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Spatial-based multicriteria decision-making model for coconut sugar agro-industry location selection: A case study at Indragiri Hilir District, Riau Province, Indonesia

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Spatial-based multicriteria decision-making model for coconut sugar agro-industry location selection: A case study at Indragiri Hilir District, Riau Province, Indonesia

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Abstract. Coconut has become a major agricultural commodity because of its significant economic multiplier effects on people in the Indragiri Hilir District, Riau Province, Indonesia. One of the superior coconut products is coconut sugar, which may serve as a healthier substitute for conventional sugar because it has a lower glycemic index. Developing coconut sugar in the agro-industry certainly requires spatial mapping that best fits the criteria of sustainable agro-industry. Therefore, a spatial-based multicriteria decision-making model is required to select the best locations for product development. The integration between geographic information systems (GIS) and the analytical hierarchy process (AHP) was applied to acquire the target. It is relatively easy to handle various criteria with spatial and non-spatial data and balance qualitative and quantitative data. The results showed that the criteria contributing to selecting the location for the coconut sugar agro-industry included economic, social, environmental, technology, and infrastructure. Tembilahan Hulu and Kuala Indragiri became the most potential locations relevant to the analysis results. This work provides significant input and data for local governments in constructing policies related to the development of the coconut sugar agro-industry.

Keywords: coconut sugar, indragiri hilir, multicriteria decision analysis, spatial analysis

1. Introduction

Coconut has had substantial economic effects on people in Indragiri Hilir District, Riau Province, Indonesia. Its derivative, coconut sugar, can be developed to provide more significant benefits. The emerging issues of using coconut sugar instead of conventional sugar are related to its low glycemic index and a good healthier diet [1]. Selection of the most potential location for product industrialization is needed, particularly considering the sustainability of the agro-industry [2].

Location is crucial as it considerably determines the continuity of meeting market demand, while discontinuity may lead to severe economic loss [2]. Selecting a proper location constitutes a strategic stage for sustainable development [3]. In addition, this stage enables cost minimization. Geographic Information Systems (GIS) is a promising approach for acquiring the best spatial decision.

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GIS-based analysis has often been applied to the determination of location. The approach strives to analyze spatial data, enabling the evaluation and selection of a particular area according to criteria previously classified by weight and conditions[4], [5]. Some studies [6]–[8] have reported using GIS for location selection covering many fields such as agriculture, environment, mining, disaster, and health (Figure 1). Intriguingly, GIS seems to be inferior in the context of the industrial sector[9], [10], primarily in the coconut sugar agro-industry.

GIS is a computer system (hardware and software) that can consult, analyze, develop, manipulate, store, and edit data, maps, and spatial information. Spatial data are data connected to a location, a place on Earth. Spatial decision-making exploits the geographic relationships within these data to make decisions. GIS organizes the geographic data so that a person reading a map can select the necessary data for a particular project or task. A thematic map with a table of contents allows the reader to add layers of information to a base map of real-world locations (Figure 2) [11].

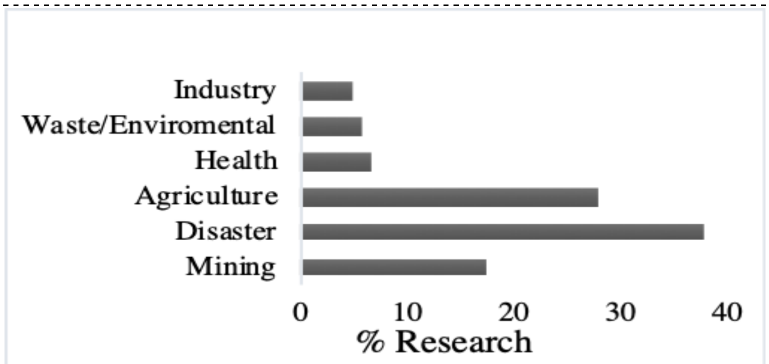

Figure 1. Discipline details of GIS papers indexed in Web of Science in 2016-2021.

