Spatial data modeling for mapping of slum region using multi-attribute utility theory method

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***Abstract*— Slums are one of the social problems that are often faced by almost all areas in big cities. The need for handling efforts to overcome slum settlements through mapping the distribution and knowing the priorities for handling slum settlements. This paper presents, spatial data modeling to map slum region using a multi-attribute decision making (MADM) approach based on geographical information system (GIS) technology. Mapping of slum region using the multi-attribute utility theory method based on multi-attribute parameters of the condition of building density, drainage, roads, drinking water supply, waste treatment, trash treatment, and fire protection. Dataset private data types from the department of public office in Mojokerto districts, was the subject of our analysis. The results of the method test show the advantages of mapping slum regions which will produce a layer of information on slum region, the level of the slum region, and the handling of slum regions with a precision value of 75%, recall 80%, and accuracy of 76%. With a kappa coefficient value of 0.62. The results of the trial state that this method has good agreement strength for use in mapping spatial data of slum regions using the MADM approach.**

***Keywords*—Spatial data modeling, mapping of slum region, multi-attribute utility theory method, GIS**

I. INTRODUCTION

Slums are one of the examples of the most marginalized forms of informal settlement and receive less attention. Thus, the importance of mapping slum regions in the right way in an effort to overcome slum settlements through mapping the distribution and knowing the priority of handling. Mapping of settlements remains challenging in fragmented landscapes, such as slum regions. This is due to the lack of handling and limited information regarding slum regions located on the outskirts of cities. The world's urban population is expected to grow by 2.5 billion urban residents by 2050 [1]. Informal settlements or slums, always refer to regions with poor living conditions in cities [2], often result in more severe economic and social constraints [3], and can lead to eviction problems, disease and crime [4].

The application of spatial data modeling that is processed into information can be used to analyze geospatial data needs as a decision-making system. Spatial decision problems are decision problems that involve geographic data [5]. Several previous studies have proposed many MADM-based models for analyzing spatial data, such as: agriculture [6], health [7][8], population [9][10] and so on. Spatial decision problems often require a large number of feasible alternatives to be evaluated based on several criteria with spatial decisions being multi-criteria [11]. As an important step for monitoring and mapping the region depends on spatial knowledge of the location, wide and structure [9][12]. The application of the multi-attribute decision making (MADM) method in the structured selection of settlements is actually an integration of the attribute method with the geometric method into the attributes [13]. The MADM-based model approach is used as a factor and its weight in mapping the suitability of the region, such as: weighted linear composition [14]; multi-attribute utility theory method [15]; analytic hierarchy process [16]; simple additive weighting; weight product model [7]; and fuzzy analytic hierarchy process [17].

The use of multi-attribute utility theory method can offer a rich collection of techniques and procedures to reveal the preferences of geographic information system (GIS) based decision making [5]. This method can achieve a measure of the attractiveness (utility) of each result from a set of the best-performing alternatives [18]. Our study, will analyze spatial data using the multi-attribute utility theory method to map slum regions based on building density conditions, drainage, road, drinking water supply, waste treatment, trash treatment, and fire protection. Before using this method, we assigned a weight and priority value to each criterion. Furthermore, the calculation process is carried out using the multi-attribute utility theory method.

This study contributes to providing information related to the mapping of slum regions which will produce layers in the form of information on the slum regions, the level of the slum regions, and the handling of slum regions. Hopefully, this paper will also be useful for future researchers as a reference for developing web-GIS-based mapping technology to find out information about slum regions. So, through this system it can be used as a decision making in tool to reduce the level of distribution of slum regions.

