Comparative Analysis of the MCDA and GFI Methods in Determining Flood-prone Areas in Jatinangor District, Sumedang

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Abstract

Flood is one of the natural disasters which has a high intensity in terms of occurrence. Despite the loss value in each event which is not as high as some natural disasters, such as earthquakes or tsunamis, the high occurrence of floods may cause high loss in total. Floods damage property and infrastructure, disrupt economic activity, displace people, harm communities, and degrade ecosystems. This study aims to compare the flood hazard model using Geomorphic Flood Index (GFI) and Multi-criteria Decision Analysis (MCDA). GFI is an established method which already used globally to identify the flood-prone area and the depth of the flood. The parameter needed to calculate GFI are the elevation, river network, and historical flood event. Meanwhile, the MCDA method tries to combine environmental, physical, and hydrographic factors, such as land use/land cover, precipitation, and runoff. The study area is Jatinangor District in Sumedang Regency which part of West Java Province, Indonesia. This location is chosen based on historical and potential flood events. Besides, Jatinangor District is the center of industry and commerce which Sumedang Regency is very dependent on. The finding of this study is expected to identify suitable methods for assessing flood hazards in Jatinangor or other areas with similar characteristics, between GFI and MCDA.

1. INTRODUCTION

In recent years, the world has witnessed an increase in the frequency and intensity of extreme weather events, with floods ranking among the most devastating natural disasters.(Wasko et al. 2021) Climate change, driven by anthropogenic factors, has significantly altered precipitation patterns, sea levels, and overall hydrological dynamics, exacerbating the vulnerability of communities to flood hazards. (Pour et al. 2020)As a result, there is an urgent need to conduct research with pivotal understanding to complexities of floods, mitigating their impacts, and promoting resilient and adaptive strategies. (de Moel and Aerts 2011)

According to the data from 2010 to 2022 of flood events in Indonesia published by the National Agency for Disaster Management (BNPB), flood event shows an increasing trend every year. Floods damage property and infrastructure, disrupt economic activity, displace people, harm communities, and degrade ecosystems.(Wijayanti et al. 2017) Each flood event may not cause high loss value compared to the other natural disaster, such as earthquakes or tsunamis. However, the high occurrence of floods may cause high losses in total. (Ajjur and Al-Ghamdi 2022; Romali and Yusop 2021)

Floods can be caused by a variety of factors, both natural and human-induced. The severity and extent of flooding can vary depending on the specific circumstances of each event. Therefore, flood hazard assessments provide vital information for decision-making, risk reduction, and emergency preparedness, contributing to the safety and resilience of communities in flood-prone areas. This study aims to compare the flood hazard model using Geomorphic Flood Index (GFI) and Multi-criteria Decision Analysis (MCDA). GFI and MCDA are two widely used methods for flood hazard assessment, each offering unique perspectives and analytical approaches. Some studies have been analyzed flood-hazard area using GFI and MCDA (Gupta and Dixit 2022; Paquette and Lowry 2012; Pham et al. 2021; Samela et al. 2018; Nigusse and Adhanom 2019; Samela, Manfreda, and Troy 2017). However, comparative analysis between these two has not been discussed.

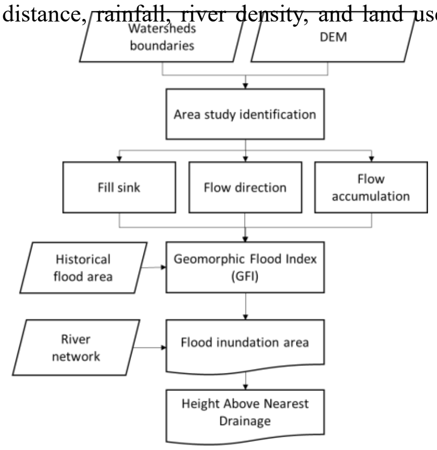
This research focused in Jatinangor District in Sumedang Regency which part of West Java Province, Indonesia as a study area. Sumedang has experienced several historical flood events throughout its history. Nestled in the northern part of West Java, Sumedang is susceptible to flooding due to its geographical features, including rivers, hilly terrain, and proximity to the mountains. The region's vulnerability to floods is further exacerbated by its tropical monsoon climate, characterized by distinct wet and dry seasons. Intense rainfall during the wet season, combined with inadequate drainage systems and land-use practices, has contributed to recurrent flooding incidents in Sumedang.

