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Flood Hazard Mapping in Bandung Regency Based on Multi-Criteria Decision Analysis (MCDA) with AHP Method

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ABSTRACT

Flooding in Bandung Regency can caused by both natural and human factors. Natural factors include high-intensity rainfall, while human factors involve extensive development, inadequate drainage, and poor environmental practices. This research aims to determine the flood probability by AHP in Bandung Regency based on MCDA. The study considers eight main factors: (1) NDVI, (2) TWI, (3) Land Use, (4) Rainfall, (5) Slopes, (6) Elevation, (7) Distance from Road, and (8) Distance from River. These factors are reclassified using natural breaks (Jenks), and the consistency ratio is calculated, also sensitivity analysis. The results are flood hazard map in Bandung Regency, validated with the ROC curve. The study identifies four risk categories: Low Risk, Moderate Risk, High Risk, and Extreme Risk. Areas near Bandung City have the highest risk, while other areas generally have lower risk levels. Validation shows 70.4% for ROC, indicating that the flood hazard map is accurate. This research provides valuable recommendations for stakeholders to address flooding in Bandung Regency, particularly in the northern areas.

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I. Introduction

a Disaster is an event or series of events that can threaten or disturb, and can even harm all living things, both materially and immaterially [1]. Disasters can be categorized into two categories, namely natural disasters and non-natural disasters [2]. By category, natural disasters can be categorized again into three categories, namely; (1) Geological natural disasters; (2) Meteorological natural disasters; and (3) Extra-terrestrial natural disasters. Apart from that, non-natural disasters can also be divided into several categories based on the initial problem, namely; (1) Disasters due to technology; (2) Disaster due to epidemics; and (3) Disaster due to modernization [3].

A geological natural disaster is an event or phenomenon that is mainly caused by processes related to the earth's geology and the movement of its tectonic plates [4]. These disasters can have devastating and often catastrophic impacts on the environment, human communities, and infrastructure. One example of a geological natural disaster is a volcanic eruption, where a volcanic eruption occurs when molten rock, gas, and ash are ejected from a volcano [5]. These eruptions can result in lava flows, ashfall, pyroclastic flows, and even the formation of volcanic islands. Volcanic eruptions can pose a threat to local communities and can have regional or global environmental impacts. Then meteorological natural disasters also known as natural disasters related to weather or the atmosphere, are events or phenomena caused by the earth's atmospheric processes and meteorological conditions [6]. Meteorological natural disaster events can have significant and sometimes catastrophic impacts on the environment, human communities, and infrastructure. One example of a meteorological natural disaster is a flood, where flooding can be caused by various meteorological factors, such as heavy rain, melting snow, or failure of an ice dam [7]. The extra-terrestrial natural disasters refer to catastrophic events that originate outside the Earth's atmosphere and have the potential to impact the planet [8]. Although the Earth often experiences various natural disasters caused by geological and meteorological processes, several space events can have a significant impact. One example of an extra-terrestrial natural disaster is the impact of asteroids and comets, where collisions with asteroids or comets are one of the most well-known space threats [9]. These impacts have the potential to cause mass extinction, widespread destruction, and climate disruption. The severity of the impact depends on the size, speed, and composition of the celestial body, although large impacts rarely occur in human timescales, the impact can cause major disasters [10].

Disasters that often result in directly felt losses are natural disasters, where natural disasters can threaten or disrupt human life directly and are sometimes very difficult to avoid. Natural disasters are very detrimental if they occur continuously, such as floods. Flooding is a disaster that can cause severe damage to houses, infrastructure, and agriculture and cause population displacement. The losses that occurred during the flood were felt, as was the case in Bandung Regency in 2017, where material losses amounted to three billion Rupiah. Apart from that, there were losses caused by floods in the city of Bandung in 2020, where there were 7 areas that were submerged at a height ranging from ten to fifty centimeters, which also submerged and damaged various housing and infrastructure.

Based on the source, flooding can originate from various factors including; (1) Rainfall; (2) River overflow; (3) Coastal flooding; (4) Flash floods; (5) Snowmelt; and (6) Dam failure. According to Merz [11], in his research states that One of the most common causes of flooding is heavy or prolonged rainfall, which can cause a rapid buildup of water in rivers, streams, and other bodies of water. If rainfall exceeds the capacity of the natural drainage system, this can result in flooding [12].