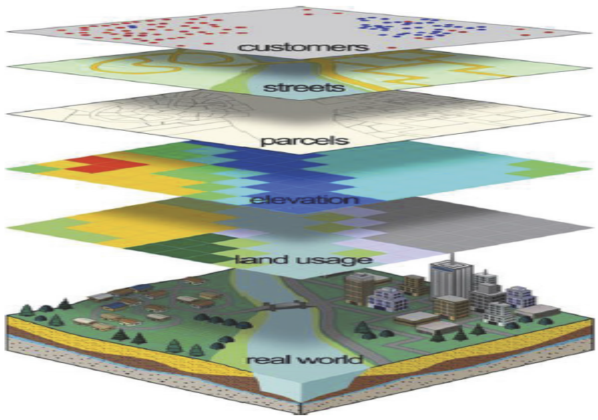

Figure 2. GIS layers model.

Source: *Journal Renewable and Sustainable Energy Reviews 2013*

Using GIS, spatial-based multicriteria decision-making modeling was carried out to select coconut sugar agro-industry locations. GIS is used to analyze and evaluate the sub-criteria of spatial and non-spatial data to select the location of the coconut agro-industry, which is classified by weight. The determination of the location of the coconut sugar agro-industry needs to consider multiple criteria. The multicriteria used in this study uses sustainability parameters so that the agro-industry can be competitive. The weighting for classifying these parameters uses the analytic hierarchy process (AHP), which is recognized to work with GIS procedures that determine the best location. Combining these approaches is expected to facilitate modeling the selection of coconut sugar agro-industry locations that consider multicriteria parameters using spatial and non-spatial data [4], [9].

The present work focused on identifying criteria and performing spatial analysis using GIS and the AHP approach. Therefore, this study aims to find the best location for the coconut sugar agro-industry in Indragiri Hilir's District to be appropriately achieved.

2. Methods

Figure 3 describes the stages of the study. GIS supported by multicriteria decision-making was used to identify the best site for developing the coconut sugar industry.

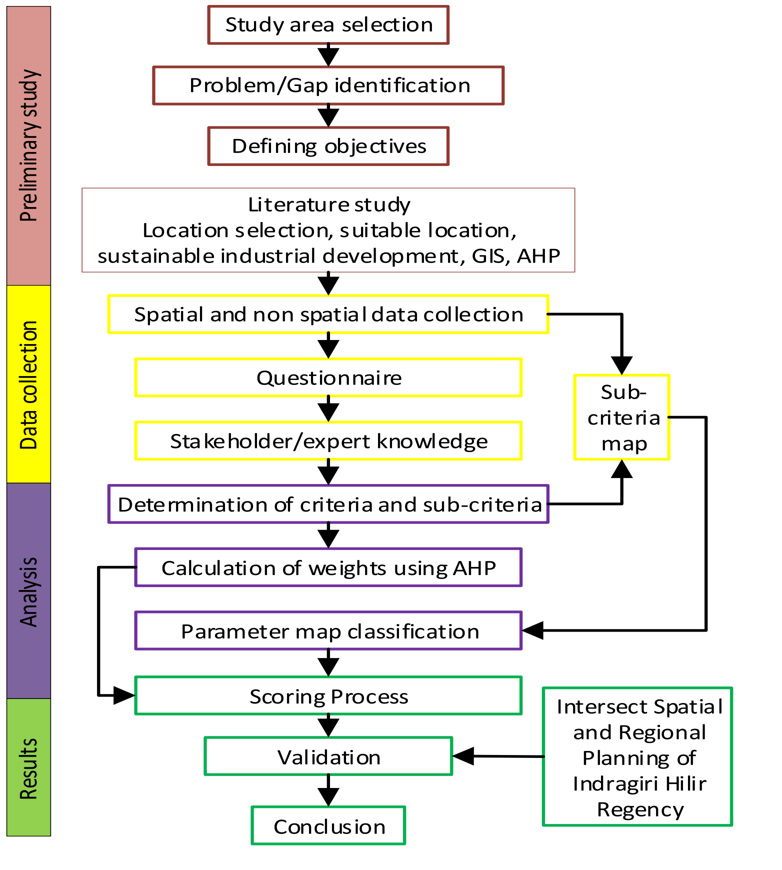

Figure 3. Procedures in the selection of the most suitable site for coconut sugar agro-industry.

