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Flood Hazzard Assessmentand Mapping in Yeh Ho Watershed Using Geographic Information System (GIS)

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-ABSTRACT-

Flooding is an increasingly pervasive global challenge exacerbated by climate change, rapid urbanization, and deforestation. In the Yeh Ho Watershed of Bali, Indonesia, recurrent floods have led to severe environmental, economic, and social consequences, highlighting the urgency for effective flood risk management. This study aims to assess flood hazards within the Yeh Ho Watershed using Geographic Information Systems (GIS) and spatial data analysis. By integrating morphometric analysis, hydrological data, and land-use characteristics, the research provides a detailed flood hazard map to identify flood-prone areas and the underlying factors contributing to flood risks. The research uses drone imagery, GIS tools, and field surveys to create a detailed flood hazard map for the region. The Yeh Ho Watershed, covering 172.943 km², is characterized by diverse soil types, varying topography, and fluctuating rainfall patterns. Using multiple spatial layers, including land use, slope, soil type, and rainfall, the study generates a Flood Hazard Index (FHI) to identify flood-prone zones. The results show that 69% of the watershed is at moderate risk of flooding, with 25% categorized as low risk and 6% at high risk. Field observations confirm the accuracy of the flood hazard map, supporting its use for flood risk assessment and the development of mitigation strategies. This research provides valuable insights for sustainable flood management in Bali, offering a comprehensive framework to address current and future flood risks.

KEYWORDS: ***Flood Hazard, Watershed, Geographic Information Systems (GIS), Mapping.***

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I. INTRODUCTION

Flooding is a pervasive global challenge that has been exacerbated by climate change, rapid urbanization, and deforestation[1], [2], [3]. The World Meteorological Organization (WMO) reports a significant increase in the frequency and severity of flood events over recent decades, impacting millions of individuals annually[4]. Beyond the tragic loss of life, floods disrupt economic systems, damage critical infrastructure, and hinder long-term development efforts. In Asia, countries such as Indonesia, India, and Bangladesh have experienced devastating floods in recent years, underscoring the urgent need for enhanced flood risk management strategies[5]. This challenge is further compounded by the increasing variability in rainfall patterns and the limited capacity of existing drainage systems to manage high-intensity precipitation events.

The Yeh Ho Watershed is a watershed located in Bali Province, Indonesia. According to the Bali-Penida River Basin Office (2012), the watershed encompasses extensive degraded lands, classified as potentially critical (28.57 km²), semi-critical (56.35 km²), critical (83.18 km²), and very critical (0.58 km²). This degradation has severe environmental repercussions, manifesting as recurrent flooding during the rainy season and drought during the dry season[6]. Between 2016 and 2023, the Yeh Ho River frequently overflowed during periods of high-intensity rainfall, inundating nearby roads and settlements. These recurrent flood events underscore the urgent need for proactive flood mitigation measures to protect the communities and infrastructure within this vulnerable watershed. Effective flood risk assessment forms the cornerstone of disaster risk management, guiding the formulation of policies aimed at minimizing adverse impacts[7]. Mapping flood risk zones is particularly critical for identifying vulnerabilities and implementing targeted mitigation strategies[8].

Geographic Information Systems (GIS) have proven to be an invaluable tool for flood hazard assessment, enabling the integration and analysis of spatial and temporal data[9]. By combining hydrological, topographical, and land-use datasets, GIS facilitates precise identification of flood-prone areas and enhances decision-making processes. This technology supports the development of targeted interventions and adaptive management strategies tailored to specific flood risk factors.

Geographic Information Systems (GIS) are particularly effective in flood hazard assessment through the application of the overlay method[10], [11], [12], [13], [14]. This approach involves layering multiple spatial datasets to identify areas at risk of flooding, providing a detailed and accurate assessment of flood-prone zones. The overlay method combines key inputs such as rainfall intensity, drainage density, topography derived from Digital Elevation Models (DEMs), land use,and soil characteristics. Each dataset is assigned a weight based on its relative influence on flood susceptibility, ensuring a robust analysis.