II. PRIOR RESEARCH

Based on several literature studies in the field of spatial data, many previous studies have proposed the development of models through mathematical approaches, MADM, or based on artificial intelligence. The MADM technique based on GIS technology is the subject of our paper. MADM is inherently tasked with several real-world spatial decision-making processes. Spatial decision making is defined as a process in which a person or a group of individuals evaluates and chooses one or more location reference possibilities based on a set of criteria. With this method, geographical decision-making analysis can be used to combine and alter spatial data (criteria map) and values related to the evaluation of decision-making priorities in order to acquire useful information [5]. The MADM method has the potential to be highly effective in spatial modeling, given the large number of criteria that might influence the site selection process. Over the last few years, MADM and GIS techniques such as: simple additive weighting (SAW) and weight product model (WPM) methods [7], weighted linear composition (WLC) method [14], multi-attribute utility theory method [15], analytic hierarchy process (AHP) [16], integrated fuzzy set theory with AHP [19], analytical network process (ANP) and fuzzy logic [20][21], and fuzzy multi-attribute decision making technique [22] has been used in several applications in the field of spatial modeling which are presented in Table 1. However, some previous researchers did not use the approach and parameters that will be presented in this paper. The authors proposed a method for determining slum region mapping using spatial data modeling.

TABLE I. EXAMPLE OF USING MADM IN VARIOUS APPLICATIONS

ID	Technique	Site selection objective
[7]	SAW-WPM	measles-prone region
[14]	WLC	suitable region for library
[15]	Multi-attribute theory methods	Accident-Prone Roads
[16]	AHP	suitability of agricultural land
[17]	Fuzzy-AHP	Landfill site selection
[19]	Fuzy-AHP	landslide region
[20]	Fuzzy-ANP	landslide risk region
[21]	Fuzzy-ANP	suitability of residential region
[22]	Fuzzy	vulnerability mapping for disaster

III. RESEARCH METHODOLOGY

The application of the MADM technique which is integrated with GIS technology is used in decision making in determining or selecting the feasibility of a location [23]. The use of spatial data as a basis for decision making supported by the MADM method can perform spatial data analysis [24]. Spatial data analysis in our study is used for mapping slum regions to produce information related to the slum region, the level of the slum region, and the handling of the slum region.

This process must input all the data that will be needed, with the aim of defining spatial data and attribute layers in the form of a spatial shapefile (*.shp). This dataset includes maps of the Mojokerto district of Indonesia for each sub-district. The dataset contains attributes, such as: condition of building density, drainage, roads, drinking water supply, waste treatment, trash treatment, and fire protection. This spatial data modeling process uses the multi-attribute utility theory method to determine slum regions. Before performing calculations on each criterion using this method. First we determine the weight and priority value for each criterion.

A. Spatial Dataset Analysis

After the data has been poured into layers and tables, the following stage is to use the multi-attribute utility theory approach to calculate the weight and priority values for each parameter criterion in order to provide an analysis of the slum region. In determining the weight vectors and priority values, this model also allows the authors to describe variations or uncertainties in expert judgment and the department of public office in Mojokerto districts.

The initial step is to examine map data in the slum region. The weight values for each slum region criteria are entered as given in Table I to calculate the parameters of this analysis. In table II, it can be explained that the use of parameters has three categories, namely 25% - 50% (good with a weighted value of 1), 51% - 75% (moderate with a weighted value of 3), and 75%-100% (poor with a weighted value of 5) which aims to determine the feasibility of conditions on each parameter attribute (Source: Ministry of Public Works and Public Housing Directorate General of Human Settlements/Permen PUPR No.2/Prt/M/2016 concerning quality improvement of slum housing and slum settlements).