2.1. *Study Location*

The research location is Indragiri Hilir Regency, Riau Province, Indonesia, because it has the highest number of coconut producers in Indonesia [13]. The regency is located at 00 36’ N latitude, 10 07’ S latitude, and 1040 10'–1020 32' E longitude. Map of the research location as in figure 4.

2.2. *Data collection*

Data collection is regarded as the most critical and time-consuming stage for supporting GIS. In this regard, criteria and sub-criteria were retrieved from a literature study [3], [14]–[18], and then validated by experts. There are seven experts used. The expert is an expert in the field of coconut agro-industry development. Accuracy in constructing a geodatabase for criteria and sub-criteria is of utmost concern for GIS and highly significant for decision-making. In short, the data collected dictate the quality of a decision considerably. Spatial and non-spatial data were collected from several government agencies in various sectors, including plantation, industry and trade, public works and spatial planning, regional planning and development, and statistics. Spatial data can explain data with different coordinates; thus, each change in the coordinate position should be determined to synchronize the reference data. The conformal mapping system in this work complied with the UTM 47 and 48 N zones, referring to WGS 84.

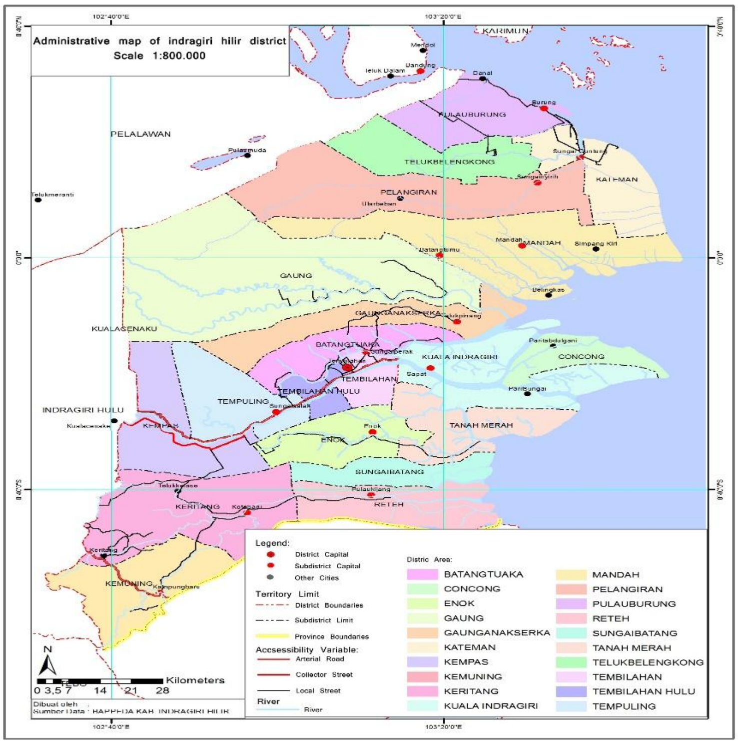

Figure 4. Map of the research location.

2.3. Method Analysis

Determination of location for coconut sugar agro-industry shall consider the material availability and appraise multicriteria-based conditions and their significance. MCDM using GIS has been reported by many researchers; in this case, AHP is one of the best approaches [19]. AHP refers to a method capable of helping decision-making based on multicriteria, as introduced by Saaty [20, 21, 22, 23]. It has been applied in many study fields owing to its mathematical and informative features that are easy to collect. AHP is a decision tool that enables the resolution of complicated cases based on multilevel hierarchical criteria to acquire the goal. The procedural steps required for the quantitative modeling of the AHP are elaborated in this section [23].

