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ORIGINAL ARTICLE

Mapping Greater Bandung flood susceptibility based on multi-criteria decision analysis (MCDA) using AHP method

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Abstract

Floods are natural disasters caused by certain factors, and these floods can cause a lot of material or immaterial losses. Bandung Raya is an area with coverage of two cities and two districts consisting of Bandung City, Cimahi City, Bandung Regency, and West Bandung Regency. Flood susceptibility mapping can be done in various ways, but one of the most effective ways is by using the MCDA-based AHP method. This study aims to map the susceptibility of flood risk in the Greater Bandung area using the analytical hierarchy process (AHP) multi-criteria decision analysis (MCDA) model, as well as validating the results obtained. The use of AHP MCDA in this research is by giving weight to each conditioning factor, and applying it by means of overlay weighting technique in ArcGIS 10.8 software. This study found that the flood risk criteria obtained were four classifications: (1) low risk; (2) quite risk; (3) high risk and (4) extreme risk. Most areas that get quite risk classification are Cimahi City, high risk in Bandung Regency, and high risk in Bandung Regency. In addition, the results of the validation by comparing the map acquisition with the flood maps that occurred in 2002–2022 get an average ROC curve percentage of 76.4%, and these results show that the Bandung Raya flood risk susceptibility map is valid. Based on the conditioning factors used, nine factors such as NDVI, TWI, LU/LC, Rainfall, Slope, Elevation, Distance from Road, and Distance from River can be used as valid conditioning factors.

Keywords AHP · Flood risk · MCDA · Spatial analysis

Introduction

Disaster is an event that can come from nature or because of human activity itself (Torani et al. 2019). The occurrence of natural disasters is due to an event that occurs naturally as nature carries out its routine, which usually natural disasters can be predicted based on their characteristics (Smith et al. 2022). It is different from disasters that are caused by human activities, where these disasters come unexpectedly and are carried out by humans because of a lack of awareness so a time bomb is created. Natural disasters can also be accelerated due to human activities themselves, so disasters that occur outside the expected time, are unexpected disasters because humans have changed the time of the disaster (Ullah and Zhang 2020). One of the unexpected natural disasters caused by humans is the flood disaster (Rehman et al. 2019).

Flood is one of the disasters that can cause material and immaterial losses such as the soul, and various urban arrangements that have been designed. In addition, flooding can hamper various jobs, social activities, and other daily human activities (Moe et al. 2018). Therefore, various studies regarding the dangers of flooding, to flood management continue to be carried out by many researchers to date. Of course, the flood disaster can be counted as a very detrimental disaster on an international scale because the losses vary from the disruption of human activities to death (He et al. 2018). Flood disasters are also sometimes unpredictable based on the season, sometimes floods can occur at any time even in summer, which is of course a big challenge for

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researchers in researching the possibility of flooding in an area (Mosavi et al. 2018).

In the global context, flooding is a disaster that takes a long time, so special attention is needed by considering various flood control variables (Al-Aizari et al. 2022; Ullah et al. 2022). An area that can be protected from flooding can pay attention to the level of vegetation, the amount and volume of drainage, the density between buildings, and human concern for the environment (Nguyen et al. 2019). Various flood problems often occur in urban areas, where urban areas have a high risk of flooding, which is most likely the main factor, namely a poor or inadequate drainage system (Shi et al. 2022). In addition to poor or inadequate drainage systems, of course, high population growth is also a factor in the occurrence of flooding when rain occurs in an urban area (Nkwunonwo et al. 2020). A high population can cause infrastructure development to increase over time, infrastructure improvements in urban areas that are not considered in terms of sewer capacity, drainage quality, and even less strict regulations prohibiting littering in ditches (Bamberg et al. 2017; Yusoff et al. 2018).

In Indonesia itself, there are many areas that have experienced flooding so it becomes a challenge for regional leaders to deal with it (Handayani et al. 2020). Some of the worst flood areas in Indonesia occurred in the Sintang area, West Kalimantan in November 2021, where the floods occurred for one full month and drowned 12 regencies (Sukayanti et al. 2022). In addition, in the city of Manado, there was a very large flood due to very heavy rains that flushed the city of Manado in January 2014 for 2 days, so that the volume of the Sario, Tondano and Sawangan rivers increased, which caused as many as eighteen people died, paralyzed in community activities, and material losses reach trillions of rupiah (Ajami et al. 2016). In Greater Bandung itself, floods often occur in every city or regency, as an example occurred in Bandung Regency in December 2020, where floods as high as 10 to 20 cm submerged as many as 7364 houses, eleven schools, and forty-two worship place like church and mosque. the worst occurred in two district, namely Baleendah and Dayeuhkolot district (Wulan et al. 2022). The condition of Bandung Raya in various aspects of environmental management, namely in urban areas is denser on the building index than the vegetation index, besides that Bandung Raya is an area full of sloping soil structures so groundwater is more prone to flow into urban areas which causes excessive accumulation of groundwater in urban areas, especially Bandung City and Cimahi City (Hardianto et al. 2020). Based on its characteristics, Greater Bandung consists of four regions, namely Bandung City, Cimahi City, Bandung Regency, and West Bandung Regency, where the four areas have long and dense rivers flowing towards the south (Supriyatin et al. 2020). In addition, Bandung Raya in urban areas has a very dense building density index, and in urban areas the vegetation density index is very small (Supriyatin et al. 2020).