Rainfall intensity maps highlight areas prone to heavy precipitation, while DEMs provide critical information on elevation and slope, which determine water flow and accumulation patterns. Land use and land cover data, such as impervious surfaces or deforested regions, reveal areas with reduced infiltration capacity, increasing flood risks. Overlaying these spatial layers, GIS enables the identification of flood-prone zones with high precision.

The primary objective of this study is to assess flood hazards in the Yeh Ho Watershed using GIS, with a focus on identifying critical flood-prone areas and understanding the underlying factors contributing to flood risks. The research integrates morphometric analysis, hydrological data, and land use characteristics to develop a detailed flood hazard map, providing a comprehensive framework for flood risk assessment.Given the increasing frequency and intensity of floods in the Yeh Ho Watershed, this research addresses a pressing need to safeguard local communities, infrastructure, and ecosystems. The study emphasizes the importance of adaptive management strategies that address both immediate threats and long-term environmental challenges.The novelty of this research lies in its holistic approach, combining GIS-based flood hazard mapping with detailed morphometric and land-use analysis specific to DAS Yeh Ho. By integrating these dimensions, the study offers a robust and innovative framework for sustainable watershed management, contributing valuable insights for mitigating flood risks in Bali Province.

II. RESEARCH METHODS

Research Location

Yeh Ho is a river with significant potential, encompassing a watershed area of 172.943 km² and a main river length of 45.145 km. The Yeh Ho Watershed is one of the key water resources in Tabanan Regency, utilized primarily for irrigation and raw water supply for a large portion of the region, especially in Tabanan Regency. Therefore, the presence of the Yeh Ho Watershed is crucial, particularly in supporting agricultural production in Tabanan Regency[15].

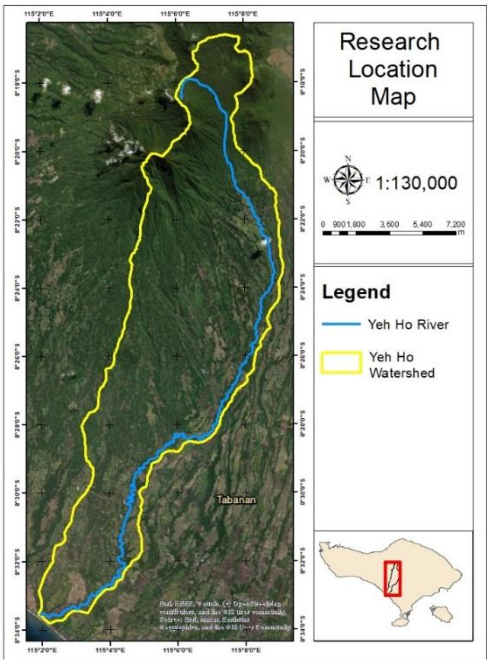

Figure 1. Research Location

Tools and Data Used in the Research

In this study, drones were utilized for aerial photography to assess the existing conditions of flood-prone areas in the Yeh Ho Watershed (DAS Yeh Ho). A GIS-based application was employed to create flood disaster maps, while Microsoft Excel was used to process the mapping data. The research utilized both primary and secondary data. Primary data were collected through direct field surveys at locations where flooding had occurred, serving to validate the maps and ensure that areas repeatedly affected by flooding were accurately identified as high-risk zones. Secondary data included slope information derived from DEM analysis using DEMNAS data (https://tanahair.indonesia.go.id/portal-web/unduh/demnas).Additional secondary data comprised shapefile maps of soil types, land use, and rainfall obtained from satellite datahttps://power.larc.nasa.gov/data-access-viewer/

Research Analysis Methods

The research analysis method is shown in Figure 2. The research begins with the integration of multiple input layers, including a land use map, which identifies anthropogenic and natural features that influence surface runoff; an annual rainfall map, which provides data on precipitation intensity and distribution; a soil type map, which characterizes soil permeability and drainage capacity; and a slope map derived from DEMNAS which quantifies terrain gradients affecting surface water flow and accumulation.

