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Geographic Information System Multi Attribute Utility Theory for Flood Mitigation in Agricultural Sector

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ABSTRACT

The agricultural system in East Java is influenced by many interacting factors, including climate change, population growth, and flood. The condition of the area certainly has the potential for disasters that have a significant impact on the agricultural sector. Floods are one of the factors that damage agricultural land. Flood management issues are complex and varied. This study aims to examine the study of flood risk in the agricultural sector in East Java. The combination of Geographic Information System (GIS) and Multi Attribute Utility Theory (MAUT) method is used in this study. The weighting of each class in all GIS is based on each criterion including rainfall intensity, slope, and soil texture using the MAUT method and then mapped using a Geographic Information System. The results showed that the MAUT algorithm was able to accurately identify flood-prone agricultural land in East Java with the same classification results based on data from the National Disaster Management Plan. The agricultural land maps obtained are categorized into three classes, namely very flood-prone, flood-prone, and not flood-prone. Agricultural land areas in East Java with categories that are very prone to flooding include the regencies of Bojonegoro, Lamongan, Tuban, and Sidoarjo. The contribution of this research is expected to assist policy making at the Department of Agriculture and Food Security in monitoring flood-prone agricultural land in order to minimize the occurrence of flood disasters in the agricultural sector and can be used for flood disaster management efforts.

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1. INTRODUCTION

East Java Province has advantages in agriculture and has a role in supplying agricultural products for national needs. The agricultural sector must continue to develop so that it remains a force in determining food security, driving economic growth, and a healthy economy [1, 2]. The agricultural system in East Java is influenced by many interacting factors, including climate change [1, 3, 4], population growth [1–3], and flood [2], [5–7]. East Java has regional conditions that include lowlands, rivers, mountains, and high rainfall in certain seasons. The condition of the area certainly has the potential for disasters that have a significant impact on the agricultural sector. Floods are one of the factors that damage agricultural land. Flood management issues are complex and varied. The flood problem involves multiple stakeholders, competing alternatives, dealing with the scarcity of technical information and different tradeoffs [8].

Flood risk management plays an important role in guiding the government in making timely and appropriate decisions for flood rescue and relief [9]. Many problems related to spatial planning [10] and disaster management [11] which can be solved with multi-criteria decision making. This is because the result of multi-criteria decision making is systematic and suitable to overcome these complex problems [8]. In a previous study conducted by Dzulkarnain [7] using the dynamic system method to determine the factors that influence flooding in the flood-prone agricultural sector. The study conduct by Li [9] using the Analytical Hierarchy Process to analyze flood risk forecasts in disaster risk management. In a previous study conducted by Luu [10] use multiple linear regression-TOPSIS to classify areas that are most at risk and have practical implications for flood risk management on a national and local scale. In a previous study conducted by Setiawan [12] using the Fuzzy Simple Adaptive Weighting method determine the flood hazard index as an indicator of the flood disaster threshold in an area.

In several previous studies, most of them focused on flood-prone vulnerability assessment but did not include the spatial distribution of flood-prone zones which were integrated in Geographic Information Systems as an alternative effort to mitigate flood hazards. The purpose of this research is a study of flood risk assessment in the agricultural sector in East Java using Multi Attribute Utility Theory by determining the weight value and priority value for each parameter. Multi Attribute Utility Theory is used in the field of decision making and allows for the incorporation of multiple criteria into decisions [13] based on preferences and behavior from decision-makers [14]. This study identifies flood-prone agricultural land based on rainfall intensity, slope, and soil texture.

In addition, geographic information system tools are used as complementary features to assist decision making which includes innovative visualization forms and output models are used to develop, prioritize, and adopt mitigation actions. So that the delivery of information quickly to the public, in the agricultural sector to be more alert to floods in the agriculture sector can be accessed online. This is expected to assist the policy making of the Department of Agriculture and Food Security of East Java Province in monitoring flood-prone areas in order to minimize the occurrence of flood disasters in the agricultural sector. This paper is organized as follows. Section 1 explains the introduction. Section 2 describes the research method. Section 3 presents the results and analysis. Section 4 presents the conclusion. And finally, section 5 presents the acknowledgments of the study.

