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RESEARCH ARTICLE

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Vulnerability Assessment to Flash Floods Disasters in the Upper Cisadane Watershed

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ABSTRACT

Flash floods are sudden flood disasters that can be triggered by several factors, one of which is landslides that occur in the upper watershed. In Bogor Regency, there are 14 sub-districts located in the Upper Cisadane watershed area that are prone to flash flood disasters. This study aimed to determine the social, economic, physical, and environmental vulnerability assessment of the community in the Upper Cisadane watershed area based on the modification assessment from Regulation of The Head of National Disaster Management Authority Number 12 of 2012. This vulnerability assessment is part of disaster risk assessment, which is an approach to show the potential negative impacts of a disaster that occurs in an area. This potential negative impact can be seen in the potential number of lives exposed, property loss, and environmental damage. According to the vulnerability index, the Upper Cisadane watershed has high and very high classes of flash flood vulnerability, with ten (10) sub-districts having high vulnerability index classes, and fourteen (14) districts having very high vulnerability index classes. The level of vulnerability in the sub-districts is influenced by the level of social, physical, and economic vulnerability, which has high to very high classes compared to other sub-districts. The vulnerability index class maps from this study are expected to be used as references for local governments and related parties in regional spatial planning and flash flood disaster mitigation planning.

Introduction

Flash flood disasters can cause physical and non-physical damage. It is caused by floating debris from landslide that occurred around steeply sloping valleys of watersheds and small catchment areas [1–3]. Climate change increases the risk of extreme rainfall, landslides, and flash floods in river basins. The large number of victims affected by flash floods indicates that they cause extensive losses and damage to society. According to several studies, flash flooding is the most devastating disaster and causes the worst damage worldwide. It is relatively fast and occurs within a short time [4–7]. A disaster risk assessment is conducted to identify the negative impacts (potential hazards) that could occur if a disaster occurs. Negative impacts can be seen in the number of affected people, property loss, and environmental damage [8].

Vulnerability is the inability of society to resist and respond to a disaster [8]. The impacts of flash floods in each area depend on the ability of society to respond to a disaster; for instance, a certain area with good socioeconomic status is relatively less vulnerable to disasters and has more efficient mitigation [7,9]. Social, economic, physical, and environmental vulnerabilities are affected by several factors. Therefore, it is necessary to understand the characteristics and vulnerability of society to the impact of hazards [7,10]. Index based vulnerability Assessment is a practical tool that helps compare and rank regions in terms of vulnerability [7]. Vulnerability assessment is an important step in determining community resilience to disasters to plan mitigation and disaster management in flash flood disaster-prone area [11–12].

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Bogor City and Bogor Regency are most likely to experience flash floods and landslide disasters. In Bogor Regency area, medium to severe landslide problem can occur in 26 (twenty-six) sub-districts, while 14 (fourteen) other sub-districts are most likely to be affected by flash floods or the flow of debris, including Caringin, Ciampea, Cibungbulang, Cigombong, Cijeruk, Ciomas, Dramaga, Kemang, Leuwiliang, Pamijahan, Rancabungur, Rumpin, Tamansari, and Tenjolaya. The 14 sub-districts are prone to flash floods and debris flows and are located in the Upper Cisadane watershed [13].

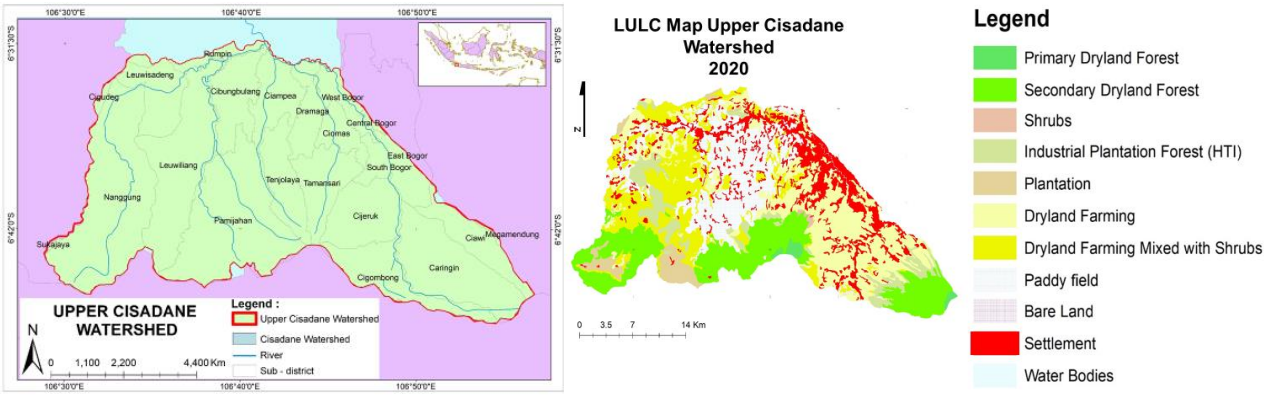
Heavy rainfall has caused flash floods and landslides in Pamijahan and Leuwiliang Districts, Bogor Regency, West Java, on June 22, 2022. At least 1,335 residents from those districts were affected, 335 of those residents were evacuated, three people were reported to have died, 11 bridges collapsed, and 281 houses were damaged [14]. The flash floods and landslides that occurred in the research area have caused many victims from the community. Research to determine the level of community vulnerability to flash flood disasters is needed for disaster mitigation planning in the study area. The objective of this study was to determine the social, economic, physical, and environmental vulnerability of the community in the Upper Cisadane watershed area based on the modification assessment from Regulation of The Head of National Disaster Management Authority Number 2 of 2012.

