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Doctoral Dissertation

Research on a Geographic Information System (GIS) to Assist Farmers in Making a Decision Regarding Commodity Selection and Land Evaluation

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Abstract

This study proposes a framework of the Geographic Information System (GIS) to assist farmers in decision-making. Bandung Regency is one of the centers of agriculture in the province of West Java. The main agricultural product of this district is vegetable commodities, but the production of food crops is also one of the pillars of the fulfillment of food needs in Indonesia. Bandung Regency area was chosen as the study area because it has good potential for agriculture. The challenge that motivates the Research on GIS is that farmers can use GIS directly and practically to assist in decision making. This study divides into three major stages. The first stage aims to develop a decision-making system for selecting potential commodities in Indonesia. This stage generates commodity rankings to support efficiency-based agriculture. This study complements the AHP method with alternative selection and classification. It is because there are so many commodities that farmers can cultivate. We select agriculture commodities based on plant characteristics and the topology of Indonesian agricultural areas to make alternative comparisons equal. The final ranking shows that the AHP method with selection and classification extension on the criteria makes the commodity ranking more valid. The second stage integrates the Multi-Criteria Decision Making (MCDM) with Geographic Information System (GIS) Method to evaluate the land suitability for potential commodities. This study proposed framework for land suitability evaluation. The first part the framework focuses on providing Georeferenced to the collected data. Part two focuses on building the thematic maps layer. In the third part, this study complements the AHP method with alternative selection and classification. We provide limitations and classifications of alternative selection based on plant characteristics and the topology of Bandung District agricultural areas. Based on the distribution of land suitability areas, then comparing with the statistical data of the current situation, this second stage concludes that the integration between MCDM and GIS methods can produce valid and relevant land suitability maps. The last research stage aims to integrate GIS with AR visualization capabilities to present interactive 3D maps. This study proposes a mobile-based system to visualize land suitability maps to make it easier for farmers to understand the map. Then to enrich the usability aspect, this study equips the system with augmented reality features. This study evaluates the system with two testing methods. The first testing method is the performance test, and the second is a qualitative test using a questionnaire that aims to find out the user's response to the system. Based on the evaluation results, this study can conclude that overall, AR-GIS can provide good information visualization. However, some farmers still have difficulties in understanding

the land suitability map. In future research, adding collaboration features to AR-GIS will be a challenging topic. Collaborative AR can facilitate the knowledge exchange between farmers, GIS experts, and other stakeholders. The system with Collaborative AR-GIS is expected to enhance the farmer's understanding of the land suitability map. Furthermore, with good insight into the land suitability map, it is hoped that it will reduce the risk of crop failure and increase the productivity of the agricultural sector in the future.
Keyword: Augmented Reality GIS, Commodity Selections, Decision-Making, Land Suitability Evaluation, MCDM.

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The author realizes that the preparation of this thesis is far from perfect, so constructive criticism and suggestions are expected so that the author can compose better work. Hopefully, this thesis can be useful, and may Allah SWT give abundant wisdom to all of us, amen.

Contents

List of Figures

List of Tables

Chapter 1.
Introduction

Global warming causes climate change which has a significant impact on various aspects of life. In agriculture sectors, changes in rainfall patterns and increases in air temperature cause a decrease in agricultural productivity [1]. In the agricultural sector, climate change threatens the sustainability of agricultural production, especially food crops and vegetables. The best bet to overcome the decline in agricultural productivity due to climate change is the innovation of technology-based agriculture [2]. The geographic information system is a specific information system that manages spatial data and information. The Agriculture GIS can make it easier for farmers to manage land effectively and in detail[3]. GIS can help farmers to find out the optimal potential of agricultural land[4].

1.1 Motivations

Indonesia has a strategic geographical location. The location of Indonesia is between two continents and two oceans. Indonesia only has two seasons. From October to April, the wind blows from the Asian continent to Australia. This wind contains a lot of water vapor, causing the rainy season. Then around April to October, the wind blows from Australia to Asia. The winds blowing from Australia contain little water vapor causing a dry season. This condition makes Indonesia only have two seasons [5]. In addition, the equator stretches along with the territory of Indonesia. It makes Indonesia have a tropical climate with balanced rainfall[2]. Indonesia's climatic conditions are very suitable for developing agriculture. Based on data from the Research and Development Agency of the Ministry of Agriculture, Indonesia can cultivate most of the plants in the globe[6]. It proves that Indonesia's agricultural area has outstanding potential.

The total population of Indonesia in 2010 was 238 million people. In 2020 the population in Indonesia was 270.20 million people. According to the Ministry of Communication and Information, Indonesia's average population growth rate is 1.25 percent per year. The value of this population growth rate is in the period 2010-2022. According to the Central Statistics Agency, the population in Indonesia will reach 321 million in 2045 [7]. The increase in population causes domestic food needs to increase. The agricultural sector has a significant role in fulfilling domestic food needs[8]. Unfortunately, the agricultural sector in Indonesia has decreased. This decrease occurred due to the conversion of land into industrial and residential land. Another crucial problem in Indonesia agriculture is crop failure. One cause of crop failure is that it is difficult for farmers to predict the weather, making it hard to determine cropping patterns[9]. This problem also makes it hard for farmers to consider and select commodities.

Geographical conditions have a crucial role in agriculture[10]. The geographical aspect is also a significant factor in decision-making in agriculture. Various open data sites provide geographic data[11], [12]. Farmers should be able to use this data as material for consideration in making decisions in the agricultural sector. Unfortunately, farmers have not been able to utilize the data optimally. Existing data have various data format[8], [13]. Geographic data is usually larger in size than regular tabular data. It is because geographic data has spatial information that distinguishes geographic data from other data. Many studies have proven that GIS can effectively process geographic data for various purposes[14]–[17]. In the agricultural sector, GIS plays a role in mapping land, mapping fertilizer distribution, mapping disease distribution, mapping irrigation channels, and evaluating land suitability[18]–[22].

Based on data from the Bandung Regency Agriculture department, most farmers in the Bandung district are sharecroppers. They do not cultivate on their agricultural land. One example is a farmer in Tarumajaya Village, Kertasari District. In this area, only 97.7 Ha or 3.6% of the total agricultural area is the land of individual farmers. Meanwhile, almost 60% of its citizens are farmers. Most farmers cultivate crops on government-owned land. The government allows the residents of Bandung Regency to manage part of the forest area for agriculture. Sometimes some of them work on forests located in other sub-districts. Therefore, it is necessary to know the suitability of the land for a large area. The large area of maps can help farmers get information about land suitability. Farmers need to know about land suitability not only in the sub-district where they live but also in other sub-districts.

Indonesia has implemented GIS in agriculture since 1974 [23]. Unfortunately, the use of GIS is only limited to large-scale companies and government agencies [24]. Most farmers are traditional farmers[8]. They cannot use GIS directly. So, farmers are not able to take advantage of GIS. In addition, decision-making in agriculture requires large amounts of spatial data[14]. In addition, it is hard for farmers to understand the information available on the map. Farmers need high spatial thinking skills, especially concerning the topographic map. Furthermore, there are some significant weaknesses in GIS agriculture. 1) Most agricultural GIS is a computer-based system. Most of the farmers are more familiar with the mobile-based system [12]. It's because few farmers use computers in daily activity. (2) GIS has a complex interface for novice users. GIS requires a high level of user expertise. (3) GIS only focuses on providing information but sometimes neglects the user aspect. These problems motivated us to develop GIS to assist farmers in agriculture decision-making.

