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Value Chain and Business Development Strategy of MOCAF Cap Kujang in Sumedang Regency

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Abstract

MOCAF Cap Kujang is one of the MOCAF (Modified Cassava Flour) produced in Sumedang that has been produced since 2012, but until now, the business development is still limited. The challenges in MOCAF Cap Kujang are the limited availability of raw materials, the lack of intensive marketing, and the government has not paid attention to the MOCAF business in Sumedang. This study aims to analyze value chain activities in MOCAF Cap Kujang, identify internal and external factors that influence the MOCAF Cap Kujang business, and determine the business development strategy for the MOCAF Cap Kujang business. The method used for value chain analysis was Porter's model and Hayami Method. Internal factor analysis was carried out using IFE, and external factors using EFE. The results of IFE and EFE were used to formulate strategies on the SWOT matrix. The resulting strategy was then prioritized using the AHP method. The study's results showed that value chain activities in the MOCAF Cap Kujang business consist of primary activities and supporting activities that generate added value at MOCAF by Rp1000/kg (33.33%). The main strength is the clean white of MOCAF Cap Kujang, and the main weakness is that MOCAF Cap Kujang's price is higher than other MOCAFs. The main opportunity of MOCAF Cap Kujang is that MOCAF can be a substitute for wheat for people who cannot consume gluten and the main threat is the lower price of wheat flour. MOCAF Cap Kujang's business development strategy prioritizes cooperation with various parties.

Keywords: *MOCAF, Porter's model, SWOT-AHP, value chain*

1. Introduction

Cassava is the third staple food for Indonesian people after rice and corn. Cassava has a low glycemic level and a high level of soluble dietary fibers, making blood glucose increase slower and feeling full longer and slowing the appearance of glucose in the blood, thereby minimizing the need for insulin [1].

Indonesia's ability to process agricultural commodities - including cassava - is still low. Only 25%-29% of agricultural products are exported in processed form, showing that most of the agricultural products (71-75%) are exported in the form of raw materials, which do not have added value [2].

One of the processed forms of cassava is MOCAF (Modified Cassava Flour). MOCAF is a flour produced from modifying cassava cells by fermentation. The modification process in MOCAF is carried out biochemically by adding enzymes that can destroy cassava cell walls and hydrolyze starch into organic acids such as pectinolytic or cellulolytic enzymes. This fermentation process causes changes such as increasing viscosity, gelation ability, rehydration power, and ease of dissolving [3].

Wheat flour consumption in Indonesia, according to the Ministry of Industry [4], in 2018 was 6.54 million tons and increased by 5% in 2019, which was 6.8 million tons. Unfortunately, Indonesia itself cannot meet this high demand, so imports are carried out to meet these needs. Based on the FAOSTAT website [5], in 2019, Indonesia imported 81,824 tons of wheat flour, an increase of about 32% from 2018, which was 61,789 tons. Processing cassava into MOCAF has a high potential as a wheat flour substitute. As a raw material for MOCAF, Cassava is more secure than wheat flour. Another advantage of MOCAF is that it is gluten-free, so it is safe for consumption by people with autism and those who are allergic to gluten [6].

The value chain is a series of activities carried out to produce products or services, from production activities and distribution of products to consumers to the final disposal of products after use (waste). According to Kaplinsky and Morris [7], the value chain consists of various actors involved, such as major producers, processors, and distributors. Value chain

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analysis can be used to understand how a product's value flows to create value for consumers by identifying the contribution of each activity of the production process [7]. The results of the MOCAF value chain analysis research by Setyaningsih et al. [8] in Wonogiri showed that the value chain of MOCAF agro-industry in Wonogiri has four patterns, there were: Pattern 1: Farmers, MOCAF Processors, MOCAF Collectors, Retailers, Consumers; Pattern 2: Farmer, MOCAF Processors, MOCAF Collectors, Consumers; Pattern 3: Farmers, MOCAF Processors, Consumers; Pattern 4: Farmers, MOCAF Processors, Retailers, Consumers. The analysis showed that the MOCAF value chain pattern in Wonogiri has not been efficient because farmers have not received high profits compared to other actors in all value chain patterns. From each pattern, the profit to farmers was only 2.5%. Meanwhile, MOCAF processors in pattern one and pattern two earned a profit of 26.67%. In the third pattern, it was 98.26%, and in the fourth pattern, it was 62.96% [8].

MOCAF Cap Kujang is one of the MOCAF products produced in Sumedang, West Java, since 2012. But, until now, the MOCAF Cap Kujang business has not developed significantly. The challenges in the MOCAF Cap Kujang business are the limited availability of raw materials and processing machines, marketing which is still limited, and the government's lack of attention to MOCAF's business in Sumedang. The problems faced can be understood and analyzed by understanding the value chain activities created in business activities to formulate appropriate strategies for business development. Therefore, this study aims to analyze the value chain in the MOCAF Cap Kujang business, identify internal and external factors that affect the MOCAF Cap Kujang business, and determine business development strategies that can be applied to the MOCAF Cap Kujang.

2. Methodology

The research was conducted using descriptive qualitative analysis in conducting value chain analysis and SWOT analysis. In contrast, quantitative research was used to calculate MOCAF added value and determine business development strategies. The research was carried out in the MOCAF Cap Kujang business in the Mekar Sari Regency Complex, Mekarjaya Village, North Sumedang, Sumedang Regency, West Java. The research was carried out from June 2021 to December 2021. Data collection was carried out through interviews, observations, questionnaires, and literature studies. The sampling method used was purposive sampling by selecting respondents according to predetermined criteria. The researcher also conducted interviews and a literature study of books, published journals, and articles related to the research topic. The respondents for the value chain analysis consist of two farmers, the owner of MOCAF Cap Kujang, three MOCAF processed entrepreneurs, two stakeholders of Masyarakat Singkong Indonesia (MSI), and the owner of a local food outlet. The respondents for strategy formulation consist of the owner of MOCAF Cap Kujang and two workers of MOCAF cap Kujang, two stakeholders of MSI, the manager of Regional Owned Enterprises, and three MOCAF processed entrepreneurs.

The value chain analysis in the MOCAF Cap Kujang business was carried out based on Porter's model, where the value chain consists of main (primary) activities and supporting (secondary) activities. Then a value chain model was formed by the ACIAR model [9], which consists of the main activities in the form of internal logistics, operations, external logistics, marketing and sales, and services. Supporting corporate infrastructure, human resource management, technology development, and procurement activities. In addition, the added value of MOCAF products was also calculated using the Hayami method. The Hayami method is a method that is used to calculate the added value and also can be used to determine the value of output and productivity [10].

The business development strategy was carried out using the SWOT-AHP Hybrid Model method. The first stage was collecting information about internal and external factors in the MOCAF Cap Kujang business. The next stage was formulating a strategy development for the MOCAF Cap Kujang business. Strategy formulation was carried out using a SWOT analysis approach, which begins with (1) IFE (Internal Factors Evaluation) analysis, (2) EFE (External Factors Evaluation) analysis, (3) IE (Internal-External) matrix analysis, and (4) SWOT matrix. Next, determining the priority of business development strategies using the SWOT-AHP Hybrid Model method. The strategy that has been formulated using a SWOT analysis approach was then determined with the implementation priority using the AHP approach. The SWOT-AHP method was carried out with the help of Expert Choice 11 software. AHP assessor consists of the lecturer, MOCAF Cap Kujang's owner, and three government officials.

3. Results and Discussion

Based on the research results, the value chain in the MOCAF Cap Kujang business starts from providing inputs or production facilities, MOCAF production, MOCAF distribution, MOCAF processing, and consumption activities. MOCAF Cap Kujang business has a simple and linear value chain that can be seen in Figure 1.

The main actors involved in the value chain of MOCAF Cap Kujang are cassava farmers, MOCAF processors, and MOCAF processed entrepreneurs as consumers of the MOCAF Cap Kujang business. The value chain governance relationship between cassava farmers and the MOCAF Cap Kujang business is a market where the MOCAF Cap Kujang business looks for cassava farmers who offer the lowest price for the cassava needed. According to Bhayangkari [11], the market type is characterized by low costs for changing

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partners on both sides. Meanwhile, the relationship between the MOCAF Cap Kujang business and the food processing business of MOCAF is in the form of a modular relationship. The supplier's specifications characterize the modular type relationship as the product's buyer (Bhayangkari, 2012)[11]. Therefore, MOCAF that is produced must comply with the required specifications, and if the MOCAF produced is not appropriate with the required specifications. The buyer will look for a new partner who can meet the required specifications.

3.1. Primary Activities and Secondary Activities

The value chain activity scheme in the MOCAF Cap Kujang business is shown in Figure 2. Primary or main activities include inbound logistics, operations, outbound logistics, sales and marketing, and services. Meanwhile, supporting activities include firm infrastructures, human resource management, technology development, and procurement.

Inbound Logistic

According to Suroso [12], activities in inbound logistics include receiving and storing raw or semi-finished materials. In the MOCAF Cap Kujang business, the raw material was obtained from farmers in Sumedang like Wado, Ciherang, Cimalaka, and Tanjungkerta. If the demand for cassava cannot meet by Sumedang, then cassava is obtained from outside Sumedang, such as Subang.

Operations

The MOCAF production process begins with cassava peeling. The peeled cassava was soaked and cleaned from mucus, then reduced in size using a chopping machine. It must be soaked in water and cleaned from the remaining mucus. Next, put it into 25 kg-50 kg sacks to be soaked again in a barrel containing 200 liters of water that contains 200 grams of Bimo-CF starter for 12 hours of the fermentation process to become chips. After that, the chips are drained with a spinner and sun-dried for 3-4 days until reaching 12% moisture content. After drying, the chips are mashed using a grinding machine until they become flour, then the flour is sieved three times, packaged, and labeled in 1000 gram, 500 gram, and 250 gram packages. The production process for the MOCAF Cap Kujang is depicted in the schematic shown in Figure 3.

Figure 1. Value Chain Flow in MOCAF Cap Kujang's Business

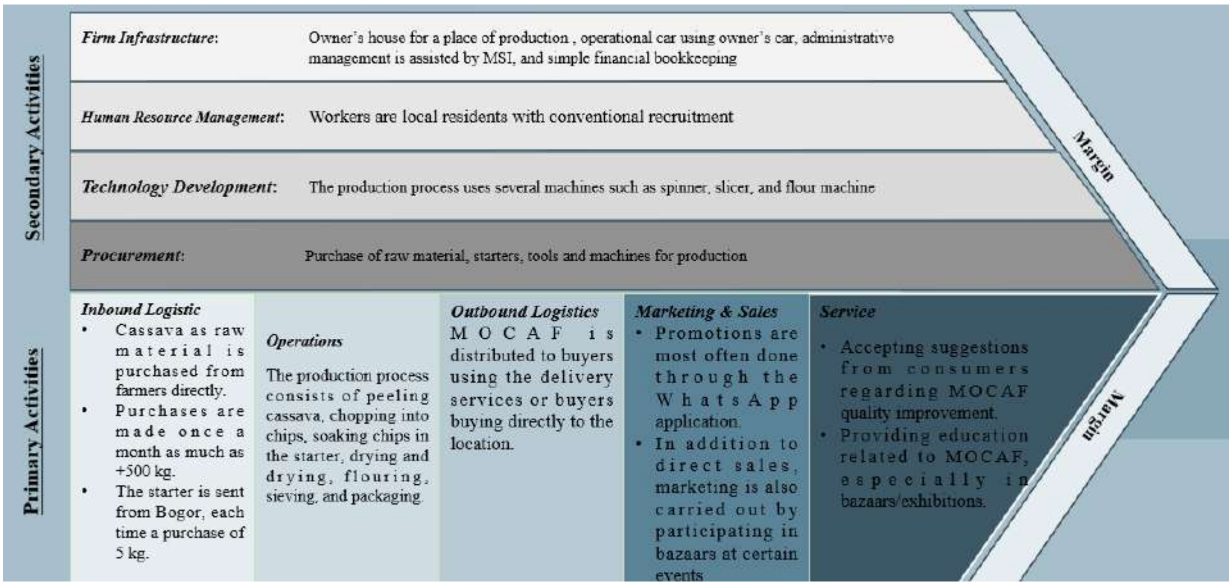

Figure 2. Primary Activities and Secondary Activities of MOCAF Cap Kujang

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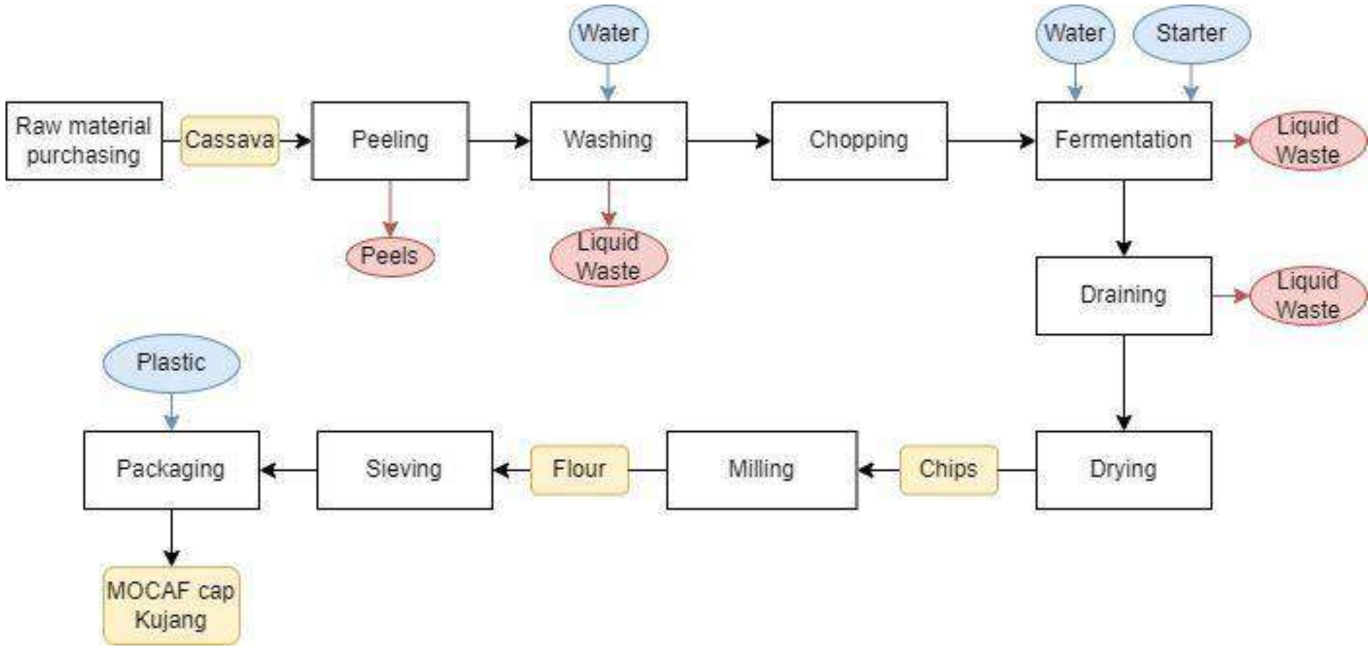

Figure 3. Production Process of MOCAF Cap Kujang

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Outbound Logistics

The packaged MOCAF Cap Kujang is then collected in a plastic box which is stored in a clean room. Products that are stored properly can last from six months to a year. The MOCAF Cap Kujang business does not yet have a warehouse for product storage. Most packaged products are shipped directly to consumers, so there is not too much product stack.

Marketing and Sales

MOCAF cap Kujang's marketing has not been intensive, the most frequent promotion is direct via phone messaging application. Marketing is also carried out by participating in bazaars at certain events, like the West Java Birthday event. Most of the MOCAF are sold to food processing entrepreneurs from MOCAF, so the type of sales from the MOCAF brand Kujang business is business to business (B2B).

Service

Service activities in the MOCAF Cap Kujang business are still limited, receiving suggestions from consumers regarding improving the quality of the MOCAF Cap Kujang. For example, there are suggestions from buyers regarding the size of the product being sold, buyers asking for small sizes, and some asking for large sizes. The owner will consider buyers' suggestions to improve the quality of MOCAF products. In addition, one of the services provided is to provide education related to MOCAF when MOCAF Cap Kujang participates in bazaars or exhibitions at certain events.

Procurement

The activities of purchasing inputs in the MOCAF Cap Kujang business include purchasing cassava as raw material, starters for fermentation, plastic packaging, and ordering packaging labels. Machinery and equipment for production were purchased at the beginning of the establishment of the business. Repeated purchases were made only when the equipment was broken, for example, such as a sieve and knife, while chopping machines, flour machines, sealers, and vats for fermentation still working until today.

Technology Development

The machines used in the MOCAF production process are a chopper machine to cut the cassava into the chips, a spinner used to reduce the water content of soaked cassava, a flour machine, and a sealer for the packaging process.

Human Resource Management

The MOCAF Cap Kujang business has three male and two female employees. They were recruited conventionally from residents and are not permanent. The wage payment system is paid daily.

Firm Infrastructure

The MOCAF Cap Kujang business's business infrastructure is the MOCAF production site, which is joined by the owner's home and the car used to pick up cassava. Business infrastructure also includes financial activities in the form of making simple financial records and administrative management activities, including processing business licenses carried out by owners with the assistance of MSI Sumedang.

3.2. Value Added Analysis

The value added analysis in this study was carried out using the Hayami method, as seen in Table 1. The added value calculation is only carried out at the stage of cassava becoming MOCAF, while the value added calculation has not been carried out at other stages. The amount of cassava that is

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processed into MOCAF in one production is 500 kg, and it produces MOCAF as much as 100 kilograms. Cassava as raw materials is purchased at Rp1,500.00/kg, and MOCAF is sold at Rp15,000.00/kg.

Table 1. Value Added Analysis on MOCAF Cap Kujang

No	Variable	Unit	Value
1	Raw materials input	kg/production process	500
2	Output	kg/production process	100
3	Labors input	HOK/production process	3
4	Conversion factor		0.2
5	Direct labor coefficient	HOK/kg	0.006
6	Product price	Rp/kg	15,000
7	Labor average wage	Rp/HOK	50,000
8	Raw material input price	Rp/kg	1,500
9	Other inputs	Rp/kg	500
10	Product value	Rp/kg	3.000
11a	Product added value	Rp/kg	1,000
11b	Added value ratio	%	33.33
12a	Labor income	Rp/kg	300
12b	Labor share	%	30
13a	Profit	Rp/kg	700
13b	Profit rate	%	70
14	Margin	Rp/kg	1,500
14a	Direct labor income	%	20.00
14b	Percentage other inputs	%	33.33
14c	Company profit	%	46.67

The value added is obtained by subtracting the product value from the price of raw materials and other inputs and obtaining an added value of Rp1,000.00/kg with a value added ratio of 33.33%. This value added is included in the medium category. According to Kipdiyah et al. [13], the value added included in the low category is less than 15%, the medium category is 15% to 40%, and the high category is more than 40%. Previous research related to the value added of MOCAF conducted by Saragih et al. [14] showed the added value at MOCAF was Rp670.27 per kg. However, the value was lower than the added value at MOCAF Cap Kujang, the ratio of added value was higher than the added value to MOCAF Cap Kujang, which was 49.64%. According to Kodrat et al. (2018)[15], added value can be increased by increasing business productivity, which is supported by improving the quality of the workforce and revitalizing the machines used in the production process is carried out efficiently.

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3.3. SWOT Analysis

The first step of SWOT analysis is to identify internal and external factors. Internal factors in the form of strengths and weaknesses of the MOCAF Cap Kujang business are listed in Table 2. External factors in the form of opportunities and threats to the MOCAF Cap Kujang business are listed in Table 3.

Table 2. Results of Internal Factor Analysis on MOCAF Cap Kujang's Business

	Internal Factor Strength
S1	Mocaf is clearly white
S2	Availability of MOCAF is always maintained
S3	The packaging is equipped with a brand and halal logo
S4	The business already has a P-IRT permit
S5	A long experience in the production of MOCAF
	Internal Factor Weakness
W1	The price of MOCAF is higher than other Mocaf
W2	The cassava peeling process takes a long time
W3	There is no successor yet
W4	No nutritional value information label yet
W5	Marketing is still in a limited way (not yet utilizing online media)
W6	Financial accounting has not been done in detail
W7	Limited capital

Table 3. Results of External Factor Analysis on MOCAF Cap Kujang's Business

	External Factor Opportunity
O1	There are still a few competitors
O2	MOCAF can be a substitute for flour for people who can't eat gluten
O3	Public awareness of health is increasing
	External Factor Threat
T1	Lack of attention from the government
T2	Limited availability of cassava
T3	The high price of cassava
T4	Unpredictable weather interferes with the drying process
T5	Wheat flour's price is lower, so MOCAF unable to compete in the market yet
T6	Suitable starters can only be obtained from one manufacturer

Internal Factors Evaluations (IFE)

Analysis of internal factors of the MOCAF Cap Kujang business is shown in Table 4. The total IFE score of 2.520 indicates that the internal condition of the MOCAF Cap Kujang business is quite strong, where the MOCAF Cap Kujang business can take advantage of existing strengths to overcome its weaknesses. A total IFE score above 2.50 indicates that the company has strong internal conditions [16]. In MOCAF Cap Kujang business, the strength element score is 1.678. This value is higher than the weakness element score, which is only 0.842. The strength factor that has the highest score is that the MOCAF Cap Kujang business already has a P-IRT (Pangan Industri Rumah Tangga or Home Industry Food) permit. This permit is issued by the City or District Health Office for household-scale industries. This P-IRT permit shows that the products produced are ensured to follow safety, quality, and product quality standards to be safe for sale [17]. Meanwhile, the biggest weakness in the MOCAF Cap Kujang business is the higher price for the MOCAF Cap Kujang compared to other MOCAFs.

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External Factor Evaluation (EFE)

Analysis of external factors in the MOCAF Cap Kujang business is shown in Table 5. The total EFE score of 3.010 indicates that the company is quite good at responding to external factors. However, this score should still be increased to a maximum score of 4.00, meaning that opportunities have been maximally utilized and threats avoided or overcome [16]. The highest score on the opportunity element is the increased public awareness factor. In contrast, the highest score on the threat element is the lower price of wheat flour, causing MOCAF not to be able to compete in the market in general.

Table 4. IFE Matrix Analysis

Element of Strength	Weight	Rating	Score
Mocaf is clearly white	0.093	3.667	0.342
Availability of MOCAF is always maintained	0.102	3.333	0.339
The packaging is equipped with a brand and halal logo	0.059	3.667	0.218
The business already has a P-IRT permit	0.102	4.000	0.407
A long experience in the production of MOCAF	0.093	4.000	0.373
Strength Total Score			1.678
Element of Weakness	**Weight**	**Rating**	**Score**
The price of MOCAF is higher than other Mocaf	0.102	1.333	0.136
The cassava peeling process takes a long time	0.076	1.667	0.127
There is no successor yet	0.068	1.667	0.113
No nutritional value information label yet	0.059	2.000	0.119
Marketing is still in a limited way	0.093	1.000	0.093
Financial accounting has not been done in detail	0.076	2.000	0.153
Limited capital	0.076	1.333	0.102
Weakness Total Score			0.842
IFE Total Score			**2.520**

Table 5. EFE Matrix Analysis

Element of Opportunity	Weight	Rating	Score
There are still a few competitors	0.101	3.000	0.303
MOCAF can be a substitute for flour for people who can't eat gluten	0.111	2.333	0.259
Public awareness of health is increasing	0.121	3.000	0.364
Opportunity Total Score			0.926
Element of Threat	**Weight**	**Rating**	**Score**
Lack of attention from the government	0.111	2.667	0.296
Limited availability of cassava	0.121	3.000	0.364
The high price of cassava	0.121	3.333	0.404
Unpredictable weather interferes with the drying process	0.101	3.000	0.303
Wheat flour's price is lower, so MOCAF unable to compete in the market yet	0.121	3.667	0.444
Suitable starters can only be obtained from one manufacturer	0.091	3.000	0.273
Threat Total Score			2.084
EFE Total Score			**3.010**

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Internal External Matrix

The total of IFE and EFE matrix scores is then used in the Internal-External Matrix (see Figure 4). The IFE value is 2.520, and the EFE value is 3.010, indicating that the MOCAF Cap Kujang is in cell II in the Internal-External Matrix. The strategy needed in this position is a growth and build strategy. The types of strategies that can be used are intensive strategies, such as market development, product development, and market penetration, and integrative strategies, such as downstream/forward integration, upstream/backward integration, and horizontal integration [18].

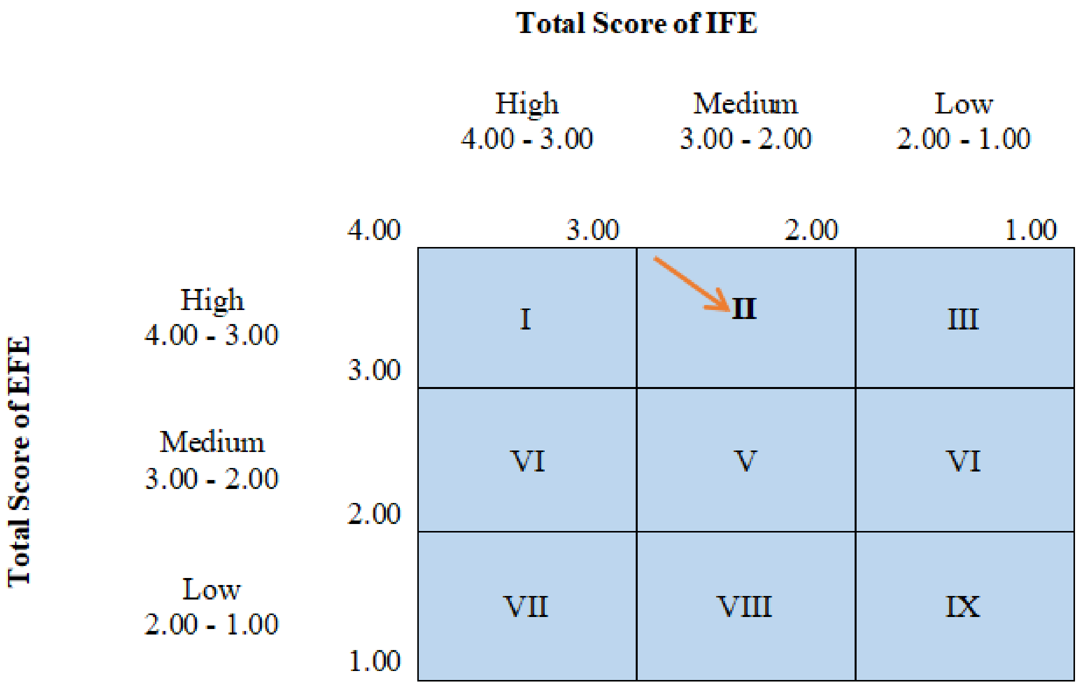

Figure 4. Internal-External Matrix on MOCAF Cap Kujang Business

The strategies formulated based on the SWOT matrix are:

1. SO (Strength-Opportunity) Strategy: This strategy is designed to take advantage of the strengths and opportunities that are owned so that they can be utilized optimally. The SO strategy made are: (a) Make bulky packaging (10 kg – 50 kg); (b) Create a campaign related to the advantages of MOCAF; (c) Establish a partnership with the autism community who generally cannot consume gluten and the healthy food community.
2. ST (Strength-Threat) Strategy: This strategy uses its internal strengths by avoiding or minimizing external threats to the MOCAF Cap Kujang business. ST strategies that are made are: (a) Cooperate with capital agencies, look for investors or business joint venture partners, and seek CSR (Corporate Social Responsibility) funding from companies [19]; (b) Use a drying machine for the production of MOCAF [2]; (c) Make processed products, so not only sell in the form of flour [19]; and (d) Look for another starter manufacturer.
3. WO (Weakness-Opportunity) Strategy: This strategy takes advantage of opportunities by overcoming weaknesses. The WO strategies made are: (a) Conduct regular promotions through social media and sell MOCAF through e-commerce [19] and (b) Include information labels on the nutritional value and advantages of MOCAF [6].
4. WT (Weakness-Threat) Strategy: This strategy minimizes weaknesses and avoids existing threats. WT's strategy is defensive, i.e., forming an organizational structure in the business so that business management is better.

These strategies are then narrowed down to obtain five alternative strategies, namely:

1. Collaboration with various parties.
2. Routine promotion through social media, making brochures and selling MOCAF through e-commerce.

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3. MOCAF sales in bulk are around 10 kg - 50 kg. This is intended to increase profits due to efficiency in the production process. In addition, selling in large quantities can be an option for buyers to increase their attractiveness [20].
4. The use of drying machines for production. This alternative strategy will facilitate the MOCAF drying process, which is carried out conventionally by utilizing direct sunlight. Using the appropriate machine following the production capacity and characteristics of the resulting product can optimize the production process [2].
5. Establishment of business organizational structure. This strategy is related to the existence of human resources. Currently, the human resources in the MOCAF Cap Kujang business are very limited. This business organization structure is intended to clarify the division of work functions so that the MOCAF production process can be more optimal and increase productivity. In addition, forming a business organizational structure can also facilitate the process of business regeneration [2].

Priority of Business Development Strategy with AHP Method

The AHP (Analytical Hierarchy Process) method determines the priority of alternative strategies. Previous studies related to the use of the SWOT-AHP method include research conducted by Djordje, et al. [21] to determine strategic priorities for the development of tourist destinations in Stara Planina, Serbia, and research conducted by Bojan, et al. [22] to improve electrical energy security in trpce, Serbia.