Materials and Methods

Study Area

The upper Cisadane Watershed covers about 835.79 km^2 which consists of Bogor City with four sub-districts (West Bogor, South Bogor, Central Bogor, East Bogor) and Bogor Regency with twenty sub-districts (Caringin, Ciampea, Ciawi, Cibungbulang, Cigombong, Cigudeg, Cijeruk, Ciomas, Dramaga, Kemang, Leuwiliang, Leuwisadeng, Megamendung, Nanggung, Pamijahan, Rancabungur, Rumpin, Sukajaya, Tamansari, and Tenjolaya) (**Error! Reference source not found.**). The Upper Cisadane Watershed has a gently undulating and hilly surface, 45.6% of which has heights varying from 200 to 500 msl (mean sea level) [15]. According to the Land Use Land Cover (LULC), the study area was classified into several classes such as primary forest (0.78%), secondary dryland forest (17.96%), plantation forest (6.41%), shrubs (0.24%), plantations (3.57%), settlements (13.36%), open/vacant land (0.14%), water bodies (0.43%), dry land agriculture (23.29%), mixed dry land agriculture (16.94%), rice fields (16.87%), and mining (0.01%)[15] (**Error! Reference source not found.**).

Topographical conditions and slope steepness in the Cisadane Watershed consist of variations in the slope from upstream to downstream. In the upstream area, the slopes were steeper, gentler, and even flatter in the downstream area. The slope was waver and undulating in the upstream area. In mountainous areas such as the Ciawi and Cijeruk sub-districts, the slope of the land is hilly to steep [16].



(a) (b)

Figure 1. Map of the study area: (a) watershed boundary, (b) land cover map, 2020 [15].

Data Collection

Sources of secondary data include data on disaster events, population, topography, LULC, protected forest area, spatial planning and regional planning map, land use/cover map, and productive land area from 2014

to 2021 was used in this study. These data were obtained from relevant agencies, such as the Regional Agency for Disaster Management, Central Agency on Statistics, Geospatial Information Agency, Ministry of Environment and Forestry (MoEF), Bogor Regency Government website (https://opendata.bogorkab.go.id/), West Java Provincial Government website (https://opendata.jabarprov.go.id/), and the website of each sub-district in the study areas (Table 1).

Table 1. Data types and sources in research area.

No	Objectives	Data types	Data forms	Sources
1	Social vulnerability	Population data (gender, poverty, persons with disabilities, age group)	Tabular	https://opendata.bogorkab.go.id/, https://opendata.jabarprov.go.id/, Central Agency on Statistics
2	Economic vulnerability	Area of productive land and resident occupations	Tabular	https://opendata.bogorkab.go.id/, https://opendata.jabarprov.go.id/ Central Agency on Statistics
3	Physical vulnerability	Total of residential houses (permanent, semi-permanent, non-permanent), public facilities (mosque, church, school, etc.) and critical facilities (health facilities) and the prices.	Tabular	https://opendata.bogorkab.go.id/, https://opendata.jabarprov.go.id/ Central Agency on Statistics, Geospatial Information Agency
4	Environmental vulnerability	Total area of natural forests, mangroves, swamps and shrubs.	Map	MoEF, Geospatial Information Agency

Data Analysis

The analysis of the vulnerability index (social, economic, physical, and environmental vulnerability) to flash flood disasters was performed based on a modification of the analytical method in Regulation of The Head of National Disaster Management Authority Number 2 of 2012 about General Guidelines for Disaster Risk Assessment. In this study, each vulnerability type has different parameters. Each parameter has different classes, which are represented by a specific score: three for the high class, two for the medium class, and one for the low class. After the scoring process, the social, economic, physical, environmental, and total vulnerability index values were divided into five classes: very high (2.4–3), high (1.8–2.4), medium (1.21–1.8), low (0.61–1.2) and very low (0–0.6) [8,11,17].

The parameters used to measure the social vulnerability index were population density, sex ratio, poverty ratio, disability ratio, and the ratio of vulnerable age groups. Population density is the number of people divided by the area in km^2. The sex ratio is the ratio between men and women. The poverty ratio is calculated from the percentage of poor people below the poverty line in Bogor Regency/City based on data derived from Bogor Regency in Figures 2021 and Bogor City in Figures 2021. The ratio of disability is the number of people with disabilities divided by the total population in each sub-district. The vulnerable age group ratio is the number of people aged 0–14 years plus the number of people aged over 65 years divided by the total population of each sub-district [8]. The weights of each parameter and equation of the social vulnerability index are listed in Table 2.

Table 2. Social vulnerability index.