This study proposes a framework of the Geographic Information System (GIS) to support farmers in selecting Potential Commodities, evaluating land suitability, and providing new ways to visualize land suitability maps. We expect that the proposed system can improve GIS usability by farmers.

1.2 Research Objective

This study proposes a framework of the Geographic Information System (GIS) to assist farmers in decision-making. This study divides the research objectives into three main research objectives as follows:

First, to determine the potential agricultural commodities in Indonesia. The determination process uses the Multi-Criteria Decision Analysis (MCDA) method by considering economic, plant characteristics, and environmental factors. The method used in this decision-making was the Analytic Hierarchy Process (AHP) method.

Second, integrate the Multi-Criteria Decision Making (MCDM) with Geographic Information System (GIS) Method to evaluate the land suitability for potential commodities. Accurate data is an essential part of GIS. In making a land suitability map, the difference in value and range of criteria can cause a difference in land suitability output. This study uses three main decision criteria and nine sub-criteria. AHP method generates weights for the thematic Layer. The weight is needed to overlay the thematic Layer using the Weighted overlay method. According to the Food and Agriculture Organization of the United Nations (FAO), Climate, soil, and topography factors are crucial in agriculture.

Last, we integrate GIS with AR visualization capabilities to present interactive 3D maps. We propose a mobile-based system to visualize land suitability maps to make it easier for farmers to understand the map. Then to enrich the usability aspect, we equip the system with augmented reality features. We utilize unity3D's capabilities in visualizing virtual environments. However, despite having a powerful ability to make the real-world environment, Unity3D does not have a projection/coordinate system. We use the Mapbox extension to cover these weaknesses. The processed map is then uploaded to the Mapbox cloud and converted into Mapbox tile set format. This research also explores Unity3D's ability to provide spatial data. We expect the use of Augmented Reality to enrich GIS with a better map visualization. Furthermore, we hope that the proposed system can improve GIS Usability by farmers.

1.3 Dissertation outlines

This Thesis divide into six chapters as follows:

Chapter one contains motivation for conducting research. First, it explains the needs, conditions, and potential of agriculture in the study area. Then this chapter also discusses the difficulties and problems experienced by farmers related to decision-making in agriculture. Finally, this chapter describes the objectives and design solutions related to the farmer's difficulty in decision-making. The solution design is described in the research objective.

The second chapter explains the theoretical background of the research. The first part of this chapter introduces the theory of GIS and other related theories. The second part describes the GIS method and how to combine GIS with MCDA. The third part introduces Augmented reality which can be an alternative in visualizing maps, and the last part reveals the research question of this research.

The third chapter describes the process of determining Potential agriculture commodities using the multi-criteria decision analysis approach. The selection of this commodity aims to support effectiveness-based agriculture. By choosing potential agricultural commodities, it is hoped that agricultural productivity will increase. This chapter describes related works, research methods, and a detailed process of determining potential agricultural commodities. The results of determining the ranking of these commodities become a reference for the next chapter.

Chapter 4 describes the integration of MCDM with GIS Methods to produce Land Suitability Maps. This chapter makes land suitability maps for the top-ranking commodity in the previous chapter. First, we describe the issues related to farmers' difficulty on current land suitability maps. Second, discuss related work. Then explain the method and detailed process of making land suitability maps. The output of this chapter is a map of land suitability for agricultural commodities.

Chapter 5 describes the process of visualizing land suitability maps using augmented reality. The first part of this chapter describes the problems faced by farmers and the weaknesses of the existing GIS. Then this chapter describes the process of creating an AR-GIS to improve the usability of land suitability maps. We evaluate the system with two methods. The first method is a performance test, while the second method is a questionnaire to analyze the user's response to the system.

At the end of the chapter, we evaluate the test results and draw conclusions.

Chapter 6 contains conclusions and future research. This chapter first concludes the research results from the previous chapter. Then the research contribution is also mentioned in this chapter. Some things that still need to be improved in this research become a reference for future research. The last part of this chapter describes the direction of future research plans.

Chapter 2. Background

2.1 Geographic Information System

Experts define GIS based on various perspectives. Some researchers focus on the map perspective. Some researchers view GIS from the perspective of a system and relational database. The others define GIS with a system application perspective. In general, experts explain GIS based on its functions and components. These two things are significant to understand GIS optimally. Here are some definitions of GIS according to experts.

GIS is a computer-based tool to analyze and map the features found on the earth. GIS integrates databases with the unique visualization and geographic analysis capabilities.

a. GIS is a computerized system for capturing, retrieving, storing, analyzing, and displaying spatial data of a region [25].
b. GIS is a system consisting of several elements of hardware, software, and procedures designed to capture, manage, analyze, model, and display spatially referenced data to solve complex planning and management problems [26]
c. GIS is a decision-making system that involves the integration of spatial data in a problem-solving environment [27].
d. GIS is a powerful tool for collecting, storing, retrieving, transforming, and visualizing spatial data from the real world [28].
e. GIS is a set of procedures used to store and manipulate geographically referenced data manually or computerized [29].
f. GIS is an institutional entity, reflecting an organizational structure that integrates technology with databases, expertise, and financial support [30].
g. GIS is a system consisting of hardware, software, data, people (brain ware), organizations, and institutions to collect, store, analyze, and disseminate information about areas on the earth's surface [31].

Based on the definition of experts, it can be concluded that GIS is a computerized system consisting of hardware components, software, and procedures for capture, store, retrieve, manage, transform, analyze and visualize data that has geographic references. GIS has developed very rapidly. Various disciplines use GIS to perform geospatial data analysis. GIS can connect data at a certain point on the earth, combine, analyze, and visualize the results. GIS can process both tabular and spatial data. Spatial data is geographically oriented data that has a coordinate system as a reference. So that GIS applications can answer several questions such as location, conditions, trends, patterns, and modeling. This capability is what distinguishes GIS from other information systems [32]

2.2 Multi-Criteria Decision Making

Multi-Criteria Decision Making (MCDM) is a method to determine the best alternative from several alternatives based on several criteria. MCDM is an extension of decision-making theory with multiple goals[33]. Belton and Steward define MCDM as a methodology for assessing alternatives to conflicting individuals then combining them into a single assessment [34]. In MCDM, criteria are usually measures, rules, or standards used in decision-making [11]. Multi-criteria Decision Making (MCDM) has several general features. These features are alternatives, attributes, conflicts between criteria, decision weights, and decision matrices. Alternatives are objects that are different but have the same opportunity to be chosen by the decision-maker [35]. Attributes are often also called characteristics, components, or decision criteria. Some criteria usually have conflicts with each other. The most common example of a conflict between criteria is that profit will conflict with costs. The weight of the decision determines the value of the relative importance of each criterion. And the last is a decision matrix which contains elements that represent the ranking of alternatives.

2.3 GIS-Multi Criteria Decision Making (GIS-MCDM)

MCDA was initially concerned about how to combine information from various criteria into a single index evaluation form [36]. In its application, the use of MCDM is becoming increasingly widespread. Many researchers integrate MCDM with other methods [14], [21], [35]one example is the integration of MCDM with geographic information systems [4], [12], [37]. GIS-MCDM is a collection of methods and tools to modify and combine geographic data and preferences (values of judgments) for decision making [37]. MCDM presents a methodology/framework for mapping arguments. MCDM is systematic and uses a dependable approach. GIS has the unique ability to store, manage, analyze and visualize geospatial power for decision making. GIS-MCDM transforms and combines geographic data with value judgments to solve spatial problems [14]. GIS-MCDM considers the geographic model data and the spatial dimensions and decision alternatives in evaluating the criteria. Figure 2 shows the integration between GIS and the MCDM approach.

