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Utilization of Google Earth Engine for Flood Vulnerability Mapping in Citarum Watershed

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ABSTRACT

Flooding is one of the dominant natural hazards in Indonesia. The Citarum watershed is one of the largest watersheds on the island of Java with significant flood hazard potential. This is caused by land use change and massive human activities. Therefore, it is necessary to map the flood vulnerability to identify the areas with the highest flood vulnerability. This can be the first step to mitigate flood hazard in the areas around the Citarum watershed. The mapping of flood vulnerability levels in the Citarum watershed is done by using a cloud computing platform, Google Earth Engine (GEE). By using Google Earth Engine, the process of data processing and visualization becomes more effective. This mapping was done using the weighted overlay method with the parameters of slope, elevation, distance from permanent water, NDVI, and rainfall. The results of mapping the level of flood vulnerability classified in five categories, namely very low, low, medium, high, and very high. The results show that 1009.791 km² area in the downstream of the Citarum watershed and around the reservoir classified as very high flood vulnerability area.

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1. INTRODUCTION

Indonesia is one of the countries in the world that frequently experiences natural disasters. According to the Indonesian Disaster Data for 2023 published by the (Badan Nasional Penanggulangan Bencana, 2024), hydrometeorological disasters accounted for 99.35% of disaster events in Indonesia. Hydrometeorological disasters are defined as disasters that occur due to the influence of weather conditions and surface flow. One of the most prevalent hydrometeorological disasters is flooding. Floods are a type of disaster that can result from several different processes, including natural phenomenon such as global climate change, sea level rise, and high rainfall, as well as human activities such as high urbanization, land use change, dam failure, and modifications to the drainage network infrastructure (Phongsapan et al., 2019; Sy et al., 2023). Floods can have significant consequences, including fatalities, minor to severe injuries, and the disruption of community activities such as economic damage, property losses, and emotional distress. Additionally, flood events can impact infrastructure, educational facilities, health facilities, agricultural activities, and places of historical value (Agustina, 2021; Sy et al., 2023; Syafitri, D.R. et al., 2024).

Badan Nasional Penanggulangan Bencana (BNPB) has recorded data on flood events in the last 10 years, from 2014 to 2023. This data indicates that there have been 10,558 events with victims due to this disaster, which represents most victims of natural disasters. This evidence shows that flood disasters are serious enough to warrant study and management to minimize the risks and impacts caused. One of the areas vulnerable to hydrometeorological disasters is West Java Province. This is influenced by several factors such as topographic diversity and high rainfall in West Java Province (Aeni & Anwar, 2024; Sakti et al., 2021). Floods can occur in watershed areas. River overflow or flooding in watersheds can occur when river water discharge exceeds the maximum capacity of river storage, causing water to overflow into the surrounding land. In addition to natural factors, flooding in watersheds in Indonesia can be caused by improper watershed management (Siregar & Indrawan, 2017; Ridwana, R. et al., 2022).

The Citarum watershed is one of the largest in Java, specifically in West Java Province. It has an area of ± 6,910 km² with the Citarum River flowing from the south to the north of Java Island. There are four main tributaries that channel water into the Citarum River, including Citarik, Cisangkuy, Cisokan, and Cipamingis. The river has an upstream location at Situ Cisanti, the foot of Mount Wayang, Bandung Regency and a downstream location at the north coast of Java Island, Muara Gembong, Bekasi Regency. The Citarum watershed has significant economic potential as well as significant potential hazards related to the existence of water resources, such as flooding, erosion, and sedimentation. Since the 1980s, there has been a substantial transformation of land around the river, rendering the Citarum River highly vulnerable to flooding (Oktaviani et al., 2021). Based on research conducted by (Paryono et al., 2016), it indicates that land conversion of vegetation and agricultural land occurred in the downstream Citarum watershed, specifically in the Bogor, Bekasi, and Karawang districts. Concurrently, there was an increase in non-vegetated land use, including settlements, industrial areas, and open land, between the years 2000 and 2014.

This is supported by previous research related to the percentage of land use in the Citarum watershed in 2014, which revealed where rice fields dominated at 26.06%, built-up land at 22.9%, while secondary forest was only 8.367% (Yusuf et al., 2018). This massive conversion causes disruption of hydrological conditions around and in the watershed area. Furthermore, (Prawirakusuma et al., 2023) have observed that annual flooding in the Citarum watershed often occurs in the upstream and downstream parts of the river. High water discharge from

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the reservoir causes the lower Citarum River to experience frequent flooding. Furthermore, the role of other watersheds also contributes to flooding in the area.

