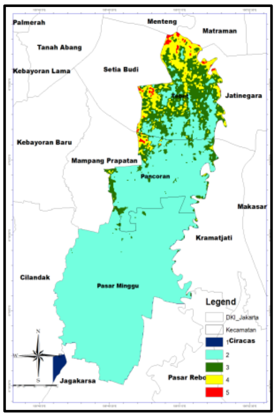
RESULTS OF FLOOD VULNERABILITY DETECTION ANALYSIS IN GEE

Figure 4 is a visualization of the weighting of the humidity score based on the DEM (Elevation Score) value. Blue indicates that the area is quite high, while red indicates that the area is lowland.

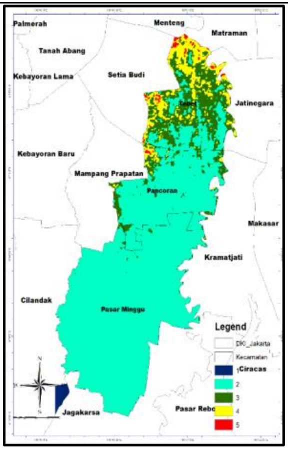
Figure 4: Elevation score period 2020-2023



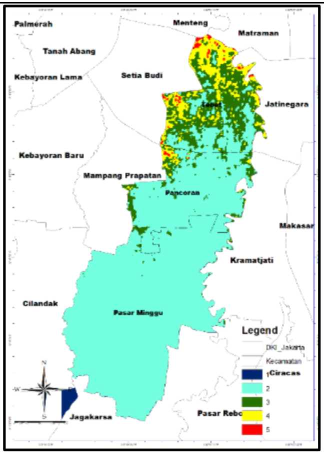
A. 2020 Elevation Score



B. Elevation Score 2021



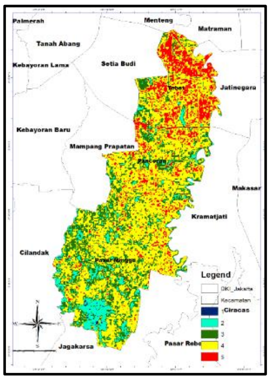
C. Elevation Score in 2022



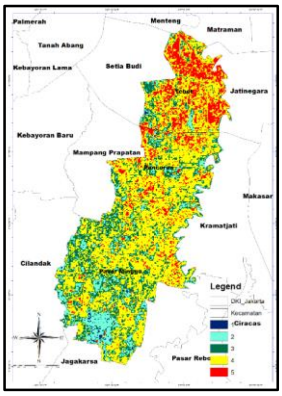
D. Elevation Score in 2023

Figure 5 is a visualization of the weighting of the NDVI (Vegetation Score). With blue indicating that the vegetation in the area is quite good, while red indicates poor vegetation conditions.

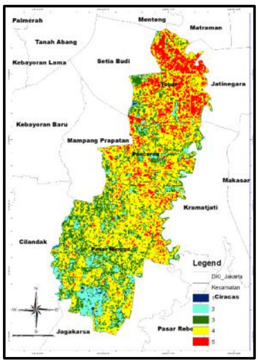
Figure 5: Vegetation score period 2020-2023



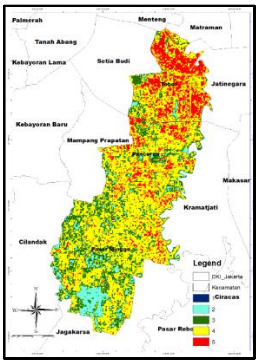
A. Vegetation Score in 2020



B. Vegetation Score in 2021



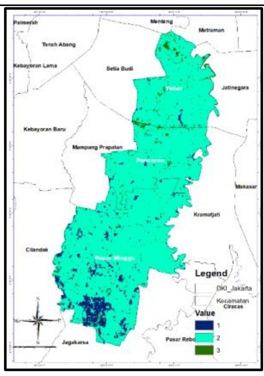
C. Vegetation Score in 2022



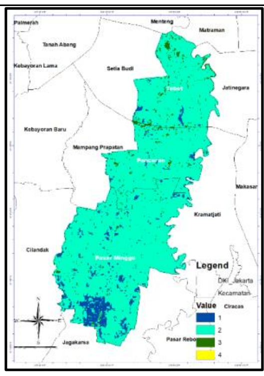
D. Vegetation Score in 2023

Figure 6 is a visualization of the weighting of the moisture score based on the NDWI (Wetness Score) value. The dark blue colour indicates an area that is quite far from the body of water, while the colour green indicates proximity to the body of water.