Each input layer undergoes a scoring process, wherein numerical values are assigned based on predefined criteria that reflect their relative contribution to flood risk. These scored layers are then overlaid using GIS techniques to synthesize spatial interactions and interdependencies among the variables. The resulting composite dataset is used to calculate a Flood Hazard Index (FHI), a quantitative metric that integrates all contributing factors to evaluate flood susceptibility across the study area.

The final step is the map of flood Hazard, which represents spatial variations in flood risk levels, categorized into hazard classes. This map serves as a vital decision-support tool for hydrological risk assessment, flood mitigation planning, and sustainable land-use management. By employing a multi-criteria spatial analysis framework, the methodology ensures a comprehensive, data-driven approach to flood hazard assessment.

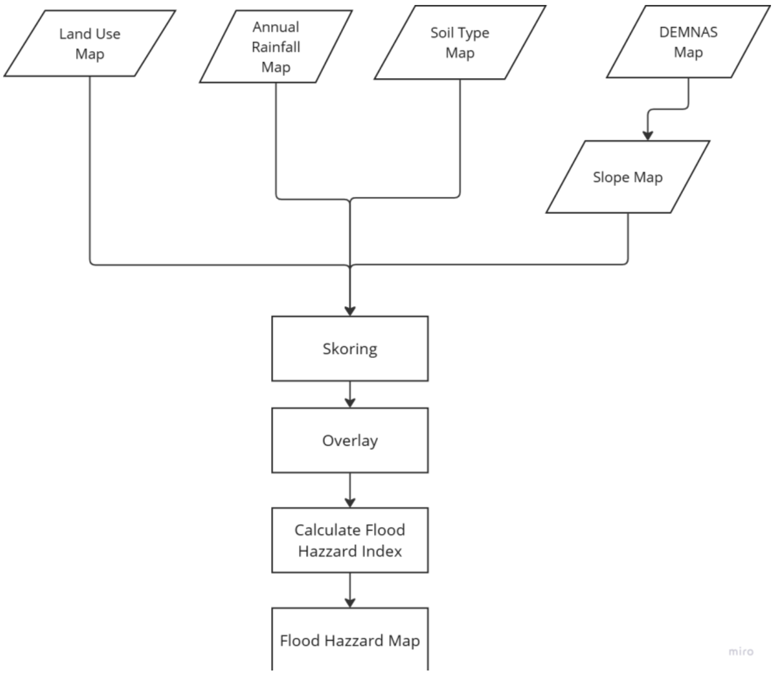

Figure 2. Research Analysis Methods

III. RESULT AND DISCUSSION

Soil Types of the Yeh Ho Watershed

Based on Figure 3 and Table 1, the Yeh Ho Watershed generally consists of Mollic Andosol, Ochric Andosol, and Eutric Cambisol. Mollic Andosol dominates the upstream part of the Yeh Ho Watershed. Mollic Andosol is characterized as soil with good drainage, deep profiles, and varying structure throughout its depth. This variation is supported by water content analysis, which shows that the water content follows a cubic quadratic function, increasing with depth. This soil has a coarse texture and, despite its deep profile, has relatively low organic content. The good drainage properties and structural variability make it suitable for agricultural use, while its deep profile allows for better water infiltration and reduces surface runoff. The central to downstream area consists of Ochric Andosol. Ochric Andosol is derived from volcanic ash with physical characteristics similar to Mollic Andosol, such as loose and porous soil structure. The difference lies in the thinner ochric layer, lower organic content, and lighter color compared to the mollic layer. As a result, Ochric Andosol has moderate fertility, lower than Mollic Andosol. Although the soil's drainage is adequate to moderate, its water absorption capacity is not as good as Mollic Andosol, making it more vulnerable to flooding during extremely high rainfall. Surface flow can occur more quickly, especially if the soil is saturated, increasing the potential for flooding. The downstream area consists of Eutric Cambisol. Eutric Cambisol has varying physical characteristics, often with a coarse to medium texture, and lacks deep horizon development as it forms from less decomposed parent material. This soil has moderate to high fertility, with relatively abundant nutrients, although its porosity is not as good as Andosol. Its drainage varies depending on the parent material and texture, but its ability to retain water is lower than Andosol. Eutric Cambisol is more prone to flooding, especially with heavier textures such as clay, as its limited drainage makes the soil more prone to water saturation, increasing surface flow and flood risk.