The recurring flooding problems in the Citarum watershed have prompted further research into the vulnerability of the area to flooding. The advent of rapid remote sensing technology has facilitated the conduct of spatial studies. Research conducted by (Fawzi, 2016) revealed that remote sensing technology is a highly effective method for obtaining information about objects on the Earth's surface without the need for direct physical contact at the location of the object or phenomenon. The application of remote sensing technology can address a diverse range of studies, particularly in the context of the Citarum watershed. In addition to remote sensing technology, the development of Geographic Information System (GIS) technology is also a significant support in conducting flood vulnerability studies. The Geographic Information System (GIS) offers the advantage of managing and analyzing data from various sources to map and determine the spatial and temporal dynamics of flood risk (Phongsapan et al., 2019). The advancement of this technology is exemplified by the integration of cloud computing to assess flood vulnerability on a more expansive scale. This method can be applied using Google Earth Engine (GEE). Google Earth Engine (GEE) has the advantage of integrating data from various sources and performing complex spatial analysis in a relatively short time (Cui et al., 2023).

The utilization of Google Earth Engine (GEE) was chosen because it can perform data analysis with the accessibility of a platform that is easily accessible to a wide scale of analysis, especially the Citarum watershed area in a relatively fast time. Based on this, the research can be conducted more effectively and efficiently. The utilization of GEE for flood vulnerability mapping in the Citarum watershed was conducted using the weighted overlay method. This method involves the addition of several parameters that can affect the occurrence of flooding. The parameters used in this research include slope, elevation, distance from permanent water, vegetation cover based on the Normalized Difference Vegetation Index (NDVI) value, and rainfall. Based on these parameters, mapping flood vulnerability in the Citarum watershed using Google Earth Engine (GEE) is expected to help determine how each parameter can affect the occurrence of flood disasters in the area. Consequently, the information obtained from this research can be the first step to identify areas with high flood vulnerability, so that mitigation can be carried out earlier.

2. METHODS

2.1. Study Area

The flood vulnerability study was conducted in the Citarum Watershed, located in West Java Province. The Citarum watershed encompasses an area of approximately ± 6,910 km^2, encompassing numerous regencies and cities, including Bandung Regency, Bandung City, Cianjur Regency, West Bandung Regency, Purwakarta Regency, Bekasi Regency, and Karawang Regency. The research was conducted using the Google Earth Engine platform for processing. The processing includes several variables, including rainfall data for 10 years, elevation and slope data derived from the Shuttle Radar Topography Mission (SRTM) digital elevation model, distance from permanent water, and vegetation density data based on the Normalized Difference Vegetation Index (NDVI).

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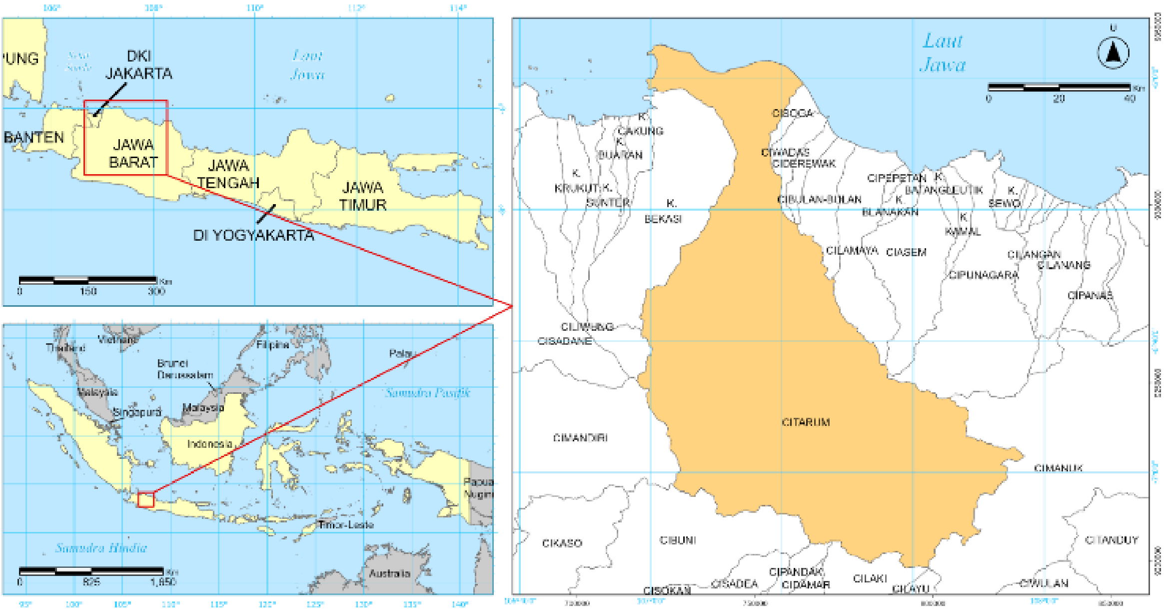