Parameters	Weight (%)	Classes			Score
		Low	Medium	High	
Population density	60	<500 people/km^2	500 – 1,000 people/km^2	>1,000 people/km^2	Class/maximum score class
Sex ratio	10				
Poverty ratio	10				
Disability ratio	10	<20%	20 – 40%	>40%	
Vulnerable age groups ratio	10				

Source : [8]

Social vulnerability index analysed based on the following equation [8]:

$$Social\ Vulnerability\ Index = (0.6 \times Population\ density) + (0.1 \times Sex\ ratio) + (0.1 \times Poverty\ ratio) + (0.1 \times Disability\ ratio) + (0.1 \times Vulnerable\ age\ groups\ ratio) \quad (1)$$

The parameters used in the economic vulnerability index in this study were the area of productive land and vulnerable occupations. These parameters were modified from Regulation of The Head of National Disaster Management Authority Number 2 of 2012, which includes productive land areas and gross regional domestic products (GRDP). The available GRDP parameter data are at the district level, so they do not describe the conditions per sub-district. The productive land area in rupiah (including rice fields and secondary crops) and types of vulnerable occupations are used as parameters for the economic vulnerability index analysis. The weight of each parameter and equation of the economic vulnerability index are listed in Table 3.

Table 3. Economic vulnerability index.

Parameters	Weight (%)	Classes			Score
		Low	Medium	High	
Productive land	60	<50 million	50 – 200 million	>200 million	Class/maximum score class
Vulnerable occupation	40	<20%	20 – 40%	>40%	

Source : [8,17]

Economic vulnerability index analysed based on the following equation [8,17]:

$$Economic\ vulnerability\ index = (0.6 \times Productive\ land) + (0.4 \times Vulnerable\ occupation) \quad (2)$$

The physical parameters of the building, such as residential houses (permanent, semi-permanent, non-permanent), public facilities (mosques, churches, schools, etc.), and critical facilities (health facilities) are the three parameters used for the physical vulnerability index analysis. Residential house density is the number of residential units per hectare multiplied by the unit price of each type of house. The weights of each parameter and the physical vulnerability index equation are listed in Table 4. Moreover, land cover, which consists of natural forests, mangroves, swamps, and shrubs, is used as a parameter for environmental vulnerability index analysis. The weights of each parameter and the equation for the environmental vulnerability index are listed in Table 5.

Table 4. Physical vulnerability index.

Parameters	Weight (%)	Classes			Score
		Low	Medium	High	
Residential house	40	<400 million	400 – 800 million	>800 million	
Public facilities	30	<500 million	500 million – 1 billion	>1 billion	Class/maximum score class
Critical facilities	30	<500 million	500 million – 1 billion	>1 billion	

Source : [8]

Physical vulnerability index analysed based on the following equation[8]:

$$Physic\ vulnerability\ index = (0.4 \times Residential\ house) + (0.3 \times Public\ facilities) + (0.3 \times Critical\ facilities) \quad (3)$$

Table 5. Environmental vulnerability index.

Parameters	Weight (%)	Classes (ha)			Score
		Low	Medium	High	
Protected forests	30	<20	20 – 50	>50	
Natural forests	30	<25	25 – 75	>75	
Mangrove	10	<10	10 – 30	>30	Class/maximum score class
Shrubs	10	<10	10 – 30	>30	
Swamps	20	<5	5 – 20	>20	

Source : [8]

Environmental vulnerability index analysed based on the following equation[8]:

$$Environmental\ vulnerability\ index = (0.3 \times Protected\ forests) + (0.3 \times Natural\ forests) + (0.3 \times Mangrove) + (0.1 \times Shrubs) + (0.2 \times Swamps) \quad (4)$$

The results from the analysis of social, economic, physical, and environmental vulnerability indices were then converted into a flash flood vulnerability index based on the following equation [8]:

$$Flash\ flood\ vulnerability\ index = (0.4 \times social\ vulnerability\ index) + (0.25 \times physical\ vulnerability\ index) + (0.25 \times economic\ vulnerability\ index) + (0.1 \times environmental\ vulnerability\ index) \quad (5)$$

Eventually, the social, economic, physical, environmental, and flash flood disaster vulnerability indices were displayed in a vulnerability index map using ArcGIS 10.3 software.

Results and Discussion

Social Vulnerability Index

Based on the social vulnerability index, the study area was divided into three classes: medium, high, and very high. The Sukajaya sub-district was identified as medium, two sub-districts (Nanggung and Cigudeg) as high, and other sub-districts as very high (Table 6). The social vulnerability index is highly affected by population density. The highest weight of the parameter is the population density, which is approximately 60%. Therefore, the sub-district with more than 1,000 person/km^2 has very high vulnerability, while the sub-district with a density between <500 person/km^2 and 1,000 person/km^2 has medium to high vulnerability, such as the Nanggung, Cigudeg, and Sukajaya sub-districts. The social vulnerability maps have three different colors: red, very high vulnerability; orange, high vulnerability; and yellow, medium vulnerability (Figure 2a).

Table 6. Social Vulnerability Index in the Upper Cisadane Watershed.