The need for attention to natural disasters such as floods is urgently needed, where various studies have been carried out to attempt to overcome and find out early flood warnings as carried out by Acosta-Coll [13] in his research, he developed a tool design to measure the possibility of flooding in an area by calculating the rainwater discharge at certain time intervals. Then there is research conducted by Zhao [14] in his research, he determined flood points based on history so that floods could be anticipated from the start. However, Dottori [15] in his research, he said that with the development of tools or determining flood risk points, there is still a need for additional measures to overcome floods, namely by carrying out flood hazard mapping which takes into account various important aspects geologically and meteorologically, so that this can be strengthened in terms of overcoming floods.

Flood hazard mapping is very necessary because it is to determine the level of flood risk in an area by taking into account conditioning factors, both geological and meteorological. Of course, carrying out flood suspicion mapping requires various supporting data and also equipment that is not cheap in terms of cost. However, according to Agustina, et al. [16], in their research revealed that there is one method that is possible to carry out, namely based on Multi-Criteria Decision Analysis (MCDA) using the Analytic Hierarchy Process (AHP) method. MCDA is a systematic approach used in decision-making to highlight and prioritize alternative options based on various, often conflicting, criteria or objectives [17]. Just as geological factors and meteorological factors sometimes conflict with each other, with MCDA this can be analyzed simultaneously. MCDA is a valuable tool for complex decision-making situations where different stakeholders, each with their preferences and priorities, need to make choices [18]. MCDA helps structure the decision-making process, consider various aspects, and reach more informed and transparent decisions. The use of MCDA to map flood hazard has been carried out by various researchers, such as that carried out by Samanta [19] who obtained the results that using MCDA was able to create a flood hazard mapping in the Markham River area. Additionally, Msabi & Makonyo [20] successfully carried out flood hazard mapping in the Dodoma area, Tanzania with valid results. The use of MCDA will be more effective if combined with the use of GIS and other methods, such as using AHP.

MCDA is very complex in management, so MCDA is designed to handle complex decision-making scenarios involving many criteria [21]. Flood hazard mapping evaluates rainfall intensity, land use, soil type, topography, and historical flood data [22]. Then, MCDA is flexible and can accommodate various data types (quantitative and qualitative) and integrate them into a coherent decision-making framework [23]. So MCDA is a very complex and flexible method, therefore MCDA can be integrated with AHP because the complexity of MCDA and AHP is aligned in concept. Because the complexity of MCDA and AHP is aligned, AHP provides a structured methodology for breaking down complex problems into a hierarchy of subproblems, making it easier to analyze and understand each component [24]. In addition, AHP involves pairwise comparisons, which helps assess the relative importance

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of various criteria and factors influencing flood hazard [25]. MCDA will determine what factors will be used for analysis, which of course AHP includes a consistency ratio to ensure the reliability of the assessments made during the decision-making process.

As an advantage, MCDA allows carrying out or giving consideration to several criteria simultaneously, resulting in a more comprehensive flood hazard assessment [16]. This will help determine priority areas based on hazard level and assist in resource allocation and implementation of mitigation measures [16]. In addition, AHP effectively integrates quantitative and qualitative data, providing a balanced approach to decision-making, so that AHP can combine objective data with subjective assessments, thereby facilitating comprehensive evaluation of flood hazards [26].

