AHP-GeoTOPSIS method to analyze priority areas for sugarcane plantation development in Lamongan Regency

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Abstract. Sugar imports are carried out every year in Indonesia to meet domestic needs. The average sugar imports from 2015 to 2019 reached 4.34 million tons. The Spatial Plan of Lamongan Regency 2011-2031 proclaims the development of sugarcane plantations, but the priority assessment of the development area which takes into account the balance of sugarcane availability in the future has not been scientifically studied. This study aimed to analyze the priority areas for sugarcane plantation development in Lamongan Regency. Analysis of development priorities was carried out using the AHP-GeoTOPSIS method and involving six experts. The criteria used include the number of agricultural households, suitability, and availability of land for sugarcane, population, and the balance of sugarcane availability in each sub-district. Land use datasets were used to calculate the suitability and availability of land and the balance of sugarcane availability in each sub-district. Based on the analysis, there were five priority areas for land development. There four subdistricts to be developed are as follows: Ngimbang, Solokuro, Mantup, and Kedungpring with weight values of 0.797, 0.776, 0.726, and 0.683, respectively. The study results can be used as input for the development of sugarcane plantations within the spatial plan of Lamongan Regency.

1. Introduction
Sugar is one of the basic needs of people in Indonesia. Sugar imports are carried out every year in Indonesia to meet domestic needs. The average sugar imports from 2015 to 2019 reached 4.34 million tons. The very high value of sugar imports is partly influenced by the limitation and decline of sugarcane plantations in Indonesia. Sugarcane plantations in Indonesia are only spread across ten provinces, including Lampung, West Java, Central Java, D. I. Yogyakarta, East Java, West Nusa Tenggara, South Sulawesi, and Gorontalo. The largest sugarcane plantations in Indonesia is in East Java Province, covering an area of 196,897 ha and sugar production of 1,110,841 tons [1].

Java Island is generally the most populous island in Indonesia. Population growth pressure is increasingly threatening agricultural land, especially sugarcane plantations to be converted into built-up lands such as settlements and infrastructure. The decline in the area of sugarcane plantations in Java makes it difficult for sugar factories to obtain raw materials. This decline in sugarcane land area is also...
influenced by infrastructure development that encourage new growth centers based on non-agriculture [2]. The development of sugarcane plantations is very important to do to secure national sugarcane and sugar production from various threats, especially on the island of Java.

Lamongan Regency is one of the regencies in East Java which is the center of national sugarcane and sugar production. Lamongan Regency has a sugarcane plantation area of 4870.13 ha in 2019. In addition, there is also a sugar factory with a large capacity of 12,000 tons cane per day, but sugarcane production in Lamongan has not yet been able to meet this capacity [3]. Lamongan Regency has enormous potential for the development of sugarcane plantations. The Spatial Plan of Lamongan Regency 2011-2031 proclaimed the development of sugarcane plantations, but the priority assessment of the development area which takes into account the balance of sugarcane availability in the future has not been scientifically studied.

This study aimed to analyze the priority areas for sugarcane plantation development in Lamongan Regency. The development of sugarcane plantations is important to increase sugarcane and sugar production in Lamongan Regency. This increase in production is expected to make a positive contribution to Lamongan Regency, East Java and to the national extent so that it can reduce sugar imports and that self-sufficiency will be achieved in the future.

2. Methods

2.1. Research Time and Location
This study was conducted from March 2021 to June 2021. The research was located in Lamongan Regency, East Java Province, Indonesia which has 27 sub-district administrative areas. Geographically, Lamongan Regency is located at 6°51'54” – 7°23'06” South Latitude and 112°33'45” – 112°33'45” East Longitude. The location of this study is shown in Figure 1.

![Figure 1. Research location](image)

2.2. Tools and Materials
The tools used were computers that have been installed with ArcGIS 10.3 software, Super Decisions, QGIS with MCDA vector plugins, and Microsoft Office. Meanwhile, the materials/data needed in this study consisted of primary and secondary data. The primary data used was the results of interviews with six experts and stakeholders for the analysis of Multi-Criteria Decision Making (MCDM) in the form of the AHP-GeoTOPSIS method. The secondary data used included data on population, area of sugarcane
plantations, productivity, sugar production, and sugar consumption, as well as data on the number of agricultural households in Lamongan Regency sourced from Statistics Indonesia; as well as a map of suitable land available for sugarcane plantations and a balance of sugarcane availability in Lamongan Regency [4].