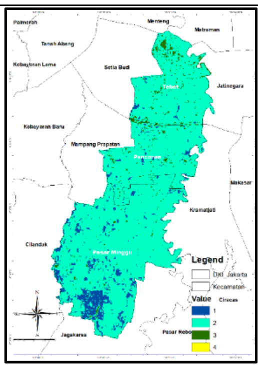
Figure 6: Wet score period 2020-2023



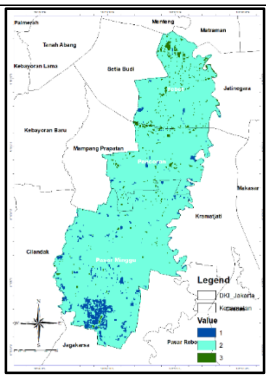
A. Wet Score in 2020



B. Wet Score in 2021



C. Wet Scores in 2022



D. Wet Score in 2023

Figure 7 is a visualization of flood-prone points based on previously calculated values. Dark blue indicates areas that are safe from flooding, while light blue indicates areas with low flood rates, then green indicates moderate flood levels, and yellow indicates relatively high flood rates.

Figure 7: Flood-prone areas for the 2020-2023 period

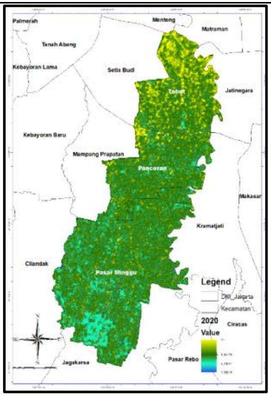
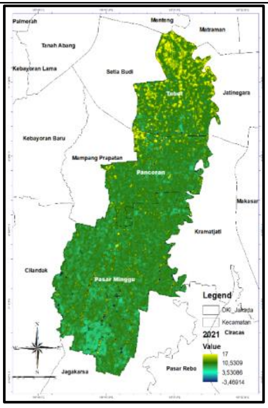
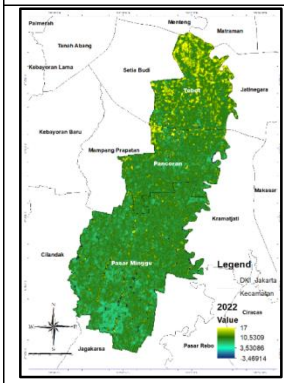
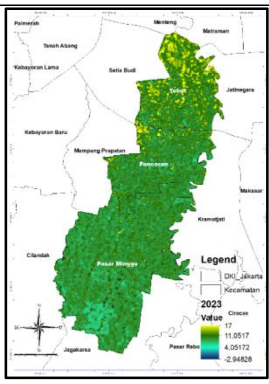
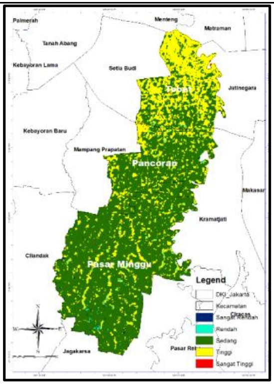
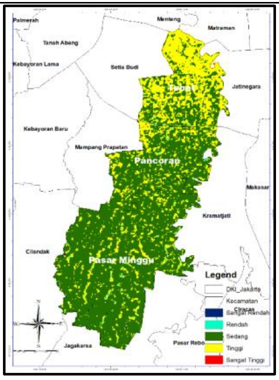
 A. Flood-prone points in 2020	 B. Flood-prone Points in 2021
 C. Flood-prone points in 2022	 D. Flood-prone points in 2023

Figure 8 is a visualization of flood danger points that have been delimited. Red indicates a very high level of flood risk, then yellow indicates a fairly high level of flood risk, green indicates a moderate level of flood risk, and finally light blue indicates a low level of flood risk and dark blue indicates a very low level of flood risk.