AHP is a structured and systematic decision making method developed by Thomas L. Saaty in the 1970s [27]. AHP is designed to make complex decisions by individuals or groups by breaking down decision problems into a hierarchical structure and comparing and prioritizing alternatives quantitatively based on a set of criteria [28]. AHP is most useful when there are multiple criteria and subcriteria, and can be applied to a variety of decision-making contexts, including business, engineering, environmental management, and more. The use of AHP in the context of flood mapping is used to find out how big the weight of each conditioning factor used is so that when flood hazard mapping is carried out you will know how big the risk is [29]. The use of MCDA with the AHP method certainly requires a weighting factor that is appropriate to the situation or has a good correlation between the weighting factors, such as research conducted by Mosavi [30] which uses conditioning factors such as rainfall, land cover, and land slope. Then research conducted by Das [26] which uses conditioning factors such as elevation, rainfall, TWI, and NDVI. Then research conducted by Boulomytis [31] which uses distance from roads, rainfall, and TWI. Based on various literature studies explaining the use of conditioning factors, there are various conditioning factors used by various researchers, so this research will focus on combining conditioning factors from various literature, so that they are formed into eight conditioning factors, namely TWI, Elevation, Land slope, Precipitation, Land Use (LU/LC), NDVI, Distance from the river, and Distance from the road. This research not only verified the conditioning factors, but applied conditioning factors that were considered valid in various regions from the Middle East and West to tropical areas, especially in Bandung Regency. So this research can find out whether these variables can be applied well and can provide a more detailed picture of the factors conditioning flood hazards in the Bandung district which has a tropical climate.

This research does not only carry out validation and will apply factors that are considered valid, but this research only provides subjective validation because it is based on expert judgement, so it does not provide objective validation based on sophisticated statistical values.

The aims of this study is to assess and analyze flood hazard at a regional level in Bandung Regency using Multi-Criteria Decision Analysis (MCDA) with the AHP method and GIS applications. A weighted linear combination method was employed to derive the final flood hazard classifications. Additionally, for validation, a GIS database containing points representing flood events from 2002 to 2022 was utilized, ensuring at least one event per year was included in the analysis.

II. Method

Bandung Regency, West Java, Indonesia is used as study area. Bandung Regency has an area of 1762 km^2 with the location of the regional capital being in Soreang District. The research area used is Bandung Regency, which can be seen on the map in Figure 1.

Bandung Regency is geographically located in an area bordering the city of Bandung, West Bandung Regency, and Sumedang Regency. Apart from that, Bandung district has the highest mountain with a height of 2617 meters above sea level, namely Mount Kendang. Bandung Regency is located in the Bandung Basin and is surrounded by mountains, including the prominent Tangkuban Perahu and Burangrang mountains in the north. The highland area of Bandung Regency is interspersed with fertile valleys and extensive agricultural land, making it a vital area for tea, coffee, and vegetable plantations. The Citarum River, one of the longest rivers in West Java, flows through this region, providing a water source and contributing to lush greenery. Bandung Regency's climate is tropical, with high rainfall throughout the year, supporting a green landscape and diverse ecosystem.

Credible data is used in data acquisition so that the data used in this research can be trusted reliably. The data used in this research was processed and processed using ArcMap version 10.8. There are eight main data used in this research under literature studies, with an data explanation provided in Table 1. Use of historical flood data from 2002 to 2022 which uses at least one event in one year, to validate the mapping results.

This research uses the ArcMap 10.8 application to collect, process, and analyze data to obtain a flood hazard map for the Bandung Regency. The conditioning and reclassification of factor maps were performed using the natural break (Jenks) method and weighted linear combination (WLC), while the validation of the Greater Bandung food hazard map was conducted using ArcGIS 10.8 software. The GIS analysis utilized only spatial functions, with no 3D analysis performed by the researchers.

The expert assessment in this research was conducted using the AHP method with Microsoft Excel

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software. This involved quantitative planning, where a preference scale was used to make decisions from a range of available alternatives [32]. Experts are selected based on their abilities and expertise in their respective fields, in terms of the conditioning factors used, the expert selected to judge the conditioning factors must have at least hydrology and/or soil expertise. Based on an expert search to judge conditioning factors, five experts were obtained, including experts in the fields of hydrology, soil, mitigation, environment, and urban design.