2.3. Data Analysis Procedure

2.3.1. Analytic Hierarchy Process (AHP).
The AHP method in this study was used to determine the weight in the TOPSIS analysis. AHP analysis aims to determine the priority of the criteria and assess the relative importance of each criterion used. Data collection for AHP was done by interview and questionnaire methods. Interviews were conducted and questionnaires were shared using the purposive sampling method to six experts and stakeholders. The criteria used included the number of agricultural households, suitability and availability of land for sugarcane plantations, population, and sugarcane availability balance, all of which using the sub-district analysis unit. The scale ranges from one to nine, indicating that the two elements are equally important. On the other hand, number nine indicates that one element is very important than the other in the paired matrix. A pairwise comparison matrix called matrix A was extracted from the data collected from the interviews. The steps for using AHP [5][6][7] are as follows.

1. Pairwise comparisons were made and relative weights were estimated. Determination of relative weights in the ANP method was carried out by pairwise comparisons as was done in the AHP analysis. A scale of 1-9 was provided to compare between the two components [8].

2. Furthermore, the calculation for the normalized weight vector (w) was carried out with the following formula:

\[ A \cdot w = \lambda_{max} \cdot w \]  

where

- A : pairwise comparison matrix;
- w : normalized weight vector; and
- \( \lambda_{max} \) : the largest eigenvalue of matrix A.

3. Next, the consistency index (CI) value was calculated by the formula.

\[ CI = \frac{\lambda_{max} - n}{n - 1} \]  

4. After obtaining the CI, the consistency ratio (CR) was calculated using the following formula.

\[ CR = \frac{CI}{RI} \]

RI is a Random Consistency Index. The recommended CR value is less than 10% (< 0.10).

2.3.2. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS).
TOPSIS analysis is used to select the best alternative based on the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution. TOPSIS has several advantages:

- simple and easy to understand;
- making efficient calculation; and
- calculating alternative decisions using simple mathematical equations.

The stages of analysis using TOPSIS were carried out using the following methods [9][10][11]:

1. Create a normalized decision matrix with the following equation:
\[ r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{n} X_{ij}^2}} \]  

where

- \( r_{ij} \): the value of normalized decision matrix; and
- \( X_{ij} \): the original value of the decision matrix.

2. A normalized weighted decision matrix was created using the following equation:

\[ Y_{ij} = w_{i} r_{ij} \]

where

- \( Y_{ij} \): normalized weighted decision matrix;
- \( w_{i} \): weighting against criterion \( i \); and
- \( r_{ij} \): the value of normalized decision matrix.

3. The positive ideal solution matrix and negative ideal solution were determined using the following equation:

\[ A^+ = (y_1^+, y_2^+, ..., y_n^+) \]
\[ A^- = (y_1^-, y_2^-, ..., y_n^-) \]

\[ y_1^+ = \begin{cases} 
\max_{y_{ij}}; & \text{if } j \text{ is a benefit attribute (benefit)} \\
\min_{y_{ij}}; & \text{if } j \text{ is a cost attribute (cost)} 
\end{cases} \]

\[ y_1^- = \begin{cases} 
\max_{y_{ij}}; & \text{if } j \text{ is a benefit attribute (benefit)} \\
\min_{y_{ij}}; & \text{if } j \text{ is a cost attribute (cost)} 
\end{cases} \]

where

- \( A^+ \): positive ideal solution matrix \( A^+ \);
- \( A^- \): the ideal solution for the negative matrix \( A^- \);
- \( y_{ij}^+ \): max \( y_{ij} \) if \( j \) is benefit attribute;
- \( y_{ij}^- \): max \( y_{ij} \) if \( j \) is a cost attribute;
- \( y_{ij}^+ \): min \( y_{ij} \) if \( j \) is benefit attribute;
- \( y_{ij}^- \): min \( y_{ij} \) if \( j \) is a cost attribute.

4. The distance between the values of each alternative with the positive ideal solution matrix and the negative ideal solution matrix were determined using the following equation:

\[ D_i^+ = \sqrt{\sum_{j=1}^{n} (y_{ij}^+ - y_{ij})^2} \]
\[ D_i^- = \sqrt{\sum_{j=1}^{n} (y_{ij}^- - y_{ij})^2} \]

where

- \( D_i^+ \): distance to positive ideal solution; and
- \( D_i^- \): distance to a negative ideal solution.

5. Determine the value of choice for each alternative with the following equation:
The value of this option is the final value that is used to sort or prioritize all the alternatives that have been made. The greater the value of \( V_i \), the higher the priority value of the alternative used. The priority ranking results from the TOPSIS method were then mapped using GIS. A geographic information system (GIS) is an information system consisting of spatial and non-spatial data based on a spatial or location system [12]. The ranking and mapping of priority areas for sugarcane plantation development in Lamongan Regency with GeoTOPSIS were calculated using the VectorMCDA plugin in QGIS software. The division of development priority classes was carried out based on natural break classification that follows the characteristics of the data. Similar values were grouped into one class and differences between classes were maximized.