No.	Sub-districts	Population density (people/km^2)		Sex ratio		Poverty ratio		Disability ratio		Vulnerable age groups ratio		Social vulnerability index	
		Sum	Score	Sum	Score	Sum	Score	Sum	Score	Sum	Score	Score	Class
1	Nanggung	618.28	2	110.64	3	7.69	1	1.72	1	28.8	2	1.9	High
2	Pamijahan	1,258.31	3	107.64	3	7.69	1	7.35	1	29	2	2.5	Very high
3	West Bogor	7,112.24	3	102.1	3	6.68	1	0.02	1	29.94	2	2.5	Very high
4	South Bogor	6,622.20	3	104.9	3	6.68	1	0.02	1	29.94	2	2.5	Very high
5	Central Bogor	11,839.85	3	101.3	3	6.68	1	0.02	1	29.94	2	2.5	Very high
6	East Bogor	10,278.52	3	102.9	3	6.68	1	0.02	1	29.94	2	2.5	Very high
7	Caringin	2,778.03	3	107.74	3	7.69	1	12.01	1	28.9	2	2.5	Very high
8	Ciampea	5,095.61	3	106.36	3	7.69	1	3.68	1	28.04	2	2.5	Very high
9	Ciawi	1,481.02	3	106.73	3	7.69	1	7.6	1	28.27	2	2.5	Very high
10	Cibungbulang	3,789.49	3	107.99	3	7.69	1	11.52	1	28.33	2	2.5	Very high
11	Cigombong	1,016.46	3	106.37	3	7.69	1	4.66	1	30.01	2	2.5	Very high
12	Cigudeg	754.07	2	110.48	3	7.69	1	2.94	1	28.71	2	1.9	High
13	Cijeruk	1,912.81	3	109.55	3	7.69	1	3.68	1	30.87	2	2.5	Very high
14	Ciomas	9,141.34	3	104.05	3	7.69	1	8.09	1	27.21	2	2.5	Very high
15	Dramaga	4,364.33	3	106.67	3	7.69	1	2.94	1	29.67	2	2.5	Very high
16	Kemang	3,120.26	3	104.37	3	7.69	1	5.39	1	27.65	2	2.5	Very high
17	Leuwiliang	1,369.55	3	107.07	3	7.69	1	7.84	1	28.71	2	2.5	Very high
18	Leuwisadeng	2,185.93	3	109.46	3	7.69	1	2.7	1	26.67	2	2.5	Very high
19	Megamendung	1,448.38	3	110	3	7.69	1	5.15	1	29.29	2	2.5	Very high
20	Rancabungur	2,678.03	3	104.37	3	7.69	1	1.72	1	29.35	2	2.5	Very high
21	Rumpin	1,066.99	3	110.82	3	7.69	1	2.7	1	28.12	2	2.5	Very high
22	Sukajaya	428.49	1	110.14	3	7.69	1	2.45	1	28.35	2	1.3	Medium
23	Tamansari	3,173.46	3	106.79	3	7.69	1	3.19	1	28.66	2	2.5	Very high
24	Tenjolaya	1,772.00	3	107.64	3	7.69	1	2.7	1	29.21	2	2.5	Very high

Source of data: [17–21]

Population density greatly affects the social vulnerability of an area to a disaster. Areas with a denser population have a greater chance of social loss from disasters than others because flash flood disasters occur in a relatively short time in a limited area [5,22]. In addition, the number of people who are vulnerable to flash flood disasters is equivalent to the workload of rescue teams in the event of a flood disaster [17]. The

high population density in the study area is caused by various factors. The research area is directly adjacent to the city area, close to the Central Business District (CBD) area and state universities, and is included in the Jabodetabekpunjur area, which has easy access to highway infrastructure (primary arterial roads and toll roads) that are integrated with suburban areas. In addition, the ease of finding large tracts of land at relatively lower prices compared to the surrounding cities has caused many investors to build housing, increasing population density [15,23].

Economic Vulnerability Index

The parameters of productive lands were paddy, corn, soybeans, and peanut fields. The income per hectare from each type of productive land uses the data from production values and production costs per planting season per hectare of lowland rice, upland rice, corn, and soybeans in 2017 [18]. The production value per hectare is IDR 4,955,540, which has the following details: IDR 2,284,080 for paddy fields, IDR 4,188,390 for cornfields, and IDR 1,228,460 for soybean field [18,24]. The parameter of job type (profession/occupation) is the type of occupation that is considered more vulnerable to flash floods, including the service sector, small businesses sector, daily wage employees, precarious workers, farmers, and fishermen[18] .

The number of residents with vulnerable jobs in Bogor City is the total number of workers in the entire region of Bogor who work in the service sectors, daily wage employees, and small to medium business sectors. To understand economic vulnerability in the study area, there are three classes of economic vulnerability (medium, high, and very high). West Bogor, Central Bogor, South Bogor, and East Bogor are identified as medium, six sub-districts (Caringin, Cigombong, Cigudeg, Ciomas, Sukajaya, and Tenjolaya) as very high, and other sub-districts as high (Table 7 and Figure 2b).

Table 7. The economic vulnerability index of Upper Cisadane Watershed.