AHP in this study consists of three levels, the first level is the goal, the second level is the criteria, and the third level is the alternative. The SWOT-AHP hierarchy in this study can be seen in Figure 5. Expert Choice 11 software was used to determine the priority value of AHP. The priority at the first criteria is the availability of human resources (0.281), followed by enhancement in marketing (0.271), access to technology (0.241), and criteria for access to capital (0.207). The inconsistency value at the criteria level is less than 0.1, which is 0.02, meaning the priority determination results at the criteria level are valid [23]. The priority of the MOCAF Cap Kujang business development strategy alternative is a collaboration with various parties (0.370), the second priority is promotion routinely through social media, making brochures, and selling through e-commerce (0.260), the third alternative priority is the use of drying machine for production (0.175). The fourth alternative priority is to sell MOCAF in bulk (0.105), and the last alternative is to form a business organization structure (0.090). The value of inconsistency at the alternative level is less than 0.1, which is 0.01, meaning the prioritization results at the alternative level are valid [23].

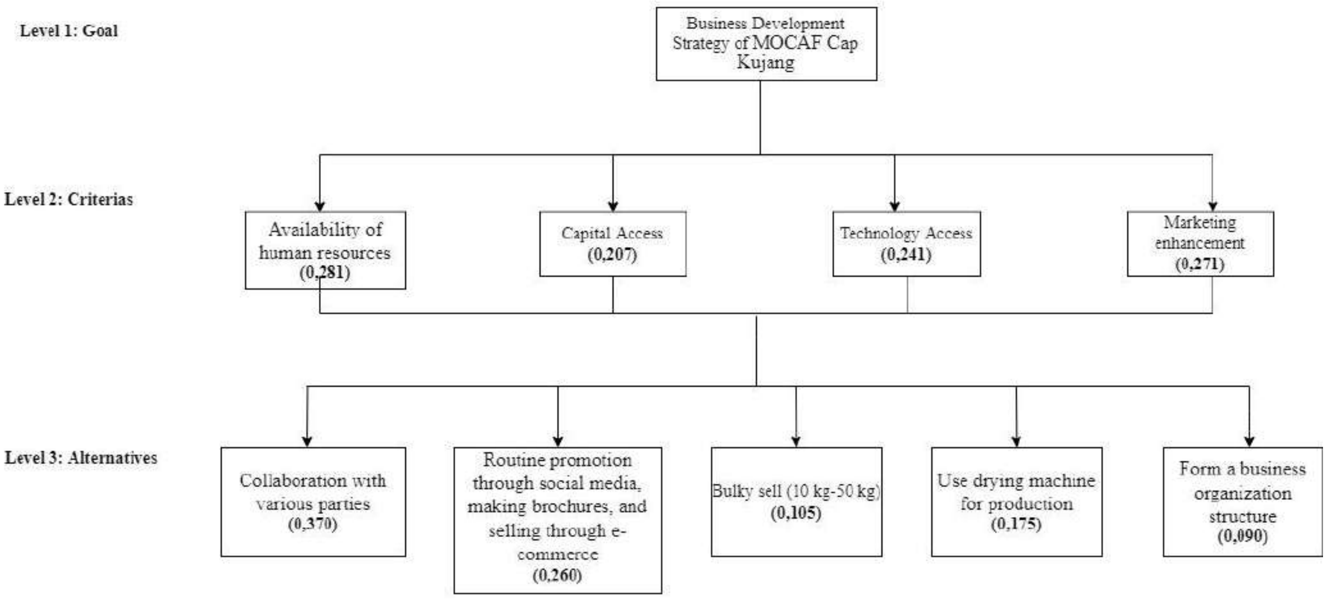

Figure 5. SWOT-AHP Hierarchy of MOCAF Cap Kujang Development Strategy

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Based on the strategic priorities generated from the SWOT-AHP, recommendations were then made for the development of the MOCAF Cap Kujang business: (1) Establish cooperation with cassava farmers through a Surat Perjanjian Kerjasama/SPK or Letter of Agreement; (2) MOCAF sales in sacks 10 kg-50 kg sacks to reduce production costs; (3) Recruitment of employees as needed so that the division of tasks can be determined such as the production division, marketing division, and administrative division; (4) Purchase a drying machine such as a drying oven to dry chips; (5) Purchase of peeled cassava from farmers; (6) Determination of the marketing division and selling MOCAF through online stores such as Shopee, Tokopedia, and Bukalapak; (7) Submission of proposals to BUMD (Badan Usaha Milik Daerah or Regional Owned Enterprises) to get business capital; and (8) Establishment of a financial division to manage finances and make detailed financial reports.

4. Conclusions

Based on the results and discussion, the conclusions of this study are:

1. MOCAF Cap Kujang's business value chain activities consist of main activities and supporting activities with MOCAF's added value of Rp1,000/kg or 33.33%.
2. The internal factor that became the main strength is the MOCAF Cap Kujang business already has a P-IRT permit, and its main weakness is that the MOCAF Cap Kujang's price was higher than other MOCAFs. The external factor that becomes the main opportunity is that MOCAF can be a substitute for wheat for people who cannot consume gluten and the main threat is the lower price of wheat flour.
3. The priority of MOCAF Cap Kujang's business development strategy is to build promotions and cooperation with various parties (Surat Perjanian Kerjasama/SPK or Letter of Agreement): routine promotions through social media, making brochures and selling through e-commerce, binding agreements with suppliers and consumers. The next strategic priority is using dryers for production, bulk sales of MOCAF, and establishing an effective business organization structure.

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Markov Chain and Cluster Model of Green Algae Phytoplankton (Chlorophyceae) Diversity and Spatial Distribution Pattern along Stream, Water Quality, and Land Use Gradients in Krukut River, Jakarta City

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Abstract

Green algae phytoplankton (Chlorophyceae) have a wide aquatic distribution, including saltwater and freshwater environments. Compared to the ones living in saltwater, green algae diversity in freshwater ecosystems in rivers is influenced by stream gradients, water quality, and land uses. Meanwhile, in Jakarta, 17 rivers have the potential to provide a habitat for green algae communities. Due to anthropogenic activities, river streams have been affected by influences that may affect the water quality and green algae community along stream gradients. One of the critical rivers in Jakarta is the Krukut river, which has the most extended stream spanning over 40 km and downstream in Jakarta bay. This study aims to model the diversity and distribution pattern of green algae in the Krukut river from its upstream segment in Jakarta city, surrounded by settlements, to the downstream segments in Jakarta bay. The distribution model uses the Cluster Analysis and Markov Chain Model to elaborate the probabilities of green algae phytoplankton distribution in downstream, midstream, and upstream segments of the Krukut river. The results show that 7 species of Chlorophyceae have been recorded in the Krukut river. All species had a high likelihood of being found downstream, particularly Cosmarium sp., Eudorina sp., Spyrogyra sp., and Volvox sp. Regarding distribution, all phytoplankton species have a high probability (4%–31%) and tendency to be distributed from upstream and midstream to downstream rather than from downstream to midstream and upstream, with probability ranges of 2%–27%. The probability and tendency of phytoplankton distribution towards downstream directions avoiding upstream were related to the deteriorating water quality in the upstream, characterized by high turbidity, low dissolved oxygen, and more acidic water.

Keywords: *distribution, Chlorophyceae, cluster, Markov chain, river*

1. Introduction

Phytoplankton is known as the earth's vascular organ's least primary producer. Phytoplankton is predominantly planktonic algae that, together with benthic algae and macrophytes, constitute the autochthonous primary producers in aquatic ecosystems, including freshwater ecosystems that range from lakes, rivers, and streams. Phytoplankton form part of the basis of the food web in terms of energy and material input in riverine ecosystems, including rivers in urban ecosystems and cities [1]. Chlorophyceae or green phytoplankton are primarily aquatic organisms that live in fresh or salt water. Freshwater forms in ponds, lakes, streams, rivers, and reservoirs. Chlorophyceae has a vital role in the aquatic

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environment since it has chlorophyll a that allows this phytoplankton to be a producer. Chlorophyceae can be found in various habitats on earth, including the sea, rivers, and lakes; on soil and walls; in animals and plants; and pretty much anywhere there is light to perform photosynthesis. With more Chlorophyceae forms being identified for commercialization, microorganisms play an increasingly important role, particularly in aquatic habitats. There must be hundreds of natural forms with different characteristics for every identified and proven species. A city like Jakarta should be recognized for the presence of a diverse range of aquatic forms, such as Chlorophyceae, considering the presence of urban water bodies that include lakes and rivers.

River in a city can provide a suitable habitat and ecosystem that can support the biodiversity of phytoplankton. In the West Banjir Kanal River passing through Semarang City, Khaqiqoh et al. [2] have recorded 4 phytoplankton families and up to 19 genera. The Shannon-Wiener diversity index (H') in the West Banjir Kanal River ranged from the lowest 0.20 to the highest 1.96. In the West Banjir Kanal River, the phytoplankton genera Nitszchia and Melosira were observed as the most abundant and common phytoplankton genera. The abundance of Nitszchia was 780 individuals/l and 2522 individuals/l for Melosira. The phytoplankton genera with the lowest abundance were observed in Ceratium, with an abundance as low as 6 individuals per liter. While in the Cisadane river in Tangerang city, Rosarina and Rosanti [3] have recorded 19 phytoplankton species. In the Cisadane river, those phytoplankton species have a Shannon-Wiener diversity index (H') ranging from 2.21 to 2.41, indicating high diversity. The highest phytoplankton abundance was observed in Synedra ulna species, with an abundance of 8.13 individuals/liter. In contrast, the lowest phytoplankton abundance was observed in Oscillatoria limosa, Anabaena spiroides, and Trachelomonas oblonga with an abundance of 0.63 individuals/liter.

Jakarta is one of Indonesia's cities with numerous aquatic ecosystems in the form of rivers. In total, 17 rivers pass through Jakarta, consisting of natural and artificial rivers, including Cengkareng and Cakung drains [4]. Based on its location, the river in Jakarta is distributed in the west, central, and east parts of Jakarta. In the west, the rivers include Mookevart, Angke, Pesanggrahan, Grogol, Krukur, Krukut Baru, and Cengkareng drain. The rivers in the central parts include Ciliwung, Banjir Kanal Barat, and Kalibaru Timur. Cakung drain, Banjir Kanal Timur, Cakung, Jati Kramat, Buaran, Sunter, and Cipinang Rivers are located in the eastern parts of Jakarta. In the western parts, the Krukut river is the longest river spanning over 40 km. According to recent studies, rivers in Jakarta city are suitable marine ecosystems as plankton habitats since the water quality in rivers in Jakarta is tolerable for plankton. Research carried out by Pambudi et al. [5] in the Ciliwung river has found about 53 genera of plankton representing Bacillariophyta, Chlorophyta, Chrysophyta, Cyanophyta, and Rhodophyta. The plankton abundance ranged from 1495 individuals per liter to 2511 individuals per liter. At the same time, the Shannon-Wiener diversity index (H') ranged from 1.21 to 2.6 in Ciliwung [6].

Considering the areas of the Krukut river that can potentially be the phytoplankton habitat in urbanized areas of Jakarta City, this study first aims to map the spatial distributions of Chlorophyceae along with the water quality in the Krukut river. Second, the spatial distribution patterns of Chlorophyceae in the Krukut river's downstream, midstream, and upstream segments were modeled using the Markov chain. The results of this study will contribute to the conservation of Chlorophyceae within urban aquatic ecosystems.

2. Methodology

2.1. Study Area

The study area was a segment of the Krukut river with its surrounding land uses (Figure 1). The studied segment of the Krukut river has a total length of 40 km and a width of 10 m, with a longitude of 106.75320^0-106.77500^0 East and a latitude of 6.13570^0-6.22050^0 South. For sampling purposes, the river was divided into three segments: downstream, midstream, and upstream. The downstream of the Krukut river in the north was directly bordered by Jakarta bay. The land uses that surrounded the river were dominated by built land uses, followed by combinations of vegetation and bare land uses. The debit of the Krukut river was 135 $m^{3,}$ and it received a daily rainfall of 129 mm/day. According to Hambali [4], water debit in the Krukut river can reach 869.299 m^3 during the rainy season and occur for at least 75 hours, or approximately 3 days.

Sampling activities were conducted for one day in each location (downstream, midstream, and upstream) in August 2021. Sampling activities were replicated 3 times in one month, for a total of 9 sampling times covering 3 locations and 3 replications.

2.2. Water quality samplings

The water quality survey includes in situ water dissolved oxygen (DO), turbidity, and pH measurements. Those water quality variables were measured in each sampling location with 3 replications for each location (Table 1). DO was measured using a multi-parameter (Lutron DO 5510), pH with a pH meter (Lutron PH 208), and turbidity with a turbidity meter (Ezdo TUB-430). The geographical locations of samplings were recorded using an Etrex Garmin GPS handheld.

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Table 1. Phytoplankton and water quality variables

Variables	Unit	Measurement methods
Phytoplankton	Cells/ml	Norpac plankton net, counting chambers
Dissolved oxygen (DO)	mg/L	Lutron DO 5510 multi-parameter
pH	na	Lutron PH 208
Turbidity	NTU	Ezdo TUB-430
Geocoordinate	Decimal degree	Garmin Etrex GPS handheld

2.3. Phytoplankton and Chlorophyceae samplings

The phytoplankton and Chlorophyceae were collected from water in each site using a modified plankton net with a mesh size of 150 microns, as described by Sidabutar et al. [7]. Collected samples were stored in bottles and preserved in 37% formaldehyde [8]. The filtered water volume was calculated using the equation v = r^2 multiplied by d, with v: filtered water volume; r: radiant of net opening; and d: plankton net depth lowered into the water. Phytoplankton and Chlorophyceae were identified using a light microscope with 400x and 1000x magnifications. The classification was carried out based on published literature on the algal taxonomy using the Book of Illustrations of the Marine Plankton of Japan by Yamaji [9] and the Book of Marine Phytoplankton of the Western Pacific by Omura et al. [10]. Phytoplankton and Chlorophyceae abundance counting was performed using Sedgwick Rafter counting chambers and the obtained abundance results were expressed in cells/ml.

2.4. Mapping and spatial analysis

Mapping and spatial distribution analysis of Chlorophyceae, water quality, and land use types consisted of developing the presence map of those variables and then the interpolation to estimate those variables' patterns. First, the recorded geo coordinate of Chlorophyceae, water quality, and land use variables in each river segment were tabulated into the table. Then, the recorded data in the table were mapped using Geographical Information System (GIS) with ArcView version 3.2 to pinpoint the geo-locations of Chlorophyceae, water quality, and land use variables in 3 segments of the Krukut river. The tabulated GIS tables containing Chlorophyceae, water quality, and land use variables were interpolated [11, 12, 13] to create a pattern map.

2.5. Chlorophyceae diversity

Chlorophyceae diversity was calculated and presented using the Lorenz graph. This graph indicated diversity based on the evenness. Within the Lorenz graph, the diversity was measured based on the curve shapes under the diagonal line representing the evenness. The farther the curve off the line of evenness lines, then the more diverse the certain species become and the more uneven the abundance of each species becomes [14, 15, 16].

2.6. Chlorophyceae cluster model

Cluster methods aim to determine the concentrations and hotspots of the Chlorophyceae community in 3 studied river segments follow current methods [17]. The input data were the abundances of Chlorophyceae species in each river species and were presented as points in the GIS interface. Cluster analysis was conducted using an extension of GIS, and the cluster calculation was based on the K-means method. This method uses an algorithm that assigns each point to the cluster whose center, or known centroid, is nearest [18]. The center is the average of all the points in the cluster, and the coordinates of the points are the arithmetic mean for each dimension separately over all the points in the cluster. The determination of the centroid, or cluster point, was as follows:

$$z1 = \frac{x1 + y1}{2}, z2 = \frac{x2 + y2}{2}, z3 = \frac{x3 + y3}{2}$$

with: z = centroid, x = coordinate in axis x, y = coordinate in axis y

2.7. Chlorophyceae Markov chain model

A Markov chain [19, 20] is a model consisting of and representing the probabilities of a certain state and the probabilities of transition between states. A Markov chain uses transition probabilities to describe the transitions between a given set of states. The set of possible states is called state space. In this study, the state is the 3 river segments, including downstream, midstream, and upstream. Transition

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probabilities describe the transition of Chlorophyceae between river segments in the chain as a conditional probability.

To run the Markov chain model [21], our study follows standard textbook treatments of Markov chains. Let $Z_t \in S$ denote the state a discrete-time Markov chain is in at t = 0,1,2,…, for some finite state space S consisting of m states. The transitions between states are governed by transition probabilities $Pr(Z_{t+1} = s_j|Z_t = s_i) = p_{ij}$ with $s_i, s_j \in S$, which capture the probability of Chlorophyceae moving from state s_i at time t to state s_j at time t + 1. Transition probabilities only depend on the current state the Markov chain is in at time t, and not on any previous states at t−1,t−2, …..

3. Results and Discussion

3.1. Water quality spatial distribution

The result of comprehensive water quality spatial distributions in the Krukut river is presented in Figure 2. The measured water quality variables consisted of turbidity, dissolved oxygen, and pH with value ranges of 20.5-64.0 NTU, 6.0-11.0 mg/l, and 4.5-7.5. along streams of Krukut river, Jakarta city. The turbidity values were observed lower downstream and higher upstream. The water downstream near Jakarta bay was clearer than other river segments.

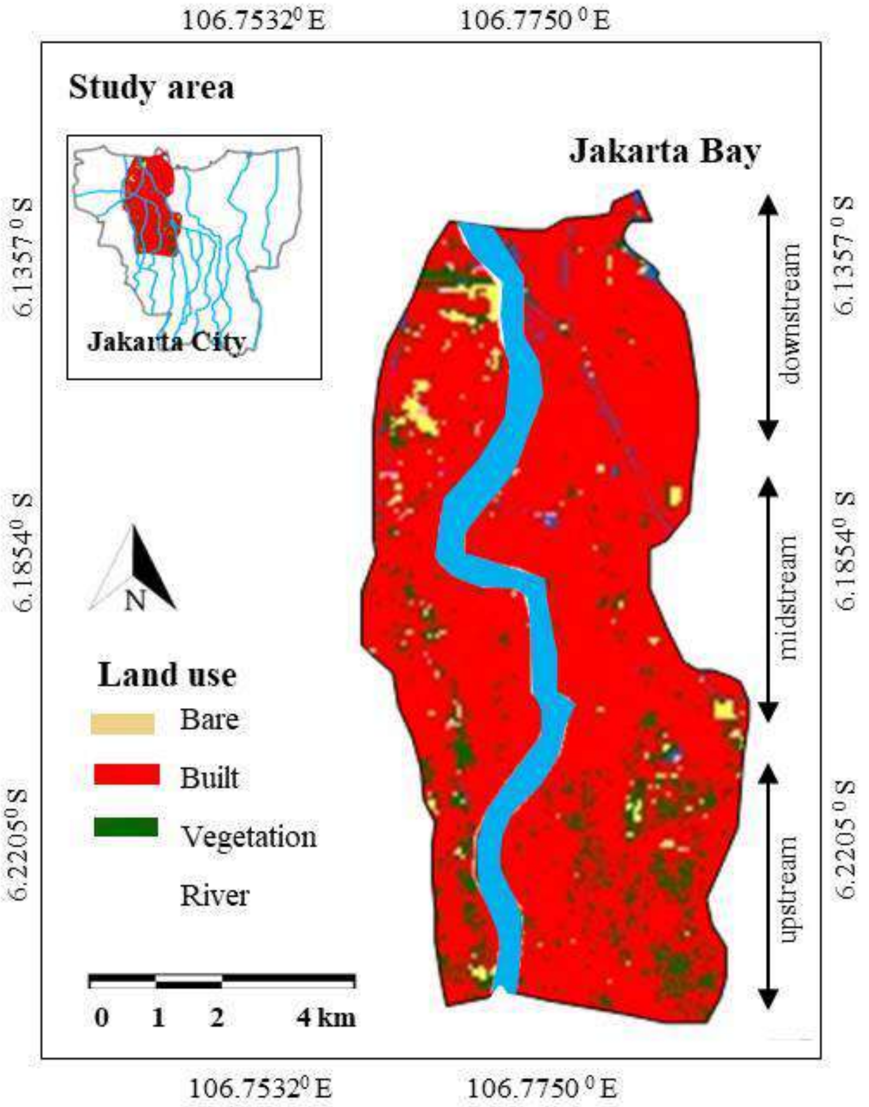

Figure 1. Study area and sampling locations in upstream, midstream, and downstream segments of Krukut river, Jakarta city.

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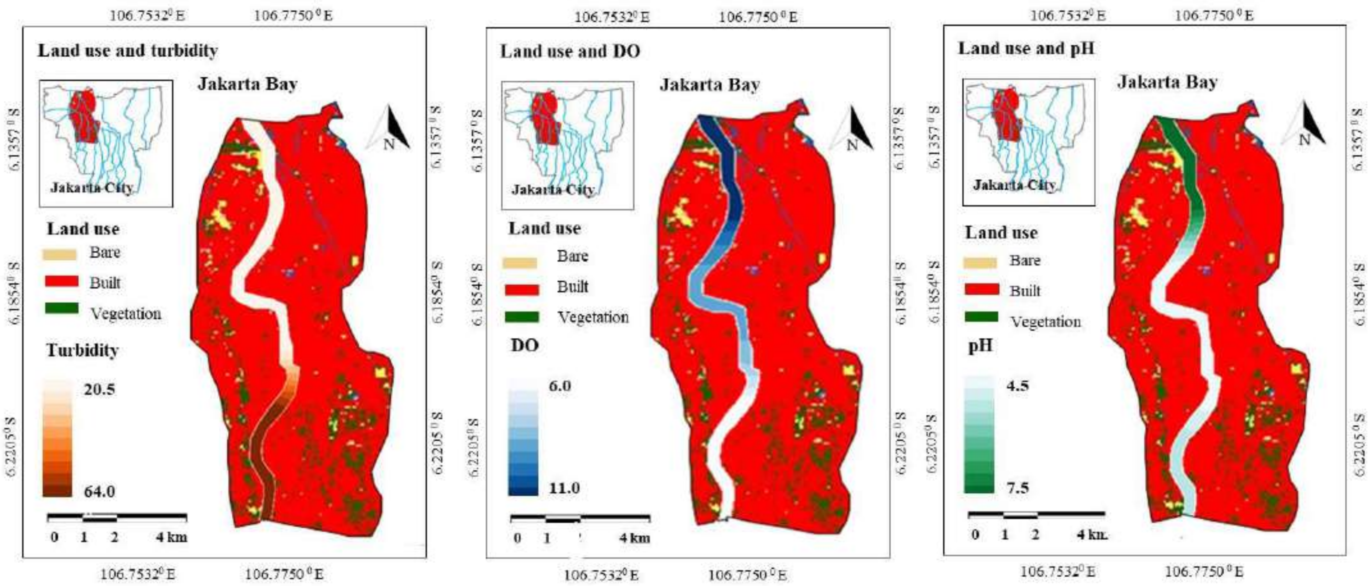

Figure 2. Spatial patterns of water quality variables, including turbidity (20.5-64.0 NTU), dissolved oxygen (6.0-11.0 mg/l), and pH (4.5-7.5) overlaid with land use types in upstream, midstream, and downstream of Krukut river, Jakarta city.

In contrast, the segments in upstream segments were murkier than those downstream. Similar patterns were also observed for DO and pH variables. The downstream has a higher DO than other segments of the Krukut river. In contrast, the DO increased towards upstream segments. It indicates that the downstream of Krukut river near Jakarta bay has high contents of oxygen dissolved in water. The upstream segments of Krukut river, characterized by murky and low DO contents in water, had low pH values indicating acidic water. In contrast, downstream of the Krukut river, characterized by clear water and enriched by oxygen, had high pH values. This value indicates the water downstream is base.

Regarding land use, there was also an observed discrepancy in land use between downstream and upstream segments. The upstream segments represent more acidic and murky water with low DO dominate by settlement land use type. In contrast, vegetation land use types dominated the downstream segments of the Krukut river that had clear, alkaline water with high DO values.

The results of water quality recorded in the Krukut river compared to previous research about water quality in rivers in Jakarta City [22, 23, 24]. A study by Anggeraeni et al. [25] observed that Jakarta's river turbidity was decreasing towards the upstream level. The turbid water in the upstream segment of rivers in Jakarta was related to the presence of settlement along the river streams.

The influences of land use in the forms of settlements observed in the Krukut river were corroborated by findings from other river streams. In India, deteriorating freshwater quality was correlated with using the Rawalakot water bodies for domestic, industrial, and agricultural purposes, introducing an influx of pollution and nutrients [26, 27].

3.2. Chlorophyceae diversity, spatial distribution, cluster model, and water quality

The result of comprehensive Chlorophyceae abundances in the Krukut is presented in Figure 3. There were in total 7 species of Chlorophyceae were observed along streams of Krukut River. Those species were *Cosmarium* sp., *Eudorina* sp., *Oocystis* sp., *Pediastrum* sp., *Scenedesmus* sp., *Spyrogyra* sp., and *Volvox* sp. Chlorophyceae in Krukut River has different abundances, with *Volvox* sp., *Scenedesmus* sp., and *Pediastrum* sp. among the most abundant species. Regarding diversity measured using the Lorenz graph (Figure 4), the Chlorophyceae diversity was high downstream. According to the Lorenz graph, the Lorenz curve downstream is farther than the curve in midstream and upstream. The curve is further away from the line of perfect evenness, indicating the more diverse the Chlorophyceae downstream of the Krukut river.

The Chlorophyceae species that had high abundances in the Krukut river were in order of *Volvox* sp., followed *by Scenedesmus* sp., and *Pediastru*m sp. with the maximum abundance values of 36.24 cells/ml, 31.6 cells/ml, and 30.5 cells/ml. While *Cosmarium* sp., *Eudorina* sp., and *Spyrogyra* sp. were observed as Chlorophyceae with low abundances, with maximum abundance values of 1.29 cells/ml, 4.15 cells/ml, and 4.31 cells/ml. In general, all Chlorophyceae species have higher abundances towards the downstream river segment, with the upstream mostly having lower abundances. Despite these general patterns, *Oocystis* sp. *Scenedesmus* sp. and *Pediastrum* sp. were observed to still have higher abundances up to the midstream and upstream segments (Figure 5).

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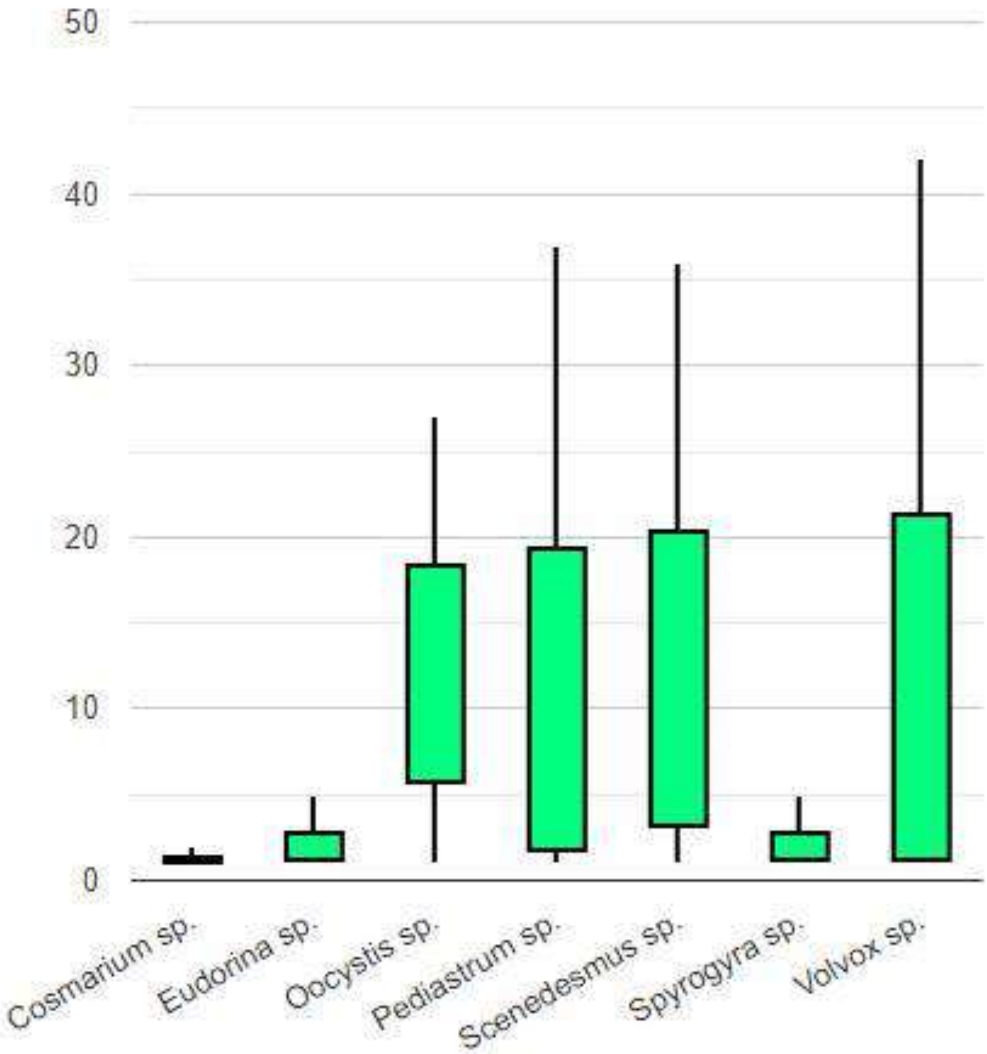

Figure 3. Abundances (cells/ml) of Chlorophyceae species in Krukut river, Jakarta city.