One significant historical flood event in Sumedang occurred in January 2011. Heavy rainfall over a prolonged period led to the overflow of the Cikeruh River, which runs through the regency. The resulting floods affected numerous villages, causing significant damage to homes, infrastructure, and agricultural fields. Thousands of residents were displaced, and casualties were reported. The 2011 flood served as a wake-up call for the local government and communities, highlighting the urgent need for improved flood management and disaster preparedness measures. (BNPB, 2019)

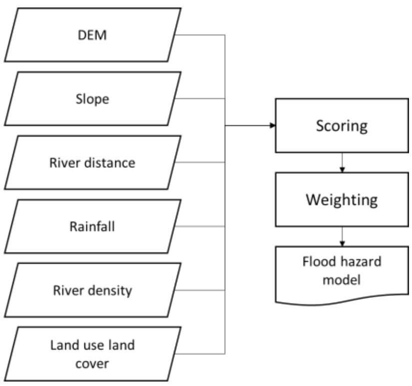
The outcomes of this study will provide valuable insights for decision-makers, researchers, and practitioners involved in flood risk management. By understanding the comparative advantages and limitations of MCDA and GFI, stakeholders can make informed choices when selecting an appropriate method for flood vulnerability assessment. Furthermore, the findings of this research will contribute to the ongoing efforts aimed at enhancing the accuracy and reliability of flood risk analysis, ultimately assisting in the development of more effective strategies for flood mitigation and adaptation.

2. METHODOLOGY

GFI is an established method which already used globally to identify the flood-prone area and flood inundation height. The parameter needed to calculate GFI are the watershed boundaries, elevation (DEM), river network, and historical flood event. Meanwhile, the MCDA method tries to combine environmental, physical, and hydrographic factors. In this study, the parameter uses in the MCDA method consist of elevation (DEM), slope, river distance, rainfall, river density, and land use/ land cover.

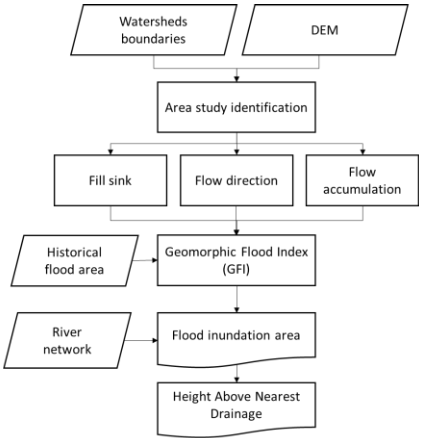


(a) GFI method (BNPB, 2019)

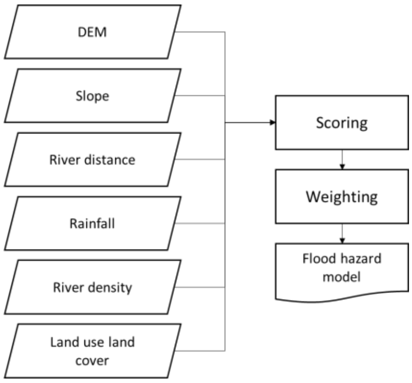


(b) MCDA method

Figure ***1*** shows the general steps of flood hazard modeling using (a) GFI and (b) MCDA.