2. RESEARCH METHOD

2.1. Type of Research and Algorithm used

The research method used in this study is a quantitative approach, explaining the relationship between the parameters of rainfall intensity, slope, and soil texture and analyzing it using the Multi-Attribute Utility Theory method and mapping it into a web-based GIS map output. There are several methods in solving this multi-criteria problem, one of which is the MAUT method. Multi Attribute Utility Theory is a quantitative method that is used as a basis for decision making through a systematic procedure that identifies and analyzes several variables. Measurement and weighting is done by considering each type of context as an item attribute. Multi-Attribute Utility Theory provides a framework for making optimal evacuation decisions. This method can provide solutions from a number of alternatives by comparing each alternative. To display information on mapping analysis of flood-prone areas using Multi Attribute Utility Theory (MAUT) by determining the weight value and priority value for each parameter. The result of the overall research is to produce a GIS application for the identification of flood-prone areas based on the parameters and the MAUT method based on data from each region.

Multi Attribute Utility Theory is a quantitative method that is used as a basis for decision making through a systematic procedure that identifies and analyzes several variables. Measurement and weighting is done by considering each type of context as an item attribute. Multi-Attribute Utility Theory provides a framework for making optimal evacuation decisions [15, 3]. The final result of this method is a ranking order of alternative evaluations that describe the choices of decision makers [16]. Calculation stages with Multi Attribute Utility Theory according to [3] there are five stages. In the first stage determine alternatives and criteria. The second stage determines the weight of the criteria. The third stage is to create a normalization matrix. The fourth stage is the multiplication of the normalized matrix with the weight of the criteria. The fifth stage is ranking or category. The form of the representation theorem for some attribute value functions is determined by the set of conditions for decision makers, with the following shown in Equation (1)

$$v_{(x)} = \Sigma_{i=1}^{n} w_i v_i(x) \quad (1)$$

When:
$v_(x)$ = Evaluate the alternative total to $-x$
w_i = Relative weight of criterion i
$v_i(x)$ = Result of evaluation of attribute (criteria) i for alternative x
i = Index to show criteria
n = Number of criteria

where $v_i(x)$ is a value function for attribute i, w_i is a weight that determines how important element 1 is to other elements. Where n is the number of elements [17]. Next is to carry out the total process of the weights, with the following shown in Equation (2)

$$\Sigma_{i=1}^{n} w_i = 1 \quad (2)$$

When:
w_i = Relative weight of criterion i
i = Index to show criteria
n = Number of criteria

The next stage is the normalization of the matrix and the multiplication of the normalized matrix that is inputted with relative weights to determine the results of each value with the following equation shown in Equation (3)

$$U_{(x)} = \frac{x - xi^{-}}{xi^{+-}xi^{-}} \quad (3)$$

When:
$U_(x)$ = utility value of each alternative criterion x
x = The criterion value of each alternative x
xi^{-} = The worst value of criterion i in all alternatives
xi^{+} = The best value of criterion i in all alternatives

2.2. Research Stages

In this study, the Geographic Information System application was built using the PHP programming language. GIS mapping of flood-prone agricultural land uses consists of several stages as follows (1) Problem identification stage, (2) definition of information needs, (3) define system requirements analysis, (4) system implementation, and (5) testing and evaluate system.