Various methods are used for flood susceptibility mapping using various determining factors depending on the conditions represent the characteristics of the area studied. Because not all variables and factors cannot be used in any area, so, based on the narrative from previous researchers, in general in mapping flood susceptibility several variables can be used such as (1) Normalized Difference Vegetation Index (NDVI); (2) Land Use; (3) Topographic Wetness Index (TWI); and (4) Precipitation (Hammami et al. 2019). Other researchers also stated that the slope, elevation, distance from the river, and distance from the road have the biggest factors contributing to flooding in an area which can later be used as variables in mapping flood susceptibility (Costache et al. 2019; Das and Gupta 2021). In addition, other researchers also attempted to vary the conditioning factors used in the hybrid flood susceptibility mapping by focusing on factors such as (1) land slopes; (2) NDBI; (3) precipitation; and (4) distance from River (Rahmati et al. 2020). However, the selection of factors in the mapping of flood susceptibility must be seen based on the spatial scale in the mapping, where if the area being analyzed has a large coverage such as one province, even one country, it usually uses few variables, because in certain cases, there are several cities that do not have these variables significantly (Vojtek et al. 2021). For example, researchers examined two areas with comparative coverage between provinces, where the first province has a very high altitude because it has lots of mountains, and the second province has a very low altitude because there are not many mountains in the second province, as a result, the altitude factor is better removed because it will cause data imbalance, or the resulting data will produce a very high error if validation is carried out (Cabrera and Lee 2020; Rahman et al. 2019).

Flood in its analysis is a phenomenon that uses multidimensional where there is the use of spatial and temporal aspects, therefore geographic information systems (GIS) is an application that is believed to be useful and beneficial in synthesizing various data and different variables using a logical and logical thinking framework. using certain mathematical equations in producing a flood susceptibility map (Khadka et al. 2021; Wu et al. 2022). Various methods have been developed in identifying and analyzing flood-prone areas, or areas whose susceptibility is to be identified, in which these methods have also been applied in various geographic areas.

One of the most up-to-date methods in assessing flood susceptibility is multi-criteria decision analysis (MCDA) (Pham et al. 2021; Tang et al. 2018a, b). In the process, MCDA performs a comparison of the weights of each variable that has been determined, and the weight is given from expert judgment, or it can also be done by pairwise weighting, where MCDA will find out the various priority variable interests of the various condition factors selected (Samanta et al. 2016; Tang et al. 2018a, b). The most common thing done in MCDA in determining flood-prone zones based on various literature reviews is using a weighted linear combination approach (Shahiri Tabarestani and Afzalimehr 2021), in which this approach multiplies each conditioning factor with its weight, which of course all the conditioning factors analyzed are able to represent the final flood susceptibility (Wang et al. 2018). In determining weights, there are several techniques that can be done, but a technique that is flexible and often found in several studies is using the analytical hierarchy process (AHP), where pairwise comparisons are used to find which variable is the most superior compared to other variables with predetermined criteria previously (Msabi and Makonyo 2021).

The advantage of the AHP technique compared to other methods is the researcher's freedom in determining the variables to be used, but by paying attention to important aspects in carrying out weighting in the flood susceptibility analysis (Hussain et al. 2021). Various other approaches besides AHP are considered less effective and less flexible in mapping flood susceptibility, for example, a method that relies on the geomorphological characteristics of the basin, which in this method cannot replace traditional hydraulic modeling, so a deeper study is needed such as conducting field studies in detail. real, so it requires more time and effort to analyze it, in addition, this method can only be analyzed in areas that have a lot of basins, and the accuracy of the results also needs to be questioned again if it is carried out in areas that generally have a flat surface (Adnan et al. 2019). In addition, there are also statistical methods such as frequency ratios and logistic regression, which in this method depend heavily on the input variables whether they have a close relationship with other explanatory parameters, and also the size of the dataset used (Shafapour Tehrany et al. 2019). There is some literature that states that the AHP technique is considered invalid and its usefulness is doubtful, because AHP is felt to be too subjective, so the accuracy in mapping flood susceptibility is lacking in precision. (Cai et al. 2021).

However, all the approaches mentioned above have their own advantages and disadvantages in terms of flood susceptibility mapping. Therefore, the method used in flood susceptibility mapping research needs to pay attention to the clarity of the cumulative nature and spatial continuity based on the influence of the parameters of the mechanism of the occurrence of floods. In addition, the most important thing in mapping flood susceptibility is that it depends on the spatial scale used, whether using a local or even national scale.

Based on the literature study presented explaining the various differences in the use of conditioning factors carried out by researchers and developing a hybrid model, in this study, the researchers focused on eight aspects, including; (1) TWI; (2) Elevation; (3) Slope; (4) Rainfall; (5) Land Use/Land Cover (LULC); (6) NDVI; (7) Distance from River; and (8) Distance from Road. The building density index is not used in this study, because according to Syahputra et al. (2021) states that building density can be represented by how close the building is to the road but taking into account the land cover. Thus, in this research using AHP method for mapping Greater Bandung flood susceptibility.

This study aims to identify and analyze flood-prone areas on the Greater Bandung regional scale which includes the City of Bandung, the City of Cimahi, the Regency of Bandung, and the Regency of West Bandung using a hierarchical analytical process and GIS. The weighted linear combination approach was used in this study to develop the final flood susceptibility class obtained. In addition, for validation purposes, a GIS database in the form of points will also be provided which contains flood events that have occurred, and the flood events used occurred during the 2002–2022 period, which contains at least one incident in each of those years.

Methods

Study area

The study area chosen in this study is in the Greater Bandung area, which includes the City of Bandung, the City of Cimahi, the Regency of Bandung, and the Regency of West Bandung. Greater Bandung is located in West Java, Indonesia, with the entire area of Greater Bandung covering an area of 3500.74 km^2, the area per area can be seen in Table 1, and Fig. 1 shows the study area.