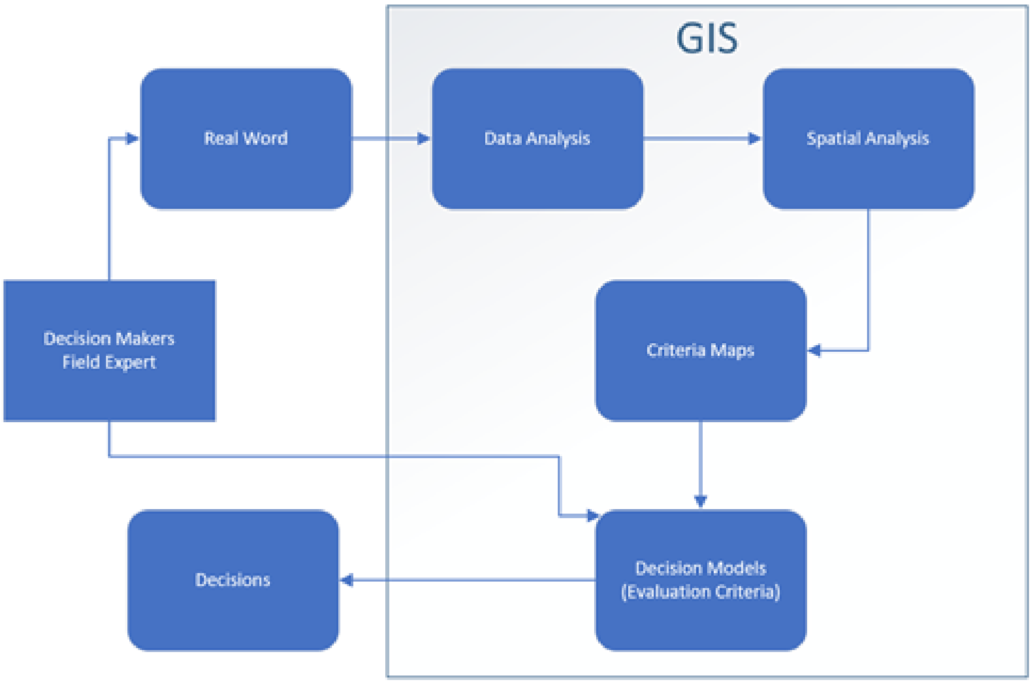

Figure 0.1 The integration between GIS and the MCDM approach

Many fields combine GIS-MCDM for decision making. In agriculture, GIS-MCDM assists farmers in evaluating land suitability, selecting fertilizer distribution channels, and making various other decisions [14], [38]. Land suitability is the suitability value of land for specific uses, for example, land for irrigation, ponds, and agriculture [38]. More specifically, the suitability of the land in terms of the physical properties of the environment. These properties such as climate, soil, drainage, topography, hydrology, and drainage are suitable for certain productive commodities [4]. Research on land suitability for specific uses is significant considering that land is a limited natural resource. Land suitability classification is specific to a particular plant, such as suitability for coffee, clove, cocoa, and other crops [39], [40]. The suitability of land use is carried out by comparing the existing physical characteristics with the physical parameters required for a purpose [41]. The evaluation of land suitability is essentially related to the land evaluation for a particular use, such as for rice, corn, and other potential crops [42]. GIS -MCDA consists of vector-based methods and raster-based methods. The system developer converts the Layer map into the appropriate format after selecting the vector or raster method. The reclassification process makes the map layers have values with the same scale. Expert opinion determines the weight of the criteria for each alternative. Decision-makers can perform sensitivity analysis by altering alternative weights value and selected Alternative decision criteria to check the reliability of the results.

2.4 Analytical Hierarchy Process (AHP)

Analytical Hierarchy Process (AHP) is a form of decision-making model for multi-criteria and multi-alternative problems. AHP synthesizes multi-criteria assessments into a comprehensive estimate of the relative priorities of various alternative courses of action. The resulting priorities are the basic units used in all types of analysis. AHP can also track inconsistencies in raters' judgments and preferences [43]–[46]. That way, the results of the decision can be more reliable.

The procedures or steps in the AHP method include:

a. Define the problem and then determine the desired solution. Then create a hierarchy based on these problems. The top-level of the hierarchical structure contains the goals to be achieved in decision making.
b. Determine the priority of each criterion by making a pairwise comparison matrix. A pairwise comparison matrix contains numbers that represent the relative importance of an alternative's criterion.
c. Synthesize the overall priority by adding up the values of each column in the matrix, dividing each column by the total value of the corresponding column, and determining the average of each row of division results.
d. Calculate the consistency index of the matrix to avoid random values when filling out the matrix

2.5 Weighted Overlay Method

The Weighted Overlay method is one of the most frequently used approaches for overlay analysis [13]. Weighted Overlay can solve multi-criteria problems such as site selection and suitability models. Map analysis using a weighted overlay requires weights to determine the level of importance of the criteria [47]. Determining the criteria weights in this method uses the Analytical Hierarchy Process (AHP) approach [19], [22], [48]. The first step of the weighted overlay method is to classify the raster maps. The classification process aims to make all the layers have the appropriate value. All raster inputs must have an integer form. Equation (1) is applied to assemble the assessment criteria.

$$s = \frac{\sum w_i s_{ij}}{\sum w_i} \qquad (1)$$

Where: W_i is the weight factor of criterion, S_{ij} is the weight of the spatial map class, and s is the value of the spatial unit output. This overlay process produces a land suitability map. Figure 3 illustrates the weighted overlay method [21].

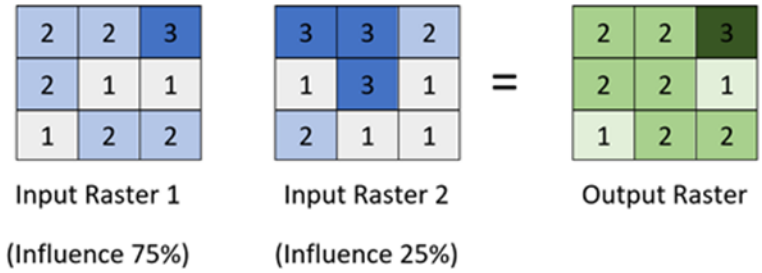

Figure 0.2 Weighted Overlay Illustration

2.6 Augmented Reality

Augmented reality is a technology that combines virtual objects into a real-world environment and then projects these virtual objects in real-time [48]. Unlike virtual reality, Augmented Reality adds or complements real-world environments with digital objects. Augmented reality use input to display digital objects in the real world. The input system can be in the form of 2D images, 3D images, Wi-Fi sensors, motion sensors, GPS, and other sensors [49]. AR uses the camera as an intermediary medium that captures the input for the system. The processor processes the input data so that it can display virtual objects in the real world. Many researchers research Augmented Reality (AR). Laksono et al. propose the marker less augmented reality technology as a medium for introducing the Kanjuruhan Malang University building [50]. In agriculture, augmented reality is used for simulation media, displaying agricultural areas, and as a tool for analyzing crop yields.

2.7 Research Questions

This study identifies three main research questions:

Firstly, how to determine potential agricultural commodities in Indonesia. Many factors influence decision-making in agriculture commodities selection. Therefore, the commodity selections require consideration factors that are in accordance with the actual conditions in the study area.