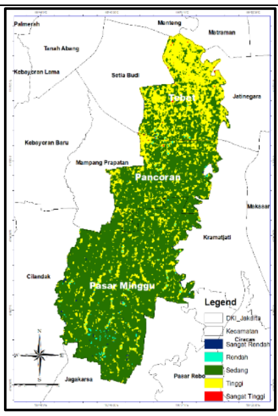
Figure *8*: Flood hazards for the 2020-2023 flood period



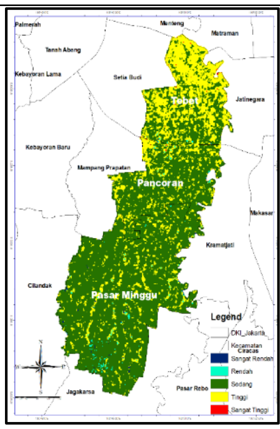
A. Flood Hazards in 2020



B. Flood Hazards in 2021



C. Flood Hazards in 2022



D. Flood Hazards in 2023

In Table 2, there is a weighting of the score applied using GEE. A score of 1, indicated in dark blue, represents a very low category; a score of 2 indicates a low category; a score of 3 indicates a medium category; a score of 4 indicates a high category; and a score of 5 reflects a very high category.

Table 2: Score weighting (natural jenks)

Color	Score	Golongan
Dark blue	1	Very low
Light Blue/*Cian*	2	Low
Green	3	Keep
Yellow	4	Tall
Red	5	Very high

Source: David V. Mako, Fajar K. Rohmala (2024)

The following in figure 9 is a comparison of the results of the detection of flood-prone points from 2020 to 2023 in Pasar Minggu, Pancoran, and Tebet Districts, South Jakarta City.