1. Problem Identification
   The problem identification stage is carried out by studying literature and field studies in observing flood-prone agricultural land areas in East Java Province. Literature study in the form of an understanding of the factors that cause flooding in the agricultural sector.
2. Definition of information needs
   Definition of information needs, this stage collects information needs to develop the system, namely collecting data on the availability of data on parameters of rainfall, slope, and regional soil texture in East Java Province. The data used in this study is secondary data obtained from data analysis studies, archives, books and other documentation owned by agencies in East Java. In this study uses data from all districts in East Java as an alternative in determining flood-prone agricultural land. The criteria used in this study include rainfall, slope, and soil texture in East Java Province. The criteria that have been determined are carried out in the process of determining the level of importance of each criterion based on the weight value used to identify flood-prone agricultural land. Table 1 shows the weight of the criteria as follows.

Table 1. Criteria and Weight

No	Criteria	Weight
1	Rainfall	0.35%
2	Slope	0.30%
3	Soil Texture	0.35%

The next step is to determine the priority of the sub-criteria for each criterion. Each sub-criteria is given a sub-criteria weight which can be seen in Table 2 as follows.

Table 2. Sub Criteria and Weight

No	Criteria	Sub-Criteria	Weight
1		$\leq$ 2000 mm/th	1
	Rainfall	2001-2500 mm/th	3
		$>$ 2500 mm/th	5
2		$>$ 15%	1
	Slope	8-15%	3
		$<$ 8%	5
3		Smooth	5
	Soil Texture	Medium	3
		Rough	1

3. System Requirements Analysis
System Requirements Analysis includes analyzing the needs of spatial data and attribute data that will be used to process the system and determine the data flow that will be used for database design by describing it into tiered diagrams and DFD. Database system design is done by designing conceptual data model (cdm), physical data model (cdm), geoprocessing layer (buffer, union, intersect layer). The next process is to build UML (Unified Modeling Language) is to define the use case diagram on the geographic information system that is built. Use case description, describes the process management of how use occurs. UML diagrams reflect the processes that occur in the use of the system [17–21].The description of the geographic information system admin use case is shown in Figure 1 below.

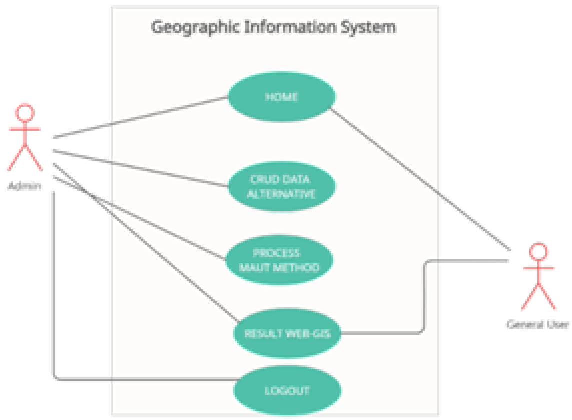

Figure 1. Use Case Diagram

In the case of using GIS Multi-Attribute Utility Theory for flood mitigation in the agricultural sector, starting with the admin login to the login form. After logging in, the admin can enter criteria data which includes parameters of rainfall, slope, and soil texture in 29 districts in East Java Province. The next process is to process the alternative data by calculating MAUT. In the last process, the admin can see the results of the calculation of the area of flood-prone agricultural land in the form of reports

and the form displayed in the form of a GIS spatial map. The process for general users can only see the home menu and the display of flood-prone agricultural land in the form of a GIS-Web map.
Next is to define the design interface (interface) required on the geographic information system that is built. Interface design is the main part of the application system that is built in every computer application programming [17]. The design of the GIS application interface on the login page will be shown in Figure 2 below.

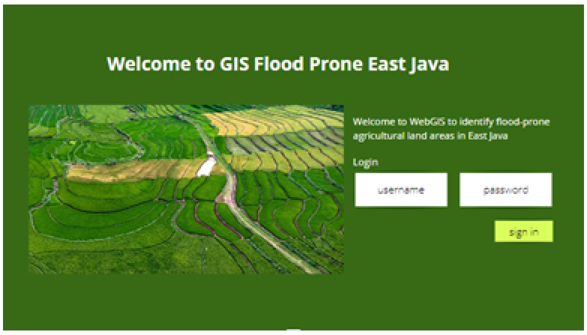

Figure 2. Design Interface Login

Login form which consists of username and password. Login button to process whether the username and password are correct or not. The design of the GIS application interface on home page will be shown in Figure 3.