Secondly, how to evaluate land and make land suitability maps for potential agricultural commodities in the study area. Land suitability maps can be one of the consideration factors in determining agricultural commodities. Currently, the open data site provides the data needed for land evaluation. Farmers should be able to use this data as material for consideration in making decisions in the agricultural sector. Unfortunately, the utilization of open data sites is still not optimal. It's hard to carry out the land evaluation process using Open data. Besides, existing data still has a variety of formats and has a different file format.

Thirdly, how to visualize land suitability maps to make it easier for the farmer to understand. Farmers have not been able to use GIS directly. That's because farmers still find it hard to operate GIS. In addition, not all farmers can read maps well. Furthermore, GIS in Indonesia still has several weaknesses. One of the weaknesses of GIS agriculture is that GIS only focuses on providing information. Whereas improving usability through visual and interactive aspects is equally important.

This study aims to address these three main research questions by proposing a framework of the Geographic Information System (GIS) to assist farmers in the decision-making process regarding agriculture commodity selections. This study provides the determination of potential Commodities Using Multi-criteria decision analysis (MCDA method), Integrating GIS with MCDA to create Land Suitability maps, and Visualizing Land Suitability Maps Using Augmented reality technology.

Chapter 3.

Multi-Criteria Decision Analysis for Determining Potential Agriculture Commodities

3.1 Introductions

Indonesia has fertile land to develop various types of agricultural commodities. Most of the plants around the globe can be grown and cultivated in Indonesia. However, the potential agricultural sector in Indonesia is still not optimal. As an example of a sustained decline in the productivity of rice fields in West Java Province by 0.755 tons/ha (data from the Indonesia Central Bureau of Statistics, 2018). One of the crucial problems causing the decline in Indonesia's agricultural production is crop failure. Climate change, floods, and pests are the most common causes of crop failure. Other problems faced by a farmer in Indonesia are high production costs, low product quality, and the use of poor-quality seeds [51]. Improper crop patterns and farmers' mistakes in determining is another problem that causes crop failure commodities [41]. One solution is to create a system to overcome the problem in agricultural commodities determination. This system aims to assist farmers in selecting potential commodities.

Potential Commodities are the most potential and are the most profitable commodity if cultivated in an area/region [9], [52]. The potential commodity is a commodity that has a comparative advantage when compared to other agriculture commodities. The comparative advantage of a commodity is the ability possessed by the commodity so that more profitable to cultivate. Indonesia is a country that has good natural potential for agriculture. Indonesia is located right on the equator so; it only has two seasons. The climate in Indonesia is suitable for developing various types of plants, especially food crops, vegetables, and fruits[24].

This study aims to develop a decision-making system for selecting potential commodities in Indonesia. This study uses the Analytical Hierarchical Process (AHP) method that uses the Multi-Criteria Decision Analysis (MCDA) approach. AHP method provides a numerical score to determine the ranking of each Alternative[43]. The selection of this commodity aims to support efficiency-based agriculture. Many researchers use the AHP method as a decision-making method in agriculture. Herzberg et al. used the AHP method to evaluate crop suitability based on land characteristics in Vietnam [14]. In India, Kaur et.al. use the AHP method for land suitability evaluation[53]. This research proves that the AHP method is effective in decision-making. In Indonesia, many researchers use the AHP method for determining superior commodities in various regions.[9], [51], [52], [54].

Contrast with previous research. This study uses more alternative criteria. This study selects decision criteria following the actual conditions of agriculture in Indonesia. This study also uses online group discussion and literature review. The discussion participants were agricultural experts from the Indonesian agricultural forum and researchers from Indonesia Computer University. Based on the discussion result, three factors are crucial factors for determining potential agricultural commodities. The selected decision criteria are economic factors, plant characteristics factors, and environmental factors.

3.2 Related Works

Determining potential Agriculture commodities is the first step towards efficiency-based agriculture development[52]. Many researchers conducted research on the determination of potential agriculture commodities of a region [14], [42], [54]–[57]. Efficiency-based agriculture can minimize the risk of cost losses experienced by farmers[52]. Indonesia has many types of cultivated plants. Therefore, it is important for farmers to determine potential commodities as consideration factors in cultivation commodities selections[51]. It aims to increase efficiency in agriculture land management. The AHP method is an established method in decision-making[12], [17], [36], [43], [58]. Many researchers conclude that this method is the most robust decision method for determining potential commodities[58]–[60]. Some researchers compare the AHP method with other decision-making methods [17], [59]–[61]. Most concluded that the results of the AHP method were more relevant than other methods.

In Indonesia, many researchers research the determination of superior agricultural commodities[51], [62], [63]. However, these studies only focus on the types of potential agriculture commodities of a region. They use productivity and economic profit factors as the basis for selecting alternatives. Several studies mix decision alternatives between plant, fishery, and livestock commodities[62]–[65]. Meanwhile, decision-making using disproportionate decision alternatives can cause less relevant decision results[12], [44], [60]. Contrast with previous research, this study provides limitations and classifications of alternative selection based on plant characteristics and the topology of Indonesian agricultural areas. It makes the commodity ranking results have high validity. Table 3.1

Shows the differences between this study and previous studies.

Table 3.1 Comparation with other study

Study	Criteria/ sub criteria used	Alternative Use	Commodity Classification	Method	Alternative
Leo et al [51].	3/7	7	No	AHP	Potatoes, cabbage, chilies, tomatoes, sweet potatoes, coffee, and oranges.
Masniadi [63].	4/19	4	No	AHP, LQ	Rice, Corn, Citrus, Cow
Lala [64].	1	25	No	LQ	12 food crops and horticulture, 6 livestock, 7 plantation crops
Novitasari & Ayuningtyas [65].	1	5	No	LQ	sugar cane, papaya, rice, chili, corn
Saediman [62].	6	6	No	AHP	Cocoa, clove, rice, beef cattle, Seaweeds, Skipjack tuna
This Study	**3/11**	**11**	**Yes**	**AHP**	**6 Food Crops and 5 vegetables with specific Classifications**

3.3 Research Method

AHP is a decision support method developed by Thomas L Saaty [46]. This method decomposes complex multi-criteria problems into a hierarchy. This study chose the AHP method as problem-solving because: (1). AHP Method has a hierarchical structure as a consequence of the criteria to the deepest sub-criteria. (2) AHP method can calculate validity up to the tolerance limit for inconsistency as criteria and alternatives chosen by decision-makers. (3) The AHP method calculates the durability of the decision-making sensitivity analysis results. Then we make clear boundaries and classifications based on Indonesian agricultural topology in making alternative choices. With these classifications we expect the ranking results of agricultural commodities to be more relevant and have a high level of validity. Figure 3.1 shows the research method for determining the ranking of Commodities

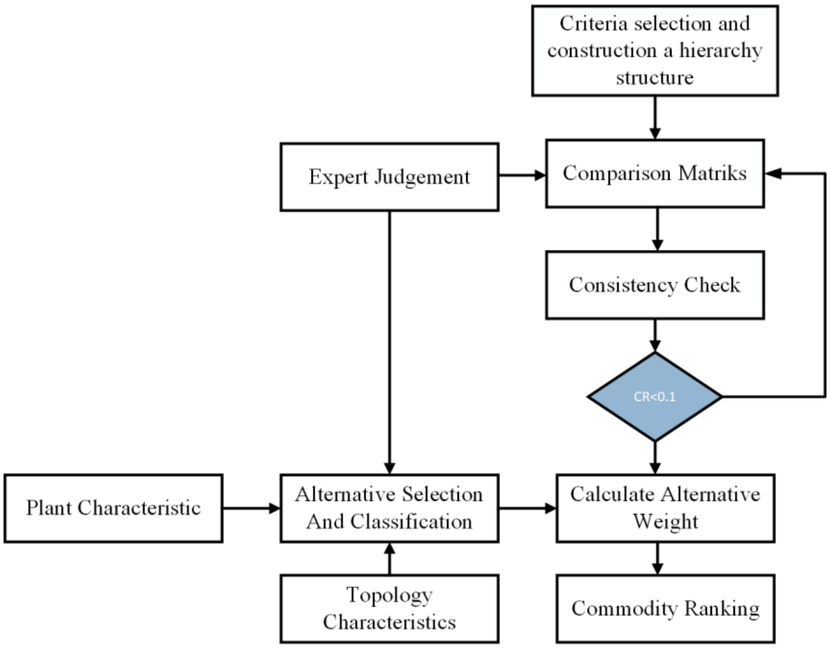

Figure 3.1 Proposed method

The AHP method has three core stages. The stages of the AHP method sequentially are determining criteria, making comparisons of matrices, and testing consistency.