Figure 9: Results of detection of flood-prone areas in 2020

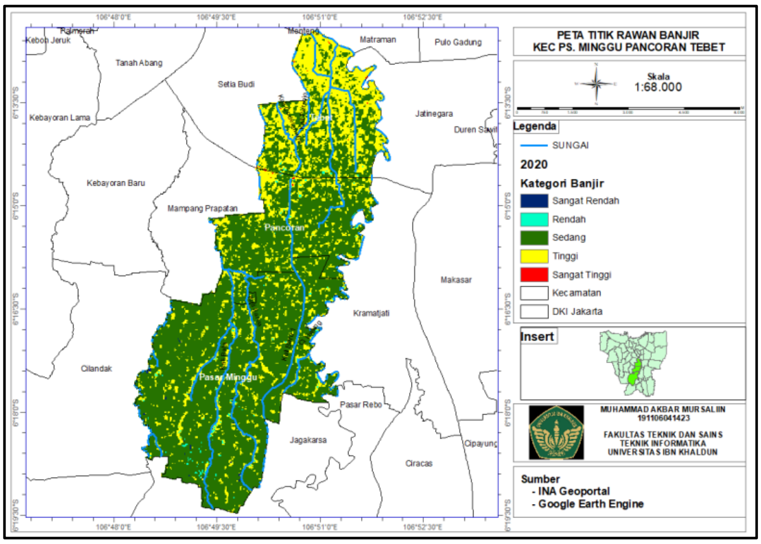


Figure 10: Results of detection of flood-prone areas in 2021

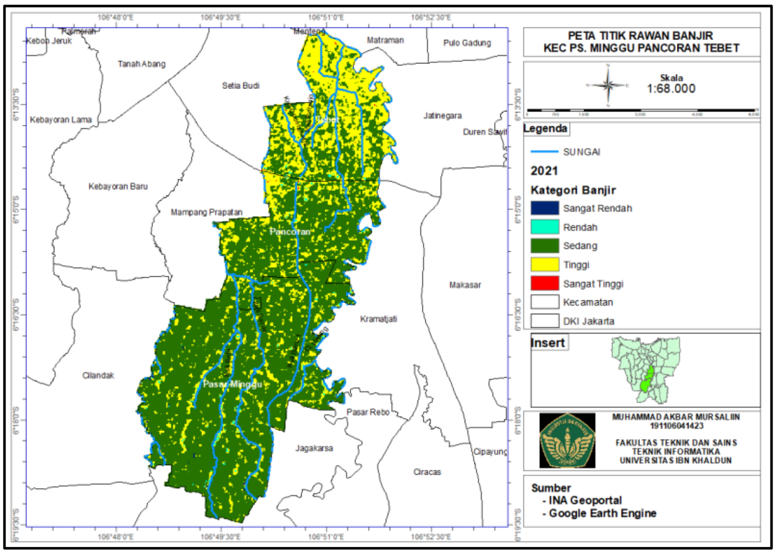


Figure 11: Results of detection of flood-prone areas in 2022

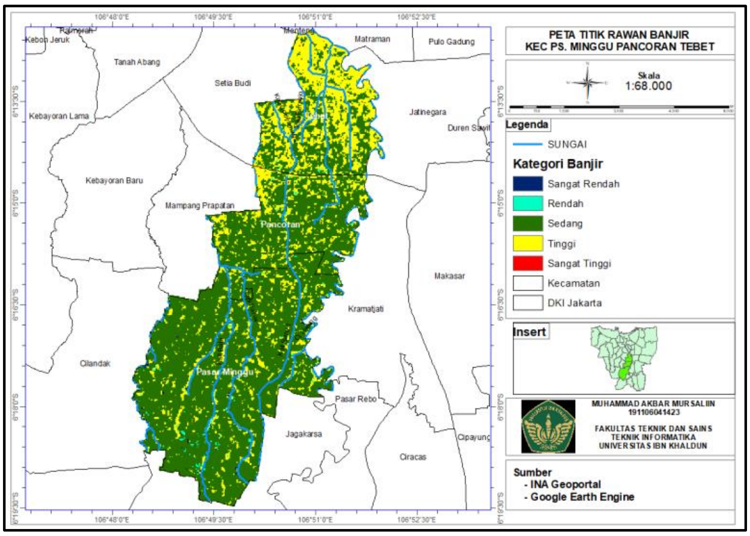
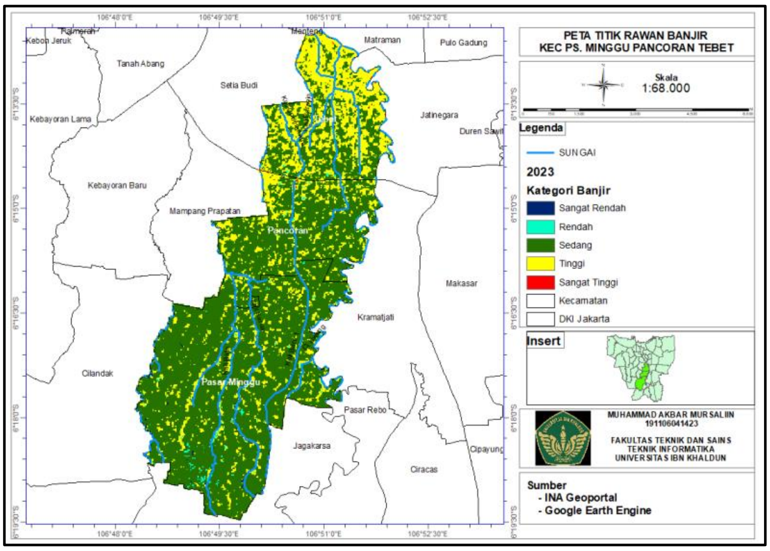