No.	Sub district	Paddy field (Ha) (2020)	Productive lands for corn and soybean (Ha) (2020)	The total of productive lands (Million)	The score of productive lands	The residents with vulnerable job (%)	Score	Economic vulnerability index	Economic vulnerability class
1	Nanggung	3,578	23	17,730.92	3	9.67	1	2.2	High
2	Pamijahan	6,580	0	32,607.45	3	13.71	1	2.2	High
3	West Bogor	0	0	0	1	29.92	2	1.4	Medium
4	South Bogor	250	0	1,238.89	1	29.92	2	1.4	Medium
5	Central Bogor	0	0	0	1	29.92	2	1.4	Medium
6	East Bogor	141	0	698.73	1	29.92	2	1.4	Medium
7	Caringin	1,926	24	9,544.37	3	23.94	2	2.6	Very high
8	Ciampea	1,007	27	4,990.23	3	14.02	1	2.2	High
9	Ciawi	704	57	3,488.70	3	19.13	1	2.2	High
10	Cibungbulang	2,183	13	10,817.94	3	13.37	1	2.2	High
11	Cigombong	1,301	25	6,530.93	3	20.24	2	2.6	Very high
12	Cigudeg	2,832	10	14,034.09	3	27.15	2	2.6	Very high
13	Cijeruk	1,366	185	7,229.99	3	13.27	1	2.2	High
14	Ciomas	366	10	1,813.73	3	20.58	2	2.6	Very high
15	Dramaga	268	10	1,328.08	3	14.22	1	2.2	High
16	Kemang	194	20	961.37	3	7.96	1	2.2	High
17	Leuwiliang	3,920	24	19,425.72	3	14.02	1	2.2	High
18	Leuwisadeng	1,705	0	8,449.20	3	14.65	1	2.2	High
19	Megamendung	274	46	1,357.82	3	17.06	1	2.2	High
20	Rancabungur	240	60	1,189.33	3	8.42	1	2.2	High
21	Rumpin	2,652	29	13,217.48	3	15.33	1	2.2	High
22	Sukajaya	2,753	1	13,643.83	3	33.99	2	2.6	Very high
23	Tamansari	658	29	3,260.75	3	11.45	1	2.2	High
24	Tenjolaya	2,169	7	10,748.57	3	35.06	2	2.6	Very high

Source of data : [18–19]

In the economic vulnerability index, the highest value of the parameter is the weight of productive land (60%), while the sub-district in Bogor City with a paddy field of less than 500 ha has a medium vulnerability index. Sub-districts with a high number of productive lands and high number of farmers have high vulnerability. Sub-districts with very high vulnerability had a medium class of vulnerable occupation (20–40%). The agricultural sector influences economic vulnerability to natural disasters, especially floods and droughts [25–26]. Land use in the study area is dominated by dry-land agriculture (23.29%), mixed dry-land agriculture (16,94%), and rice fields (16.87%) [27]. Thus, the agricultural sector contributes to economic vulnerability both in the research area and in Bogor Regency [15]. This is also related to food security in the study area; if agricultural land is damaged by flash floods, economic stability and food security will be disrupted. In addition to disrupting the economy, flash flood disasters also disrupt the movement of residents in their daily activities [28]. The duration of flash flood disasters also affects damage to agricultural land [29].

Physical Vulnerability Index

The components of the physical vulnerability index for flash flood disasters are the density of residential houses (permanent, semi-permanent, and non-permanent), public infrastructure (prayer building and school building), and critical facilities (health facility) [18]. In this study, this assumption was used to determine the housing cost. The permanent house is valued at IDR 200,000,000, the semi-permanent house at IDR 150,000,000, and the non-permanent house at IDR 75,000,000. Public infrastructure was valued at IDR 200,000,000, while critical facilities were valued at IDR 250,000,000 (Table 8).

Table 8. Physical vulnerability index of Upper Cisadane Watershed.

No.	Sub district	Housing density		Public facility			Critical facilities			Physical vulnerability	
		Total	Score	Total	Price (Million)	Score	Total	Price (Million)	Score	The Total Score	Class
1	Nanggung	399.38	1	104	20,800	3	2	500	1	1.6	Medium
2	Pamijahan	1,033.80	3	418	83,600	3	3	750	2	2.7	Very high
3	West Bogor	1,456.74	3	318	63,600	3	39	9,750	3	3	Very high
4	South Bogor	3,218.24	3	616	123,200	3	18	4,500	3	3	Very high
5	Central Bogor	6,939.24	3	221	44,200	3	38	9,500	3	3	Very high
6	East Bogor	4,678.62	3	137	27,400	3	14	3,500	3	3	Very high
7	Caringin	1,956.80	3	197	39,400	3	11	2,750	3	3	Very high
9	Ciampea	3,841.71	3	164	32,800	3	4	1,000	3	3	Very high
10	Ciawi	984.55	3	339	67,800	3	13	3,250	3	3	Very high
12	Cibungbulang	2,757.64	3	292	58,400	3	3	750	2	2.7	Very high
14	Cigombong	1,046.47	3	207	41,400	3	8	2,000	3	3	Very high
15	Cigudeg	611.97	2	150	30,000	3	10	2,500	3	2.6	Very high
16	Cijeruk	1,584.32	3	92	18,400	3	5	1,250	3	3	Very high
17	Ciomas	5,062.53	3	155	31,000	3	13	3,250	3	3	Very high
18	Dramaga	3,840.23	3	160	32,000	3	17	4,250	3	3	Very high
21	Kemang	2,816.98	3	139	27,800	3	7	1,750	3	3	Very high
22	Leuwiliang	1,070.31	3	306	61,200	3	30	7,500	3	3	Very high
23	Leuwisadeng	1,654.62	3	136	27,200	3	2	500	1	2.4	Very high
24	Megamendung	1,106.48	3	133	26,600	3	8	2,000	3	3	Very high
25	Rancabungur	2,021.32	3	140	28,000	3	4	1,000	3	3	Very high
26	Rumpin	1,029.03	3	251	50,200	3	7	1,750	3	3	Very high
27	Sukajaya	322.51	1	232	46,400	3	4	1,000	3	2.2	High
28	Tamansari	2,259.32	3	341	68,200	3	4	1,000	3	3	Very high
29	Tenjolaya	1,458.06	3	271	54,200	3	19	4,750	3	3	Very high