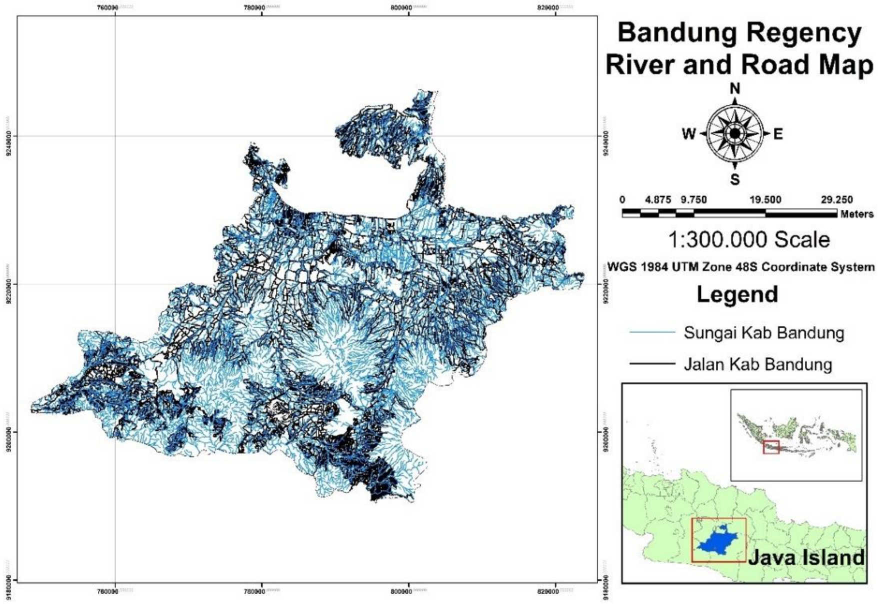

Figure 1. Area of Interest

Table 1. Type and source of Data Used

No	Type of Data	Type		Scale/Res	Data Source
		Database	Map Accuisition	Database of Spatial	
1	TWI	GRID	Topographic Wetness Index	30 m	ASTER GDEM V.3
2	Elevation		Elevation (m)		
3	Slope		Slope Gradient (°)		
4	Rainfall		Precipitation Map (mm/year)	1:50.000	UK NERC and UK NCAS
5	LU/LC		Land Cover	10 m	ESRI Land Cover 2022
6	NDVI		NDVI		Landsat 8 OLI/TIRS+Images
7	Distance from River	Line Coverage	Distance from River (m)	30 m	Indonesian Geospatial Information Agency
8	Distance from Road		Distance from Road (m)		
9	Flood History	Point (Shape)	-	-	Indonesia Board for Disaster Management

In AHP, the pairwise comparison matrix (PCM) is utilized to rank parameters. PCM helps in developing weighting factors for each criterion based on the input from individuals, by using a ranking scale [33]. The conditioning factor weighting scale ranges from 1 to 9, with scale 1 indicating equal importance between two conditioning factors, and scale 9 indicating a very high preference for one factor over the other. The average Consistency Index (CI) value, based on the randomly generated Pairwise Comparison Matrix (RI), varies depending on the number of conditioning factors used and the order of the matrix displayed. The Consistency Ratio (CR) reflects the results of data validation, which will be used quantitatively in mathematical equations, as shown in equations (1) and (2).

$$CR = \frac{CI}{RI} \quad (1)$$

$$CI = \frac{(\lambda_{max-n})}{n-1} \quad (2)$$

Information:
CR : Consistency ratio;

CI : Consistency Index; λ: Average vector consistency value;
n : Number of criteria; And
RI : Random CI of randomly generated PCM.

RI data is derived from the results of randomly selected PCMs, where the PCMs are accessed from paired tables in an inconsistent and random manner [34]. To validate the conditioning factor weights, the CR value must be less than 0.1. If the CR value exceeds 0.1, the expert must recalculate the weighting matrix. All weighting methods for normalizing PCM values are implemented using various techniques or approaches, as determined by the experts [35]. Subsequently, the weights derived from the expert assessment are applied, and multiplying each conditioning factor is aggregation method used in this research according to the obtained factor weights, as specified in equation (3).

$$FS = \sum w_i x_i \quad (3)$$

Information:
FS : Hazard to flooding;
w_i : Weight of factor i; And
x_i : Food hazard class for each factor i

Spatial maps are generated using data sourced as shown in Table 1. To prevent data imbalances, all data is standardized to consistent units. The spatial data is then categorized into five classifications based on these units. After classification, the data is weighted using weighted classes, aligning the conditioning factor values with the results from the AHP conducted during the expert judgment phase. The resulting maps are validated, and if the data is found to be insufficiently valid, the data is reviewed and rechecked from the start.