Figure 1. Study Area

2.2. Tools and Research Data

This research can be conducted with the aid of a variety of supplementary instruments, as shown in **Table 1.**

Table 1. Research Data

Tools	Data
Laptop	Rainfall Data from the Meteorology, Climatology, and Geophysics Agency over the past 10 years
Cloud Computing Platform (Google Earth Engine)	Landsat 8 Imagery OLI from dataset Google Earth Engine
	DEM SRTM from dataset Google Earth Engine
	Global Surface Water data from dataset Google Earth Engine

2.3. Weighted Overlay Method

The Weighted Overlay method is an overlay technique of several maps that is employed for spatial data analysis through vulnerability assessment based on influential factors (Adininggar et al., 2016). This method assigns weight to each influential parameter, which is then combined to produce the final output. In flood vulnerability mapping, there are five influencing factors, including rainfall, which represents the intensity and distribution of rainfall in the study location. The slope is a parameter that affects surface flow and infiltration rate. Elevation is a parameter that represents the potential for inundation and water flow. The distance from permanent water represents a potential area affected by river runoff. The Vegetation Index (NDVI) is a metric that indicates the capacity of land to absorb water.

2.4. Cloud Computing

Cloud Computing is a computing paradigm that provides processing, visualization, storage, and services requested by external users through Internet media (Foster et al., 2008). It can also be defined as a computing model that allows access to various computing resources, including servers, storage, networks, software, and other services, via the Internet. There are numerous web or cloud computing platforms, one of which is the Google Earth Engine (GEE) platform. This platform facilitates the processing and visualization of asset data and datasets owned through the creation of scripts employing either JavaScript or Python. In the context of flood vulnerability mapping, this platform can provide data such as DEM SRTM, Landsat 8 OLI Image, and Global Surface Water, as well as other supporting data for the map-making process. The process of creating maps through the GEE platform shown in **Figure 2** below.

Figure 2. Flow Chart Research of Flood Vurnability Mapping in Citarum Watershed Using Google Earth Engine

3. RESULTS AND DISCUSSION

3.1. Slope Classification

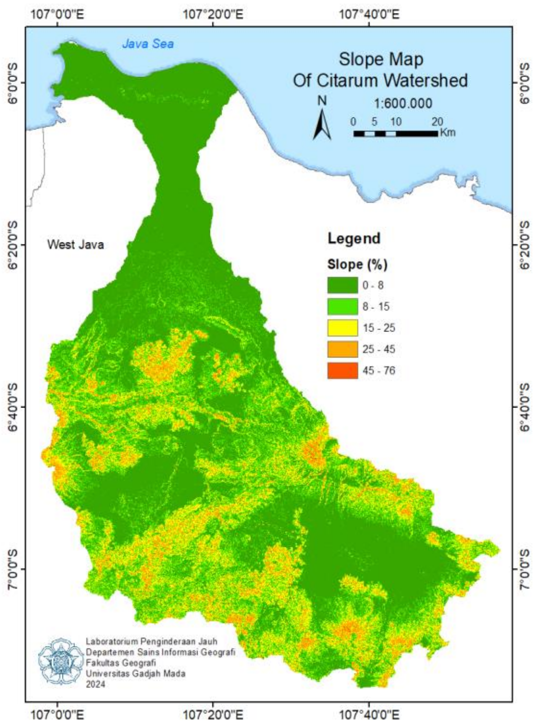

Figure 3. Slope Classification Map of Citarum Watershed

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Table 2. Slope Classification Score

Slope (%)	Description	Score
0 – 8	Flat	5
>8 - 15	Gentle	4
>15 – 25	Moderately Steep	3
>25 – 45	Steep	2
>45	Very Steep	1

Source: (Darmawan et al., 2017)

Based on the results of slope classification in **Figure 3**, the downstream of the Citarum watershed has a slope in the flatter class. The flatter slope will indicate a higher possibility of flooding. According to (Darmawan et al., 2017), the flatter slopes have the highest possibility of flooding because they become water storage areas during rainfall. Meanwhile, the upstream of the Citarum watershed has a basin surrounded by mountains, called the Bandung Basin. The upstream consists of different slope classes from flat to very steep. The flat areas are located in the basin, while the steep areas are in the hills.