Source of data: [18]

Physical vulnerability analysis shows that there are three physical vulnerability classes in the study area: medium, high, and very high. The Nanggung sub-district is medium, the Sukajaya sub-district is high, and other sub-districts are relatively high. The highest weight of parameter measurement was the weight of housing (permanent, semi-permanent, and non-permanent), with a score of 40% (Figure 2c).

Settlement location affects the level of damage, as well as access and movement of people when a disaster occurs. Settlements in rural areas in mountains are separated and scattered, which can lead to difficulties accessing residents and rescue teams [28,30]. The effects of flash flood disasters not only affect the damage to each house but also the surrounding environment and infrastructure in one village. This was due to strong flash flood currents accompanied by other materials, causing more severe damage to the environment [31].

Environmental Vulnerability Index

The components of the environmental vulnerability index parameters used to flash flood disasters, such as natural forests, mangroves, swamps, and shrubs, are obtained from the LULC Map 2020 from MoEF in Figure 1. The results of the environmental vulnerability index are listed in Table 9. Three classes of environmental vulnerability were identified in the study area: high, medium, and low. The Nanggung and Leuwiliang sub-districts have high environmental vulnerability. Pamijahan, Caringin, Ciawi, Cigombong, Cijeruk, Sukajaya, Tamansari and Tenjolaya are medium, while other sub districts are low (Figure 2d). The protected forest in the study area consisted of primary and secondary dry forests with varying vegetation.

The environmental vulnerability index in the study area is influenced by the area of protected forest and natural forest in the upstream area of the river. Flash floods can occur from the accumulation and rapid retention of water from upstream areas owing to landslides and heavy rains. The water flow can carry material in its path, so it has the potential to damage upstream areas, which are usually dominated by forests [2,31]. Therefore, sub-districts with protected forest areas and natural forests upstream are more vulnerable than other sub-districts.

Table 9. Environmental vulnerability index of Upper Cisadane Watershed

No.	Sub district	Protected forest		Nature forest		Mangrove		Shrub land		Swamp		Environmental vulnerability	
		Area (Ha)	Score	Area (Ha)	Score	Area (Ha)	Area (Ha)	Area (Ha)	Score	Areas (Ha)	Score	Total Score	Class
1	Nanggung	161.98	3	4,206.35	3	0	1	19.29	2	0	1	2.3	High
2	Pamijahan	0	1	3,723.79	3	0	1	0	1	0	1	1.6	Medium
3	West Bogor	0	1	0.00	1	0	1	0	1	0	1	1	Low
4	South Bogor	0	1	0.00	1	0	1	0	1	0	1	1	Low
5	Central Bogor	0	1	0.00	1	0	1	0	1	0	1	1	Low
6	East Bogor	0	1	0.00	1	0	1	0	1	0	1	1	Low
7	Caringin	0	1	2,588.95	3	0	1	0	1	0	1	1.6	Medium
8	Ciampea	0	1	0.00	1	0	1	0	1	0	1	1	Low
9	Ciawi	0	1	401.62	3	0	1	0	1	0	1	1.6	Medium
10	Cibungbulang	0	1	0.00	1	0	1	0	1	0	1	1	Low
11	Cigombong	0	1	941.34	3	0	1	0	1	0	1	1.6	Medium
12	Cigudeg	0	1	0.00	1	0	1	0	1	0	1	1	Low
13	Cijeruk	0	1	797.65	3	0	1	139.14	3	0	1	1.8	Medium
14	Ciomas	0	1	0.00	1	0	1	0	1	0	1	1	Low
15	Dramaga	0	1	0.00	1	0	1	0	1	0	1	1	Low
16	Kemang	0	1	0.00	1	0	1	0	1	0	1	1	Low
17	Leuwiliang	20.76	2	386.27	3	0	1	0	1	0	1	1.9	High
18	Leuwisadeng	0	1	0.00	1	0	1	0	1	0	1	1	Low
19	Megamendung	0	1	0.00	1	0	1	0	1	0	1	1	Low
20	Rancabungur	0	1	0.00	1	0	1	0	1	0	1	1	Low
21	Rumpin	0	1	0.00	1	0	1	0	1	0	1	1	Low
22	Sukajaya	0	1	68.28	2	0	1	0	1	0	1	1.3	Medium
23	Tamansari	0	1	998.67	3	0	1	46.08	3	0	1	1.8	Medium
24	Tenjolaya	0	1	994.48	3	0	1	0	1	0	1	1.6	Medium

Source of data: [27]

Flash Floods Vulnerability Index Upper Cisadane Watershed

The flash flood vulnerability index in the Upper Cisadane watershed was calculated from the social, economic, physical, and environmental vulnerability indices based on the formula in Regulation of The Head of National

Disaster Management Authority Number 2 of 2012. The calculation results from Equation (5) are listed in Table 10.