Figure 12: Results of detection of flood-prone areas in 2023



Flood-Prone Areas Based On Flood Hazard Index

Flood Hazard Areas Based on Flood Hazard Index Below is the total flood detection area covering 3 sub-districts in South Jakarta City for 2020-2023, as shown in the graph below:

Figure 13: Total flood-prone areas in 2020

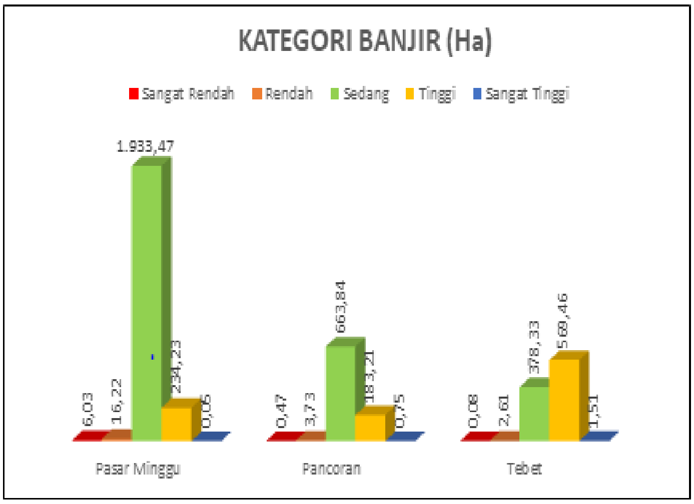


Figure 14: Total flood-prone areas in 2021

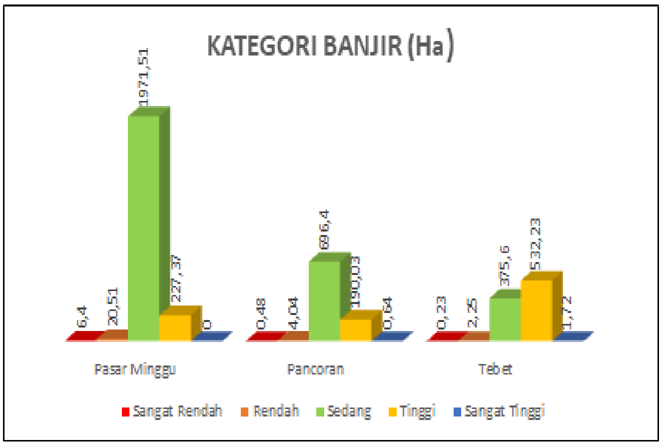


Figure 15: Total flood-prone areas in 2022

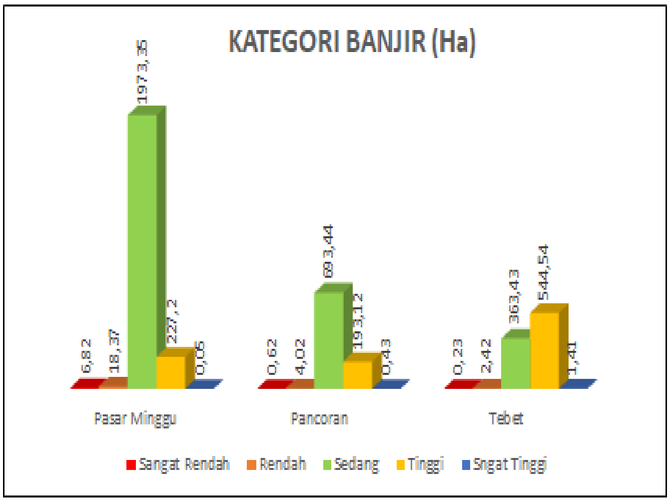
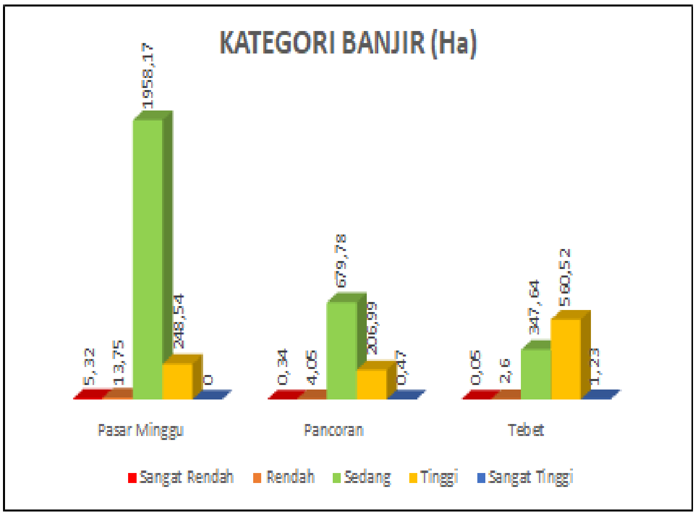