Greater Bandung is an area that has many mountains, even the Greater Bandung area is surrounded by high mountains. The highest mountain in Greater Bandung is located on Mount Kendang with a height of 2617 masl, and the lowest mountain in Greater Bandung is located on Mount Putri with an altitude of 1587 masl. In addition, the lowest temperature in Greater Bandung was recorded at 12 °C, and the highest temperature reached 31.6 °C. Rainfall Greater Bandung has the lowest annual rainfall of 1500 mm per year, and the highest is 4000 mm per year. There is the longest river in Greater Bandung, namely the Citarum River with a length of 297 km, where the river almost divides West

Table 1 Area per greater Bandung region

No	Regency/City	Area (km^2)
1	City of Bandung	167.3
2	City of Cimahi	40.37
3	Bandung Regency	1762
4	West Bandung Regency	1306

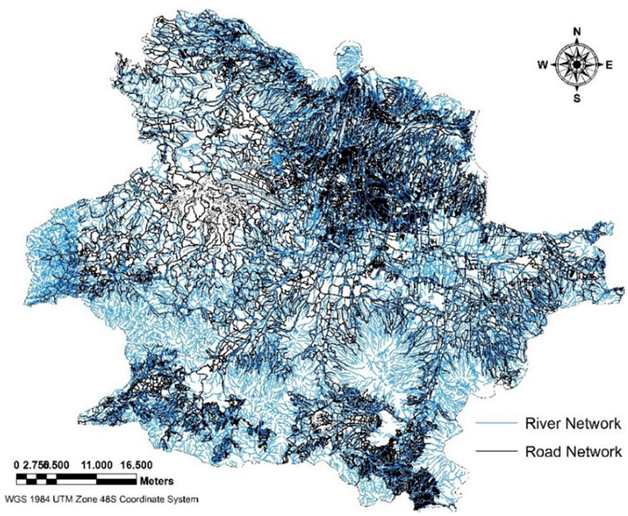

Fig. 1 Study area of great Bandung

Java Province, and the source of this river is in the Wayang mountain spring which is located south of Bandung City and flows northwards through Greater Bandung, which then empties into the Java Sea.

The city of Bandung, which is usually larger, often experiences fluvial flooding due to rising water in small rivers or ditches in urban areas, and this often occurs during heavy rains or prolonged light rain. For example, the biggest fluvial floods in the city of Bandung will occur from 2019 to 2022, especially in areas that have lots of sewer blockages. In most cases, minor river flooding results from short periods of heavy rainfall, as well as long periods of light rain.

Data and process

The data used in this research requires a variety of data collected from various credible and valid sources, which are then processed in GIS. Based on the description of the literature review that has been described in the introduction, the data used in processing flood conditioning can be seen in Table 2.

There are eight data that are used as flood conditioning factors, and these data are also selected to avoid the level of complexity of data processing on a regional scale that covers four major cities. The eight data are (1) TWI; (2) Elevations; (3) Slopes; (4) Rainfall (Annual precipitation); (5) Land Use; (6) NDVI; (7) Distance from River; and (8) Distance from Road. The ninth data are used to validate the acquisition of the Greater Bandung flood susceptibility map, where the flood data that occurred from 2002 to 2022 which at least every year provides one flood data that occurred. The research flow can be seen in Fig. 2.

In this study, researchers used ArcGIS 10.8 software to collect and analyze all flood conditioning factors in the local GIS database. All conditioning and reclassification of all conditioning factor maps, weighted linear combinations (WLC), to validation of the Greater Bandung flood susceptibility map were carried out using ArcGIS 10.8 software. All functions used in GIS analysis are only included in their spatial form, the researchers did not carry out a 3D analysis.

Table 2 Types of data used and their sources to process flood conditioning criteria

No	Data type	GIS data type		Scale or resolution	Source of data
		Spatial database	Derived map	Spatial database	
1	TWI	GRID	Slope Gradient (°)	30 m	ASTER GDEM Version 3
2	Elevation		Elevation (m)		
3	Slope		Topographic wetness index		
4	Rainfall	GRID	Precipitation map (mm/year)	1:50.000	UK's Natural Environment Research Council (NERC) and UK National Centre for Atmospheric Science (NCAS) (Harris et al. 2020)
5	LULC	ARC/INFO GRID	Land use	10 m	ESRI Land Cover (2020)
6	NDVI	ARC/INFO GRID	NDVI	30 m	Landsat 8 OLI/TIRS + Images
7	Distance from River	ARC/INFO GRID Line Coverage	Distance from River	30 m	Center for Management and Dissemination of Geospatial Information Geospatial Information Agency Indonesia
8	Distance from Road	ARC/INFO GRID Line Coverage	Distance from Road	30 m	Center for Management and Dissemination of Geospatial Information Geospatial Information Agency Indonesia
9	Flood Inventory	Point and Polygon	-	-	Disaster information Data of Indonesia National Disaster Management Agency