TABLE II. PARAMETER WEIGHT

Parameter	Percentage Range Criteria (%)	Weight
Building Density Conditions		
1. The buildings on location have no regularity	76 – 100 51 – 75 25 – 50	5 3 1
2. The building has a density that does not match the provisions	76 – 100 51 – 75 25 – 50	5 3 1
3. The buildings at the location do not meet technical requirements	76 – 100 51 – 75 25 – 50	5 3 1
Environmental Drainage Conditions		
4. Inundation region > 30 cm,> 2 hours and> 2 times a year	76 – 100 51 – 75 25 – 50	5 3 1
5. Region where there is no environmental drainage	76 – 100 51 – 75 25 – 50	5 3 1
6. Environmental drainage is not connected to the hierarchy above it	76 – 100 51 – 75 25 – 50	5 3 1
7. The region has a dirty and smelly environmental drainage	76 – 100 51 – 75 25 – 50	5 3 1
8. The region has poor environmental drainage construction quality	76 – 100 51 – 75 25 – 50	5 3 1
Environmental Road Conditions		
9. Region not served by the neighborhood road network	76 – 100 51 – 75 25 – 50	5 3 1
10. The region has poor road surface quality	76 – 100 51 – 75 25 – 50	5 3 1
Drinking water supply conditions		
11. Population unable to access safe drinking water	76 – 100 51 – 75 25 – 50	5 3 1
12. The population is not met their minimum drinking water needs	76 – 100 51 – 75 25 – 50	5 3 1
Waste treatment conditions		
13. The region has a wastewater system that is	76 – 100 51 – 75	5 3

Parameter	Percentage Range Criteria (%)	Weight
not up to technical standards	25 – 50	1
14. The region has wastewater infrastructure not in accordance with the technical requirements	76 – 100 51 – 75 25 – 50	5 3 1
Trash treatment conditions		
15. Region has trash treatment infrastructure that does not meet technical requirements	76 – 100 51 – 75 25 – 50	5 3 1
16. The region has trash system a non-standard	76 – 100 51 – 75 25 – 50	5 3 1
17. Region has trash infrastructure that is not maintained	76 – 100 51 – 75 25 – 50	5 3 1
Fire protection conditions		
18. The region does not have fire protection infrastructure	76 – 100 51 – 75 25 – 50	5 3 1
19. The region has no means of fire protection	76 – 100 51 – 75 25 – 50	5 3 1

After the first stage is carried out by determining the weight of each criteria, the next step will be to determine the priority value and the number of criteria for each parameter, see Table III more details. The total value of the priority value is 1.

TABLE III. PRIORITY VALUE

Parameter	Number of criteria	Priority values
Building density conditions	3	0.3
Environmental drainage conditions	5	0.3
Environmental road conditions	2	0.1
Drinking water supply conditions	2	0.1
Waste treatment conditions	2	0.1
Trash treatment conditions	3	0.05
Fire protection conditions	2	0.05

B. Geoprocessing Layer

The next stage is to undertake a layer geoprocessing process, which seeks to digitize the analog map by inputting all data properties, parameters, and criteria in the form of a file (*.shp) that will become the layer. Following the formation of the layer, the buffer procedure, which attempts to construct polygons from the layer region, will be carried out. After this process is created, a union process will be used to combine the data from the main layer and the data from the region layer. In the union process section, we will remove layers using the intersecting process, this is because this process produces several layers that are outside the range of the actual layer. So it can be explained that the process of analyzing the slum region is shown in Fig. 1, while the process of analyzing the slum region is in Fig. 2.

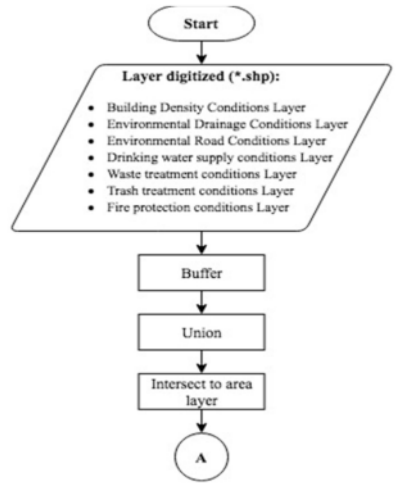

Fig. 1. Geoprocessing layer of slum region

In Fig. 1 and Fig. 2, we describe the data analysis from the initial data to obtain a decision. Layers of the condition building density, drainage, roads, drinking water supply, waste treatment, trash treatment, and fire protection in union. From the union results, the overlay stage is carried out so that the 7 layers on the map are combined. And then the results of the overlay, formed the results of data analysis from 7 layers into 1 main layer.