This study complements the AHP method with alternative selection and classification (see figure 3.1). In contrast to previous research, we conducted a rigorous selection of alternatives. It is because there are so many commodities that farmers can cultivate. Furthermore, these commodities have very different characteristics. For example, we cannot compare fruit production with vegetables; or vegetable production with farm production. We select agriculture commodities based on plant characteristics and the topology of Indonesian agricultural areas to make alternative comparisons equal. That way the ranking results have a high level of validity. It's hoped that this study resulted in a ranking of commodities that proved to be more accurate.

3.3.1 Criteria selection and construction a hierarchy structure

The first step in using the AHP method is selecting criteria and creating a hierarchical structure. This stage is called the decomposition process[43]. The first stage of the decomposition process is to identify the problem. This step aims to determine the goal/

purpose in decision-making. The next stage is to determine the elements related to the goal. The AHP method uses these elements as criteria. The final decomposition stage in the decomposition process is to determine alternatives based on the decision criteria from the previous decomposition stage. In the AHP method, the first level of the hierarchical structure is the decision goal. The second level is the criteria related to the objectives. The third level is a choice in decision-making (see Figure 3.2).

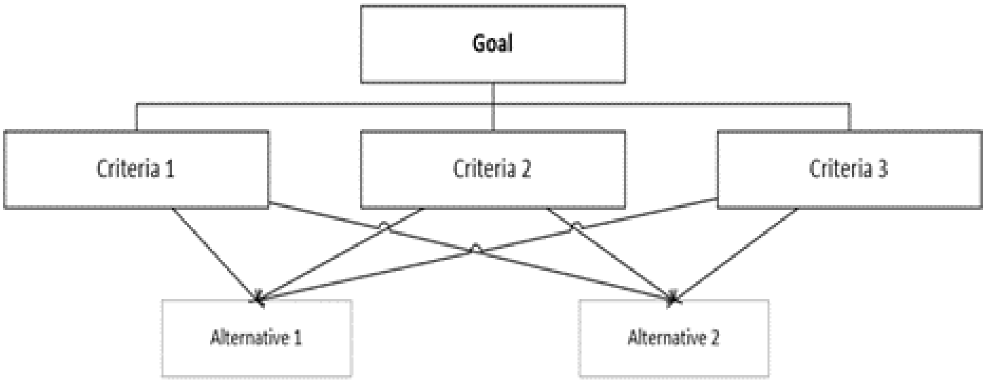

Figure 3.2 AHP method hierarchical structure

3.3.2 Comparative judgment and Pairwise comparison

The comparative judgment makes an assessment based on the relative importance of two elements at a certain level. This process has a crucial role in the AHP method. This process will affect the order of priority of the elements in the hierarchy. Pairwise comparison is a pairwise comparison matrix that contains the preference level of several alternatives for each criterion. Pairwise comparisons show the results of comparative judgment. The pairwise comparisons process aims to determine the priority order of each decision criterion in the hierarchy. The first step in creating a pairwise comparisons matrix is comparing each decision criterion and assigning a decimal value for the calculations process. Table 3.1 explains the decimal values according to Thomas L Saaty [46]. The paired matrix uses a "one" for the lowest level (equal importance) and uses “Nine" for the highest level of preference (extremely important). The second step is the matrix normalization process. The normalization process divides the internal value of the pairwise comparison matrix with the total value of the column in question. Table 3.2 describe the pairwise comparisons decimal values.

Table 3.2 Pairwise comparisons decimal values

Numeric scale	Definition
9	Criterion x is Absolutely more important than Criterion y
7	Criterion x is strongly more important than criterion y
5	Criterion x is more important than criterion y
3	Criterion x is slightly more important than criterion y
1	Criteria x is equally important as criterion y
2,4,6,8	Intermediate value, when compromise is needed

The AHP method calculates the geometric average to synthesize the results of each criterion element comparison from the expert. The first step to calculate the geometric average is to create the original matrix (A).

$$A = \begin{pmatrix} 1 & CT_{12} & CT_{1x} & CT_{1y} & CT_{1n} \\ CT_{21} & 1 & CT_{2x} & CT_{2y} & CT_{2n} \\ C_{Tx1} & CT_{x2} & 1 & CT_{xy} & CT_{in} \\ CT_{y1} & CT_{y2} & CT_{yx} & 1 & CT_{jn} \\ CT_{n1} & CT_{n2} & CT_{nx} & CT_{ny} & 1 \end{pmatrix} \quad (2)$$

$$CT_{xy} = \left(\prod_{k=1}^{m} a_{xyk}\right)^{\frac{1}{m}} \quad (3)$$

Where CT_{xy} shows the importance of decision criteria x compared to decision criteria y. A_{xyk} is an extraction from the results of the k^{th} questionnaire, which shows the level of importance of decision criteria x with decision criteria y. then the second step calculates the matrix A' which is the normalized form of the matrix A.

$$A' = \begin{pmatrix} \overline{CT}_{11} & \overline{CT}_{12} & \overline{CT}_{1x} & \overline{CT}_{1y} & \overline{CT}_{1n} \\ \overline{CT}_{21} & \overline{CT}_{22} & \overline{CT}_{2x} & \overline{CT}_{2y} & \overline{CT}_{2n} \\ \overline{CT}_{x1} & \overline{CT}_{x2} & \overline{CT}_{xx} & \bar{C}T_{xy} & \overline{CT}_{in} \\ \overline{CT}_{y1} & \overline{CT}_{y2} & \overline{CT}_{yx} & \overline{CT}_{yy} & \overline{CT}_{jn} \\ \overline{CT}_{n1} & \overline{CT}_{n2} & \overline{CT}_{nx} & \overline{CT}_{ny} & \overline{CT}_{nn} \end{pmatrix} \quad (4)$$

$$\overline{CT}_{xy} = \frac{CT_{xy}}{\sum_{x=1}^{n} CT_{xy}} \quad (5)$$

$\overline{CT}_{xy}$ is normalized value of CT_{xy}., $\sum_{x=1}^{n} CT_{xy}$ is summary result of CT_{xy} from

Matrix A Column y., and n is number of criteria in the hierarchy. The weight of each criterion is a derivative of the matrix A' using the following x equation.

$$W_i = \frac{\sum_{x=1}^{n} \bar{C}_{xy}}{n} \tag{6}$$

$$W = \begin{pmatrix} w_1 \\ w_2 \\ w_x \\ w_y \\ w_n \end{pmatrix} \tag{7}$$

Where: W is weight of criterion., w_x is weight of criterion x., and $\sum_{x=1}^{n} \bar{C}_{xy}$ is summary result of C_{xy} by Column y from Matrix A

3.3.3 Consistency check

After knowing the weights of each criterion, the next step is to check for consistency. The input for the AHP method is the perception of the decision maker source. Therefore, it is possible that the decision maker gives an inconsistent answer. To calculate the value of consistency, it is calculated using the following equation.

$$CR = \frac{CI}{RI} \tag{8}$$

CI is Consistency Index

CR is Consistency Ratio

RI is Random index provides by Saaty [44]. Table 3.3 describe the RI value for n=1 to n=12

Table 3.3 Random index table

n	1	2	3	4	5	6	7	8	9	10	11	12
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.84

Meanwhile, equation 8 is used to calculate the consistency index

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{9}$$

$$\lambda_{\max} = \frac{\sum \frac{\sum_{y=1}^{n} w_x * C_{xy}}{w_x}}{n} \tag{10}$$

if CR ≤ 0.1 then inconsistency value is acceptable [43], [44]. if the inconsistency value is acceptable, the next step is to calculate the priority score of each alternative using the steps in the AHP method, in the same order as when calculating the criteria weights.