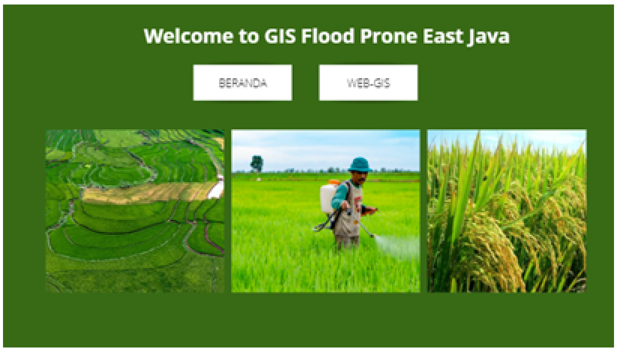

Figure 3. Design Interface Home Menu

The MAUT calculation menu displays a process button to start the MAUT calculation which is directed to the MAUT calculation form. After clicking the MAUT calculation form, the design of the MAUT calculation menu form will be shown in Figure 4.

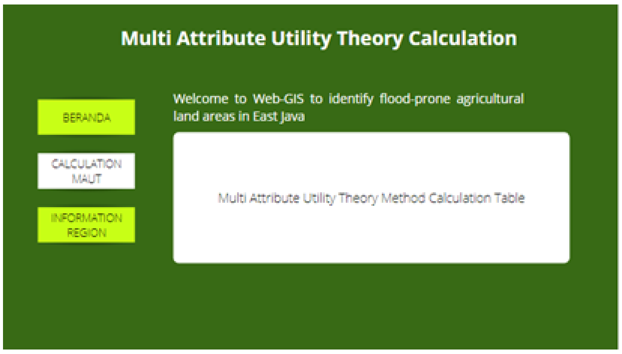

Figure 4. Design Interface Calculate Method

4. System Implementation
   System Implementation, this stage will carry out the implementation of this geoprocessing process which will later produce a digitization layer, data entry process, and program coding process using the PHP (Hypertext Preprocessor) programming language.
5. Testing and Evaluate System
   Testing and maintaining the system is done by trial error process is done by evaluating the system. Evaluate System, this stage conducts a study of the impression or interest of the user when using the system. If there is an error in the system, the system will be repaired.

3. RESULT AND ANALYSIS

The process of developing geographic information systems using the PHP programming language. The results of the geographic information system design include the following sub-sections.

1. Menu Login

This form gives access rights to grant access rights to the admin (administrator) to use the system. The admin login form consists of a username and password and a login button. The login button functions to process the username and password whether or not it is in accordance with the system. Login menu in Figure 5 and as follows.

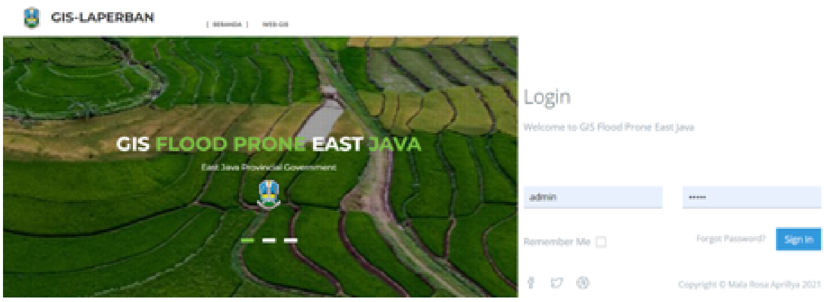

Figure 5. Login Menu

2. Menu Home

The research implementation of GIS mapping of flood-prone agricultural land using PHP programming language and MySQL database. The decision support system is built on a web-based basis. The initial display page of this system which consists of the home menu in Figure 6 and as follows.