Sensitivity analysis for assess the impact of changes in factor weights on the flood hazard map is carried out using the equation that can be seen in Eq (4).

$$W_i' = W_i \; x \; (1 + p) \quad (4)$$

W_i' is adjusted weigth of the i-th factor, and p is percentage change applied to the weight (expressed as a decimal, e.g., 0.1 for a 10% increase or -0.1 for a 10% decrease).

For accuration validation of flood hazard map derived from extensive data processing and analysis, the GIS database was utilized, encompassing flood events from 2002 to 2022, with one or more occurrences per year. The information on these flood events was sourced from the National Disaster Management Agency (BNPB) Disaster Information Data, which includes databases and flood reports. The data collection focused on floods in Greater Bandung, but only incidents classified as level one to three were gathered. According to BNPB, level one floods persist for up to six hours without receding and are considered critical. Level two floods involve expanding inundation, and level three floods feature substantial inundation but are not yet critical, or flash flooding. Validation of the mapping results was carried out using the Receiver Operating Characteristic (ROC) curve method, which took into value of the Area Under Curve (AUC). The AUC value is interpreted as a percentage to determine the quality of validity, the interpretation of which can be seen in Table 2 [36].

Table 2. Interpretation of AUC

AUC Range	Interpretation
Between 0.8 and 0.9	Good
Between 0.7 and 0.8	Enough
Between 0.6 and 0.7	Bad
Between 0.5 and 0.6	Not Valid

The quality of the data used in this research uses low-resolution satellite imagery, so within the limitations of data use, this research allows for a lack of accuracy. The problem of limited data quality can be overcome by using high-resolution images, or by fusing panchromatic and monochromatic images (fusing high-resolution images with low resolution). So with this, the accuracy problem can be resolved properly.

III. Results and Discussion

Eigth sets of data for conditioning factors used in this study that potentially impact food hazards, as detailed in Table 2. Source validation to ensure accuracy often involves the conversion of images due to discrepancies in data units compared to those desired by the researchers [37].

Once the data is acquired and verified for quality and resolution that meet the research requirements, the researcher proceeds to reclassify it based on predefined criteria. This reclassification aims to refine the specificity of the resulting classes. However, the final classification outcome may vary depending on the availability and weighting of the data, occasionally diverging from initial expectations [38]. The reclassification results can be seen in Table 3.

Natural break (Jenks) method used for classification (See Table 3) to give classification based on data distribution. Jenks is based on data distribution curve, so data gaps will not shows during classification [7]. Then five expert weighting carried out with rules that no CR value has greater than 0.1 per expert. Overal results of all expert weighting shows in Table 4.

Applying AHP enabled the determination of criteria weights through normalized principal eigenvector values. By comparing values within each row, the total weight for all flood hazard criteria in Bandung Regency was determined. The maximum sigma value was 8081, with a CR value of 0.08, indicating valid validation of the weighting data (CR < 0.1). Each conditioning factor received the following weights: TWI (16.29%), Height

(11.22%), Slope (16.31%), Rainfall (11.32%), Land Use (14.18%), NDVI (10.79%), Distance from Rivers (8.57%), and Distance from Roads (10.82%).

Table 3. Conditioning factor classes, and rank estimation for reclassification

Factor	Abbreviation	Class	Rating
TWI (Level)	TW	< 5	1
		6 – 10	2
		11 – 15	3
		16 – 20	4
		20 >	5
Elevation (m)	EL	< 500	5
		501 – 1000	4
		1001 – 1500	3
		1501 – 2000	2
		2000 >	1
Slope (°)	SL	0 – 10	5
		11 – 30	4
		31 – 50	3
		51 – 70	2
		70 >	1
Rainfall (mm/tahun)	PC	< 300	1
		301 – 350	2
		351 – 400	3
		401 – 450	4
		450 >	5
Land Use	LU	Water	1
		Agriculture Land	2
		Building	3
		Bare Land	4
		Vegetation	5
NDVI	ND	-0.118 to -0.035	1
		-0.036 to 0.127	2
		0.128 to 0.282	3
		0.283 to 0.401	4
		0.402 to 0.574	5
Distance from River (m)	DRv	< 5	5
		6 – 10	4
		11 – 15	3
		16 – 20	2
		20 >	1
Distance from Road (m)	DRo	< 5	5
		6 – 10	4
		11 – 15	3
		16 – 20	2
		20 >	1