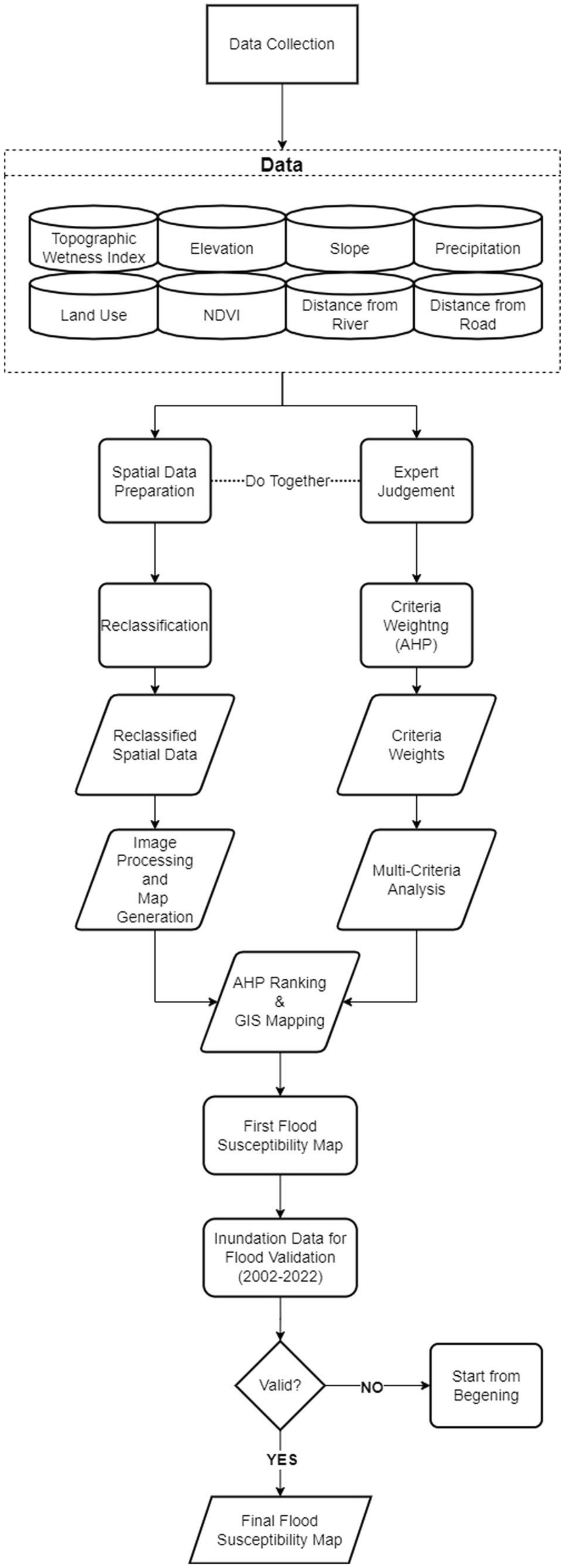

Fig. 2 Research flowchart

Expert judgement

Expert judgement in this research using AHP method, carried out using Microsoft Excel software by carrying out quantitative planning in which the preference scale is taken in making decisions from a series of available alternatives (Chourabi et al. 2019). Pair-wise comparison matrix (PCM) is used in AHP with the aim of taking a ranking of the parameters available in AHP, where this PCM can construct a weighting factor from each criterion given by each individual, by applying the ranking scale (Swain et al. 2020). The scale of conditioning factor weighting can be chosen on a scale of 1–9, where scale 1 shows the importance of the two conditioning factors being equal, to scale 9 shows a very high inclination towards the importance of one of the conditioning factors selected. The resulting random CI by PCM (RI) average values will vary according to how many conditioning factors are used, with different matrix sequences shown. Consistency ratio (CR) shows the validation results of the data that will be used later quantitatively with a mathematical equation that can be seen in Eqs. 1 and 2.

$$CR = \frac{CI}{RI} \tag{1}$$

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

where,

CR: Consistency ratio;

CI: Consistency Index;λ: Average value of consistency vector;n: Number of criteria; and

RI: Random CI randomly generated PCM.

The RI data were obtained from the results of PCM randomly selecting, which PCM accessed from the pairwise table in an inconsistently random manner (Swain et al. 2020). In validating the conditioning factor weights used, the CR value must be <0.1, if the CR value is >0.1, then the weighting matrix carried out by experts must be recalculated. Any form of weighting that aims to normalize the PCM value, is carried out with various techniques or approaches according to what experts believe (Choudhury et al. 2022). After that, the weights obtained from the results of the experts' assessment, the aggregation method is used to multiply each conditioning factor in the form of a map in ArcGIS 10.8 based on the acquisition of the factor weights using Eq. 3.

$$FS = \sum w_i x_i \tag{3}$$

where,

FS: Flood susceptibility;w_i: Weight of factor i; andx_i: Classes of flood susceptibility for each factor i

Flood susceptibility map creation

Spatial map is made by using data obtained from sources that can be seen in Table 2, then all data are adjusted in units if they are different from other units so that there is no data imbalance. All spatial data are classified into five classifications according to the unit. Then after the data has been classified, all data is weighed using a weighted class, where the conditioning factor values are adjusted to the results obtained in the AHP which was previously carried out at the expert judgment stage. The map results obtained are then validated, with a note, if the data is not valid, then the repetition and checking of the data is carried out again from the beginning.

Flood validation by flood inventory database

In an effort to validate the accuracy of the flood susceptibility map obtained from a series of data processing and analysis, the GIS database is used for flood events that have been obtained from 2002 to 2022, where in 1 year there were one or more flood events whose data was collected. Information regarding flood events during 2002–2022 was obtained and collected from databases and flood reports provided by the Disaster Information Data of Indonesia National Disaster Management Agency (BNPB), with a record of data collection for floods that have occurred in Greater Bandung, namely not all incident data were collected. only level one to three levels of flooding. Level one in BNPB is categorized that within 6 h the puddle has not receded and the condition has become critical, then level two is categorized that the inundation has begun to expand, and finally, level three is categorized that there is inundation but the condition is not yet critical, or what is often referred to as flash flood. After the flood disaster data from BNPB has been classified, then validated using the Receiver Operating Characteristic (ROC) curve method which will produce an Area Under Curve (AUC) value, then the AUC value is multiplied by 100% to produce a percentage value. The AUC value is then categorized according to the level of interpretation which can be seen in Table 3, with the limit above 0.7 being a valid result (Nachappa et al. 2020).