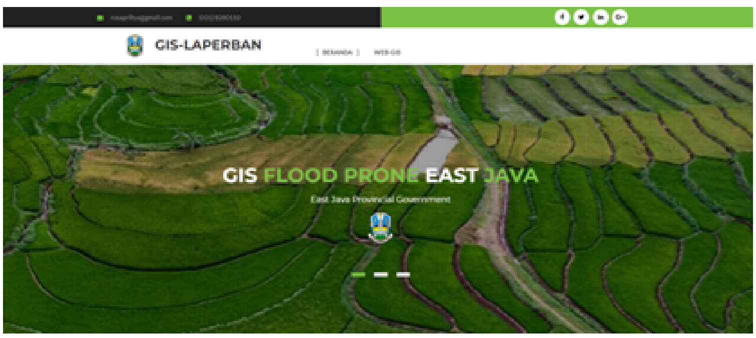

Figure 6. Menu Home

3. Menu WebGIS

Furthermore, on the main page of this system there is a web-GIS menu, this menu is a spatial map that can be selected to show flood-prone areas, areas with high rainfall, land slope classification per area, and soil texture classification per area. This menu can be seen as shown in Figure 7 below.

Figure 7. Menu Web-GIS

4. Menu Multi Attribute Utility Theory Method

The following is a display of alternative data consisting of several districts in East Java. On this page there are the results of the scoring of each criterion which is the final result of the calculation using the multi attribute utility theory method. The results of the calculation of the Multi Attribute Utility Theory in determining the classification of flood-prone agricultural land in the East Java region are then mapped in the form of a Geographic Information System. This menu can be seen as in Figure 8 below.

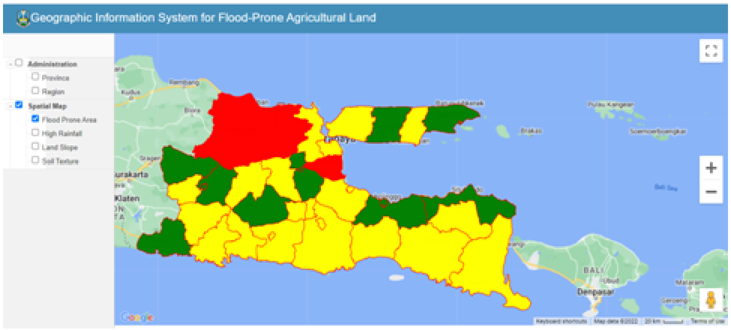

Figure 8. GIS flood-prone agricultural land

3.1. Analysis Results of Multi Attribute Utility Theory Methode

In this study uses data from all districts in East Java as an alternative in determining flood-prone agricultural land. The criteria used in this study include rainfall, slope, and soil texture in East Java Province. The criteria that have been determined are carried out in the process of determining the level of importance of each criterion based on the weight value used to identify flood-prone agricultural land. Table 1 shows the weight of the criteria as follows.

Table 3. Criteria and Weight

No	Criteria	Weight
1	Rainfall	0.35%
2	Slope	0.30%
3	Soil Texture	0.35%

The next step is to determine the priority of the sub-criteria for each criterion. Each sub-criteria is given a sub-criteria weight which can be seen in Table 2 as follows.

Table 4. Sub Criteria and Weight

No	Criteria	Sub-Criteria	Weight
1		$\leq$ 2000 mm/th	1
	Rainfall	2001-2500 mm/th	3
		$>$ 2500 mm/th	5
2		$>$ 15%	1
	Slope	8-15%	3
		$<$ 8%	5
3		Smooth	5
	Soil Texture	Medium	3
		Rough	1