a. Designing a pairwise comparison matrix by only filling in the value in the upper triangle and the main diagonal is always worth one because the comparison of criterion a with criterion a results in 1. To fill in the value of the upper triangle with a comparison of the intensity of interest is used based on a comparison scale [23]. Designing pair comparison matrix as follows:

$$A = [a_{in}] = \begin{pmatrix} 1 & a_{12} & \cdots & a_{in} \\ \frac{1}{a_{12}} & 1 & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{1}{a_{in}} & \frac{1}{a_{2n}} & \cdots & 1 \end{pmatrix} \quad (1)$$

b. Normalize the decision matrix by the summation of each column, and then each entry on each column is divided by the column sum.

c. Determining weight for each criterion by finding the average score of matrix row n and weight w, as follows: $w1, w2, \ldots, w$n

$$w_i = \frac{1}{n}\sum_{j=1}^{n} a_{ij} \quad (2)$$

d. The stages of consistency analysis from pair comparisons obtained from the previous stage are as follows:
We are determining $\lambda 1$, $\lambda 2$, …, λn obtained by multiplying the weight of each criterion with a column in stage b.
Calculating λmax, where $\lambda max = \lambda 1 + \lambda 2 + \cdots + \lambda n$. λmax constitutes the highest Eigen score in n order matrix.
Calculating Consistency Index (CI) using the formula below:

$$CI = \frac{\lambda_{\max - n}}{n-1} \quad (3)$$

in which n means several criteria.
Calculating Consistency Ratio (CR) using the formula below:

$$CR = CI\ /\ IR \quad (4)$$

Where IR is Index Random, as presented in table 1 with Note: $CR \leq 0.1$ represents consistency.

Table 1. IR Consistency.

Matrix size	1	2	3	4	5	6	7	8
IR	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41

e. Determine the suitability level as follows:

$$i = \frac{most\ significant\ aggregate\ value - smallest\ aggregate\ value}{number\ of\ classes} \quad (5)$$

$$i = B_a - B_b \quad (6)$$

Where:
X = aggregate value of mapping potential area mapping
W_i = criterion weight for parameter i
w_i = weight of sub-criteria for parameter i
X_i = class score on criteria for parameter i
x_i = class score on sub-criteria for parameter i
i = class interval
B_a = upper limit of class
B_b = lower class limit

3. Results and Discussion

3.1. Parameters for criteria and sub-criteria
Analysis of location for industrial purposes is a complex task because it needs to consider technical aspects and other vital elements such as economic, social, and environmental; in this regard, the output might be contrary to the goal [24]. Two methods, GIS and AHP, were applied to integrate the weight and criterion clusters. In this study, an industrial location map was derived from the criterion map. The criteria extracted from the literature and validated by experts are presented in Table 2. A paired comparison matrix M (n × n matrix real) was developed to determine the weight of each criterion using the AHP (Saaty 1980). An expert's judgment on criteria and sub-criteria for determining the relative importance score was made through a numerical preference scale of 1 – 9. The consistency index ratio represents the judgment consistency. In this case, the consistency index ratio included criteria of 0.06175 and sub-criteria of 0.00000. Inconsistency was neglected when the index was < 0.1; thus, further analysis could be carried out. The expert's assessment is presented in table 2 and maps of the criteria and subcriteria layers in figures 5, 6, 7, 8, 9, and 10. Each criterion has sub-criteria, including

a. Raw material availability is the availability of coconut plants according to potential products, namely hybrid coconut in Indragiri Hilir Regency in terms of land area,
b. Close to market, which is the proximity of the market,
c. Accessibility which is the ease of regional accessibility (distance to river/sea and distance to the road),
d. Utility which is the availability of regional infrastructure,
e. Technology availability, which is the availability of coconut sugar processing technology,
f. Labor availability is the number of farmers' potential to cultivate coconut sap commodities.

Table 2. Parameters of assessment consistency and evaluation of criteria and subcriteria layers.