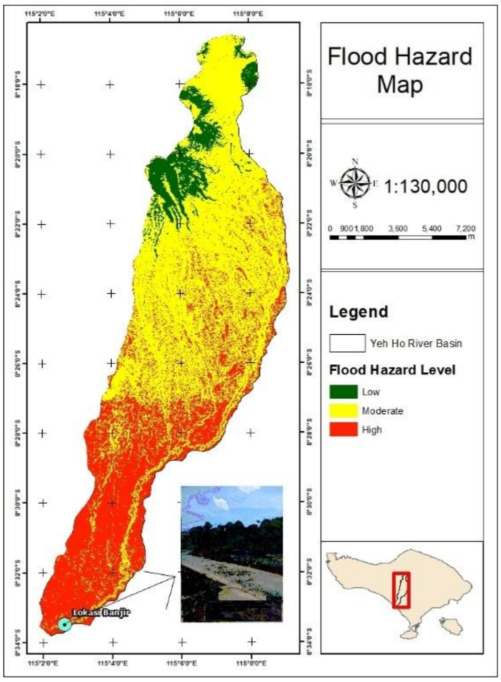

Figure 3. Soil Types of the Yeh Ho Watershed

Table 1. Soil Types of the Yeh Ho Watershed

Soil Type	Area (km²)	Percentage
Ochric Andosol	108.6	64.37%
Eutric Cambisol	12.49	7.40%
Mollic Andosol	47.62	28.23%

Topography of the Yeh Ho Watershed

Based on Figure 4 and Table 2, the elevation of the Yeh Ho Watershed generally ranges from 0 to 1500 m, with a dominant elevation of less than 300 m, covering 32.4% of the watershed area. The Yeh Ho Watershed faces a high flood risk due to its predominance of lowland areas[16], [17], [18].

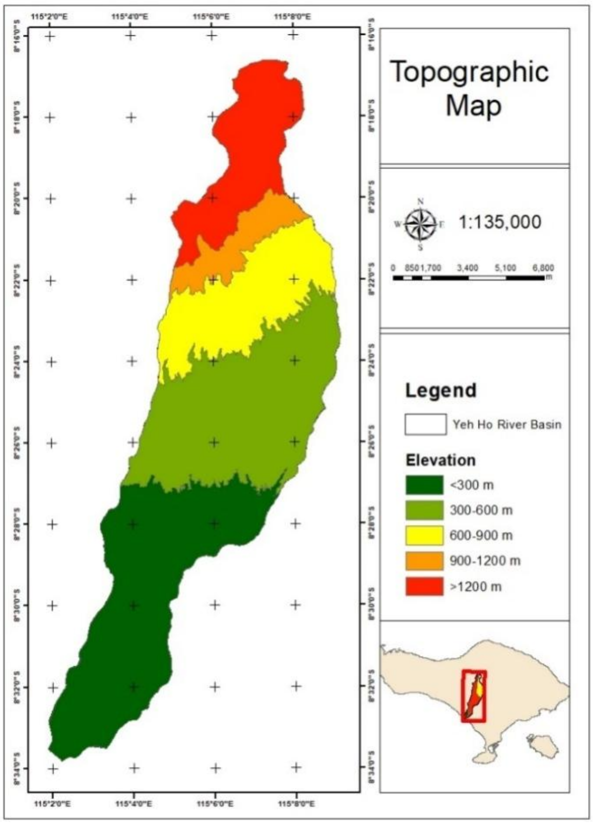

Figure 4. Elevation Map of the Yeh Ho Watershed

Table 2. Topography of the Yeh Ho Watershed

Elevation	Area (km²)	Percentage (%)
<300 m	54.71	32.40%
300-600 m	51.55	30.60%
600-900 m	28.28	16.80%
900-1200 m	9.7	5.70%
>1200 m	24.48	14.50%