Figure 16: Total flood-prone areas in 2023



The pattern of increasing flood-prone areas from 2020 to 2023 shows the potential impact of urbanization on water catchment areas. For example, an increase in humidity scores in densely populated areas indicates micro-drainage failure.

Accuracy Test Results

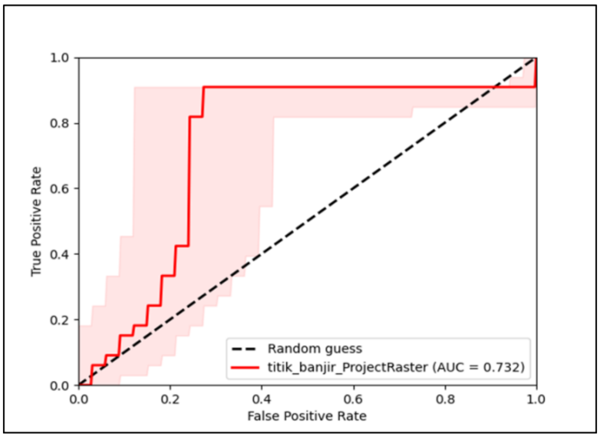
Based on the results of the field survey, 35 survey points were taken. The results of the analysis showed 27 flood points and 5 non-flood points, with results in accordance with the field survey. For the 3 survey points, the results were found to be inconsistent between the interpretation of the images and the results of the field survey. The Kappa accuracy test shows an accuracy rate of 83% with an Overall Accuracy of 91%.

Table 3: KAPPA accuracy test results

Field Survey Results					
Criteria for flood prone	**Prone to flooding**	**Not prone to flooding**	**Entire**	**User Accuracy**	**UA %**
prone to flooding	27	1	28	0,96	96%
Not prone to flooding	2	5	7	0,71	71%
	29	6	35		
Entire	0,93	0,83	Overall Accuracy	91%	
Manufacturer Accuracy	93%	83%	Kappa Accuracy	71%	

Based on the AUC/ROC accuracy test, an AUC curve value of 0.732 was obtained, indicating that the modelling can effectively distinguish between positive and negative classes. It can be seen in Figure 17.

Figure 17: AUC/ROC accuracy test results



In Table 4. there is a classification level based on the results of the AUC calculation. The higher the number, the better the model will be at distinguishing between different classes.

Table 4: AUC classification level table

Classification Values	Result
0,0-0,5	Bad
0,5-0,7	Pretty good
0,7-0,8	Good
0,8-0,9	Very good
> 0.9	Almost Perfect

SOURCE: Rakhmat Purnomo (2017)

App Design

The application design uses open-source applications from Visual Studio with system-recognized programming languages, namely Hypertext Preprocessor (PHP) and Cascading Style Sheet (CSS), which can be run using offline servers, specifically XAMPP, so that the website can be viewed as shown in figures 18 to 20.