No	Criteria and Weight	Sub-Criteria	Classification	Grade	Weight of Sub-Criteria
1	Economic (0.41004)	Raw material availability	Insufficient	≤ 945 Ha	(0.5)
			Sufficient	≥ 945 Ha	
		Close to market	Extremely suitable	0 -1000 m	(0.5)
			Suitable	1001 – 3000 m	
			Less suitable	3001 – 5000 m	
			Not suitable	> 5000 m	
2	Infrastructure (0.30124)	Utility	Poor	1	(0.5)
			Good	2	
			Very Good	3	
		Accessibility	Difficult	1	(0.5)
			Less Easy	2	
			Easy	3	
			Very Easy	4	
3	Technology (0.11778)	Technology availability	Inadequate	0	(1)
			Adequate	5	
4	Social (0.17094)	Labor availability	Insufficient	≤ 945 farmer's household	(1)
			Sufficient	≥ 945 farmer's household	

3.2. Location for coconut sugar agro-industry
Following the analysis procedures, weight was assigned to criteria that considerably affected the location selection. Further, all map layers were integrated into GIS to prepare a model for estimating the

suitability of the agro-industry location. In this case, the evaluation results produced four levels of suitability: S1, very suitable; S2, suitable; S3, less suitable; and S4, not suitable. The suitability map is depicted in figure 11, demonstrating that one-third of the proposed region was acceptable for the coconut sugar agro-industry. Based on scoring, the most suitable location included some districts, that is, Tembilahan Hulu, Kuala Indragiri, Tembilahan, Batang Tuaka, Kempas, and Enok. These areas are located at the center and the edge of the regency. Among these districts, Tembilahan Hulu and Kuala Indragiri have been deemed the most promising areas because they have proper accessibility, including roads and rivers. Besides, factors contributing to the selection of the agro-industry location were economic, social, environmental, and technology. The Indragiri Hilir Regency in Figures 2020 and Indragiri Hilir Regency Transportation Service Data in 2020, the Tembilahan sub-district is supported by the potential availability of 947 hectares of raw materials, good accessibility conditions in the form of rivers, roads, and ports, as well as the number of farmers as many as 1411 heads of the family. The Kuala Indragiri sub-district is also supported by the potential availability of 1035 hectares of raw materials, good accessibility conditions in the form of rivers, roads, and ports, and the number of farmers as many as 3100 heads of the family.

The selected location was then intersected with regional spatial planning as prepared for the District of Indragiri Hilir (from 2017 to 2035). Regional spatial planning refers to policies responsible for land use strategy owned by the local government. Accordingly, there is a need to synchronize the scoring results and regional spatial planning, enabling the comparison of the spread of coconut sugar industrial locations suggested by this work and prepared by the government. Therefore, the marked areas overlapped on the map, resulting in prioritized areas for the development of coconut sugar. After the intersection, areas of 18 Ha were obtained, as shown in figure 12.

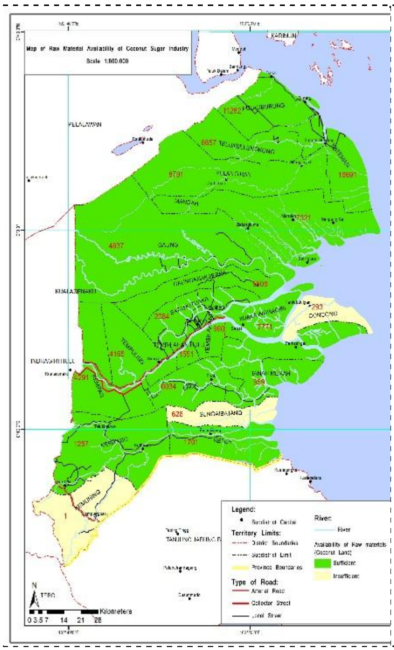

Figure 5. Map of raw material availability.