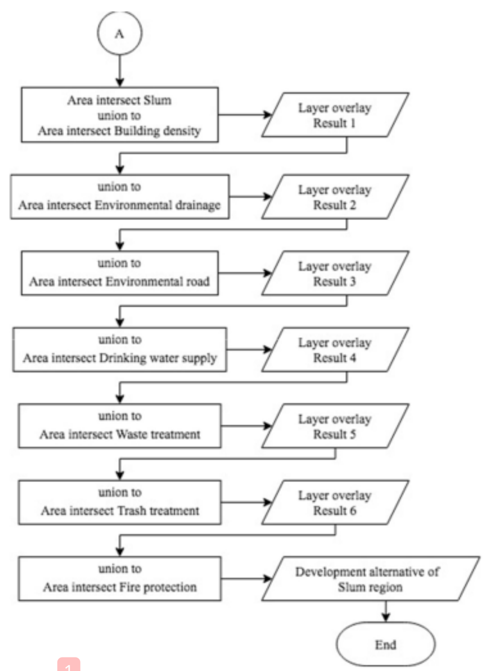

Fig. 2. Overlay result of development alternative of slum region as a consequence of slum region level

C. Framework Spatial Using Multi-Attribute Utility Theory

The multi-attribute utility theory method is a quantitative comparison method that combines several measurement criteria, such as different costs, risks, and benefits. Each existing criterion can provide several alternatives that are used as decision making as a solution to a problem. To find an alternative that is closer to the user's wishes, multiplication is done to identify it on a predetermined priority scale. So, the best and closest results from these alternatives will be taken as a solution.

In the multi-attribute utility theory method, it is necessary to develop a multi-attribute utility model, namely specifying the dimensions of evaluation problems and decision specifics [25]. The weight defines the impact of the dimension of the ith value on the overall evaluation (also known as the relative relevance of a dimension), and *v(x)* is the object's evaluation on the ith dimension of value. *n* is the number of various value dimensions.

$$v(x) = \sum_{i=1}^{n} w_i v_i(x) \quad (1)$$

Where, *wi* is the evaluation value of the ith object, and *vi(x)* is the weight which determines the value of how important the ith element is to other elements.

IV. Result and Discussion

The trial data uses a sample of private data types from the department of public office in Mojokerto districts, Indonesia, as a source of reference and guidance on multi-criteria parameters. In this paper, we will analyze the slum region. There are 18 sub-districts in the geoprocessed region studied, consisting of 1171 villages, 2208 citizens associations (C.A), and 6975 neighborhood associations (N.A) in Mojokerto districts. The test is carried out using the sampling method. The following is an example of the calculation results in the analysis of slum region in the gedeg sub-district, terusan village in Mojokerto district which was obtained from the multi-attribute utility theory method.

In step 1, in the multi-attribute utility theory method, weights and criteria are needed to determine the slum region. With pre-determined criteria, which are presented in Table II. Step 2, assign priority weights to each parameter as shown in table II. The total value of the priority value is 1. The next step, calculating the number of criteria in each parameter is also presented in Table III.