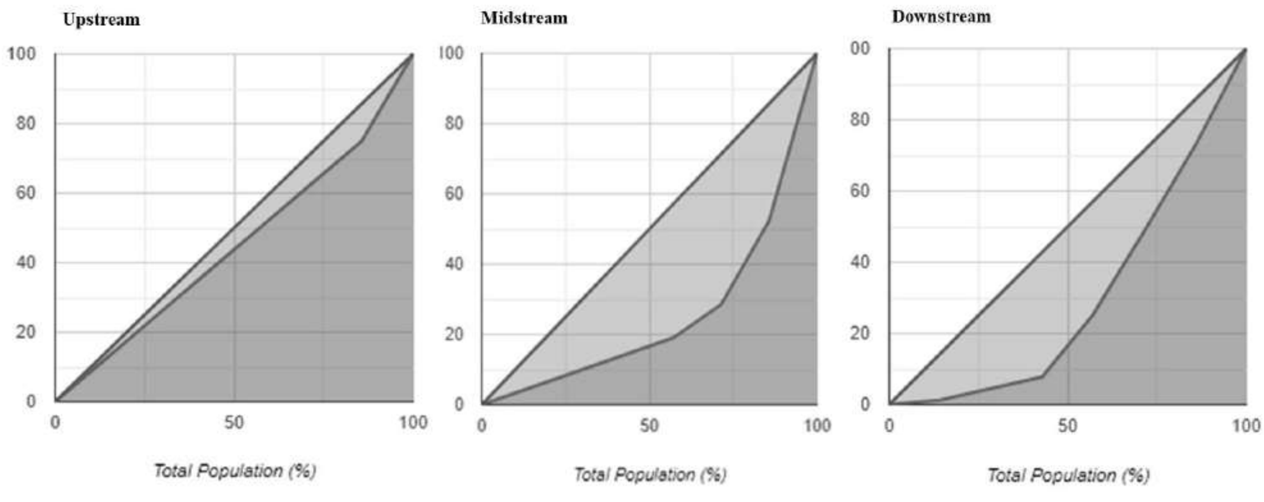

Figure 4. Lorenz curve for the cumulative proportion of Chlorophyceae population and diversity in upstream, midstream, and downstream of Krukut river, Jakarta city.

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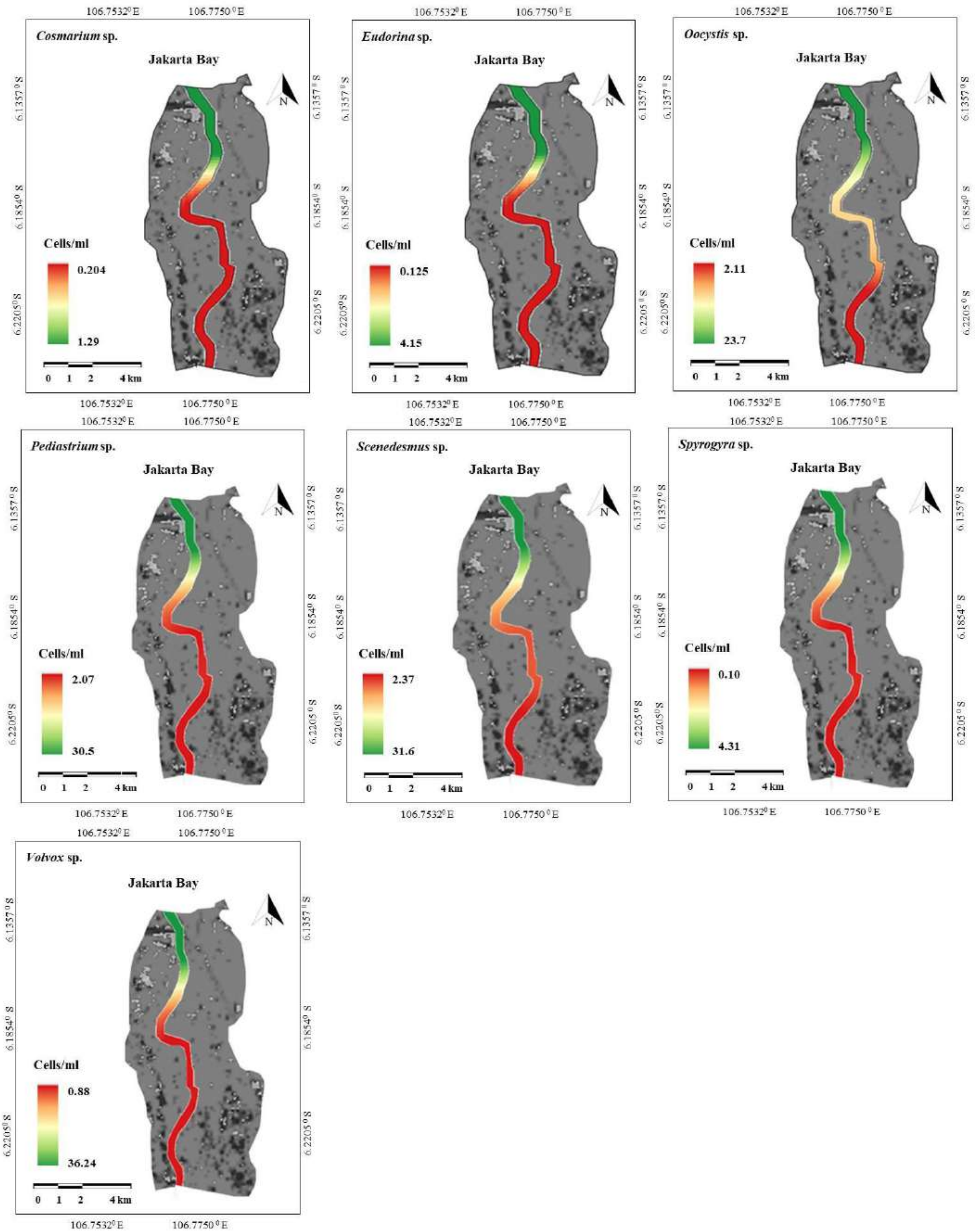

Figure 5. Abundance spatial patterns of *Cosmarium* sp., *Eudorina* sp., *Oocystis* sp., *Pediastrum* sp., *Scenedesmus* sp., *Spirogyra* sp., and *Volvox* sp. in upstream, midstream, and downstream of Krukut river, Jakarta city.

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In contrast, Chlorophyceae species, including *Cosmarium* sp., *Eudorina* sp., *Spyrogyra* sp., and *Volvox* sp., showed abundant declines in midstream river segments. Chlorophyceae species have higher abundances in the downstream segments than in other river segments (Figure 6). The cluster analysis (Figure 7) shows there are 3 clusters of Chlorophyceae abundances. The first group indicated high abundance in the downstream, the second group indicated moderate abundance in the midstream, and the third group indicated low abundance in the upstream. In contrast to the majority of the Chlorophyceae abundance cluster, a high and moderate abundance of *Oocystis* sp. were also observed in the midstream segments of the Krukut river.

The correlation of Chlorophyceae with water quality variables in the Krukut river is presented in Figure 8. There were in total of 7 species of Chlorophyceae observed along the Krukut river's streams. Those species were *Cosmarium* sp., *Eudorina* sp., *Oocystis* sp., *Pediastrum* sp., *Scenedesmus* sp., *Spyrogyra* sp., and *Volvox* sp. The river segments characterized by low DO, low pH value, and high turbidity were dominated by *Scenedesmus* sp. According to Guedes et al. [28], *Scenedesmus* sp. is a Chlorophyceae species that can tolerate and prefer acidic water characterized by low pH. This condition was related to the findings that the highest Scenedesmus sp. biomass specific growth rate was associated with relatively low pH. River segments with moderate levels of DO and pH were inhabited by *Oocystis* sp., *Pediastrum* sp., and *Scenedesmus* sp. Some Chlorophyceae species were found to be limited to the river segments with clear water and high DO. Those Chlorophyceae species include *Cosmarium* sp., *Eudorina* sp., *Spyrogyra* sp., and *Volvox* sp. Those species cannot tolerate the water quality upstream, characterized by low DO and murky water. This finding is in agreement with the result from the previous study. In contrast to *Scenedesmus* sp., *Cosmarium* sp. avoids polluted water with anthropogenic influences. High concentrations of highly polluted water inhibit the growth and physiological activities of *Cosmarium* sp. [29].

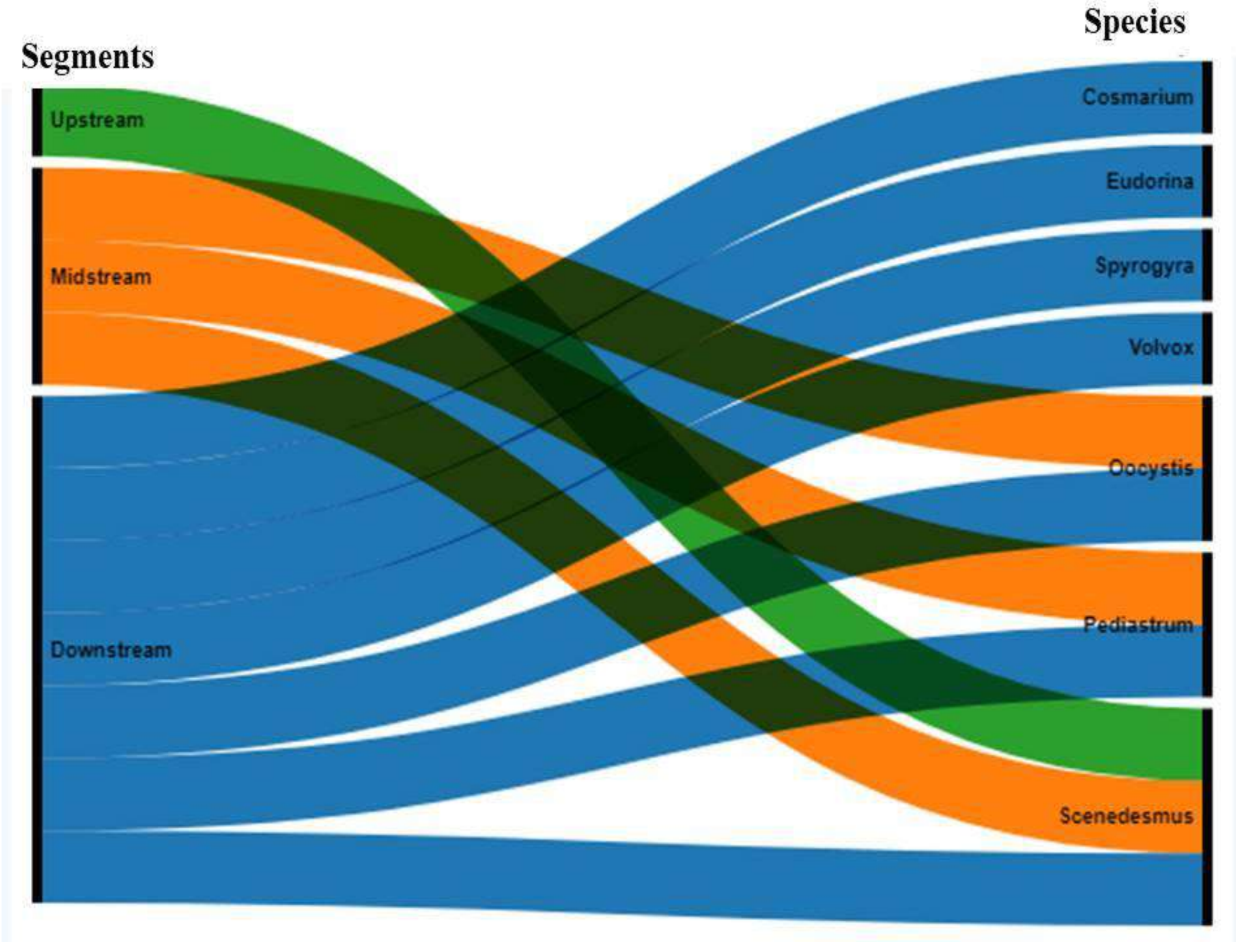

Figure 6. Sankey correlation diagrams of Chlorophyceae species abundances in upstream, midstream, and downstream of Krukut river, Jakarta city.

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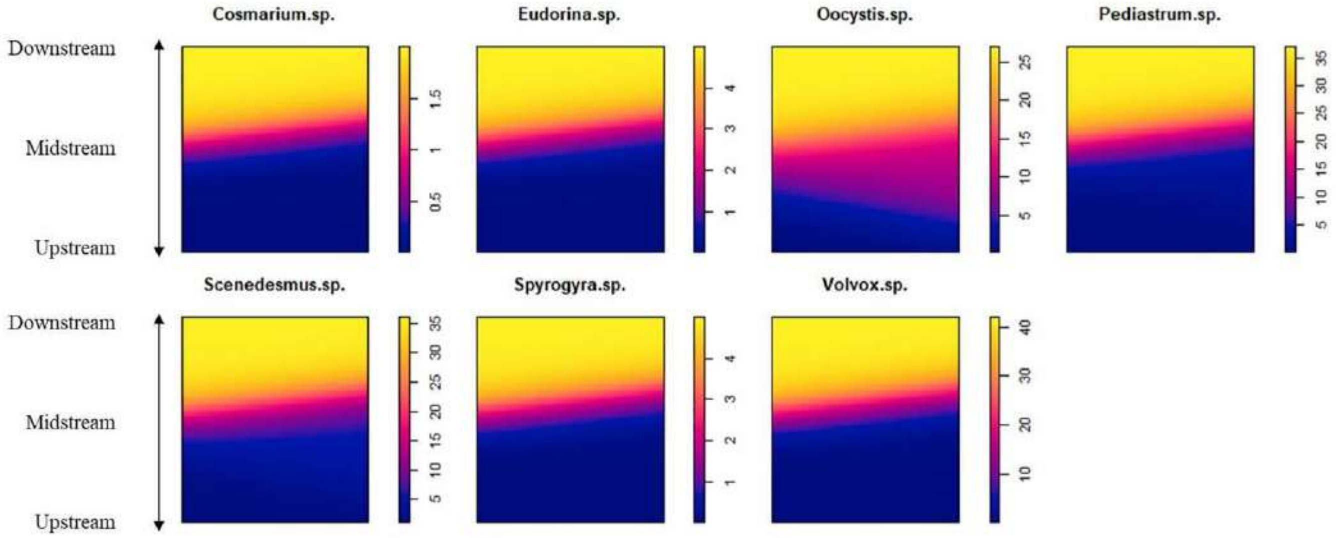

Figure 7. Cluster model of *Cosmarium* sp., *Eudorina* sp., *Oocystis* sp., *Pediastrum* sp., *Scenedesmus* sp., *Spirogyra* sp., and *Volvox* sp. in upstream, midstream, and downstream of Krukut river, Jakarta city

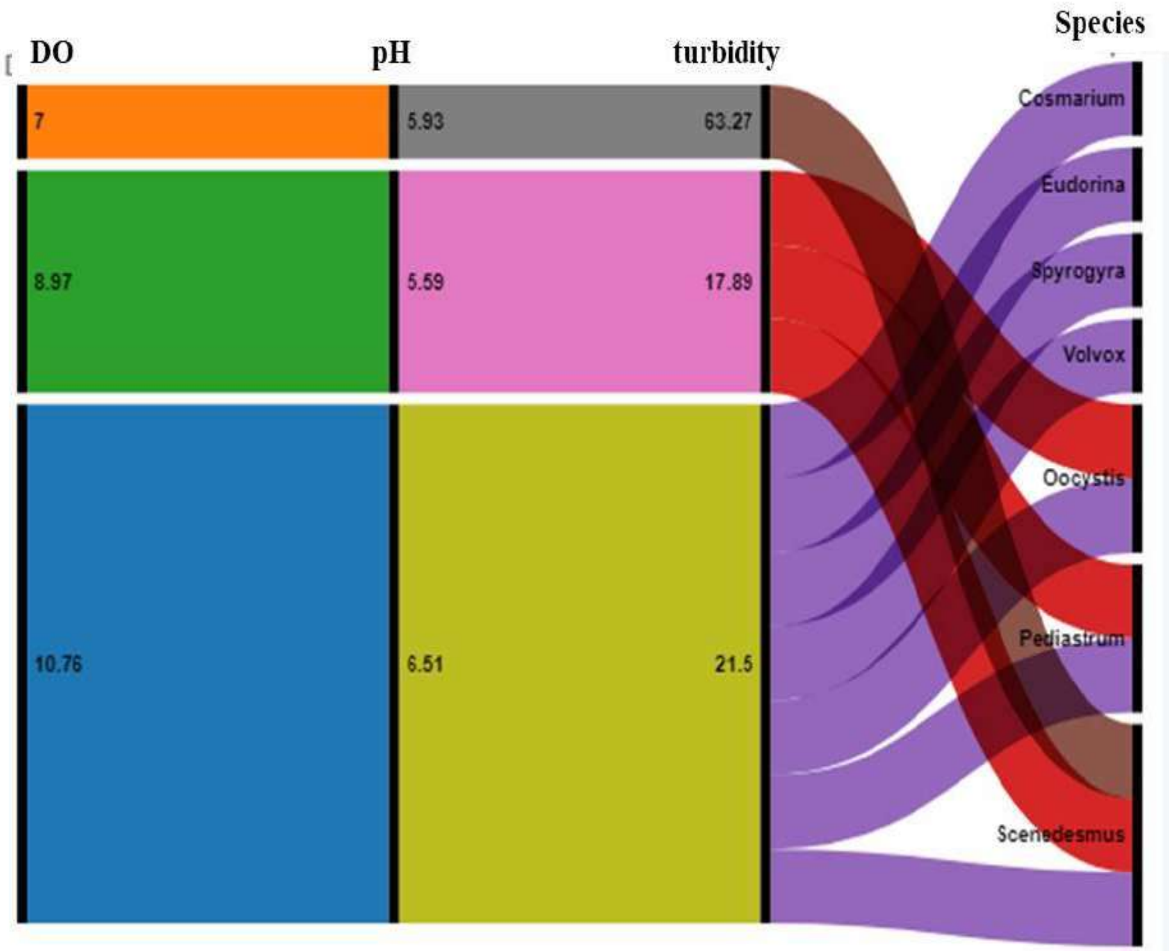

Figure 8. Sankey correlation diagrams of Chlorophyceae species abundances with water quality variables (DO, pH, turbidity) of Krukut river, Jakarta city

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3.3. *Markov chain model of Chlorophyceae distributions*

Figure 9 depicts the probabilities of Chlorophyceae in every state (downstream, midstream, and upstream) and the probabilities of transitions between states modeled using the Markov chain. There are two distribution patterns. First, some Chlorophyceae species are more likely to be distributed from midstream to downstream than from downstream to midstream and upstream. Those species were *Cosmarium* sp., *Eudorina* sp., *Spirogyra* sp., and *Volvox* sp., with probabilities of 25%, 31%, 31%, and 31%, respectively. This indicates that those species preferred the downstream segments more than the midstream and upstream segments. Low DO and murky water were limiting those species to occupying the midstream and upstream of the Krukut river. *Volvox* sp. has been observed growing in freshwater ecosystems with low turbidity and nutrient-rich water and in alkaline water with pH ranges of 7.3-7.5 [30]. The pH in midstream and upstream was acidic, with pH values of less than 7.

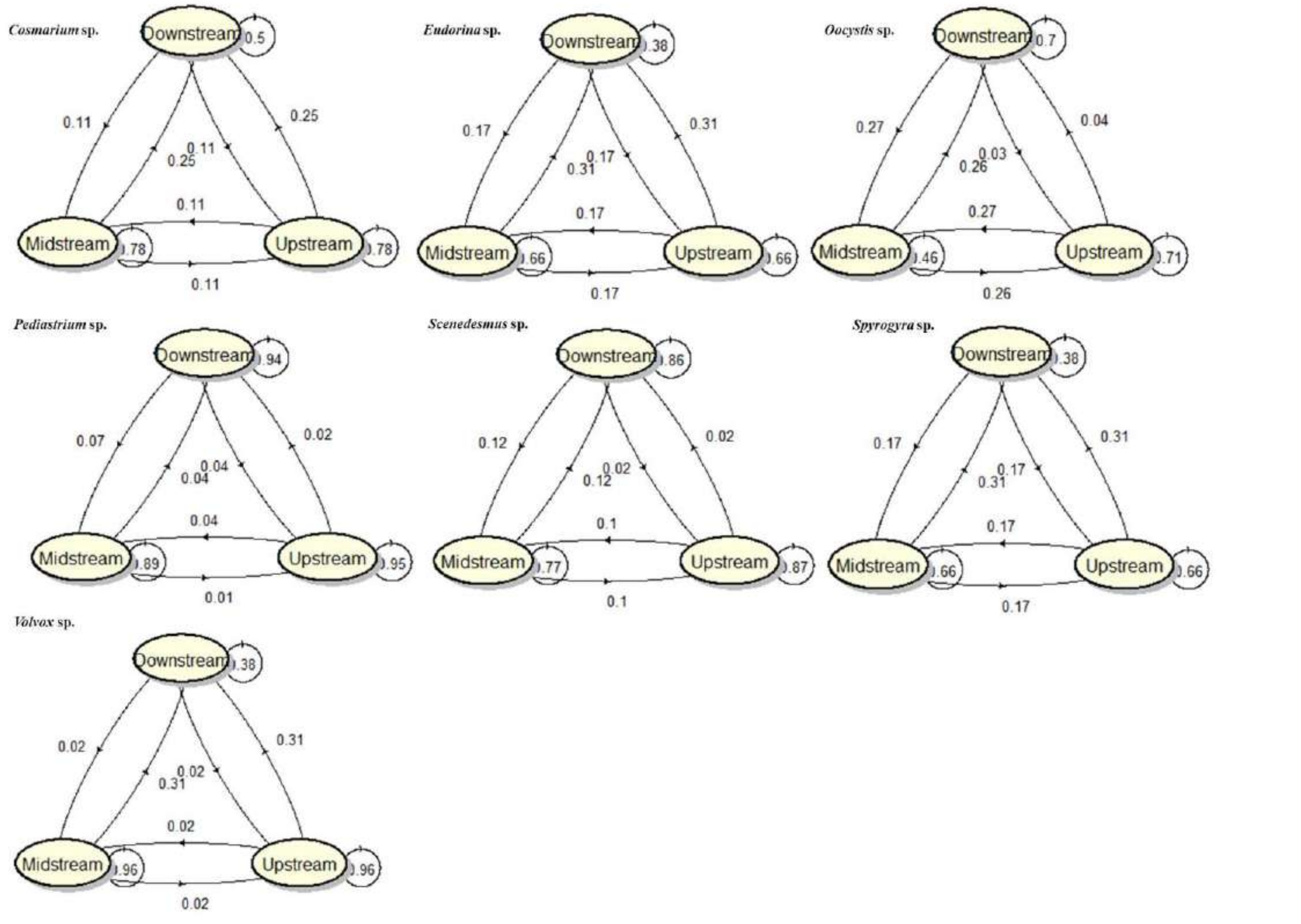

Figure 9. Markov chain model of Chlorophyceae distributions along streams of Krukut river. The numbers indicate the probabilities of Chlorophyceae in every state (downstream, midstream, upstream) and the probabilities of transitions between states

In contrast, there were species with high probabilities of inhabiting the midstream and downstream, whereas other Chlorophyceae species avoided this river segment. Those species with wide environmental tolerances are *Oocystis* sp., *Pediastrum* sp., and *Scenedesmus* sp. According to the Markov chain model, the probabilities of *Oocystis* sp., *Pediastrum* sp., and *Scenedesmus* sp. moving to polluted water are 27%, 7%, and 12%. It indicates that *Oocystis* sp. is the most tolerant species since this species has the highest probability of being found in polluted aquatic environments upstream. *Oocystis* is a common dominant species in subtropical aquatic environments and has a strong adaptability

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to environmental stress conditions [31, 32, 33]. In polluted water due to nutrient enrichment, *Oocystis* performs urea-based nitrogen removal in water. The presence and redistribution of *Oocystis* sp. in the polluted water upstream is due to nitrogen-rich water correlated with acidic water [34, 35]. This is considering that *Oocystis* sp. can consume and remove nitrogen [36, 37] from water that usually was available in the polluted water upstream surrounded by settlements.

4. Conclusions

In this study, we found a distinct segment characterizing the Krukut river. The downstream segment was characterized by clear, alkaline water and high DO. In contrast, the midstream and upstream have different environmental conditions than the downstream. This condition was also related to the presence of settlements nearby the Krukut river. There are 7 Chlorophyceae species observed in the Krukut river, with downstream segments being more diverse than midstream and upstream. *Cosmarium* sp., *Eudorina* sp., *Spirogyra* sp., and *Volvox* sp. are Chlorophyceae species with the limited spatial distribution. In contrast, *Oocystis* sp. is more tolerant toward polluted water in the Krukut river since this species is highly likely to be distributed from downstream to the midstream and upstream.

To the best of our knowledge, this study contributes to the conservation of aquatic ecosystems along with the plankton community. The progress of aquatic ecosystem conservation, particularly urban ecosystems, is dependent on information about still intact areas with fewer anthropogenic impacts. To conclude, this study has elaborated on the importance and potential of downstream river segments to be protected and conserved since these segments have high plankton diversity and better water quality than midstream and upstream segments.

Acknowledgements

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Analysis and Prediction of Water Balance Using Dynamic Modelling to Solve Water Scarcity in Cimahi

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Abstract

Cimahi is one of the most populated, fast-growing cities in Indonesia. Consequently, various environmental problems appear, primarily related to the sustainability of water resources. Exploitation and pollution of water, especially groundwater, are not accompanied by a good water conservation system that ensures proper water infiltration into the soil, causing several locations in the city to experience water deficits. The city may suffer a severe water shortage if this problem is unsolved. This study aims to predict and analyze the need and availability of water in Cimahi in the next few years to determine the right solution to deal with this problem. Analysis and prediction of water availability/needs were carried out by building a dynamic model using STELLA software for simulating the conditions in the next ten years. The results of the model were combined with the applicable spatial policies to formulate possible solutions. Results showed that Cimahi will experience a water crisis starting from 2029 with a total water deficit of 8.22 million M³. The model also predicted South Cimahi District is the area with the worst conditions where the water crisis has occurred since 2022 and peaked in 2029 with water sufficiency of only 59.83%. Based on local spatial planning laws and policies, the city's government is advised to improve its catchment area to protect its water resources. The vegetation cover area surrounding the catchment area can be improved, and water absorption capacity can be increased through civil technical actions such as building absorption wells. The model results showed that a proper solution could be done by expanding 142.8 Ha of green/vegetation cover, building 1576 units of absorption wells, and increasing the PDAM supply by 100 l/second.

Keywords: *water resources; dynamic model; vegetation cover; absorption wells*

1. Introduction

Water resources are one of the basic needs for human viability. Generally, a higher standard of living accompanies a more increased water need. But on the other hand, there is less than 0.5% of water on the earth's surface that humans can use directly [1]. Therefore, this valuable resource needs to be managed to ensure its utilization will continue sustainably used by humans.

In many large cities in Indonesia, such as Jakarta, Bandung, Surabaya, and others, hard-building construction is increasing rapidly, and a high population growth rate accompanies this. As a result, a significant amount of vegetation cover, especially in catchment areas, is continuously decreasing. It results in less water returning to the ground, plus the amount of water use and pollution continues to rise [2].

Cimahi City is one of the areas experiencing these problems. For the past few years, this city has suffered a significant loss of clean water supply [3]. Cimahi is predicted to have water supply resources of 46.71 million m³ per year, consisting of 33.10 million m³ of surface water and 13.61 million m³ of groundwater. However, the condition of groundwater utilization in Cimahi itself has been dominated by prone, critical to damaged zones, which cover 50.6% of the total area of groundwater utilization zones [3]. As a result, a water crisis occurred in several areas of Cimahi, e.g., Melong, Cibeureum, and Leuwigajah sub-districts. Furthermore, it is predicted that the city will experience a water crisis in 2030 if environmental issues cannot be appropriately managed [3].

Hence, this study aims to analyze factors affecting the availability and the needs of water (i.e., water balance) to predict its condition in the next few years with dynamic modeling as the basis for decision-making in preventing this water crisis disaster in Cimahi.

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2. Methodology

2.1. Study Area and Period

This study was conducted from February 2021 to December 2021 in three districts of Cimahi City, West Java, i.e., North Cimahi, Central Cimahi, and South Cimahi. Geographically, the study site location is at 6º50'-6º56' SL and 107º30'-107º34' EL.

2.2. Tools and Materials

This study utilized ArcMap 10.4 to analyze the land cover of Cimahi City, STELLA 9.0.2 to build and simulate a dynamic water availability/needs model, and Microsoft Excel 2019 to quantify and calculate all the variables needed. Secondary data used were climate data, water source and supply, biophysical conditions, socio-economic conditions, and satellite images obtained from the respective relevant institutions. See the complete list of data used in Table 1.

Table 1 Research Material and Data

Materials and Data	Source
Stakeholders Perspective	Dinas Lingkungan Hidup Kota Cimahi Dinas Perumahan dan Kawasan Permukiman Kota Cimahi Badan Pengelolaan dan Perencanaan Daerah Kota Cimahi
Precipitation Temperature Humidity Evapotranspiration	Badan Meteorologi Klimatologi dan Geofisika
Satellite Imagery	earthexplorer.usgs.gov
Land Slope Map	tanahair.indonesia.go.id/demnas
Soil Type Distribution Map	fao.org/land-water
Water Supply Capacity From Local Water Company (PDAM)	PDAM Tirta Raharja
River Discharge	Dinas Perumahan dan Kawasan Permukiman Kota Cimahi
Population Denseness Total Population Population Growth	Dinas Kependudukan dan Pencatatan Sipil Kota Cimahi
Economic Growth Number of Industries	Cimahi Dalam Angka Tahun 2021 (Badan Pusat Statistik)
Local Spatial Regulation and Policies	Perda Kota Cimahi No. 4 Tahun 2013 Tentang Rencana Tata Ruang Wilayah Kota Cimahi

2.3. Model Prediction of Water Availability and Water Needs

First, a preliminary analysis involving the prediction of actual land cover conditions in Cimahi was done to calculate the total water absorption potential of Cimahi City as one of the variables in the following model. Land cover analysis was carried out by interpreting satellite images of Cimahi City (year 2021) using ArcMap 10.4. Satellite images were interpreted by color patterns, e.g., the hue, textures, pattern size, shape, shadow, and object location compared to other objects [4]. Land cover types were classified based on SNI-7465-2010 (Classification of Land Cover & Land Use at a scale of 1:50,000). To simplify the process and variables included in the model, land cover classification was reduced to three classes: built-up land, open land, and vegetated land.