3. Results and Discussion

Directions for the development of sugarcane plantations in Lamongan Regency were formulated using the AHP-GeoTOPSIS method. This method is one of the MCDM (Multi-Criteria Decision Making) methods. The AHP-GeoTOPSIS method is a combination of the AHP (Analytic Hierarchy Process) and GeoTOPSIS (Geographical Information System-Technique for Order of Preference by Similarity to Ideal Solution) methods. The analysis in this method used several criteria, including the number of agricultural households, suitability and availability of land for sugarcane plantations, human population, and the balance of sugarcane availability, all of which using the sub-district analysis unit. Data for each criterion can be seen in Table 1. Meanwhile, the distribution map for each criterion can be seen in Figure 2.

Table 1. Data from each assessment criteria for the direction of sugarcane plantation development in Lamongan Regency is formulated using the AHP-GeoTOPSIS method

| No | Sub-Districts | A   | B         | C         | D        |
|----|---------------|-----|-----------|-----------|----------|
| 1  | Babat         | 304 | 2,664.01  | 99,201    | -11,542.28 |
| 2  | Bluluk        | 589 | 2,741.12  | 27,893    | 2,443.72  |
| 3  | Brondong      | 217 | 888.26    | 74,565    | -8,675.75 |
| 4  | Deket         | 128 | 4.32      | 48,991    | -5,700.25 |
| 5  | Glagah        | 192 | 92.66     | 41,666    | -4,847.93 |
| 6  | Kalietengah   | 158 | 150.56    | 40,190    | -1,460.71 |
| 7  | Karangbingang | 130 | 131.67    | 40,231    | -3,688.16 |
| 8  | Karanggeneng  | 82  | 64.67     | 42,422    | -3,786.28 |
| 9  | Kendungpring  | 583 | 3,345.95  | 68,863    | -2,059.72 |
| 10 | Kembangbahu   | 231 | 1,050.46  | 57,217    | 33,323.83 |
| 11 | Lamongan      | 144 | 138.68    | 77,861    | -9,059.28 |
| 12 | Laren         | 305 | 556.98    | 37,743    | 406.68    |
| 13 | Maduran       | 109 | 99.48     | 25,910    | -550.32   |
| 14 | Mantup        | 688 | 2,819.73  | 54,932    | 52,129.23 |
| 15 | Modo          | 747 | 1,249.42  | 54,846    | -5,645.57 |
| 16 | Ngimbang      | 677 | 4,244.65  | 59,083    | 18,793.02 |
| 17 | Paciran       | 254 | 1,930.23  | 94,139    | -10,953.26|
| 18 | Pucuk         | 411 | 196.04    | 44,821    | -5,085.47 |
| 19 | Sambeng       | 832 | 2,681.17  | 60,447    | 48,496.60 |
| 20 | Sarirejo      | 563 | 351.58    | 29,422    | -3,423.26 |
| 21 | Sekaran       | 103 | 20.03     | 30,544    | -3,553.86 |
| 22 | Solokuro      | 253 | 4,408.04  | 49,855    | -4,235.10 |
| 23 | Sugio         | 383 | 428.29    | 68,942    | -2,779.27 |
| 24 | Sukodadi      | 351 | 15.86     | 65,937    | -5,991.41 |
| 25 | Sukorame      | 419 | 1,733.26  | 26,461    | -3,078.84 |
| 26 | Tikung        | 531 | 93.98     | 53,557    | -2,183.19 |
| 27 | Turi          | 88  | 94.28     | 58,843    | -6,394.67 |
A: Number of agricultural households, B: Suitability and availability of land for sugarcane plantations (ha), C: Human population (people), D: Balance of sugarcane availability (tons)

Figure 2. Map of distribution of the number of farmer households (a), suitable and available land for sugarcane plantations (b), human population (c), and sugarcane availability balance (d)

Assessment of the weight of each criterion using the AHP was done by asking for opinions from six experts and stakeholders. Opinions from the experts and stakeholders were poured into a pairwise comparison matrix to determine the level of importance of a criterion compared to other criteria. All opinions were then aggregated using the geometric mean to obtain the combined weights of the six experts and stakeholders. The geometric mean aggregation has advantages over the arithmetic mean aggregation in the alternative weight analysis of criteria using the AHP method [13].