Table 3 AUC interpretation

Area under curve value	Interpretation
$0.8 \le AUC < 0.9$	Good
$0.7 \le AUC < 0.8$	Fair
$0.6 \le AUC < 0.7$	Poor
$0.5 \le AUC < 0.6$	Fail
$0.8 \le AUC < 0.9$	Good

Results and discussion

Results

This study presents eight data from a map of conditioning factors that may influence flood susceptibility, the data used can be seen in Table 2. The results of data acquisition obtained from various sources are required to re-check the values contained in the data, sometimes there are several images that must be converted because it has different data units than what the researcher wants (Cabrera and Lee 2019). The results of the acquisition of the data used can be seen in Fig. 3.

After the data are obtained properly, and the quality and resolution are fairly feasible to use or according to needs, then the researcher then reclassifies based on the values that have been previously defined. The purpose of this reclassification is to give specifics to the classes that will appear later, but the classes that appear at the end depend on the availability and weight of the data later, sometimes the classification that is set does not match the final result (Kanani-Sadat et al. 2019). The following are the results of the reclassification based on the class or value of each map which can be seen in Table 4.

The classification carried out in Table 3 uses the natural break (Jenks) method to provide a classification that is in accordance with the distribution of the data, because Jenks can provide a distribution of data according to the distribution curve of the data obtained, so it will not cause data voids when classification (Hadipour et al. 2020). Then the weighting is carried out by five experts, conditioned that the CR value per expert judgment does not exceed 0.1. the weighting results for each expert are then calculated and the overall results can be seen in Table 5.

With the application of AHP to find out the weighting criteria shown in the normalized principal eigenvector value, and obtained from comparing the values of each row in obtaining the total weight of all criteria for Greater Bandung flood susceptibility, the result is a sigma max value of 8081, and a CR value obtained of 0.8, this shows that valid weighting data validation can be used, because CR $(0.8) < 0.1$. Then, in each conditioning factor, TWI gets a weight value of 16.29%, Elevation gets a weight value of 11.22%, Slope gets a weight value of 16.31%, Precipitation gets a weight value of 11.32%, Land Use gets a weight value of 14.18%, NDVI gets a weight value of 10.79%, Distance from Rivers gets a weight value of 8.57%, and Distance from Roads gets a weight value of 10.82%.

Then the results of the weighting of each conditioning factor are applied to ArcGIS 10.8 by using a weighted overlay to create a flood susceptibility map for Greater Bandung, with the results of the flood susceptibility map for Greater

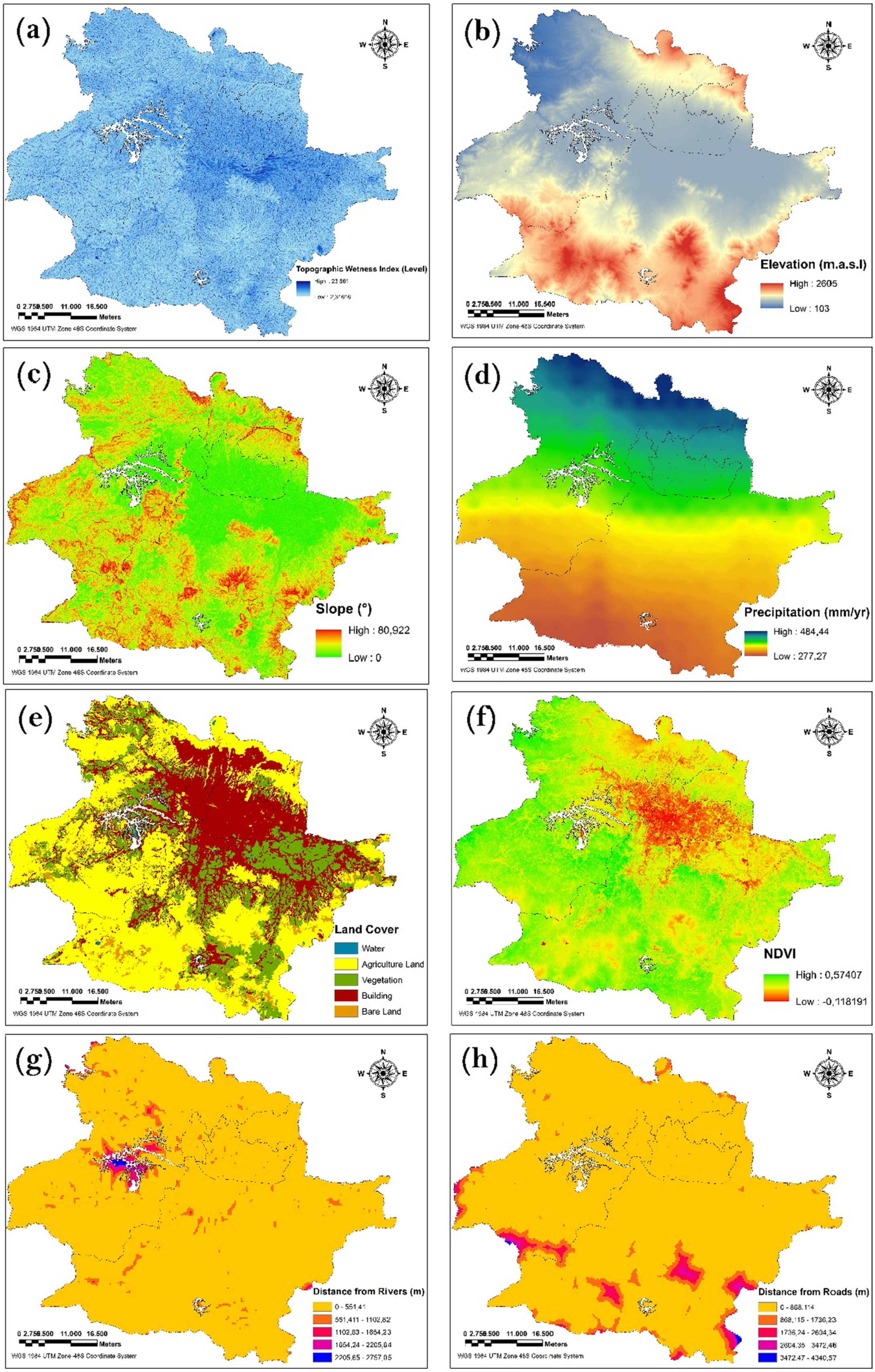

Fig. 3 The map of **a** TWI; **b** elevation; **c** slope; **d** precipitation; **e** land cover; **f** NDVI; **g** distance from rivers; and **h** distance from roads in Greater Bandung