Normalization matrix at this stage, the alternative data used is data from all districts in the East Java region. The next step is to normalize the matrix using Equation (3). Table 4 shows alternative data after normalization. From the normalization of rainfall criteria in 29 alternatives, it is known that the lowest normalization value is 0 in 23 districts, while the highest normalization value for rainfall criteria is 1 in 6 districts. In the normalization of soil texture criteria on 29 alternatives, it is known that the lowest normalization value is 0 in 6 districts, while the highest normalization value for soil texture criteria is 1 in 20 districts. In normalizing the slope criteria for 29 alternatives, it is known that the lowest normalization value is 0 in 11 districts, while the highest normalization value for slope criteria is 1 in 18 districts. The next stage is the process of multiplying the normalized matrix in Table 4 with the preference weights in Table 1. The following is the normalized matrix multiplication data from the alternatives, which can be seen in Table 5 as follows.

Table 5. Multiplication Matrix

No	Region	Rainfall	Slope	Soil texture	Weight
1	Bangkalan	0	0,35	0,3	0,65
2	Banyuwangi	0,35	0	0	0,35
3	Blitar	0	0,35	0	0,35
4	Bojonegoro	0,35	0,35	0,3	1
5	Bondowoso	0,35	0	0	0,35
6	Gresik	0	0,35	0,15	0,5
7	Jember	0	0,35	0,3	0,65
8	Jombang	0	0,35	0,3	0,65
9	Kediri	0	0	0,3	0,3
10	Ngawi	0	0	0,3	0,3
11	Lumajang	0	0,35	0	0,35
12	Madiun	0	0	0,3	0,3
13	Magetan	0	0,35	0,15	0,5
14	Malang	0	0,35	0,3	0,65
15	Mojokerto	0	0	0,3	0,3
16	Nganjuk	0	0,35	0,3	0,65
17	Lamongan	0,35	0,35	0,3	1
18	Pacitan	0	0	0,3	0,3
19	Pamekasan	0	0,35	0,15	0,5
20	Pasuruan	0	0,35	0,3	0,65
21	Ponorogo	0	0,35	0,3	0,65
22	Probolinggo	0	0	0,3	0,3
23	Sampang	0	0	0,3	0,3
24	Sidoarjo	0,35	0,35	0,3	1
25	Situbondo	0	0	0,3	0,3
26	Trenggalek	0	0,35	0	0,35
27	Tuban	0,35	0,35	0,3	1
28	Sumenep	0	0	0,3	0,3
29	Tulungagung	0	0,35	0	0,35

The next stage is the ranking and category of each alternative. Areas of agricultural land are categorized into 3, namely areas that are very prone to flooding, prone to flooding and nost prone to flooding. Classification of areas with a value of 0.0 to 0.32 is classified as a non-prone area, a range of 0.33 to 0.66 is classified as a vulnerable area, and a range of 0.67 to 1.00 is classified as very vulnerable. The following are the results of the categories of each alternative can be seen in Table 6 as follows.

Table 6. Category Region

No	Region	Weight	Category
1	Bojonegoro	1	Very prone to flooding
2	Lamongan	1	Very prone to flooding
3	Sidoarjo	1	Very prone to flooding
4	Tuban	1	Very prone to flooding
5	Bangkalan	0,65	Prone to flooding
6	Jember	0,65	Prone to flooding
7	Jombang	0,65	Prone to flooding
8	Malang	0,65	Prone to flooding
9	Nganjuk	0,65	Prone to flooding
10	Pasuruan	0,65	Prone to flooding
11	Ponorogo	0,65	Prone to flooding
12	Gresik	0,5	Prone to flooding
13	Magetan	0,5	Prone to flooding
14	Pamekasan	0,5	Prone to flooding
15	Banyuwangi	0,35	Prone to flooding
16	Lumajang	0,35	Prone to flooding
17	Blitar	0,35	Prone to flooding
18	Bondowoso	0,35	Prone to flooding
19	Trenggalek	0,35	Prone to flooding
20	Tulungagung	0,35	Prone to flooding
21	Kediri	0,3	Not prone to flooding
22	Ngawi	0,3	Not prone to flooding
23	Madiun	0,3	Not prone to flooding
24	Mojokerto	0,3	Not prone to flooding
25	Pacitan	0,3	Not prone to flooding
26	Probolinggo	0,3	Not prone to flooding
27	Sampang	0,3	Not prone to flooding
28	Situbondo	0,3	Not prone to flooding
29	Sumenep	0,3	Not prone to flooding

3.2. Black Box Testing

The following are the results of the functionality test carried out with the aim of knowing whether the system that has been built is running as shown in Table 7 below.