(a) GFI method (BNPB, 2019)



(b) MCDA method

Figure 1. Flowchart of flood hazard modelling for GFI and MCDA

2.1 Flood Hazard Modelling with GFI

The Geomorphic Flood Index (GFI) was developed by Samela et al, 2018, through an additional plugin as an analysis tool available in the QGIS software. GFI is a method used to estimate flood inundation areas on a large watershed scale and is an effective and fast procedure for areas with limited hydrological data. There are two outputs of the flood hazard model using GFI, flood-prone area and flood inundation height. Based on BNPB guideline, the steps of GFI modeling in general are to identify flood-prone areas with a geomorphological approach to a river area. This step can be calibrated with the impact of historical flood (Samela, et al., 2017); and estimating the inundation height based on the elevation height vertically above the surface of the river in the potential flood-prone area.

There are four main parameters used in conducting flood hazard modeling using GFI, which are watershed boundaries, DEM, historical flood areas, and river networks.

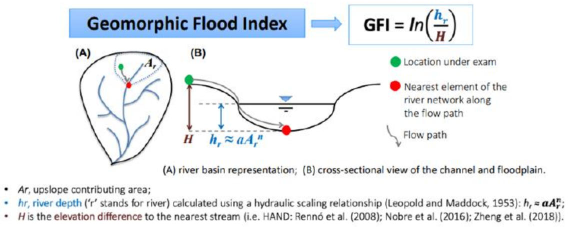


Figure 2. GFI calculation concept (Manfreda S, 2019 in BNPB, 2019)

The results of the GFI flood model are classified into a flood hazard index. The flood hazard index is classified based on the height of the flood inundation. The classification of flood inundation height for low hazard class is the area with inundation height less than 0.75 m; medium hazard class is 0.75 m – 1.5 m; and high hazard class is more than 1.5 m.

Table 1. Parameter of GFI hazard modelling

Data	Resolution	Source
Watersheds boundaries	1:50.000	
DEM	0.27 ArcSecond (8.1 m)	BIG
Historical flood	District	DIBI BNPB
River network	1:25.000	BIG

2.2 Flood Hazard Modelling with MCDA

This study use MCDA (Multi-Criteria Decision Analysis) to modelling the flood hazard in Jatinangor. The advantage of MCDA in modeling flood hazards is being able to review many aspects such as topographical, physical, environmental, social and hydrological aspects. In other words, the complexity of the explanatory variables used can be determined independently, of course the more variables reviewed, the more likely it is to get unbiased results. In this study, six parameters related to topographical data, hydrological data, and social data represent by land use and land cover were used to analysis the flood prone hazard that listed on **Table 2** and data spesification used to perform MCDA analysis described at **Table 3**. MCDA is a method that is implemented as a decision-making consideration by combining several dissimilar factors and identified to see which area is the best. (Massam, 1988) With the mathematical formula used in determining the suitability area from a geographical aspect is as follows:

$$S = \frac{\sum W_i R_{ij}}{\sum W_i} \quad (1)$$

$$S = (R_1 \times W_1) + (R_2 \times W_2) + \ldots + (R_n \times W_n) \quad (2)$$

Wi : Weight of class
Rij : Score of class
S : Class for each parameter.

2.2.1 Digital Elevation Model (DEM)

DEM provides information about the elevation or height of the land surface. In flood hazard analysis, DEM data helps identify low-lying areas that are more susceptible to flooding. Areas with lower elevation are likely to be at higher risk as they can easily become inundated during heavy rainfall or when rivers overflow.

2.2.2 Slope

Slope refers to the steepness or gradient of the land surface. It plays a crucial role in flood hazard analysis as areas with steeper slopes tend to have faster runoff and higher flow velocities, which can exacerbate flooding. Higher slope values indicate a greater potential for flood risk.

2.2.3 River Distance

The distance of an area from a river is an important parameter in flood hazard analysis. Areas closer to rivers are more prone to flooding due to the increased likelihood of river overflow or channel blockages. By considering the distance to the nearest river, the analysis can identify areas that are within the floodplain or in close proximity to rivers, indicating higher flood risk.