Table 4 Classes of conditioning factors, and estimated ratings for reclassify

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
Precipitation (mm/year)	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
		0.128–0.282	3
		0.283–0.401	4
		0.402–0.574	5
Distance from rivers (m)	DRv	< 5	5
		6–10	4
		11–15	3
		16–20	2
		20 >	1
Distance from roads (m)	DRo	< 5	5
		6–10	4
		11–15	3
		16–20	2
		20 >	1

Bandung can be seen in Fig. 4, and the area affected up to the percentage can be seen in Table 6.

Based on the percentage, it is known that the largest percentage of areas with a low risk of possible flooding is in Cimahi City with a percentage of 0.4%, the area with the biggest quite risk of possible flooding is in Cimahi City with a percentage of 73.4%, the high risk area with the biggest possibility of flooding is in Bandung Regency with a percentage of 54.1%, and the extreme risk area for the possibility of flooding is in Cimahi City with a percentage of 2.0%, but this is not comparable to the total area which is in a wider area. Areas that have a larger area, will also get a greater risk area compared to areas that have a smaller area (Rincón et al. 2018).

Then, the researcher analyzes the number of affected sub-districts in each city, by attaching the sub-district boundaries to the Greater Bandung flood susceptibility map or by using the overlay method, the researcher will know how much susceptibility occurs in each sub-district. The results of the analysis of the number of flood suspects that occurred in each sub-district are presented in Table 7.

In an effort to validate and clarify whether the flood susceptibility mapping carried out by researchers is valid or not, especially in mountainous areas or relatively flat areas, an analysis using actual flood validation event points that occurred in 2002–2022 is carried out, and compared with the results mapping from researchers, in which real flood data that has occurred are adjusted to different levels of flood vulnerability, for validation criteria that data can be said to be valid if the AUC value reach > 0.7 (Kanani-Sadat et al. 2019). The validation results can be seen in Table 8 and ROC Curve can be seen in Fig. 5

Based on the results obtained in Table 7 and the ROA Curve in Fig. 5, it shows that all data are valid, because the AUC value of the entire Greater Bandung City/Regency gets results above 0.7, or in detail, namely; (1) CB 80.6% (Valid); (2) BR 70.4% (Valid); (3) CC 74.8% (Valid); and (4) WBR 79.6% (Valid).

Discussion

Based on the sub-district, the city of Bandung is dominated by flood susceptibility on the quite risk scale, and this occurs on average in the western, southern, and central parts of Bandung City, while the eastern and northern parts have the most flood susceptibility at high risk. The acquisition of very high flood susceptibility in the eastern part of Bandung City is due to additional factors in the eastern area of Bandung City where there is a lot of construction going on, besides that, the eastern area of Bandung City has a very dense urban density so that the drainage provision will narrow, Nahrin (2018) said that dense urban growth would cause the drainage to narrow, so the narrowing of the drainage would make it more likely that flooding would occur. Plus according to other researchers who stated that the narrowing of drainage due to urban growth which tends to take up land in a crowd, will make the drainage overflow quickly when it rains so that the flow of water when it rains cannot be absorbed properly (Abass et al. 2020; Piazza and Ursino 2022). Based on the narrative of some of these

Table 5 The results of the weighting matrix along with the normalized principal eigenvector values

	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	1.32	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	0.45	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