Table 4. Weighting Matrix with Eigenvector (Normalized)

	TW	EL	SL	PC	LU	ND	DRv	DRo	Normalized principal Eigenvector (%)
TW	1	1.516	1	1.272	1.320	1.552	2.112	1.246	16.29
EL	0.66	1	0.517	1.125	0.85	1	1.246	1.246	11.22
SL	1	1.933	1	1.380	1.149	1.644	1.719	1.149	16.31
PC	0.786	0.889	0.725	1	1.114	0.922	1.149	1.246	11.82
LU	0.758	1.176	0.871	0.898	1	1.320	2.221	1.552	14.18
ND	0.644	1	0.608	1.084	0.758	1	1.380	0.871	10.79
DRv	0.474	0.803	0.582	0.871	0.450	0.725	1	0.922	8.57
DRo	0.803	0.803	0.871	0.803	0.644	1.149	1.084	1	10.82

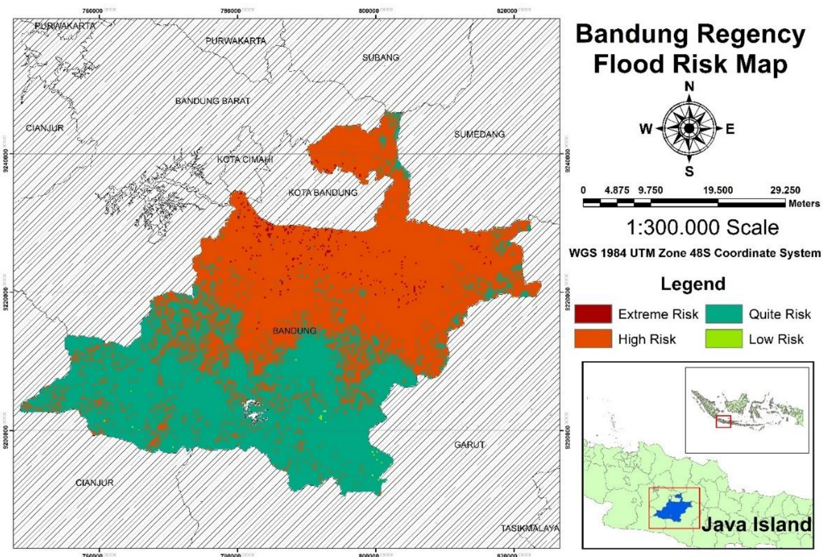

Figure 2. Bandung Regency Flood Hazard Map

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Subsequently, the weightings for each conditioning factor weighted with the Weighted Overlay tool to generate a flood hazard map for Bandung Regency. The resulting flood hazard map can be viewed in Figure 2.

To validate the accuracy of the flood vulnerability mapping conducted by researchers, particularly in high, flat, and low areas, with 20 years (2002 to 2022) flood event based on point anlayzed. These points were compared with the researchers' mapping results, adjusting the actual flood data with different intensity of flood vulnerability. The criteria indicate validity if the Area Under Curve (AUC) value exceeds 0.7 [38]. ROC Curve of validation of hazard map has been created displayed in Figure 3.