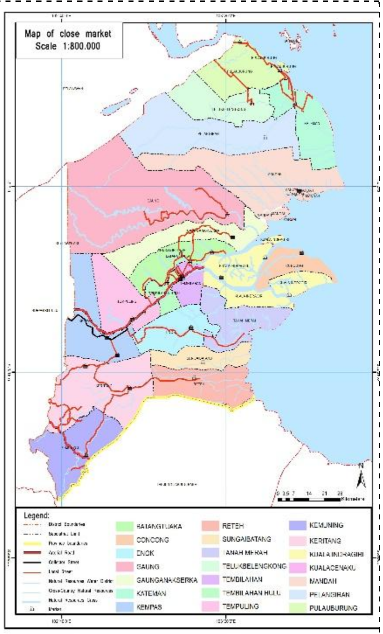

Figure 6. Map of close to market.

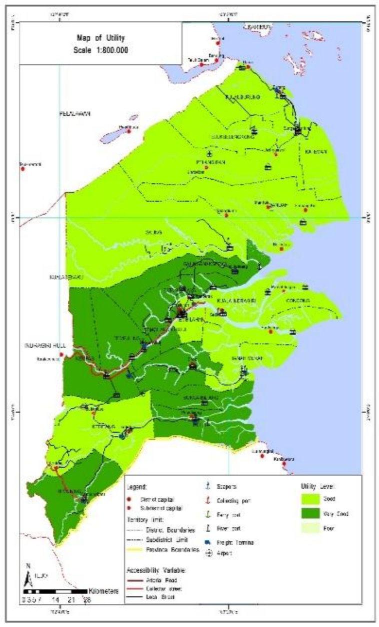

Figure 7. Map of utility.

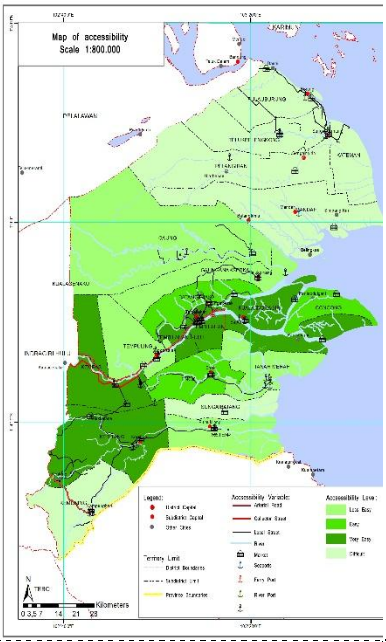

Figure 8. Map of accessibility.

Figure 9. Map of Technology availability

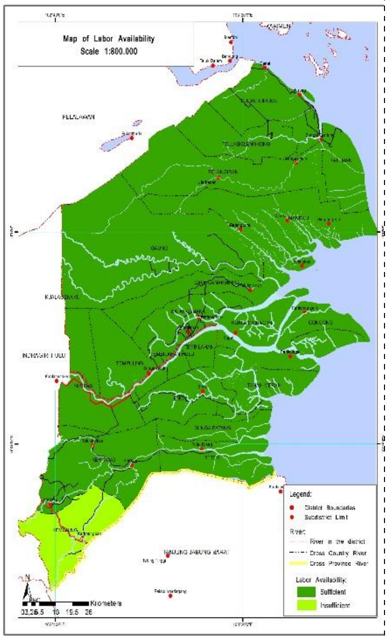

Figure 10. Map of labor availability.

4. Managerial Implication

The model established from multicriteria decision-making and the spatial approach provides a significant input and comparison study for the government of Indragiri Hilir to act decisively to develop a sustainable coconut sugar agro-industry. This commodity development has a tremendous economic impact that enables tackling current crucial problems, such as fluctuating and low prices, while also ensuring market certainty. The ultimate goal is to increase farmers' welfare. Determining the location of the coconut sugar agro-industry is challenging due to its complexity and multicriteria involved; thereby, a model is constructed in a hierarchical structure clearly and systematically, resulting in a focus and identifiable output. Other government institutions, such as the Indonesian Palmae Crops Research Institute (BALITPALMA), can also use the developed model to upgrade coconut seeds in some potential areas. Such improvement is a pivotal action to raise productivity and enhance added value. In addition, the model can be accessed by the agro-industry to recognize potential locations for coconut sugar.