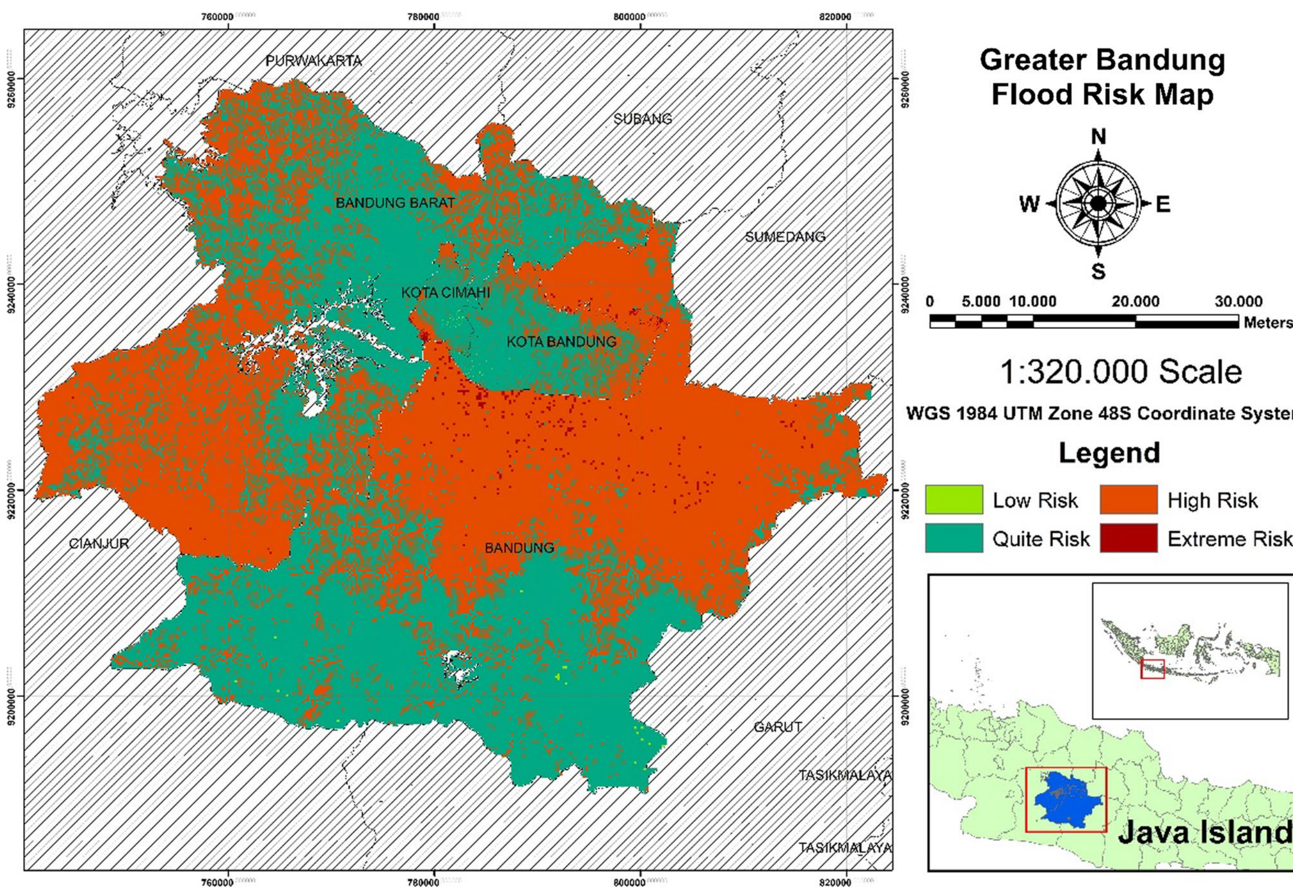

Fig. 4 Susceptibility flood map in Greater Bandung

Table 6 Area coverage of flood susceptibility by its classes

Regency	Low risk (km^2)	%	Quite risk (km^2)	%	High risk (km^2)	%	Extreme risk (km^2)	%	Total area (km^2)	Total %
City of Bandung	0.20	0.2	110.20	65.7	56.28	33.6	0.99	0.5	167.69	100
City of Cimahi	0.17	0.4	29.99	73.4	9.87	24.2	0.81	2.0	40.86	100
Bandung Regency	1.06	0.1	787.01	45.1	945.33	54.1	12.54	0.7	1745.95	100
West Bandung Regency	0.14	0.01	575.53	46.86	652.27	53.11	0.18	0.02	1228.14	100

Table 7 Number of districts with each classification of flood susceptibility

Regency/city	Flood susceptibility			
	Low risk	Quite risk	High risk	Extreme risk
City of Bandung	2 districts	24 districts	18 districts	2 districts
City of Cimahi	2 districts	4 districts	2 districts	1 district
Bandung Regency	3 districts	9 districts	26 districts	10 districts
West Bandung Regency	2 districts	13 districts	12 districts	1 district

Table 8 Flood validation based on the flood events in Greater Bandung

Regency/city	Flood susceptibility level	Number of flood validation points	AUC (%)
City of Bandung (CB)	Low risk	5	80.8
	Quite risk	120	
	High risk	328	
	Extreme risk	68	
City of Cimahi (CC)	Low risk	4	70.4
	Quite risk	272	
	High risk	102	
	Extreme risk	23	
Bandung Regency (BR)	Low risk	7	74.8
	Quite risk	187	
	High risk	334	
	Extreme risk	137	
West Bandung Regency (WBR)	Low risk	4	79.6
	Quite risk	244	
	High risk	208	
	Extreme risk	8	

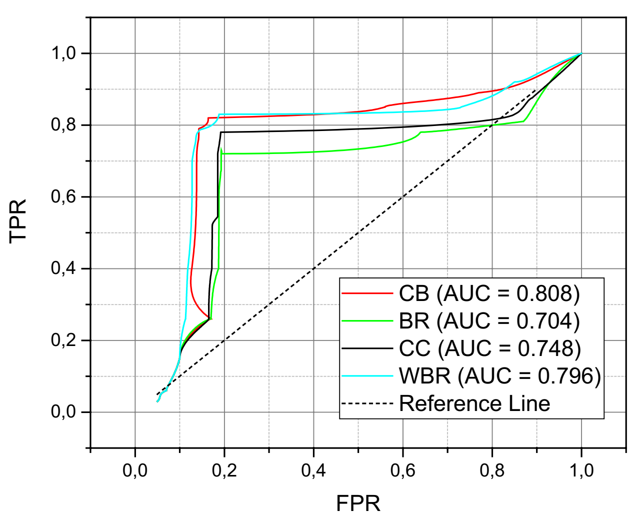

Fig. 5 ROC Curve for each district

researchers, it is very possible that flooding will occur in the city of Bandung a high risk, especially when rain hits the city of Bandung. Furthermore, in the city of Cimahi, where the most classification of flood susceptibility is at quite a risk, this is still classified as the risk is not too high, and only needs attention from the local government, this is also because Cimahi City has a relatively flat surface, and does not have surface area is high, so the thing that allows for the risk of flooding on a quite risk scale is the insufficient amount of drainage, as seen in Cimahi City which is very dense with urban areas and ongoing development. Furthermore, in Bandung Regency, there are very many high risk classifications in the northern, eastern and surrounding areas of southern Bandung City, where this occurs because the Bandung Regency area has a fairly dense urban area, which is usually an area where flooding often occurs with extreme risk in Bandung Regency, namely the districts of Margaasih, Margahayu, Dayeuhkolot, Bojongsoang, Baleendah, Katapang, Pameungpeuk, Arjasari, Ciparay, and Solokanjeruk, where these sub-districts have quite dense urban areas, but the slope of the land is irregular, so the possibility of flooding is very extreme, besides that an inadequate river because the river is relatively not wide makes it possible for this to happen, because according to previous researchers regarding an inadequate and not wide river, it will cause frequent flooding when it rains, because water absorption is inadequate (Falah et al. 2019; Wang et al. 2020). Finally, in