The next step is calculating the potential water absorption in Cimahi City area. The analysis of the water absorption potential of Cimahi City was calculated based on the water absorption formula developed by Ffolliot with the following Eq. (1) [5];

$$R = (P - Et)\ x\ Ai(Ca) \quad (1)$$

Where :

R = Volume of absorbed water (m^3/year)

P = Annual precipitation (mm)

Et = Annual evapotranspiration (mm)

Ai = Area of each land cover (m^2)

Ca = Absorption coefficient of each land cover types (Ca = 1 – surface run-off coefficient)

Table 2 shows the surface runoff coefficient, which is used as a reference to find the absorption coefficient value in each type of land cover.

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Table 2 Coefficient of Surface Runoff for Different Types of Land Cover

Land Cover	C Value (%)
Tropical Forest	<3
Production Forest	5
Shrubs	7
Paddy Fields	15
Fields	40
Settlement	70
Roadway	95
Dense Building	70-90
Scattered Building	30-70
Roof	70-90
Dirt Road	13-50
Parks or Yard	5-25
Open Land	10-30
Other Plantation	0-20

Two models were constructed to predict the need and availability of water in Cimahi for the next ten years. Each model covered each sub-district in Cimahi based on biophysical and socio-economic conditions, resulting in a total of 6 models. In general, water availability is influenced by several factors, e.g., water absorption potential, groundwater potential, river discharge, type of land cover, and supply capacity of local water companies (namely PDAM). Meanwhile, water needs are influenced by the number of industries, economic growth, population, water use per capita, and population growth rate. A causal-loop diagram was formulated for the model prediction (Figure 1).

2.4. Assumption and Research Limitations

The assumptions used to limit the scope of the model include the following:

1. The system is assumed to be closed. Cimahi residents obtain water from their territory; the surplus water remains and is used by the city.
2. All vegetation is assumed to have the same ability of water absorption.
3. There is no flood when the water is exceptionally surplus because only the minimum discharge is used in the model.
4. There are no differences in the amount of precipitation during the rainy or dry season as the model used an annual rainfall.
5. Bottled water supply is not included in the model.
6. The entire population uses the same amount of water every year.
7. There is no (or minor) change in land cover in the city for the next ten years.

2.5. Formulating the Solution for Water Scarcity in Cimahi

In formulating solutions to water shortages in the coming year, a descriptive analysis was carried out by considering, i.e., prediction results of water availability and water needs, perception of relevant stakeholders, and every policy related to the applicable spatial management in Cimahi City.

3. Results and Discussion

3.1. Land Cover Conditions

Land cover analysis of Cimahi in 2021 showed that Cimahi was mostly covered by built-up land (3179.3 Ha), followed by open-spaced land (386.7 Ha), and vegetated land (386.52) Ha. A complete land cover map and detailed information on the area of each land cover are presented in Figure 2 and Table 3.

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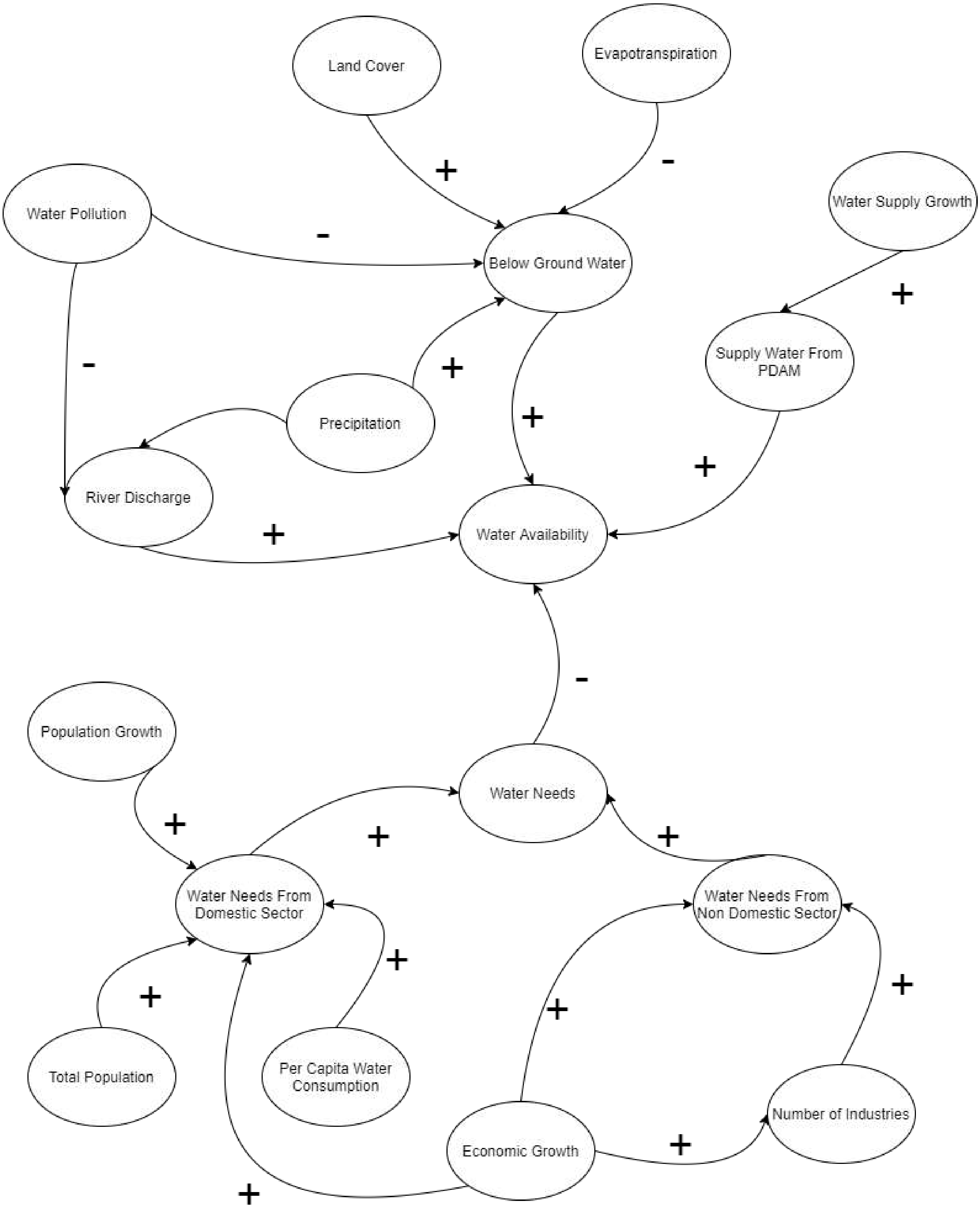

Figure 1 Causal-loop Diagram of Model Prediction of Water Needs and Availability

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Table 3 Area of Each Land Cover in Cimahi in 2021

District	Land Cover	Total Area (Ha)
North Cimahi	Vegetated Land	179.61
	Open Land	224.15
	Build-up Land	952.34
Central Cimahi	Vegetated Land	34.52
	Open Land	89.80
	Build-up Land	964.99
South Cimahi	Vegetated Land	124.68
	Open Land	146.17
	Build-up Land	1,326.69

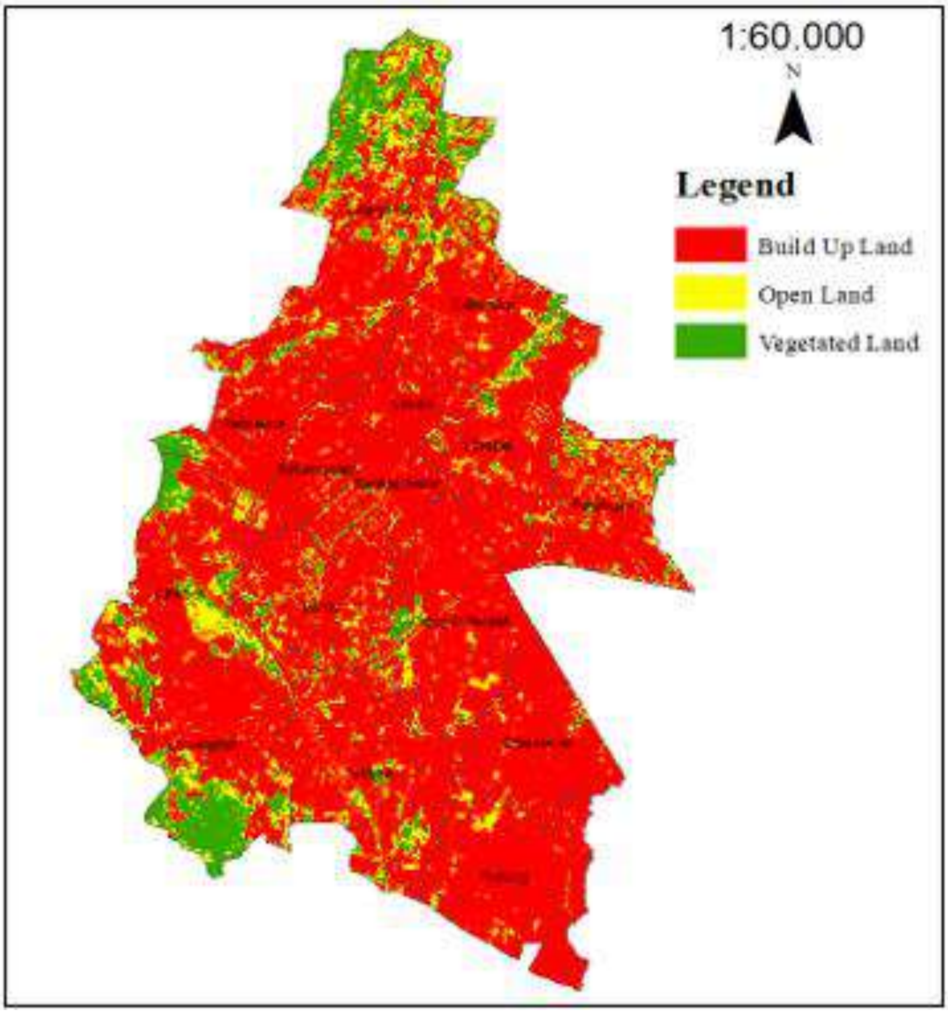

Figure 2 Land Cover of Cimahi City in 2021

Although this city seems to have been mainly occupied with built-up land, the increment rate of built-up land is relatively slow (5.78% in the last four years) compared to land cover conditions in 2017. A possible explanation is that Cimahi City used to be filled with buildings even since this area was not confirmed as a separate city in 2001 by Indonesia's government. However, the increment of built-up land is currently underway and threatens other land covers, especially vegetated land. The highest increment rate of built-up land from 2017-2021 occurred in South Cimahi District (2.83%), followed by Central Cimahi (1.15%), and North Cimahi (0.044%). Several factors cause the development of

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the built-up land area, e.g., population growth rate, land slope, and land availability surrounding roads and settlements [6].

The vegetated land area in Cimahi City is dominated by agricultural areas, such as fields, rice fields, shrubs, and other plantations. There is no forest in this city since there is no particular area appointed and stipulated as a forest area by the Indonesian Government (KLHK) in this city [7]. Compared with land cover conditions in 2017, the development of vegetated land in Cimahi City has generally decreased, even in small amounts. The reduction of Cimahi vegetated area occurred by 1.54% within four years. In contrast, there was an increase in vegetated land area in South Cimahi District (15.13%) and Central Cimahi District (3.68%). The main driver of overall vegetation land reduction in Cimahi is the area reduction in North Cimahi District (20.34%); thus, this district requires more attention concerning the problem.

On open land in Cimahi, the land cover has decreased in the area from 2017-2021. The reduction occurred in Central Cimahi by 3.24% and South Cimahi by 26.45%. In contrast, North Cimahi experienced an increment of its open land area by 9.53%. The loss of vegetated land cover into open land will undoubtedly affect the response to rain, such as increasing runoff and reducing the amount of water absorbed [8]. The results of this land cover analysis will become one of the input variables in the prediction model of water demand and availability. Simulation results will be discussed in the next point.

3.2. Model Simulation

North Cimahi District has water availability that is constantly above its needs (Figure 3). Thus, this area has always fulfilled its water needs, at least until the predicted year (2031). Even though the water needs in North Cimahi water increased annually, the rate is relatively insignificant. The water needs in 2021 were 10.07 million cubic meters and grew to 10.55 million cubic meters in 2031, meaning that the water demand will only increase by around 4.5% in ten years. This relatively low increment rate is probably since most water users in North Cimahi are from the domestic sector, such as household needs, irrigation, agriculture, or plantations. Meanwhile, water demand from the non-domestic sector only slightly affects the overall water needs. Indeed there are only a small number of medium to large industries in this sub-district since the designated land use is a catchment area and a low-density residential center [9].

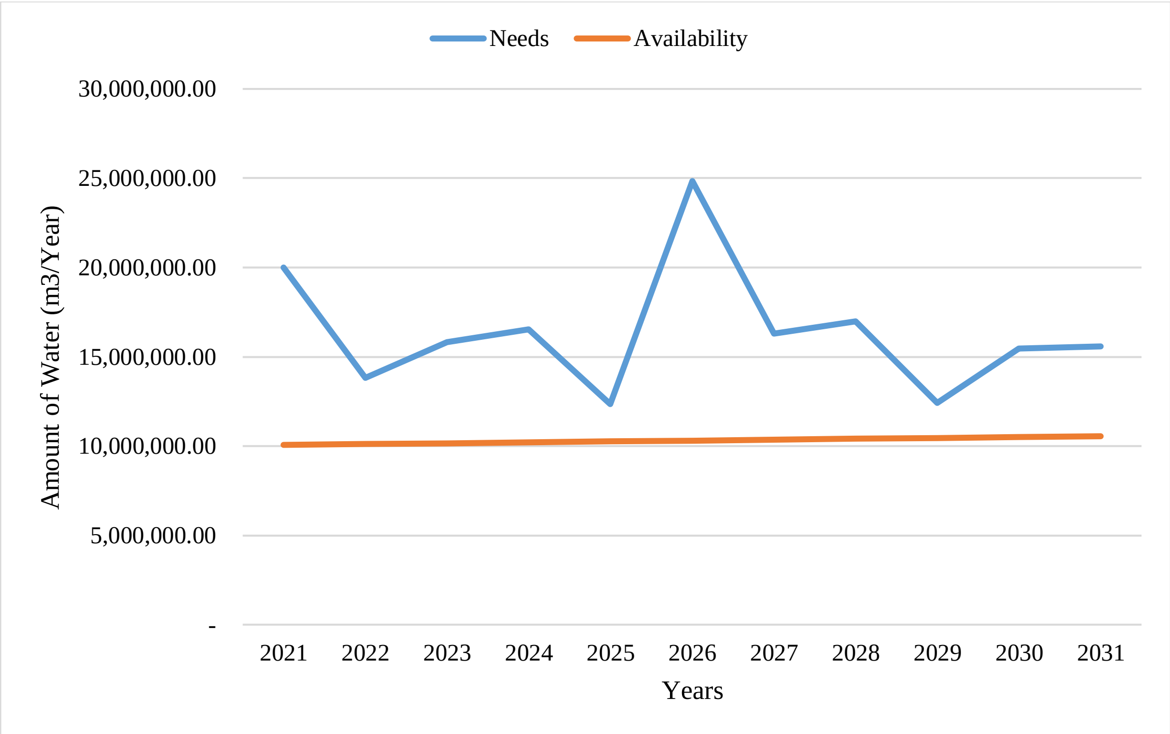

Figure 3 Graph of Water Needs and Availability in North Cimahi in 2021-2031

In contrast to the water needs, water availability in North Cimahi tend to fluctuate. The total water supply reaches 19.98 million cubic meters, or about 98% more than its needs in 2021. The water supply continues to increase and reaches its peak in 2026 with 24.84 million cubic meters, a surplus of up to 141% of the water needed. The fluctuation in the value of water availability in North Cimahi is greatly influenced by the water supply from river discharge sources. Factors that affect the river discharge amount include land slope, soil type, land cover, and rainfall [10]. The surplus in water availability in

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North Cimahi is logical since it functions as an area that supplies water for others surrounding it at a lower altitude [11].

The simulation result showed that water demand in Central Cimahi sub-district is similar to that of North Cimahi (Figure 4). However, the increase in the water needs rate in this district is not significant. In 2021, the water demand in Central Cimahi will reach 12.11 million cubic meters and will only increase by 1.8% until 2031 or by 12.34 million cubic meters. Its densely populated settlements and buildings in this area possibly contribute to the low increase. Indeed based on secondary data gathered, there were only a few medium to large industries and agricultural land/fields in this area, meaning that the household demand mainly influences the water demand. Fortunately, the water availability in Central Cimahi is sufficient, at least until 2028. However, water shortage is predicted to occur starting from 2029, when water sufficiency is only around 83-89%. One of the reasons for this lack of water availability is the increasing pressure on vegetated areas that can absorb water. The Central Cimahi area is densely populated with many settlements, buildings and a lack of vegetated areas. Do note that the water available here is limited to the ones obtained from the Central Cimahi area. Therefore, should a water shortage happen, the problem can be solved by securing water supplies from North Cimahi.

The model prediction showed a significant increase in water demand in the South Cimahi district (Figure 5) compared to the other districts. The water demand in 2021 reaches 20.37 million cubic meters and will increase by 10.5% to 22.78 million cubic meters in the next ten years. The large amount of water demand in South Cimahi is influenced by the needs of the domestic and non-domestic sectors. This district has the highest population and medium to large industrial numbers in Cimahi City. Unfortunately, the high water demand is not accompanied by the availability of adequate water. Based on the model, this area is predicted to experience a water shortage from 2022, reaching its peak in 2029 with only 13.32 million cubic meters available (60% of the water needs). But in 2026-2028, the model predicts that this region will still experience a little water surplus (2-10%). The insufficient water supply in this area is caused primarily by increasingly critical and damaged catchment areas. In addition, most industrial activities utilize excessive groundwater in this area, making the water supply more critical.

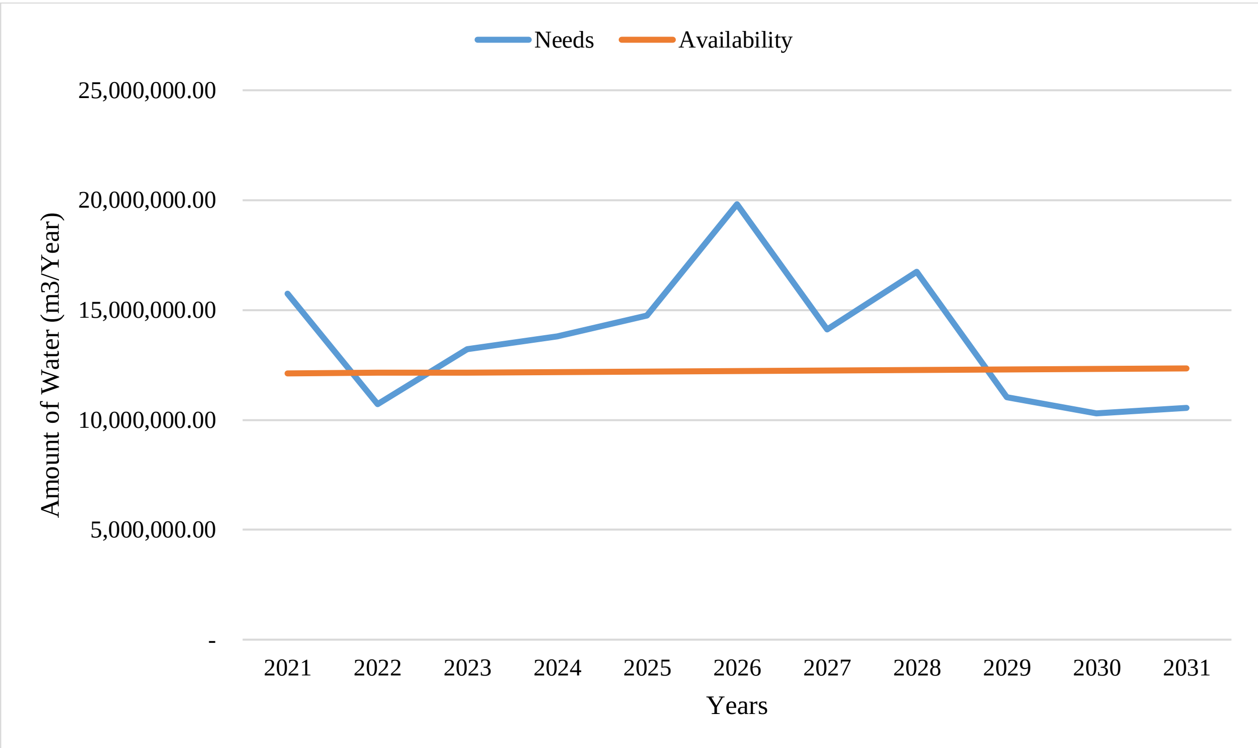

Figure 4 Graph of Water Needs and Availability in Central Cimahi in 2021-2031

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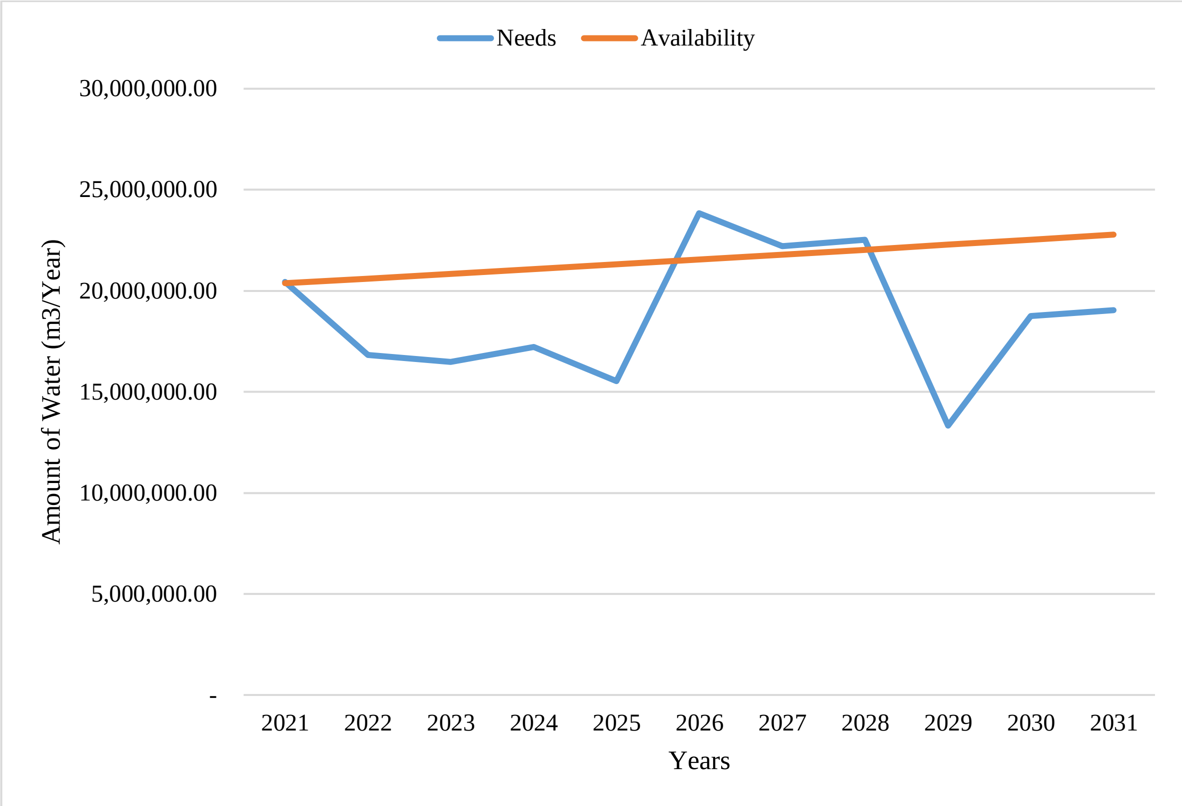

Figure 5 Graph of Water Needs and Availability in South Cimahi in 2021-2031

The previous explanation discusses the water availability and demand condition in each district without considering the input of excess water from certain districts. Figure 6 shows the accumulation and the difference between water demand and availability in Cimahi when excess water in each district is distributed to other areas lacking water. The model predicted that Cimahi will experience a water shortage in 2022, 2025, and from 2029 onwards, with a maximum need of 8.22 million cubic meters in 2029. Meanwhile, the maximum excess water will occur in 2026, up to 24.4 million cubic meters. The duration of surplus years is relatively longer than deficit years. Although not extreme, the predicted water shortage should be the government's primary concern because, without proper handling, these shortages will continue to occur in the following years.

3.3. Problem Solution

The predicted water shortages in the future are strongly influenced by the decrease in vegetation, damaging the catchment area. For this reason, improving the catchment area is a top priority in solving this water shortage. The vegetated areas of Cimahi need to be increased to maintain hydrological functions [8]. Based on regulations and policies related to spatial management in Cimahi, the improvement of this catchment area is prioritized by revitalizing or reforesting the catchment area in the North and South Cimahi districts. However, adding vegetated areas is not always feasible since the space available is limited. Therefore, improving the catchment area condition in Cimahi needs to be considered as an alternative solution to fulfill water needs in this city. From the perspective of the relevant stakeholders, another available solution is to create a rainwater infiltration system by artificially facilitating rainfall to enter the ground, for example, through absorption wells. This method can be prioritized for residential areas due to its high efficiency and minimal adverse impact without relocating the residents' settlements [12]. In addition, increasing the water supply from local water companies (PDAM) can also be considered a short-term solution.

The model simulation results found that the maximum water shortage in Cimahi occurred in 2029 with an 8.22 million cubic meters deficit. The amount of required vegetation area suggested by the model is 355 hectares. Unfortunately, only 142.8 Ha of land is available for planting vegetation in Cimahi, covering most of the North and South Cimahi areas [3]. Likely, water shortages will still occur if we only rely on this solution. Interviews with several relevant stakeholders reveal that the additional water supply provided by the water company cannot cover the predicted water shortage. The reason being the potential for additional water supply is only 100 l/second, which can only provide 7.78% of water needs in 2021. Thus, the application of absorption well

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as an alternative solution is crucial. An absorption well with a depth of 2.1 meters and a diameter of 1 meter has an average water absorption capacity of 2.43 m³/day [12]. With this assumption, 1576 units of absorption wells will be needed to fulfill the target.

The comparison of simulation before and after implementing the solutions above showed a positive outcome where water availability will be sufficient for Cimahi City until 2031 (Figure 7). By implementing the solution, annual water availability can be increased by up to 34.2%.