3.3.4 Alternative Selections

This study limits the selection of alternative commodities to make more relevant potential agriculture commodities ranking. This selection is based on plant characteristics and the topology of agricultural areas in Indonesia. This research takes food crops and vegetables as an alternative. The selected food crops and vegetables have the following requirements: (1). is a key crop with good productivity, (2). have a harvest period between 3-6 months, (3). can thrive at an altitude of 0-2500 meter above sea level, and (4). plants that can thrive at temperatures of 15-30 degrees Celsius. This requirement is based on the topology of agricultural areas in Indonesia [9], [66].

3.4 Determining Potential Agriculture Commodities

This research arranges the hierarchy into three levels (figure 3.3). The hierarchical arrangement aims to obtain relevant criteria in the decision-making process. The first level of the AHP hierarchy shows the goals/ purpose in making decisions. Meanwhile, criteria and sub criteria/alternatives fill in the second and third levels of the hierarchical structure. This study uses economic criteria, plant characteristic criteria, and environmental criteria. These criteria have a significant role in increasing commodity productivity and crop cultivation opportunities. Sub-criteria for the economic factor are market demand, seed cost, selling price, and planting cost. The sub-criteria for plant characteristics factors are Need of the human resource, quality of harvest/Ha, age of production, and endurance against disease. The sub-criteria for the environmental factors are government program support, Weather Resistance, and Land conditions.

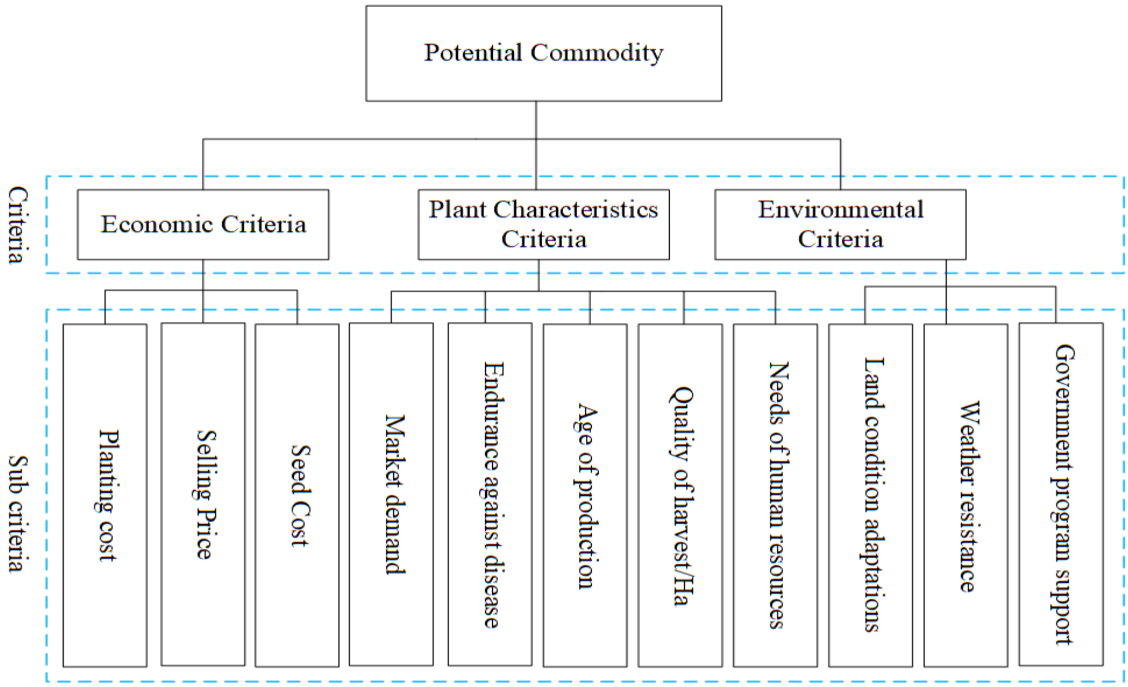

Figure 3.3 Hierarchy structure for selecting potential commodity

This study assessed the weights between criteria using online group discussions. Discussion participants involved farmers from Indonesia agricultural forum and experts from Indonesian computer universities who have competence in analyzing decision-making processes. The expert judgment process uses an instrument as the table that compares one criterion with other criteria. Table 3.4 describes the example assessment instruments of the experts.

Table 3.4 The example assessment instruments of the experts

Comparative judgement Instrument																
Government Support												Government Support				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Government Support												Weather Resistance				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Government Support												Land condition Adaptations				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Government Support												Needs of human resources				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Comparative judgement Instrument																
Government Support												Quality of harvest/Ha				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Government Support												Age of Productions				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Government Support												Endurance against disease				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Government Support												Market demand				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Government Support												Seeds cost				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Government Support												Selling price				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Government Support												Planting Cost				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

In the research instrument, the comparison of the same sub-criteria automatically has a value of 1 (equal importance). The next step is to recapitulate all the assessment results obtained from the expert responses into a pairwise comparison matrix (Table 3). Paired matrix calculation is the first step in determining the weight of each criterion. This study gives aliases to the decision criteria names to make simple the matrix table. Alphabet symbols use the characters "A" to "K" successively according to the order of the hierarchical position from right to left (figure 3.3). Table 3.5 describes the description of the alphabetic symbols for each criterion.

Table 3.5 The description of the alphabetic symbols for each criterion

CRITERIA	Symbol Character
Government Program Support	A
Weather Resistance	B
Land Condition	C
Need of Human Resources	D
Quality of Harvest	E

CRITERIA	Symbol Character
Age of Production	F
Endurance Against Disease	G
Market Demand	H
Seed Cost	I
Selling Price	J
Planting Cost	K

The next step is to recapitulate all the assessment results from the responses of farmers and experts into a comparison matrix. Table 3.6 shows the recapitulation result of the expert responses contained in the research instrument.

Table 3.6 Recapitulation result of the expert responses

	A	B	C	D	E	F	G	H	I	J	K
A	1	1/3	1/3	3	1	1	1	1/3	1	1	1
B	3	1	1/5	3	3	1	1	1/3	1	1	3
C	3	5	1	5	1	1	5	1	3	3	3
D	1/3	1/3	1/5	1	1/3	1/5	1/3	1/5	1/3	1/3	1/3
E	1	1/3	1	3	1	1	1	1	1/3	1/3	1
F	1	1	1	5	1	1	3	1	3	1	1
G	1	1	1/5	3	1	1/3	1	1/3	1	1/3	1
H	3	3	1	5	1	1	3	1	1	3	3
I	1	1	1/3	3	3	1/3	1	1	1	1	1
J	1	1	1/3	3	3	1	3	1/3	1	1	1
K	1	1/3	1/3	3	1	1	1	1/3	1	1	1

The calculation of the weight value of each criterion starts by converting the value in the recapitulation table (Table 3.5) to a decimal value. The conversion process can make it easier to calculate the weight of each criterion. After turning it into decimal, the next step is to add up each column of decision criteria. Table 3.7 describes the decimal value pairwise matrix between decision criteria.