Slope

Based on Figure 5 and Table 3, the Yeh Ho Watershed generally consists of Mollic Andosol, Ochric Andosol, and Eutric Cambisol. Mollic Andosol dominates the upstream part of the Yeh Ho Watershed. Mollic Andosol is characterized as soil with good drainage, deep profiles, and varying structure throughout its depth.

Table 3. Slope of Yeh Ho Watershed

Slope	Area (km²)	Percentage
0 - 8%	40.21	23.92%
8 - 15%	45.4	27.01%
15 - 25%	39.73	23.63%
25 - 45%	28.56	16.99%
>45%	14.19	8.44%

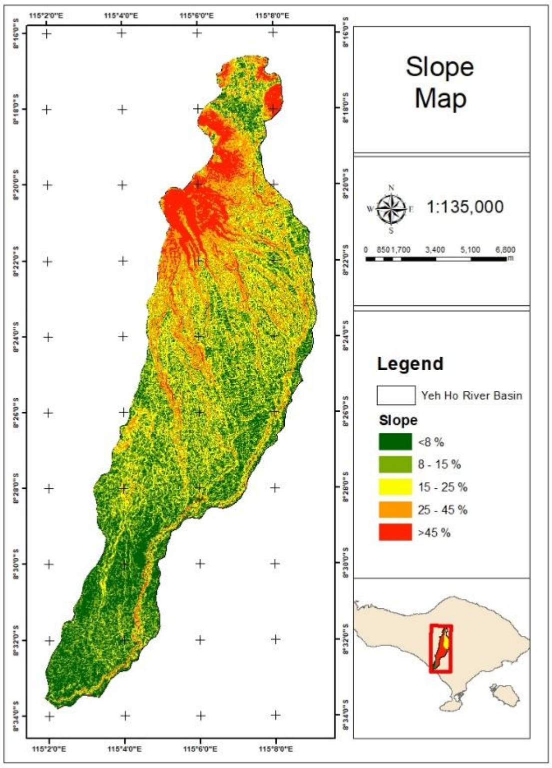

Figure 5. Slope Map of the Yeh Ho Watershed

Land Use of the Yeh Ho Watershed

Based on Figure 6 and Table 4, land use in the Yeh Ho Watershed is dominated by mixed dryland agriculture, covering 67.15 km² or 39.90% of the total area. Rice fields represent the second-largest land use, with 55.92 km² or 33.23%. Primary dryland forests cover 32.15 km² or 19.10%, while secondary dryland forests occupy 6.62 km² or 3.93%. Settlements cover 5.43 km² or 3.22%, while dryland agriculture occupies 0.77 km² or 0.46%. Forest plantations are minimal, covering just 0.17 km² or 0.10%, followed by shrubland and open land, covering 0.02 km² (0.01%) and 0.07 km² (0.04%), respectively.