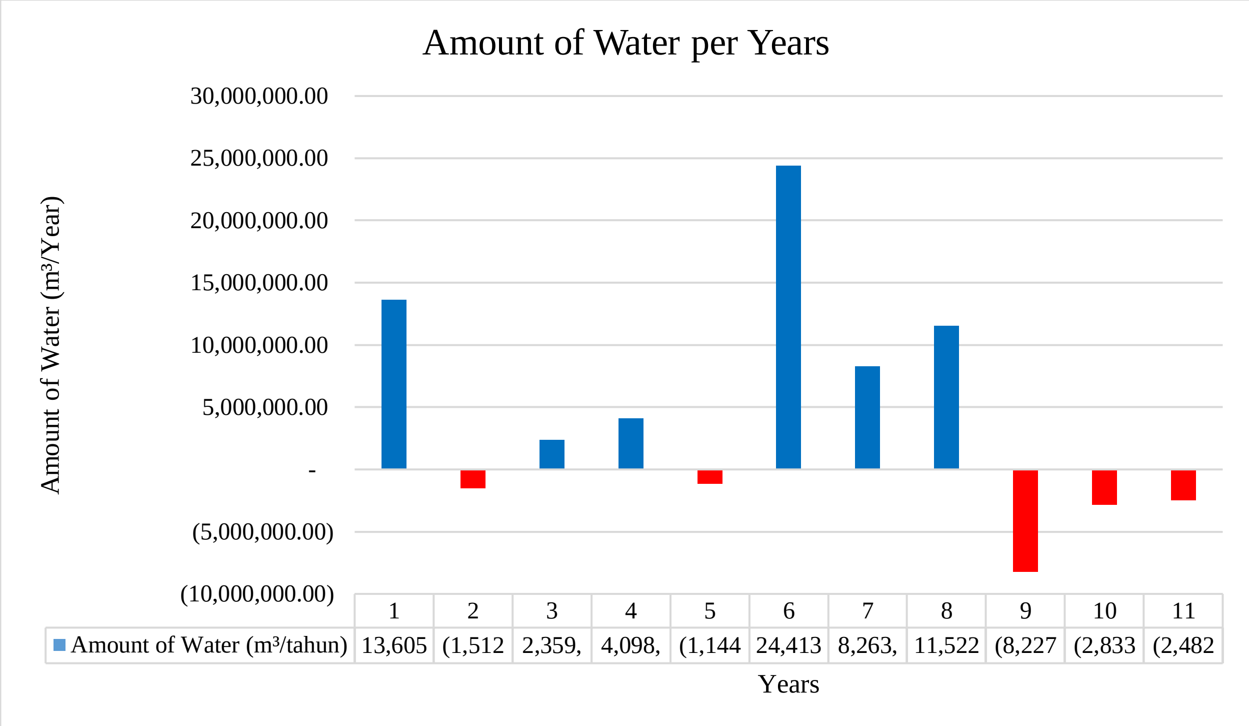

Figure 6 Graph of The Accumulation and The Difference Between the Water Needs and Availability in Cimahi 2021-2031

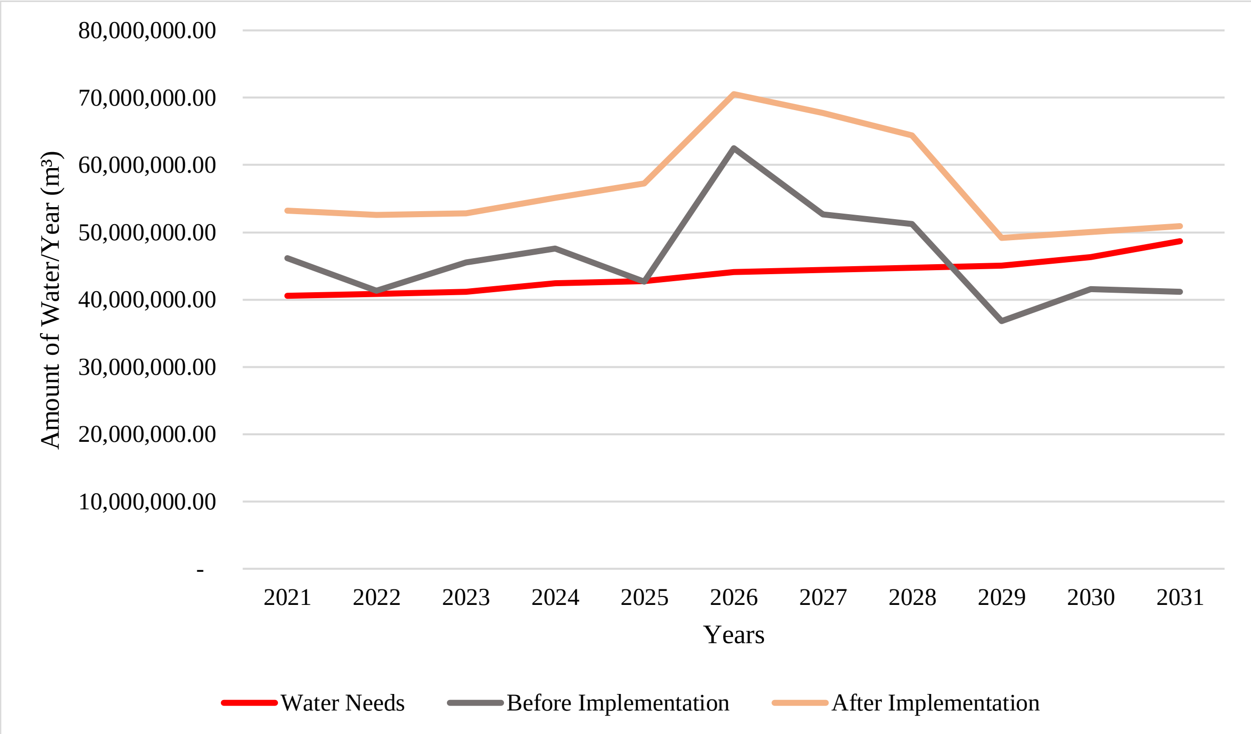

Figure 7 Comparison of The Simulation Results Before and After The Implementation of The Solutions

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4. Conclusions

Based on the results of this study, several conclusions can be drawn, i.e.,

1. The simulation results show that Cimahi will experience water scarcity starting in 2029, with the highest water shortage reaching 8.22 million m³. The worst water scarcity occurs in South Cimahi District, where water shortages start in 2022, with an average water sufficiency of only 60%. This shortage is caused by the increasingly critical catchment area exacerbated by excessive groundwater exploitation. In contrast, conditions in North Cimahi are the most ideal, where there is no water shortage, at least until 2031.
2. The solutions proposed to fulfill the water needs in Cimahi until 2031 are by adding 142.8 hectares of vegetated areas of in North and South Cimahi, increasing the number of absorption wells by 1576 units, and increasing the water supply capacity of regional water companies by 100 liters/second.

Acknowledgements

The authors thanked the stakeholders, including the speakers from Dinas Lingkungan Hidup Kota Cimahi, Dinas Perumahan dan Kawasan Permukiman Kota Cimahi, and Badan Perencanaan dan Pembangunan Daerah Kota Cimahi along with related field technical personnel, that have contributed to the survey and collection of data.

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Community Dependency and Vulnerability to Natural Resources: Case Study Mount Geulis University Forest

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Abstract

Mount Geulis University Forest (MGUF) is a university forest area surrounded by eight villages and has close relationships with the surrounding community. With a very strategic position, MGUF is vulnerable to various pressures, especially anthropogenic ones. Other studies have shown that population, development, and the economy have an essential role in environmental degradation. Thus, understanding these three things becomes essential to determine the right strategy to reduce the level of vulnerability around MGUF. This study aims to analyze the level of community dependency on MGUF and the level of vulnerability of the community around MGUF. Community dependency was analyzed using perceived value dependency on livelihood, perceived value dependency on income, and perceived value dependency on participation level. Community vulnerability was analyzed based on the population growth index, built-up land index, and economic openness index. The results showed that the farmer community had a relatively high dependency on MGUF. The lower the income, the higher the dependency on MGUF, and the participation rate increases as the dependency on MGUF increases. Raharja Village has the highest population growth index of 123.75, Mangunarga Village has the highest built-up land index with a value of 75.11, and Jatimukti Village has the highest economic openness index with a value of 33.52. In general, the village with the highest composite vulnerability index is Cikahuripan Village, with a value of 0.71, and the lowest is Jatiroke, with a value of 0.20. Based on the value of the vulnerability index and the level of security, the level of vulnerability can be reduced by carrying out collaborative management to run programs with every stakeholder in the MGUF management system.

Keywords: *Community dependency, community vulnerability, population growth, built-up land, economic openness*

1. Introduction

Mount Geulis University Forest (MGUF) is one of 16 Special Purpose Forest Areas (SPFA) whose management is given to universities by the government, with a total area of 338.31 hectares. MGUF is a protected area within the administrative boundaries of eight villages and three sub-districts, so MGUF has a very close relationship with the surrounding community. This close relationship can be seen from several aspects. From an economic perspective, people are still working on land for agricultural commodities in the MGUF area [1]. MGUF is a community liaison from a social perspective, mainly through the Forest Farmers Group (FFG). The community needs MGUF ecosystem services as a water provider in terms of the environment.

MGUF's strategic position causes various pressures to threaten MGUF, mainly anthropogenic pressure. Multiple studies suggest that population problems cause half or more of deforestation in the world [2]. The area of agricultural land in the MGUF area is quite extensive. Agricultural land created to cross the boundaries of protected areas will impact ecological functions in the long term [3]. In addition to agricultural land, settlements are overgrowing around the MGUF to press the slopes. Increased anthropogenic pressure that is not accompanied by adequate planning and improper land use can trigger landslides [4].

Only 79.65% of community members in areas surrounding MGUF graduated from elementary-junior high school [1]. Their income is low [5], with their main livelihoods dominated by entrepreneurs and laborers. Other common occupations are traders and farmers [5]. The low education level in a large population, such as the ones in

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MGUF, is the cause of the lack of innovation performance [6]. This condition causes communities around MGUF to depend on ecosystem services and resources from MGUF. In addition, the lack of academic qualifications is an essential determinant of people's vulnerability [7].

Conditions related to population, development, and economy around the MGUF community contribute to the MGUF system's vulnerability to external pressures. It is crucial to understand and measure the level of dependency and vulnerability to reduce the vulnerability level of the community around the MGUF. In determining the level of dependency, data related to income, livelihoods, and community participation [8] related to MGUF are needed. Furthermore, analyses of population growth, degradation of built-up land, and economic openness [8] around the MGUF are also required. This study aims to analyze the level of community dependency and vulnerability of the community around the MGUF.

2. Methodology

2.1. Time and Location

This research was conducted from January to May 2021 at MGUF, Sumedang, West Java (Figure 1). MGUF is located in three sub-districts, i.e., Tanjungsari, Jatinangor, and Cimanggung, Sumedang Regency, West Java Province. Specifically, MGUF is surrounded by eight villages, namely Jatiroke Village, Jatimukti Village, Cisempur Village, Mangunarga Village, Sawahdadap Village, Cikahuripan Village, Raharja Village, and Cinanjung Village. This research was conducted in three stages, i.e., a preliminary survey, data collection, and data analysis. The preliminary survey was carried out from November 2021 to January 2022, while data collection for both community dependency and community vulnerability was carried out from February to April 2022.

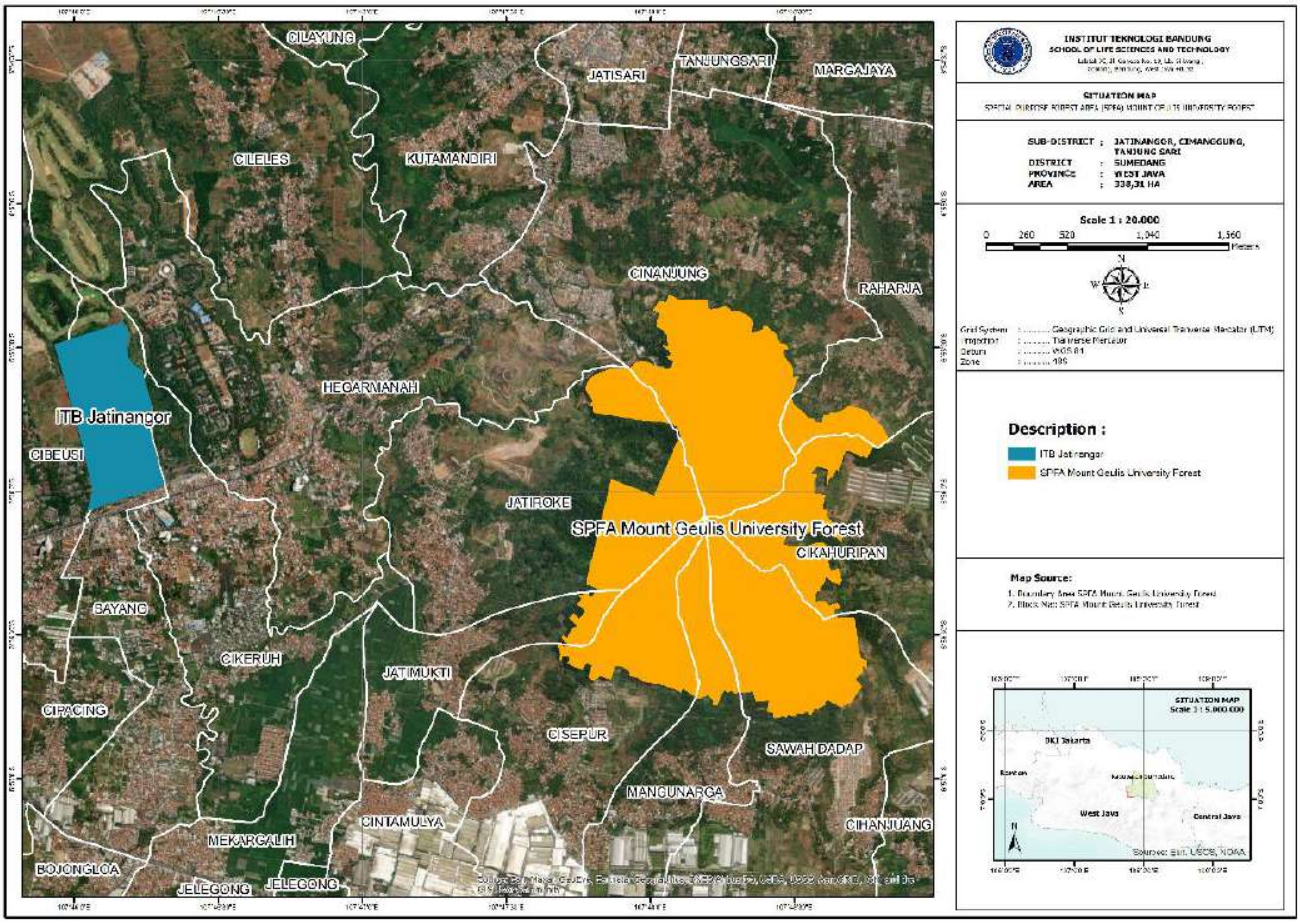

Figure 1. The location of Mount Geulis University Forest

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2.2. Data Collection

2.2.1. Community Dependency

The level of community dependency on MGUF in this study was measured using several variables, i.e., perceived value dependency on livelihoods, perceived value dependency on community income, and perceived value dependency on community participation [8]. These data are obtained by taking data directly (primary data). Data collection was carried out by stratified random sampling of people in eight villages. The eight sample areas were determined by purposive sampling based on the villages owning land within the MGUF area, namely Cisempur Village, Mangunarga Village, Sawahdadap Village, Cikahuripan Village, Raharja Village, Cinanjung Village, Jatiroke Village, and Jatimukti Village. Data were collected by filling out questionnaires by researchers related to the results of structured interviews with the community. The number of samples is 100 people. The number of samples is determined based on the following formula [9]:

$$n = \frac{N}{Ne^2 + 1}$$

n : sample size
N : population size
e : percent allowance for inaccuracy due to tolerable or desirable sampling errors

2.2.2. Community Vulnerability

The variables used in measuring the level of community vulnerability in this study were the population growth index, the built-up land index, and the economic openness index [8]. The population growth index used secondary data, population data sourced from BPS and the official website of the Sumedang Regency Government, and village area data sourced from the Geospatial Information Agency (BIG). The built-up land index uses primary data, field baselines for validation taken at random points for each village, and secondary data, Landsat 8 imagery, sourced from Google Earth Engine. As for the economic openness index, secondary data was used, i.e., population and percentage of the working population sourced from BPS and the official website of the Sumedang Regency Government; Gross Regional Domestic Product (GRDP) and total trade value, sourced from BPS.

2.3. Data Analysis

2.3.1. Community Dependency

The primary data on community dependency on MGUF were subjected to descriptive analysis. This method was employed so that problems and ways of working that apply in society (e.g., relationships, activities, and attitudes) to the influence of a phenomenon can be clearly described [10]. After the data on perceived value dependency on livelihoods, community income levels, and community participation levels were obtained, they were visualized as a bar graph (dependency of livelihoods) and point graphs (dependency of the community's income level and the level of community participation).

2.3.2. Population Growth Index

The Population Growth Index represents a measure of the pressure of the population on the environment at a specific time [10]. The population calculated in this study is the population of each village that administratively surrounds the MGUF. The Population Growth Index calculation uses the formula [10].

$$PP_{it} = \left\{ \left(\frac{AP_{it}}{50} \right) x \left(\frac{Trend_{i,t-l}}{2} \right) \right\}$$

PP_{it} : population pressure of village *i* in year *t*
AP_{it} : average population per km^2 of village *i* in year *t*
$Trend_{i,t-l}$: population growth per year in village *i*

2.3.3. Built-up Land Index

The built-up land index represents the level of land degradation caused by anthropogenic activities, especially activities related to the construction of settlements or other facilities [10]. The built-up land index was calculated in each village surrounding the MGUF. The built-up land index was calculated using the following formula [10].

$$BL_i = \left(\frac{BA_i}{VA_i} \right) x\ 100$$

BL : built-up land index (%)
BA : built-up area (km^2)
VA : village area (km^2)
i : village name

CART was applied to divide the image into forest and built-up classes. The classification results are then verified through an accuracy test using one algorithm for the and direct observation. The algorithm used for the accuracy test is random forest. Random forest is a classification algorithm consisting of a combination of classification trees. Each classification is generated using a random vector sampled independently of the input vector. Each tree votes for the most popular class for classifying the input vector [11]. Meanwhile, direct observation is carried out by comparing the classification results with field observations. Then the

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confusion matrix is used to get the overall accuracy and kappa coefficient values.

2.3.4. Economic Openness Index

The economic openness index in this study is calculated using the total value of trade in village *i* to the total GRDP of village *i* at time *t*. The following is the formula for the economic openness index [10].

$$EO_{it} = \left(\frac{TV_{it}}{2GRDP_{it}}\right) x\ 100$$

EO_{it} : economic openness index of village *i* in year *t*
TV_{it} : trading value of village i in year t
$GRDP_{it}$: Gross Regional Domestic Product of village *i* in year *t*

The value of the village GRDP is obtained from the estimated GRDP of each sub-district. The GRDP of each sub-district is obtained from estimates based on the GRDP of the Sumedang Regency. The following is a formula for estimating sub-district and village GRDP.

$$GRDP_{sub-districts} = \frac{WP_{sub-districts}}{100}\ x\ PDRB_{districts}$$
$$GRDP_{village} = \frac{WP_{village}}{100}\ x\ GRDP_{sub-districts}$$

WP : workers percentage from sub-district/village in district/sub-district
GRDP : Gross Regional Domestic Product

2.3.5. Community Vulnerability

After all variables from the vulnerability index have been obtained, standardization is carried out on all these variables so that the units used are the same and there is no bias when measuring the vulnerability index. The following is a standardized formula for each vulnerability index [12].

$$SV_{ij} = \frac{X_{ij} - Min\ X_j}{Max\ X_j - Min\ X_j}, 0 \le SV_{ij} \le 1$$

SV_{ij} : standardized variable *j* of village *i*
X_{ij} : variable value *j* of village *i*
Min X_j : the minimum value of variable *j* for all villages in the index
Max X_j : the maximum value of variable j for all villages in the index
j : PP, BL, and EO

This vulnerability index is represented by the Composite Vulnerability Index (CVI), which ranges from 0 to 1 [12]. The closer the CVI value is to 0, the lower the level of vulnerability, while the closer the CVI is to 1, the higher the level of vulnerability. The following is the formula for the adjusted CVI [12].

$$CVI_i = (EO_i\ x\ 0.4) + (BL_i\ x\ 0.3) + (PP_i\ x\ 0.3)$$

CVI_i : the composite vulnerability index value of village *i*
EO_i : the economic openness index value of village *i*
BL_i : the built-up land index value of village *i*
PP_i : the population pressure index value of *i*

3. Results and Discussion

3.1. Community Dependency

The questionnaire results distributed to the community of eight villages around the MGUF (Figure 2) show that farmers' livelihoods are in a fairly high dependency category, while breeders are in a low category but tend to be relatively high. Farmers' dependency condition is because many feel they need arable land in the MGUF area. After all, they do not have arable land outside the MGUF area, while breeders tend to be relatively high because many breeders need feed from the MGUF area for their livestock, such as honey bee breeders and goat or cattle breeders. This condition follows the opinion of other studies that forests and other environmental products are precious for marginal communities who live around them [14].

The questionnaire results obtained show that the livelihoods around the MGUF can be grouped into two categories, i.e., natural resource-based livelihoods and non-natural resource-based livelihoods. Four main ecosystem functions are related to the dependency on community livelihoods [13], i.e., services that provide products from ecosystems (e.g., providing fruit), life support services (e.g., carrying out the photosynthesis process), life regulatory services (e.g., carrying out the decomposition process), and cultural or cultural services (e.g., recreational facilities).

Various ecosystem services provided by MGUF can be used as a source of livelihood, mainly providing services. Farmers commonly use ecosystem services to produce several products, such as coffee and papaya. The condition in the community around the MGUF is that the land cultivated outside the MGUF area is decreasing over time. The main driver of this condition is the people selling their land to companies around the MGUF. Thus, the community is looking for alternative livelihoods to maintain their lives, including switching from breeders, and traders, to construction workers. The relationship between the level of community's dependency on the MGUF on their livelihoods is presented in Figure 2.

Livelihood is also related to income. Therefore the influence or relationship between community dependency on income is necessary to identify the right target for managing

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people with certain income classes. The relationship between dependency and income level can be seen in Figure 3.

Results showed that the higher the income level of the community, the lower the dependency on MGUF, or there is a negative relationship between the level of community dependency and income (Figure 3). People with low-income levels are dominated by farmers, laborers, and traders. However, some farmers feel they are not very dependent on the MGUF because they have never worked on land within the MGUF area. Similar condition also applies to high-income communities. On the other hand, some people have high incomes but feel very dependent on MGUF. For instance, a farmer has a high income because he has relatively sizeable agricultural land outside the area bordering the MGUF.

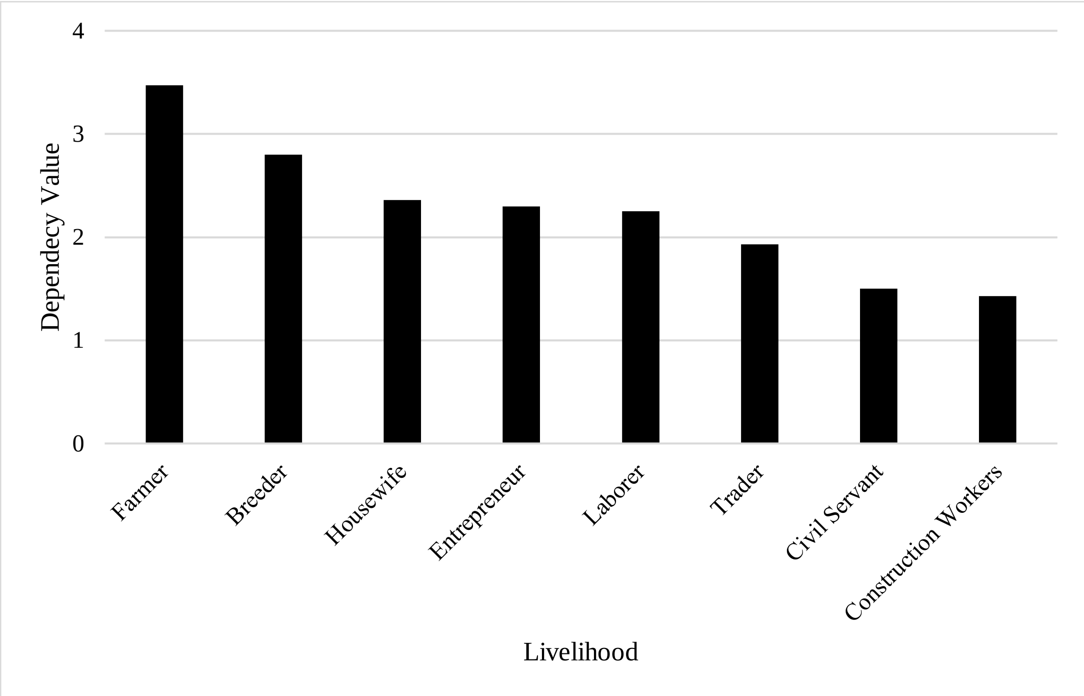

Figure 2. Perceived value dependency on livelihood

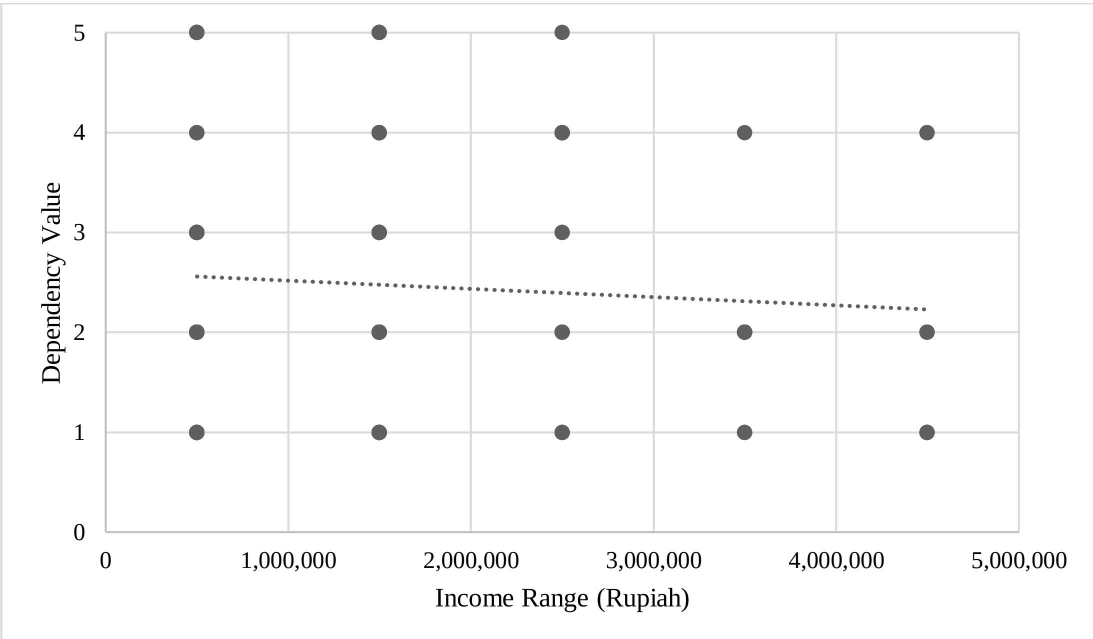

Figure 3. Perceived value dependency income level; y-axis shows value between 1 and 5, with each number described as follows: (1) Very Low, (2) Low, (3) High Enough, (4) High, and (5) Very High

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Livelihoods and income levels are also closely related to the community's intensity in activities or participation in MGUF. Participation in this context is the intensity of community involvement in MGUF management, whether with the manager or not. The relationship between dependency and level of participation can be seen in Figure 4.

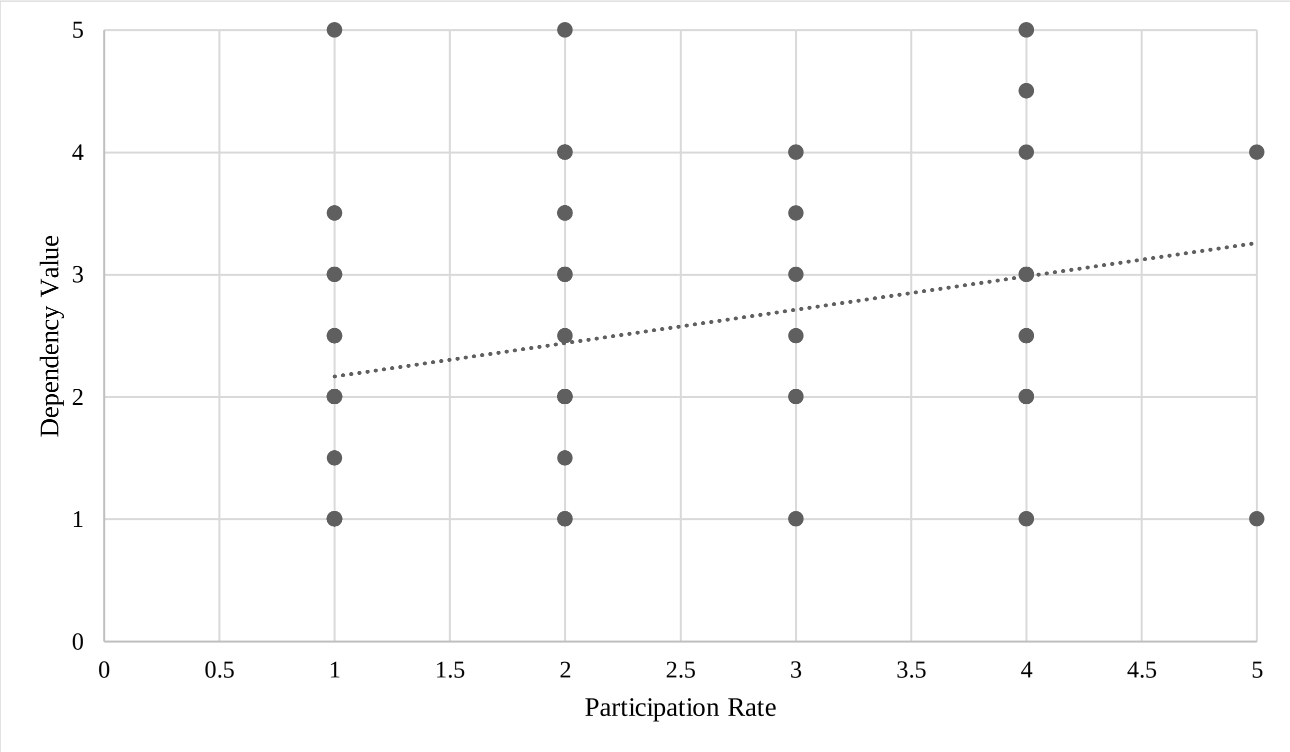

Figure 4. Perceived value dependency participation rate. y-axis shows value between 1 and 5, with each number described as follows: (1) Very Low, (2) Low, (3) High Enough, (4) High, and (5) Very High

The questionnaire results showed a positive relationship between the level of community dependency on MGUF and community participation (Figure 4). The higher the level of participation, the higher the community's dependency on MGUF. On the other hand, the lower the level of participation, the less dependent the community is on MGUF. This result is in line with the opinion expressed by other studies [15] that when resource users feel very dependent on the resource, they will tend to give their time and energy to manage it. This high involvement is reflected in one farmer of the FFG Cisempur Village, which is quite intensive and proactive in inviting the management to discuss developing a forest farmer group in their village.

Apart from the existence of parties with a high level of participation, many parties still do not actively participate in the management. Communities who do not actively participate in the management of MGUF generally feel that MGUF does not have a direct impact on their lives. Furthermore, the community has become less proactive in knowing how to manage MGUF. This condition is illustrated by the public's ignorance of the current MGUF management. From a sample of 100 respondents, 66% did not know that MGUF was currently managed by ITB, even though during the management of ITB, it was pretty often socialization of management to the community around MGUF. More proactive management requires directing the community to get more significant benefits in protecting the forest than working on land in the forest, especially the economic benefits [16].

3.2. Community Vulnerability

3.2.1. Population Growth Index

Based on the population data processing (Table 1), the village with the highest population growth index is Raharja Village (123.75), followed by Cikahuripan Village (112.76). Meanwhile, the lowest population index value was shown by Mangunarga Village (-45.09). The high population growth rate in Raharja Village is the main factor causing its high population growth index.