3.2. Elevation Classification

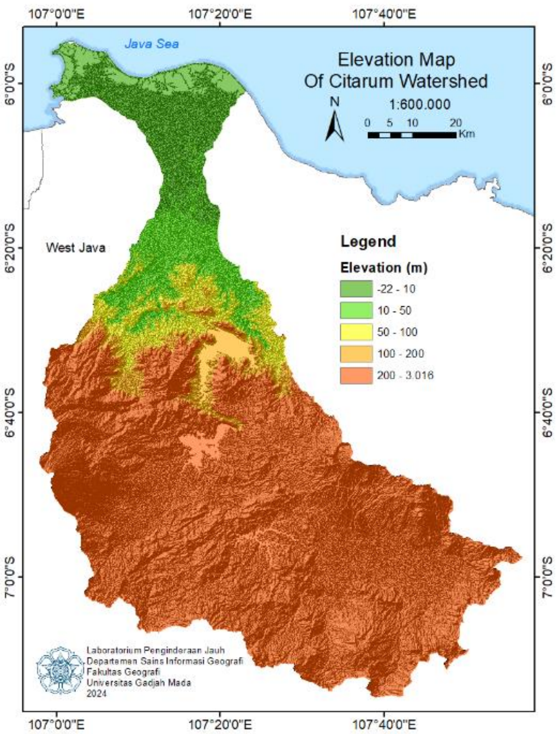

Figure 4. Elevation Classification Map of Citarum Watershed

Table 3. Elevation Classification Score

Elevation (m)	Score
<10	5
10 – 50	4
50 – 100	3
100 – 200	2
>200	1

Source: (Darmawan et al., 2017)

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Based on the results of the elevation classification shown in **Figure 4**, the Citarum watershed exhibits varying elevation levels. The downstream area has a low elevation, with values of less than 10 meters above sea level. This coastal area has a high potential for flood vulnerability. Meanwhile, the upstream region of the Citarum watershed has a high elevation, with values exceeding 200 meters above sea level. As a result, the upstream area, which is hilly, has a low level of flood vulnerability.

3.3. Distance from Permanent Water Classification

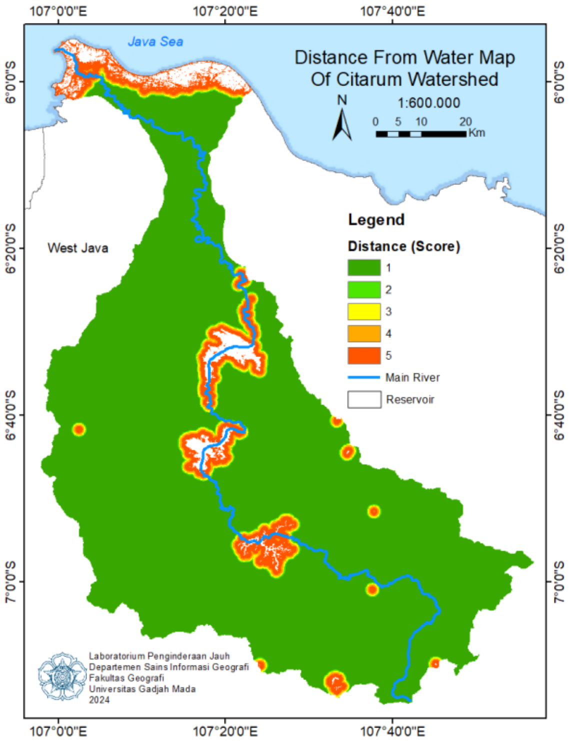

Figure 5. Map of Distance from Permanent Water Classification in Citarum Watershed

Table 4. Distance From Permanent Water Classification

Distance From Permanent Water Classification (m)	Total Score
0 – 25	5
25 – 50	4
50 -75	3
75 -100	2
>100	1

Source: (Rakuasa & Latue, 2023)

Based on the results shown in **Figure 5**, the Citarum watershed contains numerous rivers and tributaries. Additionally, the watershed has several permanent water bodies in the form of large dams and reservoirs, including Saguling Reservoir, Cirata Reservoir, and Jatiluhur Reservoir. Areas close to these permanent water bodies and around the reservoirs have a high potential for flooding. However, the reservoirs themselves act as flood control structures. Reservoirs in the Citarum watershed, such as Saguling Reservoir, have experienced an increase in sedimentation beyond the planned threshold (Manalu, 2013). This increase will certainly lead to a reduction in the reservoirs' storage capacity, which will affect their flood control effectiveness. The permanent water parameter also includes marine areas, meaning that coastal areas adjacent to the sea also have a high potential for flooding.