Table 4. Land Use Percentage of the Yeh Ho Watershed

Land Use	**Area (km²)**	**Percentage**
Shrubland	0.02	0.01%
Primary Dryland Forest	32.15	19.10%
Secondary Dryland Forest	6.62	3.93%
Forest Plantations	0.17	0.10%
Settlements	5.43	3.22%
Dryland Agriculture	0.77	0.46%
Mixed Dryland Agriculture	67.15	39.90%
Rice Fields	55.92	33.23%
Open Land	0.07	0.04%

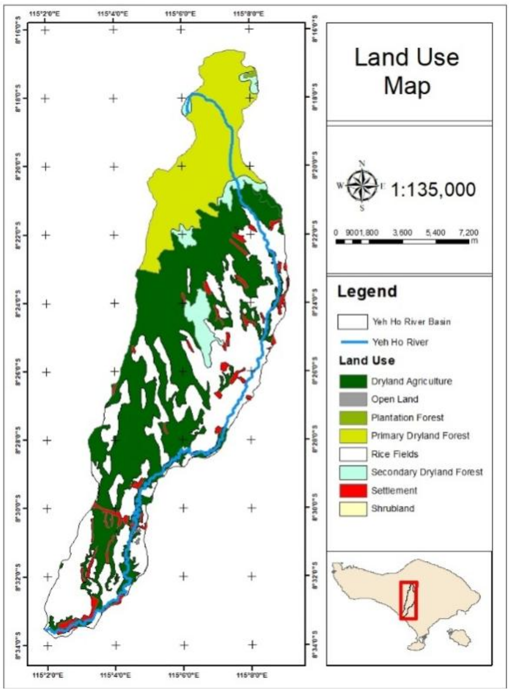

Figure 6. Land Use Map of the Yeh Ho Watershed

Rainfall of the Yeh Ho Watershed

Based on Figure 7, the annual rainfall trend from 2012 to 2022 shows significant fluctuations over the years. In 2012, rainfall was recorded at 1481.84 mm, increasing to 1924.80 mm in 2013. However, in 2014, there was a significant decrease to 1307.81 mm, continuing to decline until reaching the lowest point of 1070.51 mm in 2015. A substantial recovery occurred in 2016, with rainfall peaking at 1951.17 mm and remaining relatively high at 1935.35 mm in 2017. The trend then shifted downward again, with rainfall dropping to the lowest level of 1007.23 mm in 2019. From 2019 onward, there was a sharp increase, with rainfall rising to 1603.12 mm in 2020 and surging further to 2385.73 mm/year in 2021, the highest in the entire period. In 2022, rainfall slightly decreased to 2214.17 mm/year. The average annual rainfall of the Yeh Ho Watershed is around 1656.95 mm/year.

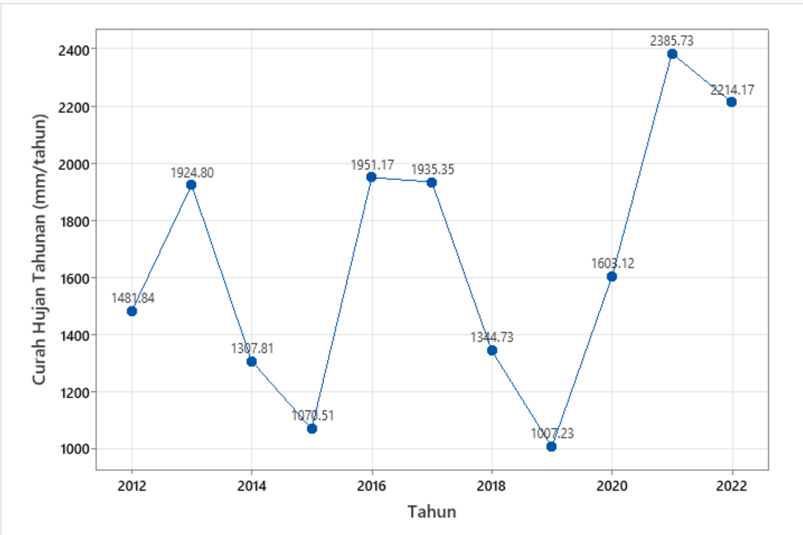

Figure 7. Annual Rainfall of the Yeh Ho Watershed (2012-2022)

Flood Hazard Map

Based on Figures 8 and 5, the flood hazard level in the Yeh Ho Watershed is categorized into three levels: low, moderate, and high. The area with low flood hazard covers 42.56 km² or 25% of the total watershed area. The majority of the area, covering 116.37 km² or 69%, falls under the moderate flood hazard category. Meanwhile, the high flood hazard area covers 9.81 km² or 6% of the total area of the Yeh Ho Watershed.