Population growth is one of the factors that determine vulnerability in an area. The Population Growth Index measures the population's pressure on resources or the environment [10]. The high population also causes an increase in population density in a fixed area. The high population density in an area can lead to increased criminal acts,

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especially if the economic conditions in the area are also low [17].

Cisempur village has the highest population density per km^2 of than other seven villages. However, the population growth index value of the population of Cisempur Village is ranked second lowest of all villages due to its low percentage of population growth. The population growth rate in Cisempur Village is meager, at -0.25%. A negative population growth rate means that the population in Cisempur Village tends to decrease over time, not increase. The mentioned explanation is evidence that population growth is the main factor determining the high or low value of the population growth index.

The high population growth causes pressure on the environment also to increase. Thus, it is necessary to control population growth in an area. Factors that affect the population growth rate include the sex ratio, the level of urbanization, employment and income, government policies, and other factors such as disasters [18]. The high population growth rate in Raharja and Cikahuripan villages is likely due to urbanization. The high level of urbanization in the two villages is also possible because of the low population density and easy accessibility with the construction of toll roads [19].

3.2.2. Built-up Land Index

Of the eight villages surrounding the MGUF, Mangunarga Village has the highest built-up land index (Table 2) due to its built-up land area that has almost filled the entire village. Apart from the large number of settlements being built, most of the area of Mangunarga Village is also occupied by factory buildings. The remaining forest area of Mangunarga Village is only the part of the village that is included in the MGUF area. Built-up land is anything that can help meet human needs that are created, maintained, and arranged by humans [20]. In the context of this research, built-up land includes buildings, yards, roads, public facilities, and other facilities. The built-up land index describes the percentage of built-up land area in an area to the area's total area.

Table 1. Population Growth Index

No.	Village	Population Density (person/km^2)	Population Growth (%)	Population Growth Index
1	Cisempur	5213	-0.25	-12.84
2	Mangunarga	3773	-1.20	-45.09
3	Sawahdadap	3008	2.97	89.45
4	Cikahuripan	2127	5.30	112.76
5	Raharja	2259	5.48	123.75
6	Cinanjung	3004	1.79	53.83
7	Jatiroke	3030	2.14	64.94
8	Jatimukti	2779	-0.17	-4.83

Table 2. Built-up Land Index

No.	Village	Village Area (km^2)	Built-up Area (km^2)	Built-up Land Index
1	Cisempur	2.06	1.16	56.22
2	Mangunarga	1.46	1.10	75.11
3	Sawahdadap	1.87	0.93	49.73
4	Cikahuripan	3.44	1.76	51.24
5	Raharja	3.89	2.02	51.96
6	Cinanjung	3.88	1.32	34.01
7	Jatiroke	2.43	0.69	28.57
8	Jatimukti	0.80	0.28	35.10

The village that has the second-highest degradation index value after Mangunarga Village is Cisempur Village. Not much different from Mangunarga Village, the high value of the built-up land index in Cisempur Village is caused by built-up land that covers more than half of the village. Of the total built-up area, half is occupied by factory buildings. The area of land that does not become built-up land is only village land included in the MGUF, such as Mangunarga Village. The

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conditions in Mangunarga and Cisempur villages follow the opinion of other research, which states that industrialization encourages the conversion of land functions into industrial land, especially on land with a flat topography [21].

Jatiroke Village has the lowest built-up land index value among other villages due to three possible explanations. First, the area of Jatiroke Village tends to be quite extensive, at 2.43 km^2. Second, before entering the MGUF area, there is land owned by PT. Kahatex, which PT. Kahatex maintains an open space. Third, the MGUF land is far from the reach of the community and is still lush because if people want to enter the MGUF from Jatiroke Village, people have to go through land owned by PT. Kahatex, which is quite extensive.

Minister of Forestry Regulation P.15/MENLHK/SETJEN/KUM.1/5/2018 concerning Special Purpose Forest Areas (SPFA) states that the determination of SPFA does not change the primary function of forest areas and does not change the landscape in protected forests. The status of the MGUF area was initially a Protected Forest area. However, the enactment of the Decree of the Minister of Environment and Forestry of the Republic of Indonesia Number SK. 633/Menlhk/Setjen/PLA.4/11/2017 changed the area's status to SPFA. However, its primary function remains as a protected forest. Thus, if we look at the value of the built-up land index for each village, MGUF plays a role in maintaining the value of the built-up land index in each village remains low. A possible explanation is that ITB, as MGUF manager, has managed to keep the MGUF from being degraded by the built-up land.

3.2.3. Economic Openness Index

The village with the highest economic openness index value is Jatimukti Village, with a value of 33.52 (Table 3). Besides Jatimukti Village, Cinanjung Village is the village with the second-highest economic openness index value, with a value of 31.27. The high value of the economic openness index in these two villages is due to the large proportion of trade value from the total village GRDP value. The more significant the proportion of trade value from the GRDP value coincides with the vulnerability index value increase. Conversely, the lower trade value proportion from the GRPD value corresponds with a decrease in the vulnerability index value. Economic openness is essential in assessing vulnerability because the higher the economic openness, the more development in an area will be influenced by external conditions or outside the village [12]. The strong influence of external conditions in development will cause a decrease in the internal capacity of a region to determine the direction of development. The economic openness index in this study was carried out by comparing the total trade value with the GRDP of each village.

Table 3. Economic Openness Index

No.	Village	Trade Value	GRDP	Economic Openness Index
1	Cisempur	Rp85,595,342,000	Rp197,691,442,028	21.65
2	Mangunarga	Rp61,520,690,000	Rp105,127,434,144	29.26
3	Sawahdadap	Rp66,990,336,000	Rp133,399,435,421	25.11
4	Cikahuripan	Rp91,680,708,000	Rp156,581,210,837	29.28
5	Raharja	Rp85,800,582,000	Rp153,188,672,905	28.00
6	Cinanjung	Rp114,144,226,000	Rp182,539,943,293	31.27
7	Jatiroke	Rp64,978,984,000	Rp172,217,637,539	18.87
8	Jatimukti	Rp54,193,622,000	Rp80,825,933,852	33.52

Many things cause a large proportion of trade value to the value of GRDP in the villages around the MGUF. One of the main reasons is the ability to create added value in the internal village. Villages whose communities do not have the independence to create added value will depend on external village parties and create more excellent trade value. Unfortunately, few villages around MGUF can create added value from their products. This increasing dependency causes progress toward becoming self-reliant in rural communities slow [22]. Thus, creating added value is essential to be developed in the villages around the MGUF.

In general, the rural economy around the MGUF is still oriented towards the upstream economy, which means that it only focuses on raw material producers. Especially for the people of Cinanjung Village, whose land for agricultural production tends to be small compared to other villages. However, one example of the success of creating added value in villages around MGUF can be seen in Jatiroke Village. One of the commodities that are given added value is coffee. Jatiroke village produces coffee to be roasted beans which have a much higher value than freshly picked coffee beans, as seen in the value of the economic openness index. Jatiroke

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Village is the village with the lowest economic openness index value compared to other villages. The creation of added value in rural areas increases direct income for farmers, artisans, and entrepreneurs to rural communities in general and makes villages able to meet their own needs [23].

3.2.4. Composite Vulnerability Index

Cikahuripan and Raharja are villages with the highest composite vulnerability index (CVI), with values of 0.71 and 0.70, respectively (Table 4). The population growth index, the built-up land index, and the economic openness index in this section will be integrated into a composite vulnerability index so that this composite vulnerability index will be able to assess the level of external disturbances that exist in a system. As a result, the increasing level of vulnerability is represented by CVI [10]. The high composite vulnerability index in Cikahuripan and Raharja is caused by the population growth index and the high index of economic openness. The village with the lowest composite vulnerability index around the MGUF is Jatiroke Village, with a value of 0.20. The cause of the low composite value of the vulnerability index in Jatiroke Village is the low value of the built-up land index and the index of economic openness. The following is a diagrammatic illustration to illustrate the composite position of the vulnerability index of each village surrounding the MGUF (Figure 5).

Table 4. Composite Vulnerability Index

No.	Village	Population Growth Index	Built-up Land Index	Economic Openness Index	Composite Vulnerability Index
1	Cisempur	0.19	0.59	0.19	0.31
2	Mangunarga	0.00	1.00	0.71	0.58
3	Sawahdadap	0.80	0.45	0.43	0.55
4	Cikahuripan	0.93	0.49	0.71	0.71
5	Raharja	1.00	0.50	0.62	0.70
6	Cinanjung	0.59	0.12	0.85	0.55
7	Jatiroke	0.65	0.00	0.00	0.20
8	Jatimukti	0.24	0.14	1.00	0.51

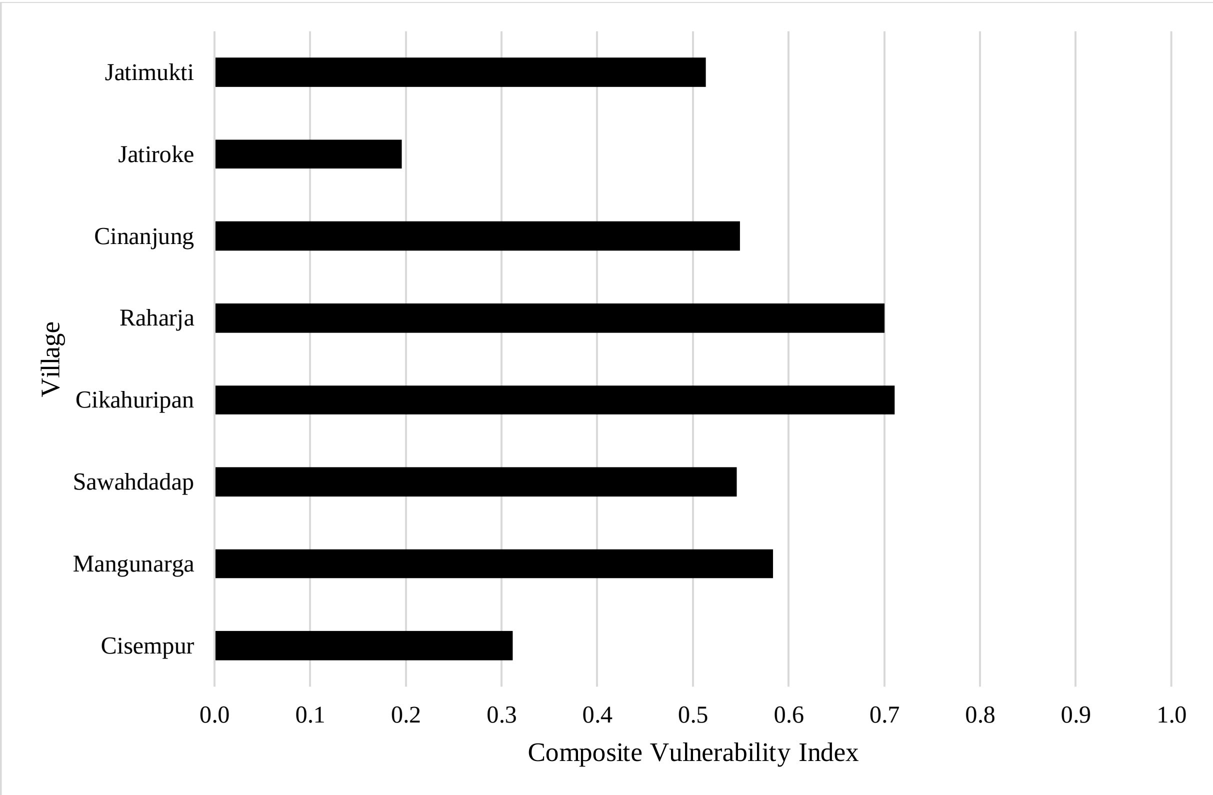

Figure 5. Composite Vulnerability Index comparison

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Vulnerabilities in villages surrounding the MGUF were assessed to identify the villages most vulnerable to external hazards and actions to reduce vulnerability. The composite value of this vulnerability index is in the range of 0 to 1 [24]. The composite value of the vulnerability index close to 0 indicates that an area has a low level of vulnerability; on the other hand, a composite value of the vulnerability index close to 1 indicates that the area has a high level of vulnerability. A moderate vulnerability level is around the composite value of the vulnerability index of 0.5.

By referring to the assessment criteria, villages with a high level of vulnerability are Cikahuripan and Raharja villages because they have a composite vulnerability index value of > 0.70. On the other hand, the villages of Mangunarga, Sawahdadap, Cinanjung, and Jatimukti have a moderate level of vulnerability because they have a composite vulnerability index value in the range of 0.5. Finally, Jatiroke and Cisempur villages have a low level of vulnerability because they have a composite vulnerability index value lesser than 0.35. Therefore, MGUF is dominated by villages with a moderate level of vulnerability.

Villages with a high level of vulnerability, such as Cikahuripan and Raharja villages, need further attention, especially from the index, which causes a high level of vulnerability. In this case, the population growth index strongly influences the high level of vulnerability in the Cikahuripan and Raharja villages. Another example, the moderate level of vulnerability in Mangunarga Village is strongly influenced by the built-up land index. Likewise, with other villages, the level of vulnerability needs to be addressed by looking at the constituent indices that lead to the high composite value of the vulnerability index.

4. Conclusion

Communities with farmers' livelihoods are pretty dependent on MGUF. People with low-income levels also tend to have a high dependency on MGUF. The higher the level of dependency on MGUF, the community will tend to participate in the management of MGUF actively. In addition, Cikahuripan and Raharja villages have a high level of vulnerability, mainly influenced by high population growth and high levels of economic openness. While Jatiroke Village has a low level of vulnerability, it is strongly influenced by the low openness of the economy, which is supported by the ability of the Jatiroke Village community to create added value. Thus, this study recommends carrying out collaborative management among all stakeholders. Collaborative management programs focusing on increasing the ability to create added value to reduce vulnerability can solve problems related to population growth, environmental degradation, and economic conditions.

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Dynamics of Competitiveness and Efficiency of Rice Farming in Java Island, Indonesia

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Abstract

Rice is the major crop in Indonesia and the staple food for more than 90% of Indonesians. Given the vital role of rice, efforts to develop rice production are a priority, especially in solving farming efficiency problems. However, inefficiency is one of the major causes of low performance in Indonesian rice production. If farming has high competitiveness and efficiency, Indonesia is encouraged to be able to become an exporter of rice. As a result, national rice farming must continue to improve its competitiveness and efficiency. This study aims to determine the economic efficiency and competitiveness of rice farming in several provinces in Java, i.e., West Java, Central Java, and East Java. The data used in this study is PATANAS survey data obtained from the Center for Socio-Economic Studies and Agricultural Policy, Indonesian Ministry of Agriculture. This study used a quantitative analysis approach and analytical descriptive analysis. The level of competitiveness was analyzed using Policy Analysis Matrix (PAM), while the efficiency level was analyzed using the Stochastic Frontier Method (SFM). The results showed that rice farming in Java Island has a positive profit value on private and social prices. In addition, rice farming in all research locations has competitiveness as measured by indicators of comparative and competitive advantage as characterized by the coefficient values of DRC (Domestic Resource Cost Ratio) and PCR (Private Cost Ratio), which are less than one in the study period 2007-2020. The result of a technical efficiency study shows the average technical efficiency of three provinces in Java is around 0.82, and the factor input that significantly increased the technical efficiency was land and intermediate input.

Keywords: *competitiveness, efficiency, Policy Analysis Matrix (PAM), stochastic frontier*

1. Introduction

The rice crop has a significant role in Indonesian society since it promotes agricultural activities and contributes to feeding a growing population. Rice is a staple food for more than 270 million Indonesians, accounting for most of their caloric intake. Furthermore, the rice sector provides food and is the primary source of income and employment for most Indonesians living in rural areas [1]. Rice is a strategic product from a political standpoint. Political instability could result from either a shortage of rice in domestic markets or a highly variable price. The lack of rice stocks in domestic markets has become a more pressing issue in the stability of the Indonesian economy. As a result, the Indonesian government must maintain rice supplies to achieve food security [2].

Food security is a critical concern in Indonesia. The notion of food security at the national scale, by definition, places a greater emphasis on the commitment to supply adequate food in the context of food production. In contrast, at the individual and family level, the attention is on the household's capacity and accessibility to obtain enough nutritious and safe food without difficulty. The commitment of Indonesia to achieving food security is stated in Undang-Undang No. 18 year 2012. The achievement of food security is directed at increasing the production of agricultural commodities for diverse foods by applying the principles of comparative and competitive advantage, efficiency, and competitiveness. In addition, the government prioritizes food security and attempts to attain self-sufficiency in rice production through strengthened regulation, a fertilizer subsidy program, government procurement and a reserve, and Raskin distribution (cheap rice distribution program). The advancement of the agricultural sector is marked by increased production and productivity of food commodities, as well as the ability to meet domestic needs (self-sufficiency food), which in turn increases farmers' income [3].

Rice production has evolved in an unpredictable trading environment, marked by price volatility over time, and driven

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by significant fluctuations in commodity supply and demand. This is one of the primary problems with sectoral constraints [4]. As a result, the profitability of rice farmers varies. Furthermore, in a dynamic environment influenced by political, technological, economic, and trade challenges, the Indonesian rice sector constantly faces obstacles to increasing its competitiveness. Globalization and international trade have significantly impacted Indonesia's national development, but they also have consequences for the rice sector, which must compete with other international producers [5].

Indonesia is linked by the Uruguay Round Agreement on Agriculture as a participant of the World Trade Organization (WTO). These agreements include domestic support policies and regulations, non-tariff measures, and market access. The comparative advantage of Indonesian rice production determines whether or not it is profitable from a comprehensive economic standpoint under conditions of no subsidies or limited subsidies permitted by the rules for all trading partners. Therefore, assessing Indonesia's comparative advantage in rice production will be essential in this study.

Thus, this study will discuss the competitiveness and efficiency of rice farming by providing an overview of the phenomena that occur and analyzing the history of rice in Indonesia using time series data. The study's research objectives are to determine the level of competitiveness of rice farming in Java; to measure and analyze the efficiency of rice production; and, thirdly, to formulate the implications of Indonesian rice farming policies on changes in international commodity prices, international fertilizer prices, labor wages, currency exchange rates, and international policies. As a result, this research is expected to be used as a reference material for farmers to maximize profits and minimize costs in rice farming activities, as a consideration in making agricultural development policies, and as a reference material for conducting similar research with a broader and deeper scope.

2. Methodology

The policy analysis matrix (PAM) is a policy research instrument that enables researchers to identify policy distortions and inefficiencies and, as a result, recommend policy changes that will increase the profitability of an industry, sector, or country. The PAM approach can be used to investigate three major issues concerning agricultural policy: the first is a comparison of competitiveness and farm profits before and after the policy change; the second is a comparison of efficiency on agricultural systems before and after new public investment; and the third is the impact of agricultural research on changing new technology [6]. We can evaluate the level of policy transfers caused by the set of policies acting on the system and the system's inherent economic efficiency by filling out the elements of the PAM for an agricultural system.

PAM analysis begins with measuring prices in private prices (the observed market prices) and social prices (world prices). The following step is to create two tables for both private and social budgets and then enter all the prices into the PAM table, as shown in Table 1. The PAM table contains two cost columns: one for tradable inputs and one for domestic factors. Intermediate inputs, including fertilizers, pesticides, and purchased seeds, are tradable inputs. Domestic factor components include arable land and labor. The social prices of tradable input or output are determined by comparing world prices. The social prices for tradable input and/or output are calculated, as shown in Table 3 and 4, by calculating import parity for goods that substitute for imports and export parity prices for goods that enter export markets [7].

Table 1. Policy Analysis Matrix (PAM)

	Revenue	Cost		Profits
		Tradable Input	Domestic Factors	
Private Prices	A	B	C	D = A-B-C
Social Prices	E	F	G	H= E-F-G
Divergencies Effect	I = A - E	J = B - F	K = C - G	L = I-J-K=D-H

The policy analysis matrix is an array of numbers that follows two rules of accounting identities. One defining profitability identity is the accounting relationship across the columns of the matrix. The other one defines divergences identity, which is the relationship down the rows of the matrix. These accounting relationships are known matrix identities since they are true by definition.

Profitability identity is the accounting relationship across the column of the matrix or can be measured horizontally in the PAM, as shown in Table 1. All entries in the PAM matrix under the column "profits" are thus identically equal to the difference between the columns "revenues" and "costs" (including both costs of tradable inputs and costs of domestic factors). Thus, profits are defined as revenues minus costs.

The first row of a PAM contains price measures in private prices (the observed market prices). The symbol A represents private revenue, B represents tradable input costs in private prices, C represents domestic factor costs in private prices, and D represents private profit. The symbol D, profits in private prices, is found by applying the profitability identity. According to that accounting principle, D is identical to A - (B + C). The calculation of private profits from data in farm

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and processing budgets reflects the actual market received by the agricultural system's farmers [6][8]. Thus, private profitability calculations provide information on the agricultural system's competitiveness.

The second row of a PAM contains price measures in social prices (prices that would result in the best allocation of resources and, thus, the highest income generation). Social prices are a policy benchmark for comparisons because they are assumed to be the prevailing prices in a free market without any policy interventions, distortions, or market failures [6]. The symbol E represents revenues in social prices, F represents tradable input costs in social prices, G stands for domestic factor costs in social prices, and H represents social profit. The symbol H, profits in social prices, is found by applying the profitability identity. According to that accounting principle, H is identically equal to E - (F + G). The calculation of social profits estimates from the world prices (free on board) for exports are used for international traded outputs E and inputs F. While the domestic factors are not tradable internationally and thus do not have world prices, their social opportunity cost is estimated through observations of rural factor markets and cost insurance freight prices (CIF) are used. Countries achieve rapid economic growth by encouraging high-profit activities, which are characterized by large positive H. In contrast, negative H indicates that the country would be better off in terms of national growth by not producing the commodity. Thus, social profitability is a signal for determining international comparative advantage [9].

The third row of a PAM is **Divergence Identity,** which is defined as the difference between entries in the first row, measured in "private prices," and those in the second row, measured in "social prices." As a result, all entries in the third row are defined as "effects of divergences." Three sources cause divergences: the existence of market failure, distorting policy, and efficient policy. In principle, the most efficient outcome could be achieved if the government is capable of implementing an effective policy that offsets market imperfections and if the government decides to override non-efficiency objectives and remove distorting policies; therefore, the disparities between private prices and social prices will be reduced [6][9].

The arrangement of PAM presents an essential indicator for measuring the protection rate by different ratios, i.e., DRC, PCR, NPCO, NPCI, and EPC, which are used to assess competitiveness and comparative advantages [6][7][10].

PCR is the ratio that assesses the farm-level competitiveness of a commodity system. If PCR was less than one, the commodity system was competitive. The PCR can be expressed using the PAM framework as follows:

$$PCR = (C / (A-B))$$

The DRC, or domestic resource cost ratio, is used to determine comparative advantage (DRC). If the DRC is less than one, the agricultural system is efficient in domestic resource use and has a comparative advantage. If DRC is greater than one, the agricultural system is inefficient in domestic resource use and suffers from a comparative disadvantage. The following is the DRC formula:

$$DRC = (G/ (E-F))$$

The NPC, or nominal protection coefficient, is a ratio of the commodity's private and social prices. This ratio illustrates the effect of policy on domestic and international prices, which causes a divergence. NPCO determines the protection of the output. If the value of NPCO is greater than one, it indicates output subsidies. NPCO can be expressed as:

$$NPCO = (A/E)$$

NPCI determines the protection of the input or input subsidies if the value of NPCI is less than one. If the value is greater than one, implying that the production is inefficient, the producers are protected while the consumers are taxed. NPCI can be expressed as:

$$NPCI= (B/F)$$

The EPC, or effective protection coefficient, is the ratio of value added in private prices (A-B) to value added in social prices (E-F). This coefficient indicates the degree of policy transfer from output and tradable input distortions. If the value of EPC is greater than one, it indicates that government policies provide positive incentives to producers. If the value is less than one, it indicates that policy interventions do not protect producers. EPC can be expressed as:

$$EPC = (A-B) / (E-F)$$

In addition, the stochastic frontier model (SFM), also known as the composed errors model, is used to estimate technical efficiency using a parametric method. The SFM is very advantageous because it considers measurement errors or random effects [9]. The SFM provides techniques for designing the frontier concept within a regression framework to estimate inefficiency. In the first stage, the parameter of the stochastic production function is estimated by Maximum Likelihood Estimation (MLE). The inefficiency term of the model (u_i) and technical efficiency model (ξ_i) are then predicted from results of the first stage [11]. The Cobb-Douglas stochastic frontier equation considers the decomposed error as written below.

$$\ln(q_i) = \beta_0 + \sum_{j=1}^{k} \beta_j \ln(z_{ji}) + v_i - u_i$$

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In the second stage, either of the two measurements is regressed on independently and identically distributed variables of firm characteristics. The technical efficiency of the firm will be determined using the following equation:

$$\xi_i = exp(-u_i) = \exp[(-E(-u_i|\xi_i)]$$

Stochastic Frontier is defined as a function model in which disturbance term, and it is composed of two parts, pure random error v_i and inefficiency u_i. Pure random results from measurement error and statistical noise, while the inefficiency error term is due to inherent firm characteristics which cause firms to deviate from frontier production level. The chance of including a pure random error component, denoted v_i, at every input level is given. Therefore, it is assumed to be a homoscedastic, independently, and identically distributed error term across firms, with a mean at 0, and has a variance σ^2_{vi}. Parameters of pure random error are thus denoted as $N(0, \sigma_v^2)$ [12].

The second component of the error term represents the technical inefficiency of firms, influenced by their characteristics. Battese and Coelli (1995) have advocated that inefficiency is assumed to be a one-sided, non-negative error since an inefficient firm can only produce below and never above the frontier level. Because of this condition, the distribution of the inefficiency term is a truncation of normal distributions. It takes different forms, which can be half-normal, exponential, truncated normal, or gamma distributions [13]. Therefore, the inefficiency error term has a mean at μ, and has variance σ^2_{ui}. Parameters of inefficiency are represented as $N^+(\mu, \sigma_u^2)$.

The output of this study is rice production. It is the result of multiple inputs. The production frontier model specification for this study is shown below, assuming that the farmers are producing a single output from multiple inputs:

$$\ln(q_i) = \beta_0 + \beta_1 \ln v + \beta_2 \ln l + \beta_3 \ln k + \beta_4 \ln a + v_i - u_i$$

Where q_i denotes the paddy rice produced in kg; β_j(j = 1,2,3,..N) describe the parameters to be estimated; v represents the quantity of intermediate input applied per hectare (kg/ha); l constitutes family labor plus hired labor (person-days); k stands for a total capital asset in monetary terms (IDR); and a is cultivated area for rice production (ha); $v_i - u_i$ is error term; v_i is a two-sided random error component beyond the control farmer; u_i is a one-sided inefficiency component. The technical inefficiency determinants are specified as:

$$u_i = \delta_0 + \delta_1 z_1 + \delta_2 z_2 + \delta_3 z_3 + \delta_4 z_4 + \delta_5 z_5 + \delta_6 z_6 + w_i$$

Where u_i denotes technical inefficiency; δ_j (j = 1,2,3,..N) are the parameters to be estimated; z_1 is the gender of the household head; z_2 is the age of the household head; z_3 is the status of land ownership; z_4 is education level of the household; z_5 is the ratio of family labor; and z_6 is crop intensity within a year. The stochastic frontier is estimated from both equations jointly by maximum likelihood using STATA version 15 software.

The datasets were gathered from a variety of national and international publications. We required a comprehensive data set to estimate the PAM, including yields, input requirements, and market and social prices of inputs and outputs. PATANAS and the National Bureau of Statistics (BPS) provided the aggregated output and input data for the three granary areas (West Java, Central Java, and East Java). PATANAS is a panel data set compiled by the National Farmers' Household Panel Survey conducted by the Indonesian Ministry of Agriculture. We used a relatively large-scale survey that covers the same agroecological zones and focuses on generating information on rice production costs for provinces from 2007 to 2020. These output and input coefficients were then compiled on a per-hectare basis.

3. Results and discussion

Analysis of the cost of tradable inputs and domestic factors is based on perfect market conditions (social prices) or conditions without any government policies (Table 2). The calculation of social prices for tradable inputs and outputs, as well as domestic factors, is reflected by shadow prices or based on the estimation of the social opportunity cost. The shadow prices are used to adjust to international market prices. Tables in Appendix 1 are examples of parity price calculations for rice and fertilizer in Indonesia.

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Table 2. Policy Analysis Matrix (PAM)

		Revenue	Cost		Profit
			Tradable Input	Domestic Factor	
West Java 2007	Private	8.439.576	1.315.845	3.953.494	3.170.237
	Social	8.236.770	1.135.500	3.738.146	3.363.124
	Divergences	202.806	180.345	215.349	-192.888
2010	Private	13.503.688	1.468.588	5.633.906	6.401.194
	Social	13.754.884	1.453.710	5.383.397	6.917.777
	Divergences	-251.196	14.878	250.510	-516.584
2016	Private	22.490.376	2.876.739	7.294.575	12.319.062
	Social	22.426.650	1.443.600	7.038.715	13.944.335
	Divergences	63.726	1.433.139	255.860	-1.625.273
2020	Private	28.754.100	1.783.931	12.198.998	14.771.171
	Social	33.040.467	1.766.646	12.068.696	19.205.125
	Divergences	-4.286.367	17.285	130.301	-4.433.953
Central Java 2007	Private	4.286.373	816.389	1.474.961	1.995.023
	Social	4.423.965	896.160	1.379.951	2.147.854
	Divergences	-137.592	-79.771	95.009	-152.830
2010	Private	4.554.564	868.787	2.265.581	1.420.196
	Social	5.690.448	888.898	2.148.745	2.652.805
	Divergences	-1.135.884	-20.111	116.837	-1.232.610
2016	Private	7.869.868	1.553.297	3.926.976	2.389.595
	Social	9.342.150	1.373.969	3.839.718	4.128.463
	Divergences	-1.472.282	179.328	87.258	-1.738.868
2020	Private	22.567.500	1.857.531	8.760.230	11.949.739
	Social	24.463.170	1.766.259	8.639.295	14.057.616
	Divergences	-1.895.670	91.273	120.935	-2.107.878
East Java 2007	Private	4.939.335	774.957	1.621.674	2.542.704
	Social	4.332.750	696.819	1.643.273	1.992.658
	Divergences	606.585	78.138	-21.599	550.046
2010	Private	7.728.777	1.151.532	3.252.506	3.324.739
	Social	7.633.360	1.151.532	3.132.198	3.349.630
	Divergences	95.417	0	120.308	-24.891
2016	Private	9.199.695	1.436.275	3.749.094	4.014.326
	Social	9.859.125	1.666.916	3.936.241	4.255.968
	Divergences	-659.430	-230.641	-187.147	-241.642
2020	Private	26.085.000	1.935.331	11.139.205	13.010.464
	Social	27.422.550	1.928.331	11.019.524	14.474.695
	Divergences	-1.337.550	7.000	119.681	-1.464.231

Figure 1. depicts a graph of the PCR calculation results, or the ratio between domestic costs and the difference between income and costs of tradable inputs at the private price level, in three Java provinces from 2007 to 2020. The PCR value assesses a farm's level of competitive advantage and is one indicator of competitiveness. Based on the data presented above, each province has a different dynamic of PCR scores each year, but it has a PCR of 1. That is, it can be identified that all of these provinces have a level of competitive advantage or competitiveness in general.