In step 4, calculate the analysis value using the multi-attribute utility theory method according to equation (1), so that equation (2) is obtained.

$$v(x) = \Sigma((n_1/v_i(n_1))*w_in_1+((n_2/v_i(n_2))*w_in_2+ ((n_3/v_i(n_3))*w_in_3+((n_4/v_i(n_4))*w_in_4+ ((n_5/v_i(n_5))*w_in_5+((n_6/v_i(n_6))*w_in_6+ ((n_7/v_i(n_7))*w_in_7 \quad (2)$$

Where, n_1 = building density condition parameters; n_2 = drainage parameters; n_3 = road parameters; n_4 = drinking water supply parameters; n_5 = waste treatment parameters; n_6 = trash treatment parameters; and n_7 = fire protection parameters. While, v_i is the number of criteria for each parameter, and w_i is the priority value for each parameter. So that it can be obtained the calculation value presented in equation (3).

$$v(x) = \Sigma(15/3)*0.3+(23/5)*0.3+(10/2)*0.1+ (8/2)*0.1+(10/2)*0.1+(15/3)*0.05+ (10/2)*0.05= 4.78 \quad (3)$$

The next step is to determine the minimum and maximum values from the results of the sum that has been done. In table IV, the minimum value that has been determined by the public office department is 19, while the maximum value is 95. Because the determination value for the analysis does not match the calculation of the multi-attribute utility theory method, a transformation is carried out on that value so that it matches the total value that has been calculated using the multi-attribute utility theory method.

TABLE IV. OVERALL VALUE RANGE

Slum Region Level	Total Value	Value Range
Light slum	19 – 44	25
Moderate slum	45 – 70	25
Heavy slum	71 – 95	25

After that, perform a value transformation by determining the minimum (0) and maximum (4.85) values from the calculation using the multi-attribute utility theory method. Divide the result from the maximum value by the number of levels owned for the determination of the slum region, according to equation (4).

$$\text{New range} = \frac{\text{max value}}{\text{Number of slum region level}} \quad (4)$$

Obtained the new range value is 4.85/3 = 1.61. Add to the new range the number of levels owned with a minimum value. So, the value of determining the level of a slum region is obtained based on the multi-attribute utility theory method presented in table V. In the table, it can be explained that if the results ≥ 0 until ≤ 1.61 then it has a light slum category, a value of ≥ 1.62 until ≤ 3.23 means moderate slum, and a values of ≥ 3.24 until ≤ 4.85 means heavy slum.

TABLE V. DETERMINATION OF THE LEVEL OF SLUMS

Slum Region Level	Total Value	Value Range
Light slum	≥ 0 – ≤ 1.61	1.61
Moderate slum	≥ 1.62 – ≤ 3.23	1.61
Heavy slum	≥ 3.24 – ≤ 4.85	1.61

The geoprocessing layer is to determine the mapping of slum regions using the multi-attribute utility theory method, as presented in Fig. 3.

The geoprocessing layer is to determine the mapping of slum regions using the multi-attribute utility theory method, as presented in Fig. 3. We will conduct this test, by analyzing the slum region in the Gedeg sub-district. The total weight on the parameters of the building condition is 15, the total weight on the parameters of environmental road conditions is 10, the total weight on the parameters of environmental drainage conditions is 23, the total weight on the parameters of the condition of drinking water supply is 18, the total weight on the parameters of waste treatment is 10 , the total weight on the trash treatment condition parameter is 15, and the total weight on the fire protection condition parameter is 10 which refers to Table II. After all the parameters are included, the calculation process is performed using the multi-attribute utility theory method which refers to (1) in which the priority value of the parameter refers to Table III. The result of the calculation in the Gedeg sub-district is Heavy Slum. Then it is known that the village of terusan, gedeg sub-district is a slum region with a level of heavy slums because it has a final value of 4.78 which refer to Table V.