Table 10. Flash Floods Vulnerability Index of Upper Cisadane Watershed.

No	Sub district	Social vulnerability		Physical vulnerability		Economic vulnerability		Environmental vulnerability		The total of vulnerability	
		Weight	Class	Weight	Class	Weight	Class	Weight	Class	Weight	Class
1	Nanggung	1.90	High	1.60	Medium	2.20	High	2.30	High	1.94	High
2	Pamijahan	2.50	Very high	2.70	Very high	2.20	High	1.60	Medium	2.39	High
3	West Bogor	2.50	Very high	3.00	Very high	1.40	Medium	1.00	Low	2.20	High
4	South Bogor	2.50	Very high	3.00	Very high	1.40	Medium	1.00	Low	2.20	High
5	Central Bogor	2.50	Very high	3.00	Very high	1.40	Medium	1.00	Low	2.20	High
6	East Bogor	2.50	Very high	3.00	Very high	1.40	Medium	1.00	Low	2.20	High
7	Caringin	2.50	Very high	3.00	Very high	2.60	Very high	1.60	Medium	2.56	Very high
8	Ciampea	2.50	Very high	3.00	Very high	2.20	High	1.00	Low	2.40	Very high
9	Ciawi	2.50	Very high	3.00	Very high	2.20	High	1.60	Medium	2.46	Very high
10	Cibungbulang	2.50	Very high	2.70	Very high	2.20	High	1.00	Low	2.33	High
11	Cigombong	2.50	Very high	3.00	Very high	2.60	Very high	1.60	Medium	2.56	Very high
12	Cigudeg	1.90	High	2.60	Very high	2.60	Very high	1.00	Low	2.16	High
13	Cijeruk	2.50	Very high	3.00	Very high	2.20	High	1.80	Medium	2.48	Very high
14	Ciomas	2.50	Very high	3.00	Very high	2.60	Very high	1.00	Low	2.50	Very high
15	Dramaga	2.50	Very high	3.00	Very high	2.20	High	1.00	Low	2.40	Very high
16	Kemang	2.50	Very high	3.00	Very high	2.20	High	1.00	Low	2.40	Very high
17	Leuwiliang	2.50	Very high	3.00	Very high	2.20	High	1.90	High	2.49	Very high
18	Leuwisadeng	2.50	Very high	2.40	Very high	2.20	High	1.00	Low	2.25	High
19	Megamendung	2.50	Very high	3.00	Very high	2.20	High	1.00	Low	2.40	Very high
20	Rancabungur	2.50	Very high	3.00	Very high	2.20	High	1.00	Low	2.40	Very high
21	Rumpin	2.50	Very high	3.00	Very high	2.20	High	1.00	Low	2.40	Very high
22	Sukajaya	1.30	Medium	2.20	High	2.60	Very high	1.30	Medium	1.85	High
23	Tamansari	2.50	Very high	3.00	Very high	2.20	High	1.80	Medium	2.48	Very high
24	Tenjolaya	2.50	Very high	3.00	Very high	2.60	Very high	1.60	Medium	2.56	Very high

Calculation of the flash flood disaster index based on Regulation of The Head of National Disaster Management Authority Number 12 of 2012 indicated that there are two classes of vulnerability (high and very high). According to the vulnerability map of the Upper Cisadane Watershed to flash flood disasters, orange color represents high vulnerability of the sub-district, while red color indicates very high vulnerability of the sub-district. There are ten sub-districts (Nanggung, Pamijahan, West Bogor, South Bogor, Central Bogor, East Bogor, Cibungbulang, Cigudeg, Leuwisadeng, and Sukajaya) are categorized into high vulnerability, while 14 sub districts (Caringin, Ciampea, Ciawi, Cigombong, Cijeruk, Ciomas, Dramaga, Kemang, Leuwiliang, Megamendung, Rancabungur, Rumpin, Tamansari, and Tenjolaya) are categorized into very high class (Figure 3). All sub-districts in the Upper Cisadane Watershed are highly vulnerable to flash floods, based on four types of vulnerability analysis (social, economic, physical, and environmental indexes). Very high vulnerability indicated that the social, economic, physical, and environmental conditions in the sub-district were relatively more vulnerable than the sub-districts with high vulnerability.

Each parameter in social, economic, physical, and environmental vulnerability affects the other. The population density parameter of social vulnerability affects land requirements, infrastructure facilities, housing, and livelihood, as well as economic, physical, and environmental vulnerability [15]. Local governments can lower the value of the vulnerability index by assisting the community in improving the economy and mitigating efforts by carrying out physical and non-physical activities. Increasing economic value can help communities increase agricultural productivity after disasters. The local government can also provide educational activities to the community for socializing the potential hazards of landslides and flash floods in the research area as non-physical activities [32–33]. Vulnerability analysis of flash floods is important for creating a disaster mitigation map and a regional spatial planning map (RTRW) of Bogor Regency and Bogor City.