The competitive advantage performance in Central Java is inversely proportional to the West Java Province. The score tends to rise from 2007 to 2016, then fall in 2020. In 2016 the smallest PCR was 0.335, then the score increased to 0.452 in 2020. The PCR value means that to get a rice output value of Rp. 1,000,000, an additional domestic factor cost of Rp. 335,000 in private prices is required in 2016, and it increases to Rp. 452,000 in 2020. This phenomenon shows that the performance of competitive advantage in West Java declined in 2020. The smaller the PCR score indicates, the more

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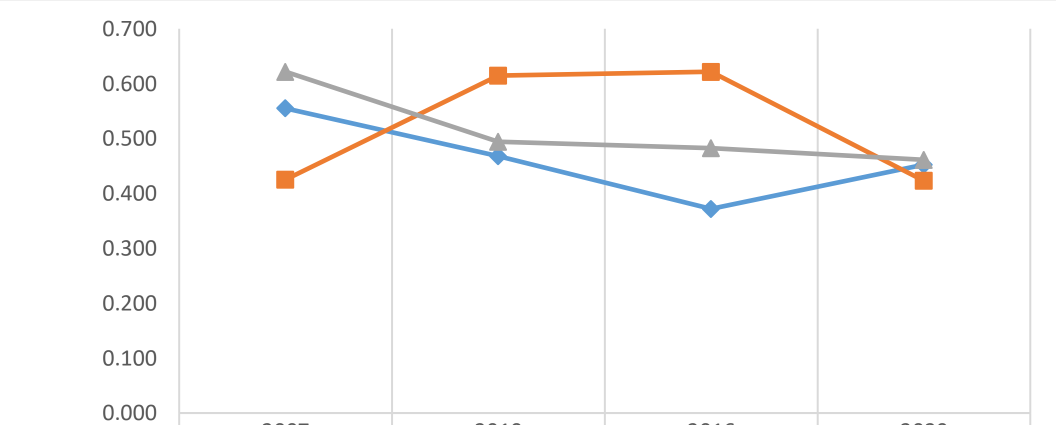
competitive the farm is because rice farming in each province has a competitive advantage or competitiveness over private prices.

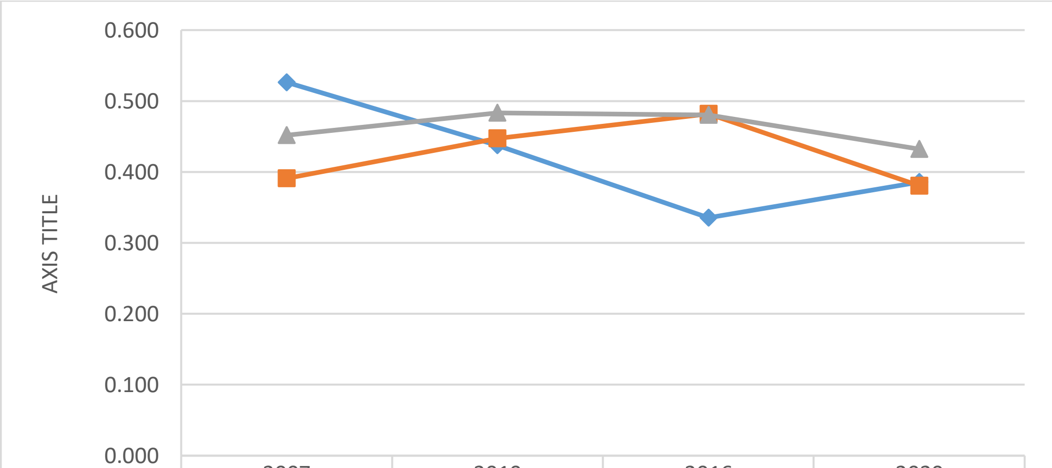
The competitive advantage performance in Central Java is inversely proportional to the West Java Province. The score tends to rise from 2007 to 2016, then fall in 2020. The highest PCR score in Central Java in 2016 was 0.622, but it dropped to 0.423 in 2020. Furthermore, from 2010 to 2020, the dynamics of competitive advantage in East Java show stagnation. During that time, the PCR value in East Java ranged from 0.49 to 0.46. In 2020, the PCR scores in all three provinces tended to be the same. This demonstrates that each province has the same level of competitive advantage. A commodity will be competitive if efficiency and productivity are high.

Figure 2. depicts a graph of the DRC calculation results, or the ratio between domestic costs and the difference between income and costs of tradable inputs at the social price level in West Java, Central Java, and East Java from 2007 to 2020. According to the graph, the DRC score for each of these provinces is less than one. The lower value of the DRC score, the greater the farm's comparative advantage. This implies that all provinces have comparative advantages and effective agricultural systems even though the score of DRC has disparity.



	2007	2010	2016	2020
Jabar	0.555	0.468	0.372	0.452
Jateng	0.425	0.615	0.622	0.423
Jatim	0.622	0.495	0.483	0.461

Figure 1. Private Cost Ratio



	2007	2010	2016	2020
Jabar	0.526	0.438	0.335	0.386
Jateng	0.391	0.448	0.482	0.381
Jatim	0.452	0.483	0.480	0.432

Figure 2. Domestic Resource Cost Ratio

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West Java's comparative advantage dynamics tended to decrease scores from 2007 to 2016, then slightly increase in 2020. DRC scores of 0.33 and 0.38 were recorded in 2016 and 2020, respectively. This suggests that rice farming in West Java is becoming more resource efficient and economically efficient and has a high comparative advantage [10]. The findings of this study are consistent with those of [14][15], who found that the efficiency level in West Java was quite efficient, with a percentage of more than 70%, and that the level of technology gap was relatively low. The irrigation condition in West Java is more developed than that in Central and East Java. The government is always concerned and pays closer attention to rice farming in West Java due to its proximity to the capital city. Moreover, an industrial area in West Java is located in the middle of rice barn regions such as Karawang and Indramayu, where PATANAS research also takes place. The industrial area is built on infertile land rather than on converted farmland; surplus labor is therefore reduced since many small-scale farmers lease their land and choose to work in the factory. As a result, large-scale farmers can expand their farm size. Therefore, rice farming in West Java is more dynamic than in Central and East Java. To examine this condition more comprehensively, it is also necessary to review the level of efficiency and productivity using a parametric approach.

Furthermore, the dynamics that occur in Central Java Province have a DRC value that is quite efficient and has a comparative advantage. The increasing score proves this from 2007 to 2016, which ranged from 0.48 to 0.48, then decreased in 2020 to 0.38. This phenomenon indicates that comparative advantage and efficiency in rice farming in Central Java are increasing. The DCR score tends to stagnate at 0.4 in the dynamics that occur in East Java Province. According to previous research [16], the efficiency and productivity of rice farming in East Java have stagnated due to unbalanced inputs.

The development of rice policy dynamics in Indonesia in 2007, 2010, 2016, and 2020 depicts in Table 3. According to Figure 3, the progression of output protection policies in West Java is quite volatile. In 2007, the output price in the domestic market was higher than the import parity price, indicating that the government's policy intervention on rice output in West Java was protective in 2007 and 2016. In 2010 and 2020, the output price in the domestic market was lower than international market prices. This shows that the government does not protect policy output. This situation contradicts the statement regarding the intervention policy output from the government, which explains that protection for rice in Indonesia is national or comprehensive in all provinces of Indonesia.

Different situations in Central Java Province, which show NPCO < 1 from 2007 – 2020, indicate that the output price in the local market is lower than the social price. The protection policy carried out by the government is in the form of import duties, so the cost per unit of commodities imported from outside will be much more expensive than commodities in the Central Java area. This phenomenon is consistent with research conducted by [17]. Furthermore, the phenomenon that occurred in East Java showed changes or dynamics in output prices, which were initially protected in 2007-2010, and then the output price became lower than the social price so that it was not protected in 2016-2020.

According to the three provinces, the output price in all provinces is not protected in 2020, or the output price in the local market is less than the global price. The COVID-19 pandemic is one of the causes of this condition, which affects the stability of the country's economy and thus indirectly affects rice HPP [2]. In addition, the government has implemented HPP to align with the COVID-19 conditions. This condition had previously occurred in Indonesia during the 1997-2000 monetary crisis. The rice economy in Indonesia experienced turmoil in 1998. Suryana and Rachman [18] investigate the key factor that renders price policies ineffective in these circumstances: the rice economy's liberalization by opening opportunities for rice imports to the private sector. This aims to meet domestic rice needs. There is a very large amount of rice imports. At that time, the international price of rice was relatively low compared to the domestic price, even though a tariff of 30%, or Rp. 450/kg was applied later. This tariff policy could not stem the entry of imported rice. Based on these conditions, domestic rice must compete in price with imported rice.

Furthermore, the development of the agricultural input price policy is shown by the NPCI ratio in Figure 4. The NPCI value that occurs in West Java shows a fluctuating value and is more than one. This indicates that there is no protection for input prices, especially tradable inputs such as seeds and fertilizers, from 2007–2020. In other words, farmers in West Java have to pay higher prices for tradable inputs than in the international market. This condition is consistent with research by [19] which states that the prices of tradable inputs, especially urea and TSP fertilizers, in West Java in the period 2000–2016 have increased by 11.42 and 11.80 percent per year, respectively. The increase in the price of urea and TSP fertilizers in this region was only followed by a slight decrease in fertilizer use during that period.

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Table 3. Unit price of Input-Output

	Quantities	Input/Output				Private Price per unit				Social Price per unit			
		2007	**2010**	**2016**	**2020**	2007	**2010**	**2016**	**2020**	**2007**	**2010**	**2016**	**2020**
Tradable Input	Seed (kg/ha)	16	17	16	18,5	3.652	5.817	7.636	12.000	2.500	5.750	8.618	12.000
	Ferilizer												
	a. Chemical Fertilizers (kg/ha)												
	- Urea	202	184	202	145	1.227	1.375	1.968	1.800	1.200	1.688	1.960	1.867
	- TSP/SP-36	115	67	115	111	1.925	1.151	1.892	2.400	1.550	1.400	1.763	2.000
	- ZA	57	103	57		3.689	1.772	2.370	0	1.050	2.254	2.359	1.400
	- NPK	80	120	80	116	2.628	2.074	2.587	2.500	1.750	2.619	2.542	2.650
	b. Other fertilizers (pack)	1	1	1	1	379.362	150.652	369.938	0	275.000	107.944	147.483	0
	c. Pesticide (pack)	1	1	1	1	119.385	350.000	391.298	744.531	100.000	200.000	121.741	744.531
	d. Herbicide (Pack)	1	1	1	1	68.928	107.534	1.036.161	0	100.000	97.182	100.000	0
	Total												
Domestic factors	Labor (hr/ha)					1.763.682	2.761.955	3.865.183	5.509.375	1.763.682	2.761.955	3.865.183	5.509.375
	Working capital					13%	12%	10%	9%	7%	6%	8%	7%
	Land rent (ha)					1.775.000	2.364.286	2.755.200	6.050.000	1.775.000	2.364.286	2.755.200	6.050.000
	Total												
Output	**Production (kg/ha)**	3.558	3.806	4902	6687	2.372	3.548	4588	4300	2.315	3.614	4.575	4.941

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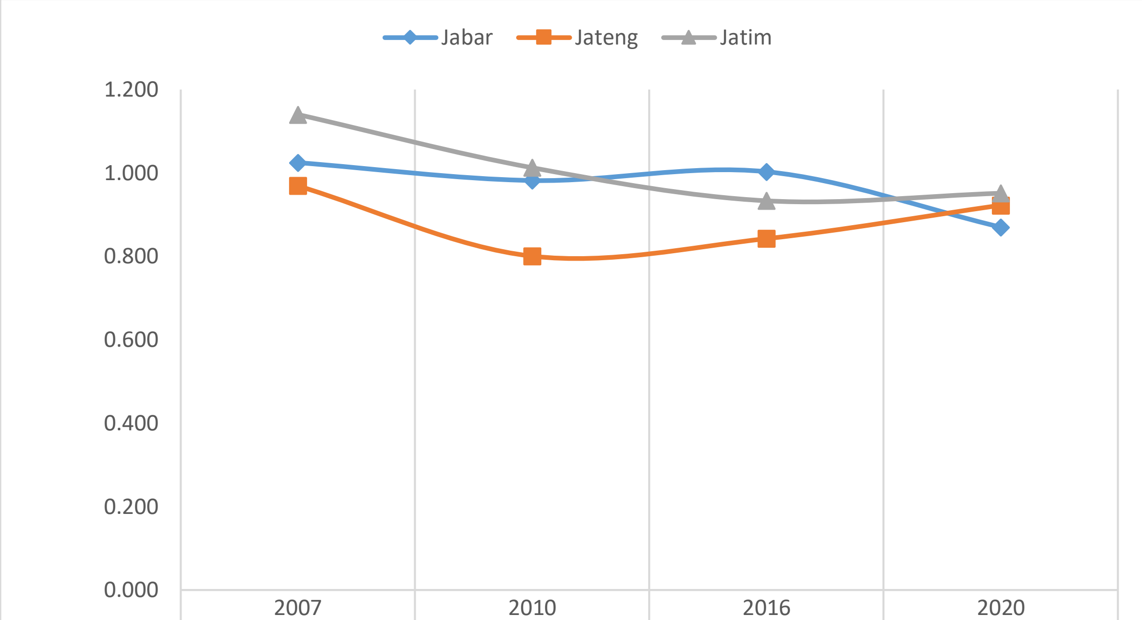
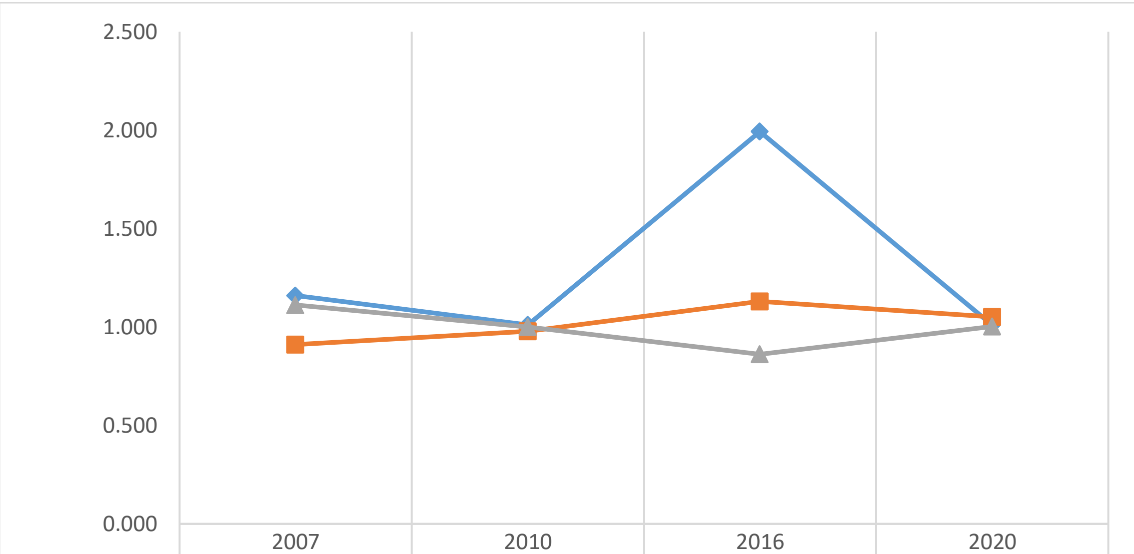


	2007	2010	2016	2020
Jabar	1.025	0.982	1.003	0.870
Jateng	0.969	0.800	0.842	0.923
Jatim	1.140	1.013	0.933	0.951

Figure 3. Nominal Protection Coefficient on Output



	2007	2010	2016	2020
Jabar	1.159	1.010	1.993	1.010
Jateng	0.911	0.977	1.131	1.052
Jatim	1.112	1.000	0.862	1.004

Figure 4. Nominal Protection Coefficient on Input

In contrast to market conditions in East Java, the dynamics of the input policy or NPCI value that occurred experienced a decrease in value from the 2007-2016 period, which was initially worth more than one, then decreased. The NPCI value that became less than one, meaning that the tradable input price policy was protected in this period. However, there was an increase again in the 2020 period, so it can be said that the input price policy is not protected. This condition is also similar to the research conducted by [19], which stated that in East Java, tradable input prices in maize farming in East Java,

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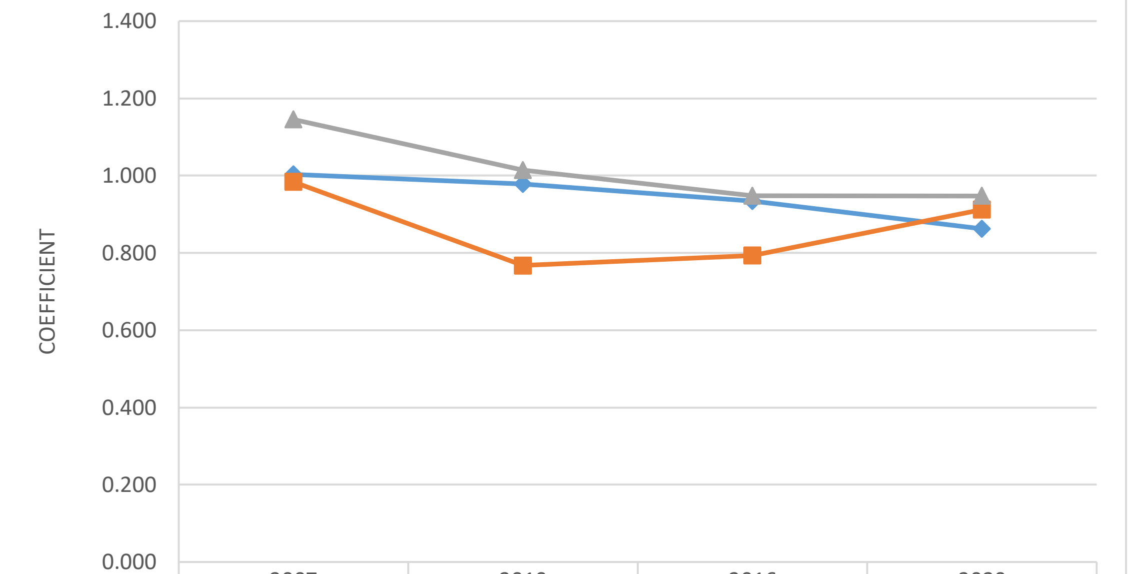
especially Urea and TSP fertilizers, in the same period also showed a significant increase of 10.97 and 11.32 percent per year, respectively.

Figure 5. depicts the progression of the combined input-output policy or EPC ratio. The policy dynamics that occurred in West Java began in 2007 and were protected. The policy could then not protect input-output from 2010 to 2020. This is clearly reflected by the EPC value, which continues to fall over time. A similar situation occurred in East Java, where the EPC value continued to fall, resulting in rice farming being unprotected from 2016 to 2020.



	2007	2010	2016	2020
Jabar	1.003	0.978	0.935	0.862
Jateng	0.984	0.768	0.793	0.912
Jatim	1.145	1.015	0.948	0.947

Figure 5. Efective Protection Coeficient

Meanwhile, from 2007 to 2020, the EPC value in Central Java remained stagnant and unprotected. This implies that the difference in income and tradable costs is higher at social prices than at private prices. This means that government policies, such as tax policies, reduce farmers' incentives; in other words, government protection becomes a disincentive that burdens farmers. Farmers, for example, must pay higher fertilizer prices, implying that they are taxed.

Furthermore, Table 4 shows the result of technical efficiency in rice farming on Java Island. It showed that the variable of intermediate input was significantly positive at a significance level of 1%. The increase in intermediate input led to a rise in total production. A one percent increase in intermediate input enhances total output by approximately 0.138%.

The labor coefficient was negative but not significant, implying that increasing the labor will decrease the yield of rice production. Small-scale family farming units majorly manage the rice production on Java Island and have always been labor-intensive because of the scarcity of arable land and abundant labor. As a result, it is not surprising that labor productivity in rice production is declining. This finding is consistent with the study conducted by Wang [20]. It concluded that surplus labor in the same plot of land leads to crowded plots and inefficient farming.

The coefficient of arable land has a positive sign and is statistically significant at 1%. An increase of 1% in the arable land input will escalate the total output by approximately 0.806%. It indicated that the average farm size was very small in almost all provinces; thus, increasing arable land increases total production. This result is in accordance with the previous work [21].

The coefficient of the capital variable has a positive sign but is not significant statistically. The dummy variable of provinces 1 and 2 is denoted for West Java and Central Java. The coefficient of West Java is positive and significant from the baseline of East Java. In contrast, the coefficient of Central Java is negative but not significant from the baseline of East Java. The dummy variable for years 1 and 2 is denoted for 2007 and 2010. The coefficient of the dummy year is negative, while the coefficient of dummy 2 is positive, indicating that productivity has increased during the observation period.

The result of the inefficiency model is shown in the lower part of Table 4. The dependent variable in this model is the

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inefficiency score, and the explanatory variables are farm characteristics and farming households' socio-economic status. The negative sign of the gender variable describes the outcome that male producer household heads are positively correlated to technical efficiency; it implies that increasing technical efficiency is possible if the principal rice producers are men.

Table 4. Determinants of Technical Efficiency of Rice Production in Java Island

Variable	Coefficient	Std. Error
General Model		
Constanta	7.9490***	0.2068
Intermediate input	0.1381***	0.0287
Labor	-0.0160	0.0167
Capital	0.0058	0.0097
Cultivated Area	0.8061***	0.0320
Province dummy 1	0.1356***	0.0313
Province dummy 2	-0.0201	0.0277
Year dummy 1	-0.0936**	0.0298
Year dummy 2	0.6190**	0.0278
Inefficiency Model		
Constanta	-3.1566	2.0958
Gender	-0.3413	0.2616
Age	0.0396	0.0750
Age2	-0.0003	0.0006
Land status	0.7718***	0.1661
Education	-0.0502**	0.0217
Ratio	0.6090**	0.2580
Crop intensity	0.0362	0.1364
Number of observation	525	
Log-Likelihood	-54.6274	
Wald chi^2 (8)	4173.43	
Prob>chi^2	0.000	
Average TE	0.8225	

Note: *Significant at 10% level; **Significant at 5% level; ***Significant at 1%level

The household head's age had a slightly positive effect on the inefficient. A farmer's age can be a proxy for his farming experiences; thus, the older household head is more experienced and capable of making an efficient rice farming decision [22]. In addition, the age square has been found to have a negative effect on inefficiency, but not significantly. This is partly because, as age increases, farming experiences and efficiency improve. However, it will have a negative effect on efficiency after a certain age interval because elderly farmers are thought to be more conservative in trying to implement modern technologies. This implies that the u-shaped relationship between age and efficiency has been inverted; in other words, efficiency increases with age up to a point and decreases with age increase. As a result, the elderly and younger farmers are not as efficient as the middle-aged farmers. Farming is like any other profession and requires accumulated knowledge, skill, and physical capability, the age of the farmer, is important in evaluating efficiency. Farmer's

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knowledge, skills, and physical capability will likely improve as they age. However, after a certain age, this tends to decrease. Elderly farmers will have the less physical capacity to carry out farming tasks efficiently. This finding is in accordance with [4] findings, which showed that aging the labor force exacerbates production efficiency.

The land ownership status significantly had a negative effect on efficiency. According to this finding, non-landholders are more technically efficient than landholders. This could be explained by self-selection in the land market and farmer behavior in the study area. Smallholder farmers who lease or sharecrop the land have the better managerial ability and good agricultural practices. Because the tenant farmers strive to manage production professionally and are receptive to new technology, allowing them to increase production and income. This finding is consistent with previous work by Fukui [23] in Central Java which stated that the production efficiency under tenancy land was equal with the landholders.

The education of the household head has been found to affect farm inefficiency. The findings suggest that farmers with a higher level of education can manage rice farming more efficiently. It is because education can improve their ability to acquire information, allowing them to make better decisions. Moreover, it will help them adopt modern agricultural technologies and produce more output while using existing resources more efficiently. In the studies of Rice farming in Eastern India [24] education was found to improve technical efficiency significantly. It explained that acquiring agricultural knowledge through education and training could increase production capacity and improve a farm's technical efficiency.

The ratio of family labor variable had a positive effect on the inefficiency. The presence of a positive coefficient indicates that family farmers are less efficient than hired labor. This interpretation contrasts with the previous work [25], arguing that family farmers had efficiency advantages over non-farm household producers or hired laborers. Family labor might be efficient and effective because they are more motivated as a residual claimant on farm revenues. In addition, they require fewer operational costs to operate their farm. However, this inconsistency may be due to family labor's lack of entrepreneurial spirit and other specialized skills, such as managerial abilities. The involvement of family labor might be a solution for family members to find work because of a lack of alternative job opportunities in rural Java Island and/or low opportunity costs, as well as to preserve family traditions and values. This may result in underemployment, a decrease in the marginal product of labor used, and a decrease in farm efficiency [26].

4. Conclusion

The following conclusions can be drawn from research and discussion on the competitiveness, profitability, and efficiency of rice farming in West Java, Central Java, and East Java

1. Rice farming is profitable in the three provinces at private and social prices. It is evident in the private and social benefits, which are both positive and increasing over time.
2. Rice farming in the three provinces remains competitive, even though the level of economic feasibility is decreasing. The indicators of comparative advantage and competitive advantage (DRC<1; PCR<1) show the level of competitiveness of rice farming. West Java, East Java, and Central Java had the highest competitiveness from 2007 to 2020.
3. Government policies affecting the output (NPCO) include government purchase price (HPP) and import tariff policies. The NPCO policy has not been maximized in Central Java, as the NPCO < 1 indicates that the domestic output price is less than the efficiency price (world price).
4. Input-related government policies (NPCI) have failed to protect rice farming in West Java, as evidenced by NPCI >1, indicating that the price of tradable inputs in the domestic market is higher than the price of efficiency (world prices).
5. The level of protection for simultaneous input-output policies in 2007-2020 is ineffective in all provinces, as indicated by an EPC <1.
6. The average technical efficiency of the three provinces in Java is around 0.82.
7. Land and intermediate inputs were the factor inputs that significantly increased technical efficiency. The land variable proved to be the most responsive input variable that boosts production; thus, the government and stakeholders should consider land expansion as a first option in raising the output quantity of small-scale rice producers in Indonesia, either in Java Island or outside Java in Indonesia. Increases in intermediate input lead to increases in total output.
8. Lastly, the inefficiency factors that significantly increased technical efficiency were land status, education, and the ratio of family labor.