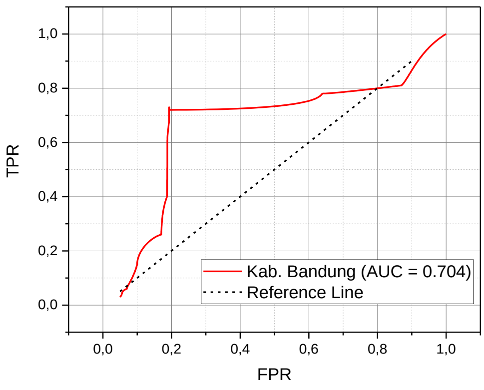

Figure 3. Curve of Receiver Operating Characteristic

Based on the results shown in Figure 3 of the ROC curve, the flood susceptibility map for Bandung Regency is deemed valid with an AUC value of 0.704 (AUC > 0.7). Bandung Regency exhibits a high-risk classification surrounding Bandung City except for the western area. This pattern is attributed to the region's dense urbanization, which frequently experiences flooding, especially in sub-districts such as Margahayu, Bojongsoang, Katapang, Margaasih, Pamengpeuk, Ciparay, Solokanjeruk, Baleendah, Dayeuhkolot, and Ciparay. These areas, characterized by dense urban development and irregular land slopes, face extreme flood risks. Additionally, inadequate river capacity exacerbates the situation, as narrow rivers struggle to manage rainfall, resulting in frequent flooding, as observed in previous research [39], [40].

Looking at Figure 2, it is evident that areas with high to extreme flood risk are predominantly located to the north near the Bandung City area, while regions in the south exhibit low to very low flood risk. The lower vulnerability to flooding in the northern and southern parts of Bandung Regency can be attributed to rapid urbanization near Bandung City in the north and direct access to the sea in the south, facilitating easier groundwater flow and reduced accumulation. The northern urbanized areas dominate Bandung Regency, thereby increasing flood vulnerability. These observations affirm the validity of the conditioning factors used, as indicated their validation values. According to literature, cities are particularly susceptible to flooding due to insufficient urban vegetation indices, highlighting the need for policymakers to focus on mitigating flooding in urban areas. The proximity of buildings and vegetation to main roads and rivers significantly influences flood risk, underscoring the importance of managing river width effectively [41].

These findings can certainly be a reference for stakeholders in conducting policy analysis. As the findings obtained show that the northern area of Bandung Regency has a high flood hazard, stakeholders are expected to make efforts to overcome this high flood hazard.

Based on the results obtained, show that TWI has the highest eigenvector value, while DRv has the lowest eigenvector value. This shows that the results obtained are different from research conducted by Sakmongkoljit [42] which shows that the DRv factor has the highest value. Then different results were found in research conducted by Hammami [24] which showed that NDVI had the highest factor. This difference is due to different geographical conditions, and especially in the DRv, Bandung Regency has many rivers that flow through densely populated urban and suburban areas. Due to rapid urbanization and population growth, residential areas are increasingly expanding closer to the river banks. In addition, many rivers have naturally meandering flows, which can be altered by urban development and infrastructure projects. So this shows why there is a difference in the lowest value of the eigenvector produced in this research and other research.

This research certainly has limitations in the methods used and the use of data. The main method used in this research only produces subjective validation of conditioning factors based on the assessments of only five experts. So using more experts to judge conditioning factors will produce better results. In addition, because the validity carried out in this research is subjective, it would be better to develop it into objective validity by sophisticated statistical results.

The use of satellite image data in this research has a relatively low resolution, so it would be better for future research to use high-resolution satellite images or use image fusion to increase image resolution. So this can increase accuracy in conducting a flood hazard analysis.

IV. Conclusion

Research mapping the flood vulnerability of Bandung Regency Based on AHP-MCDA, analyzed by ArcGIS 10.8 software identified four flood vulnerability classifications, there are low, moderate, high, and extreme risk. These classifications were derived from the reclassification of each conditioning factor and weighted assessments by five experts. The total flood-prone area in Bandung Regency is 1,745.95 km², with the high-risk category covering the largest portion at 945.33 km². The flood vulnerability map was validated with a 70.4%

accuracy rate. This map can guide local governments in addressing areas with high and extreme flood risk.

The northern area of Bandung Regency has highest area for flood risk, so it is highly recommended that stakeholders overcome this by taking several actions such as increasing green space for water absorption and making better development policies such as limiting housing development permits in dangerous areas. high floods, and creating a one house one tree policy to provide maximum natural water absorption.

This research has limitations in terms of objectivity for validation and the relatively low resolution of satellite imagery. So it is recommended for future research to apply the model to other areas, consider more objective methods, and explore additional factors that might be able to analyze flood hazards in an area. Apart from that, it is also recommended to use images that have high resolution with the hope of high accuracy.

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Declarations

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