West Bandung Regency, it is almost the same as in Cimahi City, where the classification of flood susceptibility is highest at quite a risk, because West Bandung Regency has quite high vegetation with relatively varying ground heights but not too high, because according to previous researchers it was revealed that tall vegetation will allow very high water absorption also when rain occurs, so that water is quickly absorbed rather than stagnant (Das 2020; Mahmoud and Gan 2018), but it should be noted in the southern area of West Bandung Regency, there are quite a lot of areas with high risk, this is because the area looks like a basin from an observation of the elevation and slope of the area, this allows the possibility of flooding with high risk to occur because areas that have basins are relatively vulnerable affected by flooding because according to previous studies stated that areas that have land such as basins tend to have high floods because when it rains it will hold more water and not spread it to other areas (Janizadeh et al. 2019).

Judging from the map in Fig. 4, it can be seen that the areas that have a high to extreme risk are the eastern, central, and western parts of Greater Bandung, but the northern and southern parts are dominated by low-risk and quite risk. The low susceptibility of flooding in the north and south areas of Greater Bandung is because the northern area is the highland area of Greater Bandung, and the southern area of Greater Bandung has direct access to the sea so groundwater will flow more easily without accumulation. Greater Bandung is dominated by urban areas in the eastern, central, and western parts so this can support higher flood susceptibility. This finding can determine that the eight factors of the conditioning factors used in this study are valid, by showing validation values that can be considered valid. Based on a literature review, urban areas are indeed very vulnerable to flooding, because the urban area's vegetation index is felt to be lacking, and this should be the main focus of policymakers in dealing with flooding in urban areas. A very small distance from the road will increase the possibility of flooding, coupled with a very small distance from the river will increase the probability of flooding, so it is very necessary to pay attention to the distance between the road and the building and its vegetation, in addition, the width of the river is very important (Hammami et al. 2019).

The use of the AHP method in MCDA is still valid because the results show a validation value above 0.7 or 70%, so the AHP method in MCDA is still valid as long as selecting the right conditioning factor for the area under review. The selection of flood conditioning factors also greatly influences the results obtained, so the selection of conditioning factors must be very precise and careful in choosing if in research want a high level of validity, besides that the spatial scale used also influences, because the smaller the scale used in spatial research, the more accurate and valid the data will be (Al-Juaidi et al. 2018; Wing et al. 2017). In this study, the main problem is that the input data source has a scale that is felt to be lacking in the scope of the research area, because the research area, although regional in nature, is very broad in its coverage area. Similar to research conducted by previous researchers, where the coverage area is too wide will result in validation that tends to be low, and also the details in the data are not too detailed due to the spatial resolution not being proportional to the coverage area (Hasanloo et al. 2019). In addition, in determining the susceptibility of flooding using the MCDA AHP, there is a possibility that subjectivity will be high, because some experts will have different opinions, and require quite a lot of expert opinion, especially on a regional scale which includes two or more research cities, as a result of expert opinion making conditioning factor weights, so sometimes the conditioning factor weight tends to be heavier on one or two conditioning factors. As in previous studies where there were several conditioning factors that were felt to be too one-sided, so it was not uncommon for research to determine flood susceptibility using the AHP MCDA method to re-modify the data so that all conditioning factors were considered equal, and there was no tendency to overdo it (Doorga et al. 2022; Ha-Mim et al. 2022; Vignesh et al. 2021).

Conclusion

The research conducted to map Greater Bandung flood susceptibility using AHP MCDA with the help of ArcGIS 10.8 software found that based on the reclassification of each conditioning factor, and the weight assessment of five experts, the results in the Greater Bandung area were four classifications of flood susceptibility, namely; (1) Low risk; (2) Quite risk; (3) high risk; and (4) Extreme risk. The city of Bandung has a total flood susceptibility area of 167.69 km^2, with the most classification being the quite risk classification, which is 110.20 km^2, then Cimahi City has a total flood susceptibility area of 40.86 km^2, with the most classification being the quite risk classification, which is 29.99 km^2., then Bandung Regency has a total flood susceptibility area of 1745.95 km^2, with the most classification being the high risk classification, which is 945.33 km^2, and finally, West Bandung Regency has a total flood susceptibility area of 1228.14 km^2, with the most classification being the high classification. risk, namely an area of 652.27 km^2. Based on its validation, the Greater Bandung flood susceptibility map obtained valid data validation, with an overall average of 76.4%. This Greater Bandung flood susceptibility map can be used as a benchmark for the local government to pay further attention to areas that have high and extreme flood risks.

Author contributions RDA wrote the main manuscript text, reviewed and corrected the results of all analysis map, lead the research. RPP wrote the main manuscript text, find all primary data from available credible sources, and analyze the data using ArcMap 18.0. SS wrote the main manuscript text, reviewed and corrected the results of all analysis map.

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Data availability Data are available from the corresponding author upon request.

Declarations

Conflict of interest All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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