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3.4. NDVI Classification

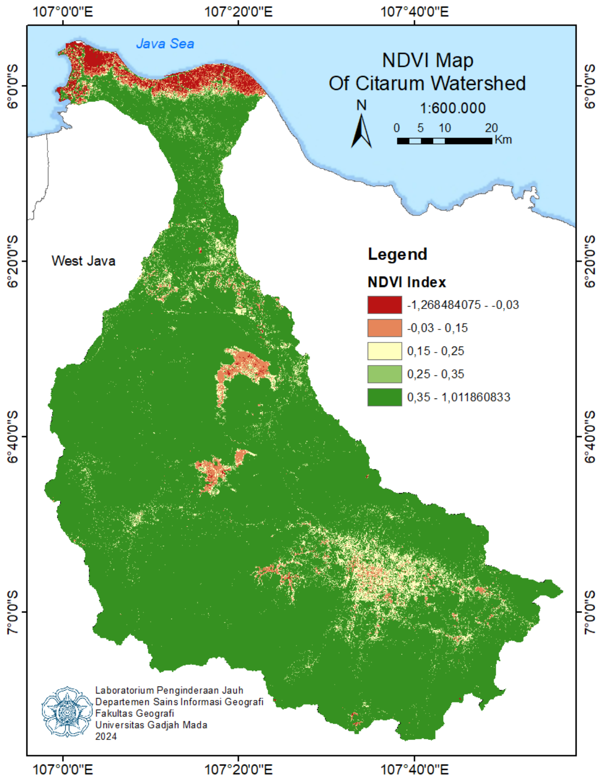

Figure 6. NDVI Classification Map of Citarum Watershed

The results of the NDVI classification shown in Figure 6 indicate that the Citarum watershed is dominated by high NDVI values above 0.36. This suggests that the watershed is primarily covered by forests or lush vegetation. Areas with low NDVI values are found in coastal regions and reservoirs, which consist of water bodies or unvegetated land. The lower the NDVI value, the higher the potential for flooding, as low NDVI values indicate a lack of vegetation in the area. The absence of vegetation makes it difficult to reduce the rate of runoff on the land surface (Hidayah et al., 2022).

Table 5. NDVI Classification Score

NDVI Value	Description	Score
-1 < NDVI < -0.03	Non-Vegetated Land	5
-0.03 < NDVI < 0.15	Very Low Vegetation	4
0.15 < NDVI < 0.25	Low Vegetation	3
0.26 < NDVI < 0.35	Medium Vegetation	2
0.36 < NDVI < 1	High Vegetation	1

Source: (Mahesti et al., 2020)

4. CONCLUSIONS

The results of the research indicate that the flood vulnerability characteristics of the Citarum watershed are determined by several parameters, including distance from water, slope, elevation, rainfall, and NDVI. These parameters are weighted based on subjective and subjective-objective weights, which are ranked from highest to lowest. Distance from water is identified as the parameter with the highest impact, as evidenced by the high and very high

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flood vulnerability classes located in proximity to permanent water sources such as reservoirs and the sea. The next parameters that affect flood vulnerability are low slope conditions, low elevation, and low NDVI values. The results of the parameter calculations are weighted to produce a flood vulnerability classification in the following order: very low class (score of 1), low class (score of 2), medium class (score of 3), high class (score of 4), and very high class (score of 5).

The Citarum watershed produces five classes of flood vulnerability: very low, low, medium, high, and very high. The distribution pattern of the vulnerability map is considered uneven, as the low and medium classes are more dominant than the other classes. Based on this distribution, the upstream area in the south produces a low vulnerability class, while the downstream area in the north produces a very high vulnerability class. Each parameter tested has its own weighting condition across the five classes. Therefore, the upstream area has low values for the parameters, while the downstream area has high values, resulting in a vulnerability score according to its classification when the weighting process is carried out. Flood vulnerability mapping in a watershed can be conducted by utilizing Google Earth Engine, using data or assets available on this platform, which allows for more effective data processing and visualization.

5. RECOMMENDATIONS

The results of the flood vulnerability classification must be validated through field tests and the incorporation of secondary data. Conducting these validation tests will ensure that the research findings are more accurate in estimating flood vulnerability in the study area. Additionally, the resulting flood vulnerability map should be enhanced by including additional variables to improve its accuracy.

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