2.2.4 Rainfall

Rainfall is a critical factor in flood hazard analysis as it directly contributes to the volume and intensity of runoff. Areas with higher average or extreme rainfall patterns are more susceptible to flooding. By incorporating rainfall data, the analysis can highlight areas that experience heavy precipitation, thereby increasing their flood vulnerability.

2.2.5 River Density

River density refers to the concentration of rivers or watercourses in a particular area. Higher river density indicates a higher potential for flood risk as there are more channels that can potentially overflow during heavy rainfall or flooding events. Areas with dense river networks are more likely to experience frequent flooding, and this parameter helps in identifying such areas.

2.2.6 Land Use Land Cover

Land use and land cover information provides insight into how the land is being utilized and the type of surface that exists in a given area. Certain land uses, such as urban areas with extensive impervious surfaces like concrete and asphalt, can contribute to increased surface runoff during rainfall events. Additionally, land cover types like forests or wetlands can play a role in flood mitigation by absorbing and slowing down water. By considering land use and land cover data, the analysis can identify areas with characteristics that either exacerbate or mitigate flood risk.

Table 2. Parameter flood hazard resulting from (Virtriana et al., 2022; Darmawan & Suprayogi, 2017; Morea & Samanta, 2020; Samanta et al., 2016).

Parameter	Class	Score	Weight (%)
DEM	<40 m	5	11.20%
	40 - 80 m	4	
	80 - 200 m	3	
	200 - 500 m	2	
	>500 m	1	
Slope	<2 Degree	5	12.56%
	2 - 4 Degree	4	
	2 - 10 Degree	3	
	10 - 20 Degree	2	
	>20 Degree	1	

Parameter	Class	Score	Weight (%)
River Distance	<100 m	5	24.60%
	100 - 350 m	4	
	350 - 700 m	3	
	700 - 1000 m	2	
	>1000 m	1	
Rainfall	>291.67 mm/month	5	25.00%
	250 - 291.67 mm/month	4	
	166.67 - 250 mm/month	3	
	125 - 166.67 mm/month	2	
	<125 mm/month	1	
River Density	<0.62 km/km2	5	10.57%
	0.62 - 1.44	4	
	1.45 - 2.27	3	
	2.28 - 3.10	2	
	>3.1	1	
Land Use Land Cover	Water	5	16.07%
	Urban	4	
	Bare land	3	
	Cropland	2	
	Shrub land	1	

Table 3. Data used for MCDA Method

Data	Temporal	Resolution	Source
DEM	2022	10 m	Field Survey
River Dataset	2017	1:25000	BIG, 2017
CHRIPS Precipitation	2022	5566 m	Funk et al., 2015
LULC	2022	10 m	Field Survey

3. RESULT AND DISCUSSION

3.1 GFI Method

The flood hazard model using GFI which is already classified is shown in **Figure 3**. As mentioned before, the low hazard class (green) is the area with an inundation height which less than 0.75 m; the medium hazard class (yellow) is 0.75 m – 1.5 m; and the high hazard class (red) is more than 1.5 m. The GFI model defines the flood-prone area based on the river network and historical flood area. So, the hazard model is not covering all of the Jatinangor area. Sayang, Cikeruh, and Hegarmanah are three villages with the largest area covered by flood inundation using the GFI model. The detail of the flood hazard area by village using GFI is shown in **Table 3**.