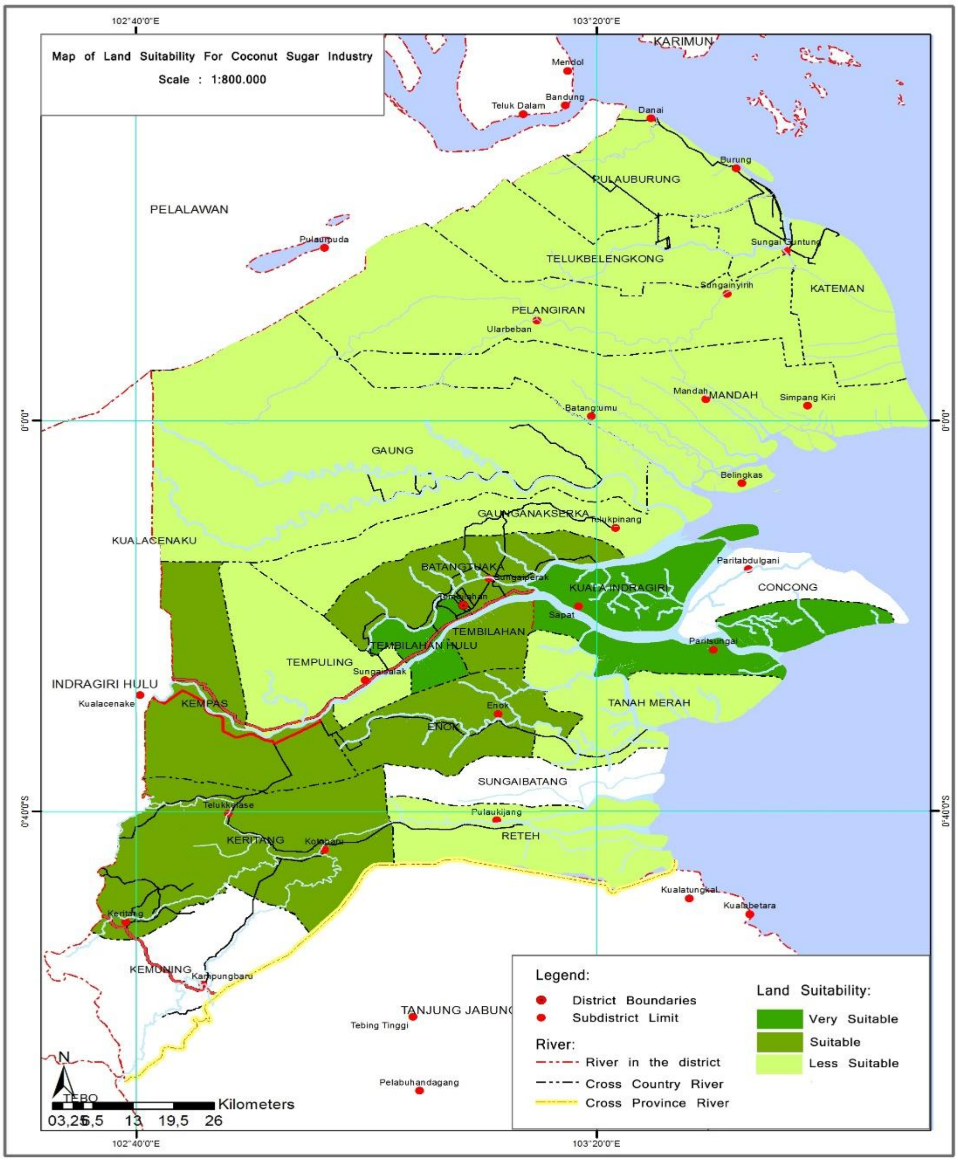

Figure 11. Mapping of a potential location for coconut sugar.