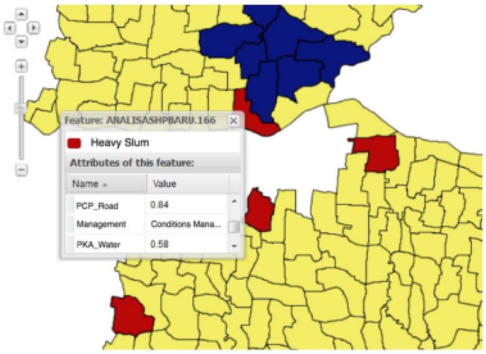

Fig. 3. The mapping result of slum region level

By using the multi-attribute utility theory method, the geoprocessing layer assumes that the mapping of slum regions is the result of several results. The criteria used in the survey are in the domain of the condition of building density, drainage, roads, drinking water supply, waste treatment, trash treatment, and fire protection as shown in the results in Fig.4. The results of this mapping can display an analysis of the three conditions of the slum region as shown in the legend. The condition of the region includes: the yellow color indicates that the region has a light slum level (values between of ≥ 0 - ≤ 1.61), the blue color indicates that the region has a moderate slum level (values between of ≥ 1.62 - ≤ 3.23), while the red color indicates that the region has a heavy slum level (values between of ≥ 3.24 - ≤ 4.85), that refers to Table V.

An important factor in the accessibility of research and methods is the availability of tools that implement them, for example, the ArcGIS product suite applies a multi-attribute utility theory method including weighting overlays and map algebra. The final result of the MADM in GIS is a recommendation for future action for decision makers which is presented in the form of a conformity map. In Fig. 4 is presented a map of the suitability of raster and vector output for distribution mapping and finding out priorities for slum region management in the Mojokerto region generated in ArcGIS using the multi-attribute utility theory method plugin. The yellow color represents a region with a light slum level, the blue color represents a region with a moderate slum level, while the red color represents a region with a heavy slum level. The criteria used in the survey are in the domain of the condition of building density, drainage, roads, drinking water supply, waste treatment, trash treatment, and fire protection.

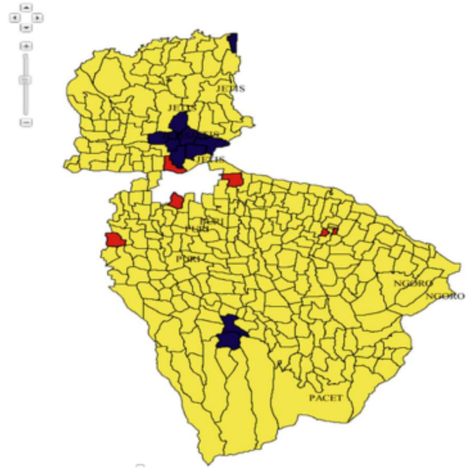

Fig. 4. Slum Mapping Analysis

Testing the application of slum region mapping in Mojokerto district based on GIS technology calculates the success rate of the calculation of slum region analysis using the multi-attribute utility theory method. Calculation experiments were carried out 15 times. From the tests carried out, it can be identified that the analysis value of slum region mapping using the multi-attribute utility theory method is included in the enough good category, this is because the level of slum region analysis system produced using cohen's kappa for the feasibility method obtained a value of 0.62 [26], while 75% precision, 80% recall, and 76% accuracy.

V. Conclusion

Based on the results obtained on the geoprocessing layer based on the calculation of the multi-attribute utility theory method, in determining the weighting of criteria and priority values in the slum region, it produces 3 levels based on light, moderate, and heavy levels. Spatial data modeling to map slum region using a GIS-based MADM approach. The use of this method shows the advantages of mapping slum regions which will produce layers of information on slum regions, the level of slum regions, and the handling of slum regions. There is a clear need for models such as decision support systems, enabling efficient solving of complex problems such as mapping distributions and knowing priorities for slum management. The Mojokerto district government as a decision making can use this system as an alternative option to control and monitor the development of the slum regions.

VI. Further Works

Despite the achievements of this development, there are still many things that need to be improved from the analysis of spatial data using the MADM method in our paper. It is hoped that further research can develop the use of models by collaborating with the MADM method and data mining classification methods such as naïve bayesian, decision trees, and others. The aim is to compare the results of the regional suitability classification given to each type of method used. Comparing the classification results of each method to be tested for the accuracy of the method used through the induction test method.

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