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Appendix 1: Examples of Input-Output Parity Price

(a) Input-Output Parity Price (Rice)

NO		2007	2010	2016	2020
1	F.o.b Bangkok (Thailand) ($/Ton)	243	365	420	488
2	Freight and Insurance	24	37	42	49
3	C.i.f Indonesia (c/: Tanjung Perak Port, Jakarta)	267	402	462	537
4	Exchange Rate (Rp/$)	9.419	8.991	13.436	14.105
7	C.i.f in domestic currency (Rp/ton)	2.517.699	3.609.887	6.207.432	7.571.564
8	Weight conversion factor	1.000	1.000	1.000	1.000
10	Handling	126	180	310	379
11	Transportation and handling to merchant/ wholesaler (Rp/kg)	134	160	180	80
12	Marketing (Rp/kg)	6	10	10	6
13	Price before processing (grain → rice)	2.784	3.960	6.708	8.036
14	Processing Factor Conversion (grain → rice)	64%	64%	64%	64%
15	Cost of Rice Milling	334	330	182	100
16	Wholesaler-level Import Parity Price (Rp/kg grain)	1.781	2.535	4.293	5.143
17	Distribution costs to farmer (Rp/kg)	200	231	100	102
18	Farm-level Import Parity Price (Rp/kg grain)	2.315	3.096	4.575	4.941

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(b) Input-Output Parity Price (urea and sp-36)

		Urea	SP-36
1	F.o.b Yuzhny ($/Ton)		
	➢ F.o.b Yuzhny ($/Ton)	200	-
	➢ F.o.b Tunisian ($/Ton)	-	284
2	Freight and Insurance	88	37
3	C.i.f Indonesia (eg/:Tanjung Perak Port, Jakarta)	288	402
4	Exchange Rate (Rp/$)	13.436	13.436
7	C.i.f in Indonesia currency (Rp/ton)	3.857.472	5.062.932
8	Weight conversion factor	1.000	1.000
10	Handling	54	54
11	Transportation and handling to merchant/ wholesaler (Rp/kg)	115	115
12	Marketing (Rp/kg)	6	10
13	Price before processing	3.911,47	5.116,93
14	Processing Factor Conversion	100%	100%
15	Wholesaler-level Import Parity Price (Rp/kg)	4.026,47	5.2231,93
16	Distribution costs to farmer (Rp/kg)	30	30
17	Farm-level Import Parity Price (Rp/kg)	4.056,47	5.261,93

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Coffee Plants' Endomycorrhizae Potential to increase the growth and nutrient uptake of Arabica Coffee (*Coffea arabica* L.) under Field Condition

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Abstract

Inorganic fertilizers utilization is the most common way to increase plant productivity. However, the intensive use of organic fertilizer can harm the environment. Therefore, alternative fertilization by utilizing soil microorganisms to provide plant nutrients is needed. Endomycorrhizae is known as a microorganism that can increase the availability of nutrients and plant growth. This study aimed to determine the potential of endomycorrhizae to increase the growth of arabica coffee seedlings under field conditions. A Randomized Complete Block Design (RCBD) with 5 replications was used with four treatments, i.e., (P0) control: without endomycorrhizae and fertilizer, (P1) inorganic fertilizer: NPK recommended dose for seedlings nine months after sowing (N 184 kg/ha, P_2O_5 72 kg/ha, and K_2O 120 kg/ha from 400kg/ha urea, 200 kg/ha SP-36, and 200 kg/ha KCl, respectively), (P2) endomycorrhizae: 1:1 (w/w basis) endomycorrhizal inoculum-planting medium, and (P3) endomycorrhizae + organic fertilizer: 1:1 (w/w basis) endomycorrhizal inoculum-planting medium with the addition of chicken manure at a dose of 10 tons/ha. The results showed that endomycorrhizae could increase the growth of arabica coffee seedlings by increasing plant height, plant dry weight, and plant N, P, and K uptake by 15.4%, 23.3%, 52.5%, 90.8%, and 75.6%, respectively compared to the control with 67,5% of root colonization at 16 weeks after transplanting (WAT). In conclusion, endomycorrhizae can potentially increase the growth of arabica coffee seedlings under field conditions.

Keywords: *endomycorrhizae, growth, arabica coffee, fertilizer*

1. Introduction

Indonesia is the fourth largest coffee-producing country in the world after Brazil, Vietnam, and Columbia (1). Coffee is a commodity that has a vital role in the economy of Indonesia. The area of coffee plantations in Indonesia is around 1.245 million hectares, with average productivity is 794 kg/ha in 2019 (2). However, it is relatively low compared to coffee productivity in Vietnam which reached 2.78 tons/ha in the same year (3).

One of the factors that cause low productivity of coffee in Indonesia is suboptimal maintenance, especially fertilization (4,5). Fertilization is a critical process for growing coffee plants because it replaces nutrients lost from the soil due to sedimentation, volatilization, and absorption; thus, the plant's nutrients can be fulfilled. Plant's nutrient deficiencies can affect growth, such by inhibiting metabolic processes and negatively affecting crop productivity (6). Coffee is an annual plant that requires a lot of nutrients during its life cycle. A hectare of coffee plantation requires 53.2-172.0 kg N, 10.5-36.0 kg P_2O_5, and 80.7-180.0 kg K_2O annually. Thus, fertilization needs to be applied annually to fulfill the nutrient needs of coffee plants (7,8).

Inorganic fertilizers are the most common way to supply plant nutrients and increase plant productivity (9). However, the intensive use of inorganic fertilizers can harm the environment and other organisms, e.g., soil and water pollution through nutrient leaching, destruction of soil physical characteristics, accumulation of toxic chemicals in water bodies, as well as causing loss of biodiversity (10–12). Alternative fertilization by utilizing soil microorganisms that have specific activities in providing nutrients for the plant is needed in coffee cultivation (13).

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Arbuscular mycorrhizal fungi (AMF) or endomycorrhizae is a well-known biofertilizer that usually replaces inorganic fertilizer because it can increase plant productivity by optimizing the absorption of nutrients in the soil (11). It can also improve soil fertility, such as soil aggregation, nutrient availability, microbial activities, nitrogen, carbon, and phosphorus cycling (14). AMF can recruit Phosphate Solubilizing Bacteria (PSB) that produce phosphatase to mineralize insoluble phosphate in the soil and release soluble P that can easily be assimilated by plants (14,15). Endomycorrhizae have a mutualistic symbiosis with plant roots by forming intra-extraradical mycelium, spores, vesicles, and arbuscular structures that provide additional nutrients for plants (16). More than 150 endomycorrhizal species can be symbiotic, with 90% of vascular plant species and 80% of terrestrial plants, including coffee (17,18). The results of previous studies reported that endomycorrhizal inoculation in coffee plants improved the growth of arabica coffee plants at the initial production phase (1.5 years after planting) by increasing plant height, stem diameter, and the number of branches compared to the plant without endomycorrhizae application (8). Moreover, endomycorrhizae also potentially reduce the dose of NPKMg fertilizer by up to 50% (4).

Based on previous research conducted by Sari (19), isolates of endomycorrhizal, *Fusarium oxysporum*, from Arabica coffee plants in Malabar coffee plantations, Bandung Regency, and Genteng Village, Sumedang Regency, have enzymatic activities such as hydrolysis of starch and cellulose, phosphate solubilization, and IAA production. It also can hasten the time of arabica coffee seed germination from 31 to 20 days after sowing. However, the potential of endomycorrhizal isolates in the growth of Arabica coffee seedlings under field conditions was not known yet. Thus, this study was carried out to determine the potential of endomycorrhizal *F. oxysporum* in increasing Arabica coffee seedlings' growth and nutrient uptake under field conditions.

2. Methodology

2.1. Preparation of Endomycorrhizae Inoculum

The endomycorrhizal starter inoculum, *Fusarium oxysporum*, was obtained from the Microbiology Laboratory, SITH-ITB, Bandung, West Java, Indonesia, in a solid media containing sterile soil and potato extract 1:1 (w/v basis) as a carrier medium. The endomycorrhizal starter inoculum was multiplication in the soil-compost substrate (1:1 w/w basis) with the ratio of 1:10 (w/w basis) and incubated for 72 hours to obtain the endomycorrhizal density of 2 x 10^6 CFU/g (20).

2.2. Experimental Design, Endomycorrhizal Inoculation, and Planting

The experiment was carried out in Suntenjaya Village, Lembang District, West Java (6°49'19" S, 107°42'18" E, and an altitude of 1,307 masl) from October 2020 to February 2021. The experiment was carried out under field conditions with an average temperature of around 22.3-24.5°C, relative humidity of around 57.1-84.4%, and rainfall of about 2,000 mm/year. A Randomized Complete Block Design (RCBD) with five replications was used with four treatments, i.e., (P0) control: without endomycorrhizae and fertilizer, (P1) inorganic fertilizer: NPK recommended dose for seedlings nine months after sowing (N 184 kg/ha, P_2O_5 72 kg/ha, and K_2O 120 kg/ha from 400kg/ha urea, 200 kg/ha SP-36, and 200 kg/ha KCl, respectively), (P2) endomycorrhizae: 1:1 (w/w basis) endomycorrhizal inoculum-planting medium, and (P3) endomycorrhizae + organic fertilizer: 1:1 (w/w basis) endomycorrhizal inoculum-planting medium with the addition of chicken manure at a dose of 10 tons/ha.

Polybags 25 cm x 25 cm were filled with planting medium. P0 and P1 treatments were filled with 5 kg soil as a planting medium. In comparison, P2 and P3 treatments were filled with 2.5 kg soil and 2.5 kg endomycorrhizal inoculum (1:1 w/w basis) as a planting medium, resulting in the medium weight of 5 kg for each treatment. In the P3 treatment, 28.41 g of chicken manure (dose of 10 tons/ha) was added to the planting media at the same time with endomycorrhizal inoculum application. All polybags containing planting media were incubated for seven days before transplanting Arabica coffee seedlings (21). Application of NPK fertilizer for P1 treatment was carried out once at 4 weeks after transplanting. The chemical properties of the soil used in this study are listed in Table 1.

Table 1. Chemical characteristics of the soil in the experimental area

Soil Properties	Value	Criteria*
pH H_2O	5,6	Slightly acid
C-Organic (%)	3,37	High
Total N (%)	0,41	Moderate
C/N Ratio	8	Moderate
Available P (mg/kg)	491,1	Very high
Available K (mg/kg)	60,4	Very high

*Criteria for Soil Research Hall in Technical Guidelines for Chemical Analysis of Soil, Plants, Water, and Fertilizers (2009)

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Arabica coffee seedlings used in this study were eight months old after sowing. The planting technique was done according to the Technical Guidelines for Good Coffee Cultivation (22). According to the treatment, each polybag containing planting media was planted with an Arabica coffee seedling with a straight-down root position, then the coffee plants were watered. Watering and controlling plant pest organisms was carried out manually for 16 weeks during the experiment (23). Plant's height and diameter were measured after initial planting as initial data (day 0) for this experiment.

2.3. Growth Parameters of Arabica Coffee Seedlings

The growth parameters of arabica coffee seedlings were observed and collected four times during the 16 weeks experiment. Plant height was measured using a ruler from the base of the stem to the tip of the shoot. The stem diameter was measured using a digital caliper of 2 cm from the planting medium (23).

2.4. Endomycorrhizal Root Colonization

Fine root samples from each treatment and replication were collected randomly at 16 weeks after transplanting. Root samples were carefully washed with distilled water and cut into 1 cm long segments, then soaked in 10% (w/v) KOH for 12 hours, rinsed in tap water, acidified in 2% HCl (v/v) overnight, and stained with 0.05% (w/v) trypan blue in lactoglycerol. Excess solution on the roots was removed with lactoglycerol solution (24). The stained root segments were arranged on the object-glass and observed under a microscope at 400 times magnification. The root colonization rate was calculated using the following formula (25) :

$$\text{Root colonization rate (\%)} = \frac{\text{number of infected roots}}{\text{numbers of all observed root}} \times 100\% \quad (1)$$

2.5. Plant Analysis

The seedlings from each treatment and replication were harvested randomly at 16 weeks after transplanting (WAT), then cleaned from the soil particles. The dry weight of plants was determined by drying them in the oven at 70°C to a constant weight (about 48 hours) and weighed as plant dry weight (21). The dried plants were ground to a fine powder (<2 mm). Fine plant powder was used for the analysis of plant nutrient contents. The plant nutrient contents were determined as follows: N content was determined by distillation after digestion by the Kjeldahl method, and a spectrophotometer determined P content at 889 nm. In contrast, K content was determined by atomic absorption spectrophotometer after wet digestion (26). Plant nutrient uptake was calculated using the following formula:

$$\text{Nutrient uptake (g/plant)} = \text{plant dry weight (g)} \times \text{plant nutrient content (\%)} \quad (2)$$

2.6. Statistical Analysis

The obtained data were analyzed with one-way analysis of variance (ANOVA) after checking the normality of data and homogeneity of variances. It was then followed by Duncan Multiple Range Test (DMRT) at a significant level of 0.05 using IBM SPSS Statistics version 25.0 (20).

3. Result and discussion

3.1. Seedlings Growth

Figure 1 shows plant height at 0 to 16 weeks after transplanting. This study showed that endomycorrhizal (P2) increased plant height by 15.4% at 16 WAT compared to the control (P0), although not statistically significant ($p > 0.05$). The application of endomycorrhizae and chicken manure (P3) increased the plant height by 32.2% at 16 WAT. These differences were statistically significant ($p \leq 0.05$) compared to the control (P0). This result showed that a combination of organic fertilizer and biofertilizers gives better growth than a single use of biofertilizers and has almost similar growth with a recommended NPK fertilizer (P1) as standard fertilization. It might be because organic fertilizer contains organic sources that are useful for biofertilizers' growth and increase the soil's activity (27). In addition, using chicken manure as organic fertilizer increases the mineral content in the soil compared to without chicken manure, so the plant's nutrients can be fulfilled and produce optimal growth (28).

Figure 2 shows the stem diameter of the plant from 0 to 16 weeks after transplanting. All treatments in this study did not have any significant differences based on one-way ANOVA statistical analysis ($p > 0.05$). However, plants treated with endomycorrhizae, either P3 or P2 in this study, had a larger diameter than the control (P0) during 16 weeks of the experiment by 3.51 mm and 3.43 mm, respectively. The highest stem diameter was found in the P1 treatment (3.80 mm), while the lowest stem diameter was found in the P0 treatment (3.28 mm). This finding was in line with the study by Daras et al. (8) and Wang et al. (27). They mentioned that the growth of the plants inoculated with endomycorrhizal was increased compared to the non-inoculated plants. It might be because endomycorrhizae can increase plant nutrient uptake, resulting in increased growth. Clark and Zeto (28) and Heijden et al. (18) stated that various plant nutrients such as P, N, K, Ca, Mg, Cu, and Zn can be absorbed efficiently by endomycorrhizae through the role of extraradical mycelium (29).

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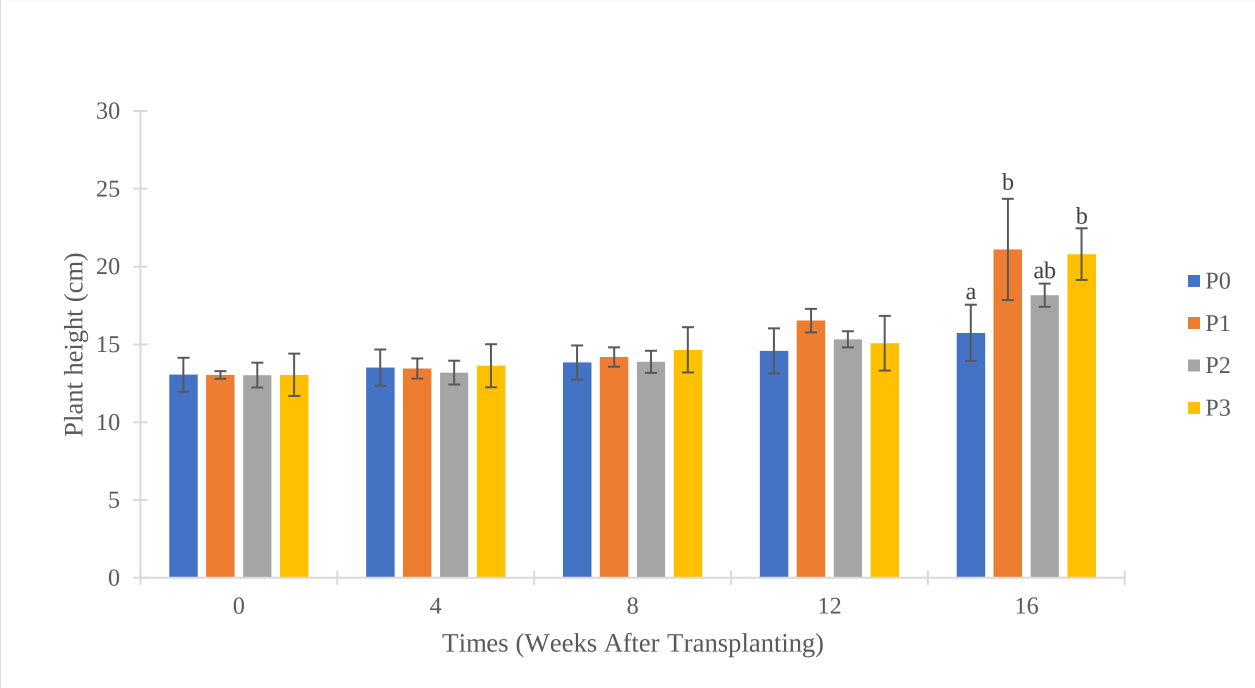

Figure 1. Arabica coffee plant height at 0, 4, 8, 12, and 16 weeks after transplanting (MSP). P0: control (without endomycorrhizae and fertilizers), P1: inorganic fertilizer (NPK recommended dose for seedlings nine months after sowing (400 kg/ha urea, 200 kg/ha SP-36, and 200 kg/ha KCl)), P2: endomycorrhizae (1:1 (w/w basis) endomycorrhizal inoculum-planting medium), P3: endomycorrhizae + organic fertilizer (1:1 (w/w basis) endomycorrhizal inoculum-planting medium) with the addition of chicken manure at a dose of 10 tons/ha. The vertical bar represents the standard deviation. Different letters represent significant differences on the Duncan Multiple Range Test at a significant level of 0.05.

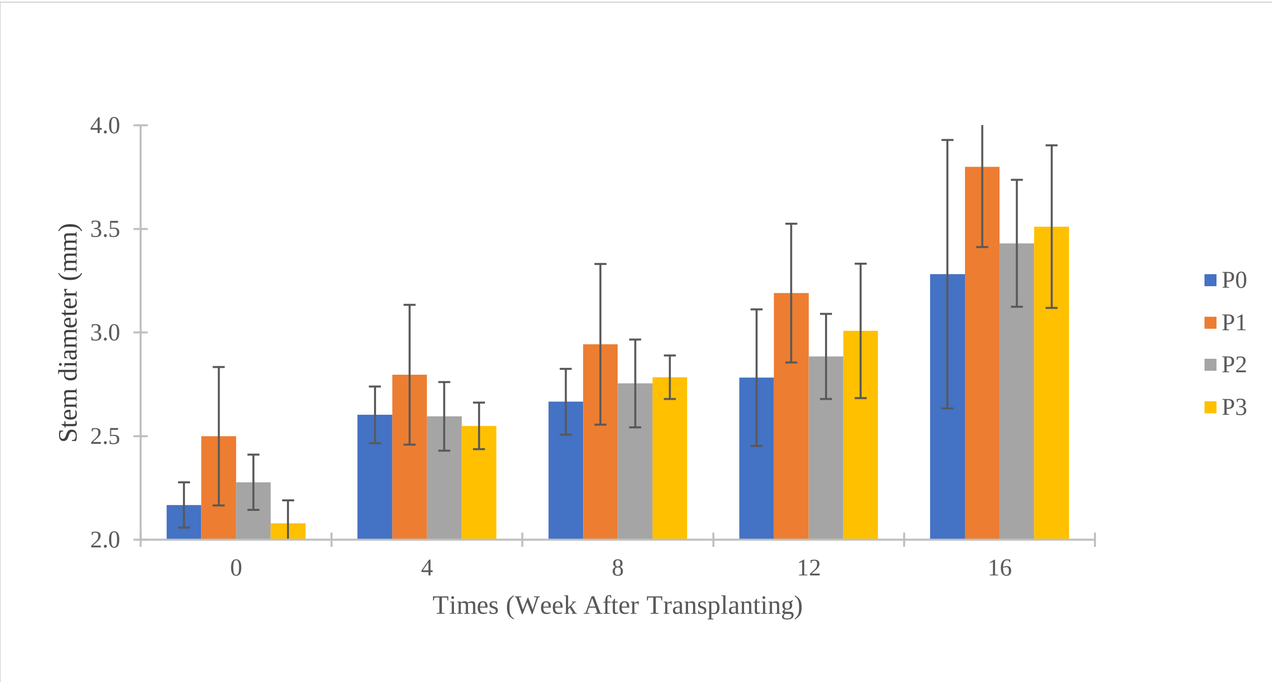

Figure 2. Stem diameter of arabica coffee plants at 0, 4, 8, 12, and 16 weeks after transplanting (MSP). P0: control (without endomycorrhizae and fertilizers), P1: inorganic fertilizer (NPK recommended dose for seedlings nine months after sowing (400 kg/ha urea, 200 kg/ha SP-36, and 200 kg/ha KCl)), P2: endomycorrhizae (1:1 (w/w basis) endomycorrhizal inoculum-planting medium), P3: endomycorrhizae + organic fertilizer (1:1 (w/w basis) endomycorrhizal inoculum-planting medium) with the addition of chicken manure at a dose of 10 tons/ha. The vertical bar represents the standard deviation.

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3.2. Endomycorrhizal Root Colonization

The colonization of endomycorrhizal on coffee plant root was observed in all treatments. It was characterized by intercellular and intracellular mycelium, arbuscules, and vesicles in the root tissue. Analysis of variance indicated a significant effect of treatments ($p \leq 0.05$) at 16 WAT (Figure 3). P2 and P3 treatments significantly had higher root colonization than the treatment without endomycorrhizal inoculation (P0, P1). The highest root colonization (67.5%) was found in the endomycorrhizal treatment (P2), while the lowest root colonization (2.7%) was found in the recommended dose of NPK treatment (P1). This finding was in line with the study by Juntahum et al. (20), who mentioned that the plant inoculated with endomycorrhizal had higher root colonization than without inoculation. Low endomycorrhizal colonization on plant roots in fertilizer treatment, both organic and inorganic, was due to the inability of endomycorrhizae to colonize plant roots in a high concentration of soil nutrients. Verbruggen and Kiers (30) stated that fertilizer application, especially the application of mineral-P and N fertilizer, causes the reduction of the resource allocation for mycorrhizae by the host plant, thereby reducing the rate of root colonization.

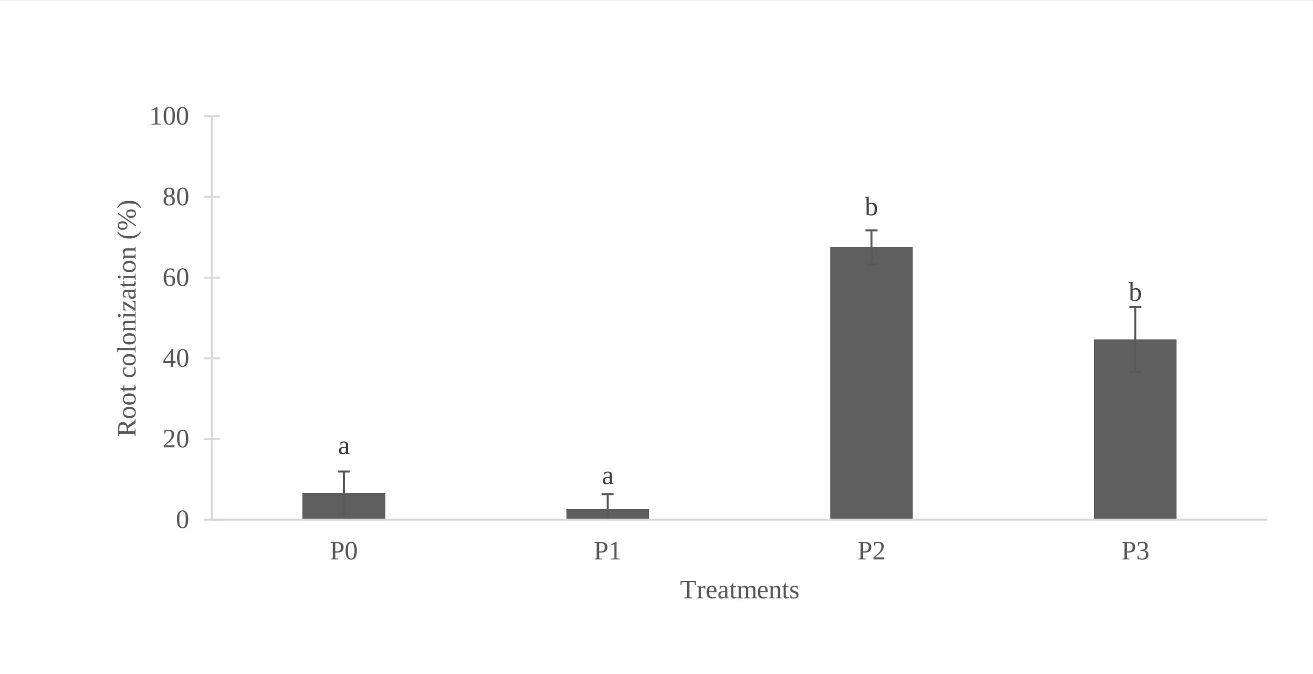

Figure 3. Percentage of root colonization at 16 weeks after transplanting (MSP). P0: control (without endomycorrhizae and fertilizers), P1: inorganic fertilizer (NPK recommended dose for seedlings nine months after sowing (400 kg/ha urea, 200 kg/ha SP-36, and 200 kg/ha KCl)), P2: endomycorrhizae (1:1 (w/w basis) endomycorrhizal inoculum-planting medium), P3: endomycorrhizae + organic fertilizer (1:1 (w/w basis) endomycorrhizal inoculum-planting medium) with the addition of chicken manure at a dose of 10 tons/ha. The vertical bar represents the standard deviation. Different letters represent significant differences on the Duncan Multiple Range Test at a significant level of 0.05.

3.3. Plant Dry Weight and Nutrient Uptake

Analysis of variance indicated a significant effect of treatment ($p \leq 0.05$) to plant dry weight and nutrient uptake at 16 WAT (Table 2). Application of endomycorrhizal with the addition of chicken manure (P3) and recommended dose of NPK fertilizer (P1) treatments significantly enhanced plant dry weight than the control (P0). Meanwhile, endomycorrhizal inoculation (P2) slightly increased plant dry weight by 16.6% compared to the control (P0); thus, it was not significant statistically (p>0.05). The plant dry weight showed a higher value, an increase of around 38.7% compared to the control (P0) in endomycorrhizal treatment with the addition of chicken manure (P3). These differences were statistically significant ($p \leq 0.05$), suggesting that the endomycorrhizal application needs to be supplemented with organic fertilizer to increase plant dry weight. This finding was in line with the study by Abreu et al. (31). They mentioned that the application of endomycorrhizae with the addition of organic fertilizer could increase plant dry weight due to better physiological performance by root colonization than without endomycorrhizal application. Yang et al. (32) mentioned that the addition of organic matter had a beneficial effect in stimulating endomycorrhizae hyphal growth, sporulation, and root colonization. The production of endomycorrhizae extraradical mycelia can increase the plant's capacity to uptake

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nutrients and water efficiently for biomass accumulation, increasing plant dry weight (33).

Plant nutrient uptake was increased in the recommended dose of NPK fertilizer (P1) and endomycorrhizal (P2 and P3) treatments compared to the control (P0) (Table 2). Generally, plant nutrient uptake in the control treatment (P0) always shows a minor performance and recommended dose of NPK fertilizer (P1) was more effective than the other treatments in increasing N uptake. However, P and K uptake were more effective under endomycorrhizal with the addition of chicken manure (P3) treatment. Meanwhile, endomycorrhizal treatment (P2) was significant statistically ($p \leq 0.05$) to N and K uptake compared to control (P0) with an increase by 52.5% and 75.6%, respectively, but was not significant statistically ($p > 0.05$) to P uptake. This finding was in line with the study by Juntahum et al. (20), who mentioned that N and K nutrient uptake in endomycorrhizal inoculated plants was higher than in the control treatment. P uptake by endomycorrhizae was not significantly different compared to control due to a very high soil available P (Table 1), thereby endomycorrhizae reducing the capacity of P uptake in P-rich soils (30).

Table 2. Effect of endomycorrhizal inoculation and fertilization on dry weight and nutrient uptake of arabica coffee plants at 16 weeks after transplanting

Treatments**	Plant dry weight (g)*	Nutrient uptake (g/plant) *		
		N	P	K
P0	12,47 ± 2,07 ^{a}	29,26 ± 2,84 ^{a}	7,30 ± 1,57 ^{a}	13,75 ± 0,97 ^{a}
P1	20,61 ± 2,13 ^{c}	57,56 ± 15,60 ^{c}	18,34 ± 8,52 ^{b}	34,87 ± 11,73 ^{c}
P2	14,54 ± 2,68 ^{a}	44,66 ± 1,39 ^{b}	13,93 ± 2,45 ^{ab}	24,15 ± 1,13 ^{b}
P3	17,30 ± 2,32 ^{b}	49,42 ± 5,31 ^{bc}	20,70 ± 4,65 ^{b}	39,81 ± 1,80 ^{c}

*Values represent mean ± SD (n=5). Values with different letters in each row indicate significant differences between treatments (p-value ≤ 0.05; DMRT test).

**P0: control (without endomycorrhizae and fertilizers), P1: inorganic fertilizer (NPK recommended dose for seedlings nine months after sowing (400 kg/ha urea, 200 kg/ha SP-36, and 200 kg/ha KCl)), P2: endomycorrhizae (1:1 (w/w basis) endomycorrhizal inoculum-planting medium), P3: endomycorrhizae + organic fertilizer (1:1 (w/w basis) endomycorrhizal inoculum-planting medium) with the addition of chicken manure at a dose of 10 tons/ha.

Generally, plants with endomycorrhizal treatment have a better NPK uptake because endomycorrhizal form a network of very massive mycelium on the roots of the host plant and the rhizosphere area, allowing mycorrhizal plants to exploit large volumes of soil, which results in increased nutrient uptake (4). The increase in nutrient uptake occurs because endomycorrhizae have inorganic phosphate (Pi) *Pt4* transporters with high affinity on the surface of extraradical mycelium; thus, it can accumulate polyphosphate (polyP) along their mycelium, which then enters the host plant tissue (34). In addition, plants colonized by endomycorrhizae also have nitrogen transporter *AMT2*, which is active in absorbing NH_4^+ and NO_3^- (35). Meanwhile, plant K uptake increased along with P uptake because plants absorb K+ as a counter ion of short-chain polyP granules in mycorrhizal vacuoles to regulate Pi homeostasis (36).

4. Conclusion

Endomycorrhizae treatment (P2) have the potential to increase the growth of arabica coffee seedlings under field condition with an increase in plant height, plant dry weight, and plant N, P, and K uptake by 15.4%, 16.6%, 52.5%, 90.8%, and 75.6%, respectively compared to the control (P0) with 67.5% of root colonization at 16 WAT. Plant growth increment is due to the ability of endomycorrhizae to efficiently absorb water and plant nutrients through the role of extraradical mycelium. However, added endomycorrhizae with chicken manure increases plant growth and nutrient uptake more than using endomycorrhizae as a biofertilizer.

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