Table 7. Black Box Testing

Process 1	**The system is able to validate username and password**
Input	Admin input username and password
Output	1. Admin has successfully entered the main menu 2. A failed login notification appears if there is an error in the username or password entered
Description	Correct
Process 2	**The system is able to display the criteria data page**
Input	Admin can manage criteria data
Output	Admin can perform criteria data management activities including add, edit, and delete
Description	Correct
Process 3	**The system is able to display district data**
Input	Admin can manage housing data
Output	Admin can perform region area data management activities including adding, editing, and deleting
Description	Correct
Process 4	**The system is capable of displaying GIS flood-prone agricultural land**
Input	Stakeholders select the web-GIS menu, and check the sub-menu for flood-prone agricultural land
Output	Displaying GIS of flood-prone agricultural land in East Java based on the calculation of the MAUT method
Description	Correct

3.3. Result Analysis

In the previous research conducted by Nurdiawan [4] mapping flood-prone areas using slope and land use parameters. The previous research conducted by Nuryanti [5] carry out flood hazard mapping using the AHP analysis method. Both of these studies do not consider the type of soil and rainfall that affect the flood. The results obtained from grouping using the Multi Attribute Utility Theory method are not much different from the manual grouping process carried out by the According to the 2015-2019, National Disaster Management Plan [11]. So it can be concluded that the system built with a web-based programming language with the Multi Attribute Utility Theory method is able to help produce flood-prone agricultural land mapping. The Multi Attribute Utility Theory method is tested by comparing manual calculations from National Disaster Management Plan as shown in Table 8 below.

Table 8. The results of the National Disaster Management Plan with grouping using the MAUT

No	Data	Amount of data	Total East Java Flood Prone Area
1	Result from National Disaster Management Plan 2015-2019	29 Districts	4 Districts include Bojonegoro; Lamongan; Tuban; Sidoarjo
2	Result from Multi Attribute Utility Theory Methode	29 Districts	4 Districts include Bojonegoro; Lamongan; Sidoarjo; Tuban

4. CONCLUSION

The implementation of the MAUT method for identifying flood-prone agricultural land in East Java Province can be concluded that the MAUT algorithm can help classify flood-prone areas. There are 4 areas that are very prone to flooding, including Bojonegoro; Lamongan; Sidoarjo; Tuban, 16 flood-prone areas, and 9 areas not prone to flooding. In other words, the application that is built is able to provide fast information delivery to the community, especially people who have a livelihood in agriculture to be more alert to floods in the agricultural sector. The advantage of the built WebGIS is that it is cloud-based or Web-based so that it can be applied anywhere. This study considers rainfall, land slope, and soil texture which have not been studied by previous researchers. In further research, it is necessary to add new variables, namely river buffers and simulations with dynamic system methods are needed to determine future flood scenarios for agricultural land so that the Department of Agriculture and Food Security can take policy steps.

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6. DECLARATIONS

AUTHOR CONTIBUTION

Fisrt author Carry out library research and field studies, data collection parameters, system analysis, database design, coding programming using PHP, evaluating the system using blackbox, and compiling publication scripts. Second author perform parameter data collection, perform MAUT method calculations, documentation and publications.

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COMPETING INTEREST

Research interest in Artificial Intelligence midwives by developing technology and natural disaster management by developing a disaster mitigation information system with a combination of Decision Support Systems and Geographic Information Systems covering the distribution of tsunami-prone areas, flash floods, landslides, drought (dry) in East Java

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