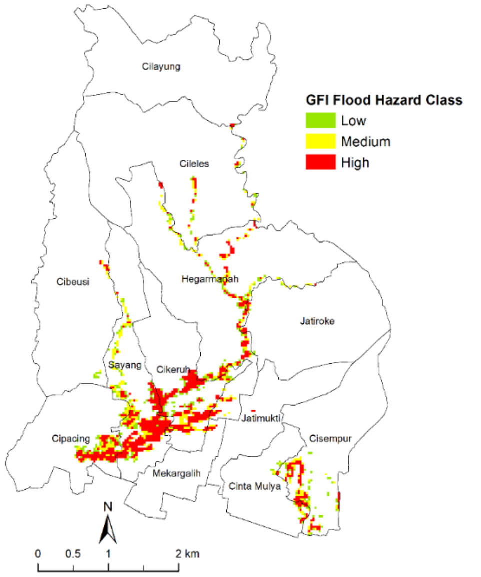


Figure 3. Flood Hazard Class with GFI Method

Table 3. GFI Flood hazard area per village in Jatinangor

Village	Flood Hazard Area (Ha)			Total Area (Ha)
	Low	Medium	High	
Cibeusi	0,63	0,99	0,54	2,16
Cikeruh	4,95	5,31	20,25	30,51
Cilayung	0,09	0	0,27	0,36
Cileles	1,98	2,52	1,8	6,3
Cinta Mulya	1,44	1,26	1,53	4,23
Cipacing	3,6	5,04	9,36	18
Cisempur	3,69	4,59	7,38	15,66
Hegarmanah	6,03	9,99	12,69	28,71
Jatimukti	0	0	0,18	0,18
Jatiroke	0,54	0,72	1,08	2,34
Mekargalih	0	0,36	0,63	0,99
Sayang	7,38	10,71	25,65	43,74

3.2 MCDA Method

The results of the flood hazard area analysis using MCDA are shown in **Figure 4**. The green color indicates a very low level of hazard and red indicates a very high level of flood hazard. From the MCDA results it is known that the river bank area in the southern part of Jatinangor is classified as high hazard. While the northern and western parts are dominated by green which indicates a low hazard level.

Residential areas that are less than 500 meters from the river are also classified as having a high hazard level. This is due to the influence of the river distance parameter which has a relatively greater weight than the other parameters.

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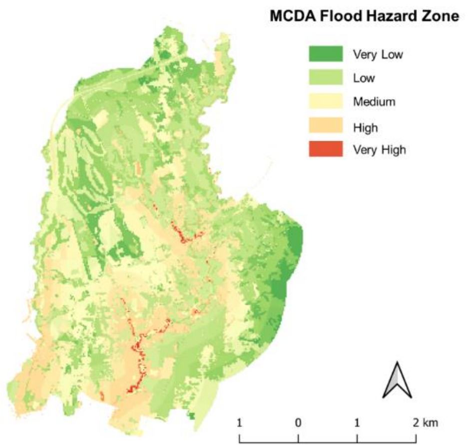


Figure 4. Flood Hazard Zone with MCDA Method

In contrast to GFI, the MCDA method classified all data and area into flood hazard zone. MCDA also has advantages in terms of considering the parameters used, where many aspects can be considered and the magnitude of the influence can be hierarchized. However, scoring and weighting are important in the MCDA method, besides that the more parameters used, the more data is needed to be prepared. Often data for each parameter is limited in terms of access and availability.

In accordance with the results of the MCDA analysis per village in Jatinangor, the villages of Sayang, Cipacing, and Cikeruh have the highest risk of flooding areas of 182.05 ha, 138.14 ha, and 99.18 ha. Sayang, Cilayung, and Cileles villages have the highest proportion of the overall flood hazard area of the "Very High" class. **Table 4** shows the breakdown of each MCDA flood hazard class by village.

Table 4. MCDA Flood Hazard per Village in Jatinangor

Village	**Flood Hazard Area (Ha)**		**Total Area (Ha)**
	High	Very High	
Cibeusi	4.84	23.13	27.96
Cikeruh	76.91	22.27	99.18
Cilayung	4.37	28.74	33.11
Cileles	14.94	25.12	40.05
Cinta Mulya	0.00	0.62	0.62
Cipacing	134.16	3.98	138.14
Cisempur	0.00	2.42	2.42
Hegarmanah	38.53	23.48	62.01
Jatimukti	3.74	14.59	18.33
Jatiroke	3.59	14.77	18.36
Mekargalih	54.44	0.39	54.83
Sayang	142.43	39.62	182.05