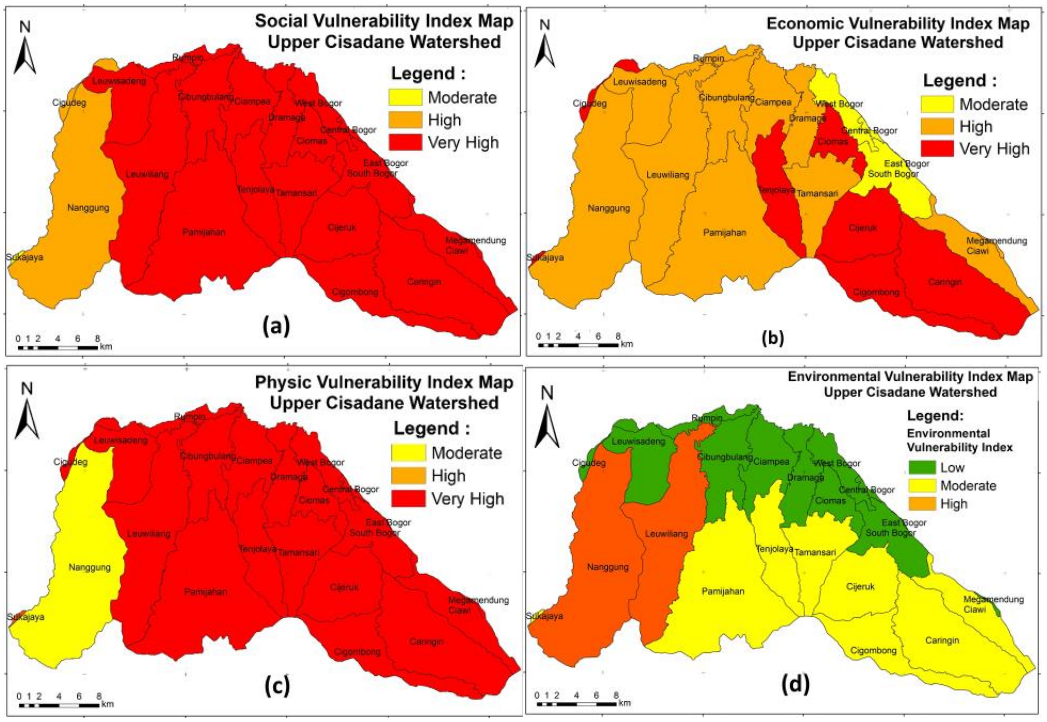


Figure 2. Vulnerability maps of the Upper Cisadane Watershed: a) Social vulnerability, (b) Economic vulnerability, c) Physical vulnerability, d) Environmental vulnerability.

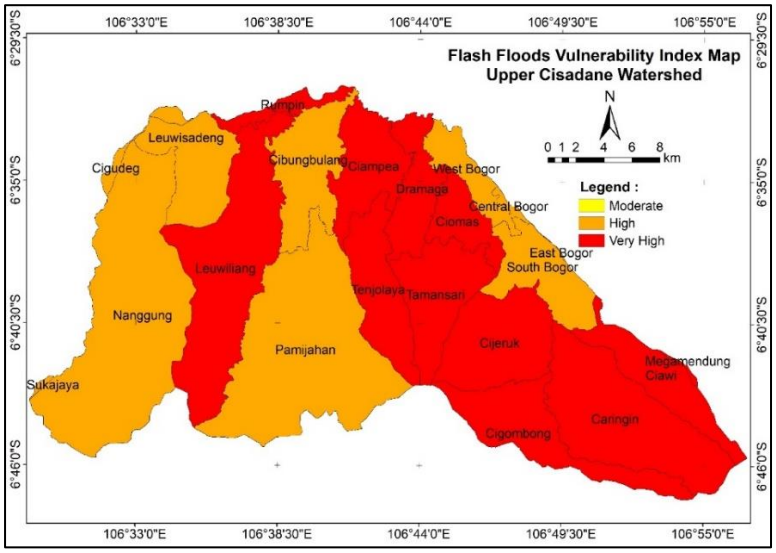


Figure 3. Vulnerability index map of the Upper Cisadane Watershed to flash flood disasters.

Conclusions

The social, economic, physical, and environmental vulnerability of the community in the Upper Cisadane watershed area needed for disaster mitigation planning in the study area. The study found variations in vulnerability indices for flash floods ranging from moderate to very high. It is worth considering whether these findings are reasonable, given the physical and demographic conditions of the study area. Special attention needs to be given to areas with very high vulnerability, which include districts Kecamatan Caringin, Ciampea, Ciawi, Cigombong, Cijeruk, Ciomas, Dramaga, Kemang, Leuwiliang, Megamendung, Rancabungur, Rumpin, Tamansari, and Tenjolaya are very high. In conclusion, it is hoped that local authorities will consider these study findings seriously and use them to plan measures to reduce community vulnerability to flash floods.

Regulation of The Head of National Disaster Management Authority Number 2 of 2012 used two parameters of economic vulnerability: productive land area and gross regional domestic product (GRDP). The available GRDP parameter data do not describe conditions per district; therefore, it is modified by the number of people with vulnerable jobs [17]. This modification is expected to show the real economic conditions of the community at the sub-district and village levels. The flash flood disaster vulnerability map from this research sufficiently describes the real conditions, where sub-districts with very high flash flood disaster vulnerability are affected by flash floods. Based on this map, the upstream area is prone to flash flood disasters. Research in downstream areas needs to be conducted to determine the level of vulnerability to flash floods downstream.

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