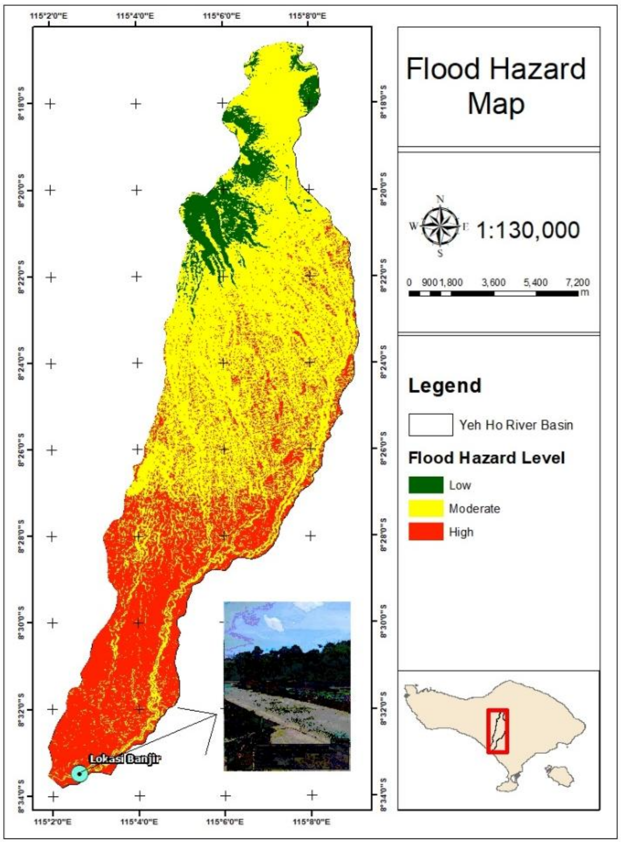

Figure 7. Flood Hazard Map in Yeh Ho Watershed

Map Calibration

The process of calibrating the map results through overlay and field observations (Figure 8) is carried out to verify the flood vulnerability levels in a given area. Initially, thematic maps such as slope, land use, soil types, and rainfall maps are overlaid to identify potential flood-prone areas. After the overlay map is created, the team conducts field observations at locations marked as flood-prone, particularly in zones with moderate to high flood risks. During the field observation, GPS devices are used to pinpoint the exact locations of floodwater inundation. The GPS data is then matched with the overlay map results, and it is found that there is consistency where surveyed locations align with the map's indications, showing a moderate to high flood risk. This agreement indicates that the overlay map can be relied upon to predict flood vulnerability in the area. The calibration results help strengthen the validity of the map as a flood disaster mitigation tool and serve as a basis for designing appropriate management measures.

Figure 8. Field Observation

IV. CONCLUSION

The Yeh Ho watershed's soil is dominated by Mollic Andosol in the upstream, Ochric Andosol in the central region, and Eutric Cambisol in the downstream areas. These soils exhibit different drainage capacities and fertility levels, contributing to water absorption and flood susceptibility. The topography of the watershed is primarily lowland, with over 30% of the area below 300 meters in elevation, which increases the flood risk. The land use is predominantly mixed dryland agriculture and rice fields, which can exacerbate runoff during heavy rainfall. The annual rainfall data show significant variability, with recent years experiencing sharp fluctuations, including periods of extreme rainfall. The flood hazard map indicates that the majority of the watershed faces moderate flood risks, with some areas at high risk, especially in zones with poor drainage or steep slopes. Calibration of flood hazard predictions through field observations supports the reliability of these maps for flood disaster mitigation planning. These findings highlight the need for targeted flood management strategies, including improved land use practices, soil conservation, and infrastructure development to mitigate flood risks in the Yeh Ho Watershed.

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