Table 3.7 The decimal value pairwise matrix between decision criteria

	A	B	C	D	E	F	G	H	I	J	K
A	1.00	0.33	0.33	3.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00
B	3.00	1.00	0.20	3.00	3.00	1.00	1.00	0.33	1.00	1.00	3.00
C	3.00	5.00	1.00	5.00	1.00	1.00	5.00	1.00	3.00	3.00	3.00

	A	B	C	D	E	F	G	H	I	J	K
D	0.33	0.33	0.20	1.00	0.33	0.20	0.33	0.20	0.33	0.33	0.33
E	1.00	0.33	1.00	3.00	1.00	1.00	1.00	1.00	0.33	0.33	1.00
F	1.00	1.00	1.00	5.00	1.00	1.00	3.00	1.00	3.00	1.00	1.00
G	1.00	1.00	0.20	3.00	1.00	0.33	1.00	0.33	1.00	0.33	1.00
H	3.00	3.00	1.00	5.00	1.00	1.00	3.00	1.00	1.00	3.00	3.00
I	1.00	1.00	0.33	3.00	3.00	0.33	1.00	1.00	1.00	1.00	1.00
J	1.00	1.00	0.33	3.00	3.00	1.00	3.00	0.33	1.00	1.00	1.00
K	1.00	0.33	0.33	3.00	1.00	1.00	1.00	0.33	1.00	1.00	1.00
∑	16.33	14.33	5.93	37.00	16.33	8.87	20.33	6.87	13.67	13.00	16.33

After calculating the sum of each column, the next stage is the calculation process is to normalize the matrix by dividing each cell by the sum value of each column. This calculation process uses equation 5. Table 3.8 describes the normalization matrix of the paired matrix.

Table 3.8 : The normalize pairwise matrix

	A	B	C	D	E	F	G	H	I	J	K
A	0.06	0.02	0.06	0.08	0.06	0.11	0.05	0.05	0.07	0.08	0.06
B	0.18	0.07	0.03	0.08	0.18	0.11	0.05	0.05	0.07	0.08	0.18
C	0.18	0.35	0.17	0.14	0.06	0.11	0.25	0.15	0.22	0.23	0.18
D	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.03	0.02	0.03	0.02
E	0.06	0.02	0.17	0.08	0.06	0.11	0.05	0.15	0.02	0.03	0.06
F	0.06	0.07	0.17	0.14	0.06	0.11	0.15	0.15	0.22	0.08	0.06
G	0.06	0.07	0.03	0.08	0.06	0.04	0.05	0.05	0.07	0.03	0.06
H	0.18	0.21	0.17	0.14	0.06	0.11	0.15	0.15	0.07	0.23	0.18
I	0.06	0.07	0.06	0.08	0.18	0.04	0.05	0.15	0.07	0.08	0.06
J	0.06	0.07	0.06	0.08	0.18	0.11	0.15	0.05	0.07	0.08	0.06
K	0.06	0.02	0.06	0.08	0.06	0.11	0.05	0.05	0.07	0.08	0.06

The next stage is the calculation process adds up each row of criteria $\sum_{x=1}^{n} C_{xy}$ then divides that number by the number of decision criteria (n) to calculate the weight of the decision criteria. This calculation uses equation 5. The calculation process produces a final ranking for each sub-criterion. Table 3. 9 shows the final ranking for each sub-criterion

Table 3.9 The final ranking for each sub-criterion

Criterion	Sub Criterion	Weight	Ranking
Environmental Criterion	Government Program Support	0.0640	9
	Weather Resistance	0.0997	4
	Land Condition	0.1851	1
Plan Characteristics Criterion	Need of Human Resources	0.0239	11
	Quality of Harvest	0.0740	7
	Age of Production	0.1145	3
	Endurance Against Disease	0.0548	10
Economic criterion	Market Demand	0.1502	2
	Seed Cost	0.0814	6
	Selling Price	0.0884	5
	Planting Cost	0.0641	8

The AHP method evaluates the results of the calculation of the weights and rankings of each criterion. The first testing stage is to calculate the eigenvalue ($\lambda_{\max}$) using equations (10). The calculation process of the maximum eigenvalue using the order matrix value of 11(n=11). It's because there are eleven criteria in the matrix. The calculation results show that the maximum eigenvalue is 12.0734. After defining the maximum eigenvalue, the next stage is calculation is to determine the Consistency Index (CI) using equation (9). CI value for this matrix is 0.1073. The Random Index (RI) for n = 11 is 1.51. The calculation of the consistency ratio using equation (8) produces a CR value of 0.0718. According to Saaty, if $CR \leq 0.1$, the pairwise comparison matrix for decision criteria is consistent.

This study performs calculations on alternative decision-making. The alternative calculation process still uses the AHP calculation method. This stage also conducts group discussions with farmers and experts to determine paired matrices for the AHP method. This study limits the selection of plants so that the results of decision-making are more accurate. These commodities are the most suitable commodities to be cultivated in Indonesia's topography. The crops selected were rice, soybeans, corn, peanuts, cassava, sweet potatoes, potatoes, onions, cabbage, chili, and tomatoes. The research instrument is also similar to the discussion instrument used when determining the weight of the criteria. For example, table 3.10 shows the result of a paired matrix calculation for the government program support sub-criteria for each decision alternative. Alphabet symbols use the characters "a" to "k" to represent the commodity name in the table. Table 3.10 describes the description of the alphabetic symbols for each alternative.

Table 3.10 The description of the alphabetic symbols for each alternative.

CRITERIA	Symbol Character
Rice	a
Soybeans	b
Corn	c
Peanuts	d
cassava	e
Sweet potato	f
Potato	g
Onion	h
Cabbage	i
Chili	j
Tomato	k

Similar to the criteria ranking calculation, the AHP method converts the pairwise comparison matrix into decimal numbers. Table 3.11 describes the paired matrix values for the Government program support sub-criteria for alternatives.

Table 3.11 the paired matrix values for the Government program support

	a	b	c	d	e	f	g	h	i	j	k
a	1.00	2.00	3.00	5.00	5.00	5.00	5.00	3.00	3.00	3.00	3.00
b	0.50	1.00	3.00	3.00	5.00	5.00	3.00	3.00	3.00	3.00	3.00
c	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
d	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
e	0.20	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
f	0.20	0.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
g	0.20	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
h	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
i	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
j	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
k	0.33	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
∑	3.97	5.73	15.00	17.00	19.00	19.00	17.00	15.00	15.00	15.00	15.00

After getting the sum of each decision alternative column, the calculation process continues by performing matrix normalization calculations. Table 3.12 describes the normalized matrix of the paired matrix.