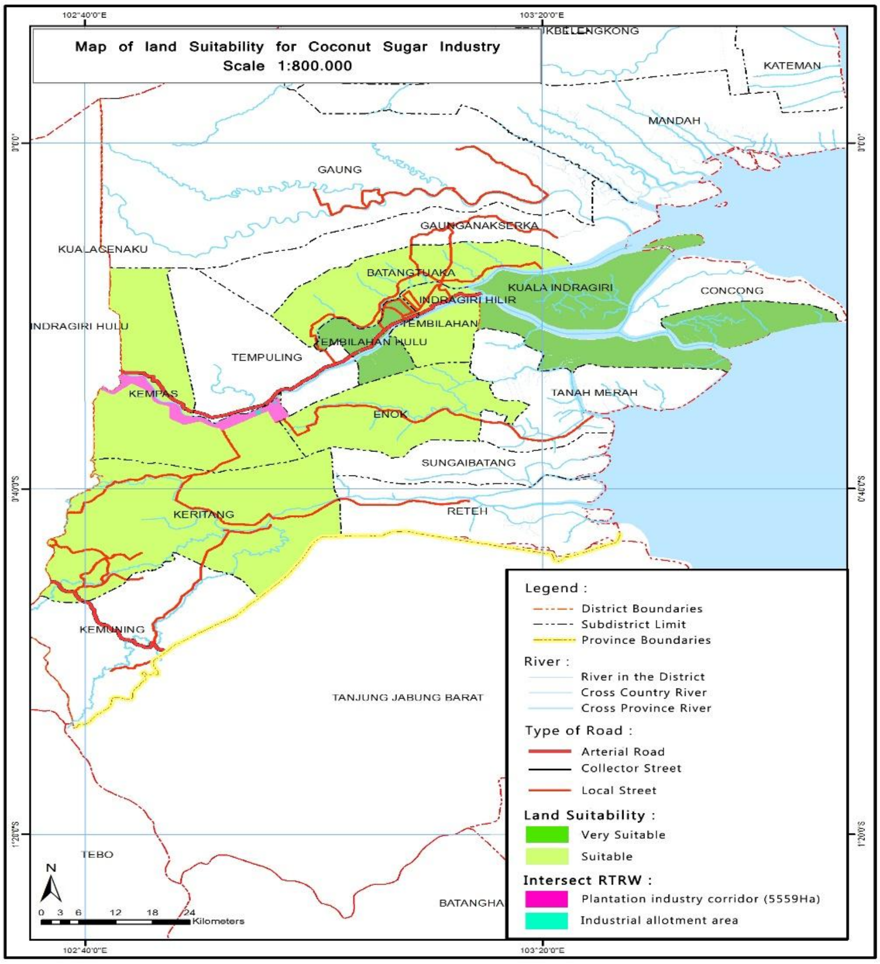

Figure 12. Mapping of a potential location for coconut sugar with an intersected map.

5. Conclusion and Recommendation

This research aimed to define criteria and potential locations for the development of the coconut sugar agro-industry, using a case study on the Regency of Indragiri Hilir District, Riau Province, Indonesia. The established model successfully integrated GIS and AHP, evaluating the locations potentially developed as coconut sugar producers. Stages of research conform to the multicriteria approach, conduct further analysis, and construct them in a hierarchical structure. In this study, ArcGIS was used to analyze spatial data, while the AHP was employed to determine the weight of each criterion. Finally, the developed map was compared and intersected with the data owned by regional spatial planning to check its synchronization.

The resulting criteria are economy weight 0.41004, the social weight of 0.17094, technology weight of 0.11778, infrastructure with a weight of 0.30124, and the environment in the form of RTRW to be intersected. In addition, the resulting sub-criteria include the availability of raw materials, market position, utility, accessibility, technological convenience, and labor availability. The resulting sub-criteria are the availability of raw materials, market position, utility, accessibility, and weight 0.5, while the ease of technology and labor availability is 1. Tembilahan, Batang Tuaka, Kempas, and Enok were rated "suitable", and Tembilahan Hulu and Kuala Indragiri were rated "very suitable". The output of this research provides input and comparative studies for the government of Indragiri Hilir Regency in the development of a sustainable coconut sugar agro-industry. Other stakeholders, such as BALITPALMA and agro-industry, can benefit from this model.

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