Table 2. Combined pairwise comparison matrix of all expert opinions, weights, and ranking of each criterion

|     | A       | B       | C       | D       | Weight | Ranking |
|-----|---------|---------|---------|---------|--------|---------|
| A   | 1.00    | 0.03    | 0.05    | 0.29    | 0.02   | 4       |
| B   | 30.27   | 1.00    | 2.02    | 7.48    | 0.61   | 1       |
| C   | 18.87   | 0.49    | 1.00    | 2.07    | 0.28   | 2       |
| D   | 3.46    | 0.13    | 0.48    | 1.00    | 0.09   | 3       |

A: Number of agricultural households, B: Suitability and availability of land for sugarcane plantations (ha), C: Human population (people), D: Balance of sugarcane availability (tons)
Table 2 is a combined pairwise comparison matrix of all experts and stakeholders, weights, and rankings of all criteria. The weight of the highest criteria was found in the criteria for land suitability and availability, which was 0.61. The inconsistency of the calculation with AHP was 3% (less than 10%), so it can be used for analysis. The AHP method was used to determine the weight of each criterion by seeking expert opinions. After the weight of each criterion was obtained, then the priority ranking of sugarcane plantation development in each sub-district was carried out using the GeoTOPSIS method. The GeoTOPSIS method could map the ranking results using the regular TOPSIS method because it was combined with the geographic information system in the study area. The GeoTOPSIS method was processed using the VectorMCDA plugin in QGIS software. The administrative map per sub-district was filled with the attributes of the criteria used in the analysis, then the ranking could be done, so that the resulting output was a priority map of sugarcane plantation development in Lamongan Regency (Figure 3). The output of the AHP-GeoTOPSIS analysis was a list of rankings that ranges from 0 to 1. The closer the value of an alternative is to 1, the better and ideal the alternative is. Conversely, the closer the value of an alternative is to 0, the worse and not ideal the alternative is [14].

![Figure 3. Priority of sugarcane plantation development in Lamongan Regency](image)

Based on Figure 3, it can be seen that there are five levels of priority for the development of sugarcane plantations in Lamongan Regency, namely development priorities 1 to 5. Development priority 1 is the most important area to be developed, while the development priority 5 consists of areas that can be put aside first. Four sub-districts are within the main priority (priority area 1), meaning that they are directed to develop sugarcane plantations. The four sub-districts from the highest ranking to the least are: first, Ngimbang (0.797); second, Solokuro (0.776); third, Mantup (0.726); and fourth, Kedungpring (0.683). Directions for the development of sugarcane plantations in Lamongan Regency can follow this priority order. Overall, the results of the priority ranking of sugarcane plantation development in Lamongan Regency using the GeoTOPSIS method can be seen in Figure 4.
Figure 4. Results of ranking priorities for sugarcane plantation development in Lamongan Regency

The description of the four sub-districts to be directed as priorities for the development of sugarcane plantations in Lamongan Regency is as follows: Ngimbang Sub-district has a total of 677 agricultural households, suitable and available land for sugarcane plantations covering an area of 4,144.25 ha, a population of 48,794 people, and a surplus in sugarcane availability balance of 17157.27 tons. Next, Solokuro Sub-district has 253 agricultural households, suitable and available land for sugarcane plantations of 4,335.50 ha, a population of 48,667 people, and sugarcane availability balance of -4,661.09 tons. Meanwhile, Mantup Sub-district has 583 agricultural households, suitable and available land for sugarcane plantations covering an area of 3,278.25 ha, a population of 47,132 people, and sugarcane availability balance of 75,023.64 tons. Last but not least, Kedungpring Sub-district has 688 agricultural households, suitable and available land of 3,275.49 ha, a population of 61,618 people, and sugarcane availability balance of -2,867.24 tons.

Development directions can increase sugarcane production in potential areas to support sugar self-sufficiency in Lamongan Regency in the future. If the need for sugarcane and sugar in the regency has been fulfilled, sugar production from Lamongan Regency can help meet the needs of sugarcane and sugar, both regionally in East Java, as well as at the national level. Currently, plantations in the Spatial Plan of Lamongan Regency 2011-2031 are mostly concentrated in Sambeng and Mantup sub-districts. Therefore, the results of this study can be used as input in the review and preparation of the spatial planning for the next period so that sugarcane plantations can be developed more broadly based on the directions of sugarcane plantation development to support sugar self-sufficiency in Lamongan Regency.

4. Conclusions

Based on the assessments of the four experts, land suitability criteria have the biggest role in the development of sugarcane plantations in Lamongan Regency. The development of sugarcane plantations in Lamongan Regency can be directed to follow development priority area 1 which has been analyzed using the AHP-GeoTOPSIS method. The first priority areas are Ngimbang, Solokuro, Mantup, and Kedungpring sub-districts. These areas have advantages on all four criteria used in the analysis. If the sugarcane plantation development has been carried out in priority area 1, then the development can be continued to the next priority area.

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