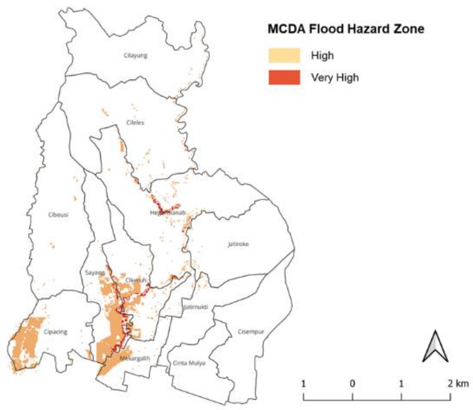
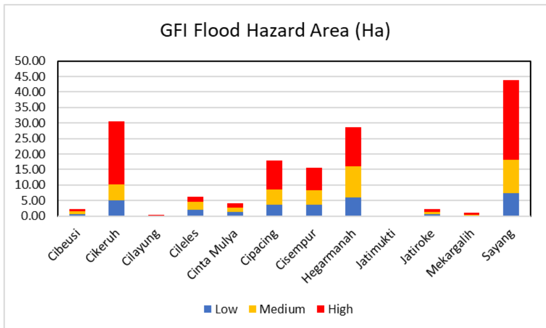
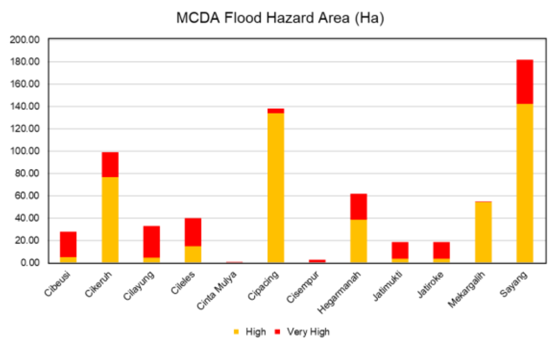


Figure 5. Flood Hazard Zone with MCDA Method in High and Very High Class

In the MCDA method, classification is done using the quantile method into five classes. In contrast to GFI, where the low-high class is an inundation hazard area, MCDA cannot identify and separate inundation areas; further analysis is needed to determine which value is considered flood hazard-prone. However, from the results of processing using MCDA, it was found that the "High" and "Very High" classes have similarities to the flood hazard area using GFI, thus it can be said that the two classes in the MCDA method represent inundation areas as shown in **Figure 5**. However, there is a significant difference between GFI and MCDA in that MCDA lacks hazard level analysis in flood-prone locations, which cannot be as detailed as GFI. Meanwhile, the comparison of flood hazard area by village using the GFI method and MCDA method shows in the chart **Figure 6**.



(a) GFI



(b) MCDA

Figure 6. Flood hazard area by village comparison using (a) GFI and (b) MCDA method

3.3 Limitation and Future Study

The GFI method has several limitations in this study. The DEM resolution used in the GFI model is around 8.1m. The higher resolution of DEM will provide more representative results, especially for district area as unit analysis. Because of the data limitation, the historical flood area is not a real delineation of the historical flood, but only based on the village. As well as GFI, The MCDA method certainly has limitations in this study, where rainfall data with a very high influence is only available with a spatial resolution of 5 km (CHIRPS by Funk et al., 2015), so interpolation is necessary to obtain a higher resolution. The use of rain gauge data will be better if there is an observation station in the area. Furthermore, the hydrological parameters have not been completely considered in the MCDA method, so the addition of other parameters such as soil moisture and runoff discharge can increase the accuracy of the analysis results.

4. CONCLUSION

This study aims to compare the GFI and MCDA methods in delineating flood-prone areas in Jatinangor District, Sumedang Regency, Indonesia. Where this comparison is made to determine the limitations of each method of determining flood hazard in urban areas. The results obtained from this study are that the GFI method can analyze flood-prone areas in more detail than MCDA. However, the flexibility of considering many factors such as social, environmental, and physical using the MCDA method is more possible.

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