Figure 18: Home page interface

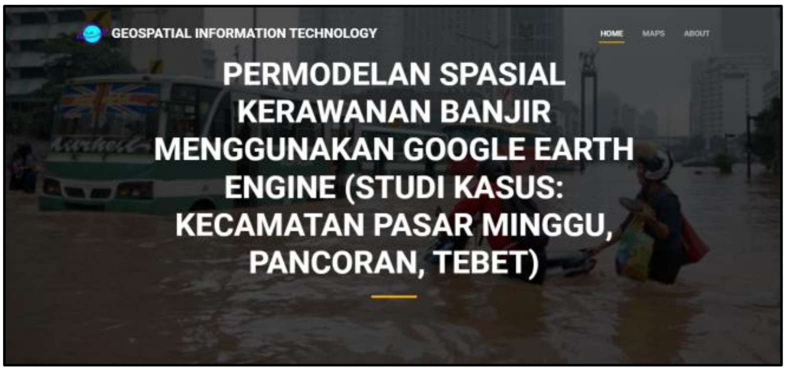


Figure 19: Map page interface

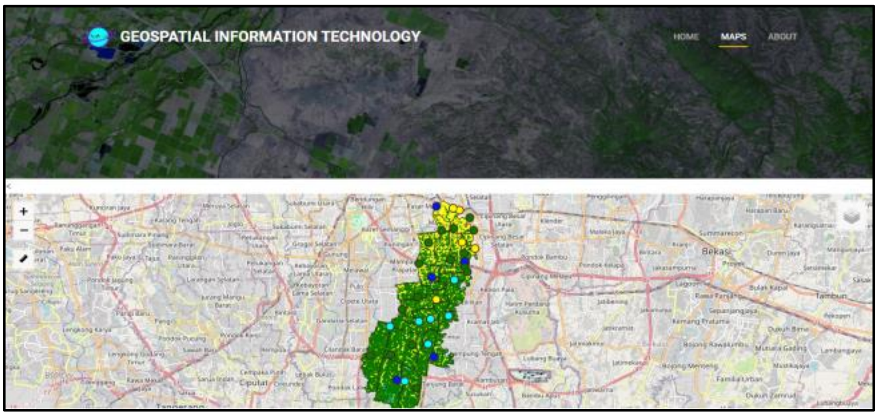
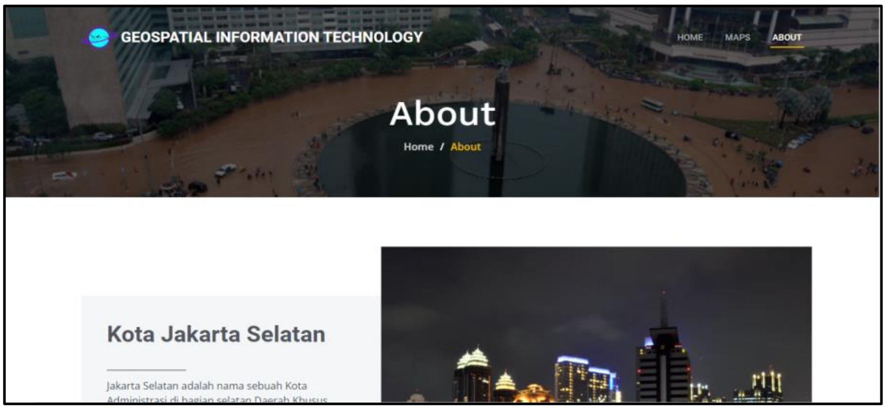


Figure 20: Interface about



CONCLUSION

The conclusions of this study can be summarized as follows:

1. The results of the analysis of the flood disaster located in Pasar Minggu, Pancoran, and Tebet Districts. every year has a high average flood prone category in Tebet Regency and a moderate average level in Pasar Minggu and Pancoran Districts.
2. The accuracy test results showed a Kappa Accuracy of 83% and an Overall Accuracy of 91%. Then, the accuracy results using the AUC/ROC method produced a curve value of 0.732. which means that this model is in the good category for detecting flood-prone areas
3. Displaying an information system in the form of a WebGIS-based distribution map by displaying several data results from the GEE method and identifying the most prone areas to flood disasters in Pasar Minggu Pancoran and Tebet Districts, South Jakarta.

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