Table 3.12 The normalized matrix

	a	b	c	d	e	f	g	h	i	j	k	Weight
a	0.25	0.35	0.20	0.29	0.26	0.26	0.29	0.20	0.20	0.20	0.20	0.247
b	0.13	0.17	0.20	0.18	0.26	0.26	0.18	0.20	0.20	0.20	0.20	0.198
c	0.08	0.06	0.07	0.06	0.05	0.05	0.06	0.07	0.07	0.07	0.07	0.063
d	0.05	0.06	0.07	0.06	0.05	0.05	0.06	0.07	0.07	0.07	0.07	0.060
e	0.05	0.03	0.07	0.06	0.05	0.05	0.06	0.07	0.07	0.07	0.07	0.058
f	0.05	0.03	0.07	0.06	0.05	0.05	0.06	0.07	0.07	0.07	0.07	0.058
g	0.05	0.06	0.07	0.06	0.05	0.05	0.06	0.07	0.07	0.07	0.07	0.060
h	0.08	0.06	0.07	0.06	0.05	0.05	0.06	0.07	0.07	0.07	0.07	0.063
i	0.08	0.06	0.07	0.06	0.05	0.05	0.06	0.07	0.07	0.07	0.07	0.063
j	0.08	0.06	0.07	0.06	0.05	0.05	0.06	0.07	0.07	0.07	0.07	0.063
k	0.08	0.06	0.07	0.06	0.05	0.05	0.06	0.07	0.07	0.07	0.07	0.063

The calculation results show that the maximum eigenvalue for the 11 alternatives is 11.1016. The next step is the calculation process to determine the Consistency Index (CI) using equation (9). Based on the calculation result CI value for this matrix is 0.0101. The calculation of the consistency ratio using equation (7) produces a CR value of 0.0067. This study also performs a calculation process on each decision alternative to determine its relationship with each sub-criterion. The calculation process for each decision alternative produces a CR value between 0.006-0.075. This result shows that the Pairwise comparison matrix for each alternative agriculture commodity is consistent. The priority weight of each decision alternative produces a matrix of relations between each decision alternative and the sub-criteria. Table 3.13 describes the priority weight of each decision alternative based on the sub-criteria.

Table 3.13 The priority weight of each decision alternative

	A	B	C	D	E	F	G	H	I	J	K
Rice	0.247	0.065	0.065	0.164	0.044	0.054	0.088	0.164	0.108	0.031	0.103
Soybeans	0.198	0.087	0.087	0.065	0.016	0.058	0.095	0.126	0.071	0.075	0.088
Corn	0.063	0.138	0.138	0.036	0.025	0.198	0.106	0.109	0.057	0.053	0.092
Peanuts	0.060	0.087	0.087	0.046	0.016	0.074	0.095	0.077	0.087	0.165	0.079
Cassava	0.058	0.170	0.170	0.030	0.154	0.017	0.186	0.081	0.246	0.069	0.118
Sweets	0.058	0.178	0.178	0.020	0.157	0.030	0.186	0.086	0.246	0.033	0.119

	A	B	C	D	E	F	G	H	I	J	K
Potatoes											
Potato	0.060	0.041	0.041	0.107	0.075	0.172	0.039	0.080	0.072	0.144	0.082
Onion	0.063	0.101	0.101	0.063	0.048	0.101	0.077	0.066	0.039	0.224	0.088
Cabbage	0.063	0.043	0.043	0.135	0.194	0.099	0.041	0.066	0.041	0.045	0.077
Chili	0.063	0.043	0.043	0.146	0.108	0.099	0.048	0.073	0.016	0.079	0.072
Tomato	0.063	0.047	0.047	0.186	0.161	0.099	0.039	0.073	0.016	0.081	0.081

The last step is to calculate the ranking of commodities. This stage multiplies the priority weight of each decision alternative with the sub-criteria weight (see table 3.13). Table 3.14 describes the final priority ranking for each decision alternative.

Table 3.14 Final priority ranking for each decision alternative

Alternative	Total weight	Final Rank
Rice	0.0950	4
Soybeans	0.0888	6
Corn	0.1057	3
Peanuts	0.0826	7
Cassava	0.1219	2
Sweet Potato	0.1261	1
Potato	0.0801	8
Onion	0.0921	5
Cabbage	0.0696	10
Chili	0.0659	11
Tomato	0.0721	9

3.5 Discussion

This chapter explains the determination of superior commodities to be cultivated in general in the territory of Indonesia. The method used is the AHP method. The use of the AHP method has received criticism from various parties[58]. This criticism is because several problems arise when applying the AHP method. One of these problems is the problem of the rank reversal phenomenon[46]. The rank reversal phenomenon is a condition where the ranking of two decision alternatives can be reversed when adding or removing decision alternatives. However, to select potential commodity, the AHP method is the most appropriate[58]. In addition, according to Wang et al., the rank reversal phenomena can also occur when using other decision methods with the MCDM approach

[59], [60]. In his research, Wang revealed that problems such as rank reversal are common in multi-criteria decision-making[11].

This study selects potential commodities using the AHP method. The decision process uses criteria that have a significant influence on plant cultivation. Data from the Indonesia ministry of agriculture, relevant literature, and agricultural expert suggestions serve as a reference in selecting criteria and sub-criteria. As shown in Figure 1, this study uses environmental, plant characteristics, and economic factors as criteria. Then the next step is to determine the sub-criteria so that the decision-making process has high validity. The results of the calculation of the priority ranking criteria affect the alternative ranking process. Based on table 3.8, the land condition is the highest priority sub-criteria on environmental factors with a value of 0.185 or 18.5 percent. Land conditions also have the highest priority of all other priorities. The highest priority of the plant characteristics factors is the age of production criteria with a value of 0.1145 or 11.45%. Age of productivity is the third priority of all other priorities. Then Market demand is the sub-criteria with the highest priority from the economic criteria with a value of 0.1502 or 15.02%. Market demand is the second priority of all other priorities.

Based on the analysis of the priority weights of each criterion and sub-criteria, the results show that the economic criteria are more dominant than other criteria. This result is in line with the results of other studies that state that economic criteria are the criteria that most influence the determination of agricultural commodities in Indonesia[51].
Many researchers research the selection of commodities for a region in Indonesia. The researchers focused on plants according to the location of the farm. Sometimes these commodities have very different planting periods. So, it is hard to compare the potential of annual and seasonal crops in one decision making. This study limits alternative agriculture commodities that use in decision-making. This limitation can increase the validity of the decision results. This research takes food crops and vegetables as an alternative. The selected food crops and vegetables have the following requirements: (1). is a key crop with good productivity, (2). have a harvest period between 3-6 months, (3). can thrive at an altitude of 0-2500 meter above sea level, and (4). plants that can thrive at temperatures of 15-30 degrees Celsius. This requirement is in line with the topology of agricultural areas in Indonesia[9], [66]. Based on the plant growth requirements published by the Indonesian Research and Development Agency, the food crops that meet these requirements are rice, cassava, sweet potatoes, soybeans, peanuts, and corn. Meanwhile, vegetables that meet the requirements are potatoes, cabbage, onions, chili, and tomatoes.

This study found that generally, food crops have the potential to be developed in vegetables. This finding is supported by the results of previous studies which show that food crops have good potential in each region. Table 3.15 describes the comparisons of the resulting commodity ranking between this study and others.

Table 3.15 The comparisons of the resulting commodity ranking between this study and others.

Study	Study area	Commodity Ranking
Leo et al [51].	Nort Sumatra	1. Coffee, 2. chilies, **3. sweet potatoes,**
Masniadi [63].	Sumbawa	**1. Rice, 2. Corn,**3. Citrus, Cow
Lala [64].	Nort Maluku	**1. Rice,** 2 Coconuts, 3. Cassava
Novitasari & Ayuningtyas [65].	Cirebon Regency west Java	1. sugar cane, 2. papaya, **3. rice**, 4. chili, **5. corn**
Saediman [62].	Southeast Sulawesi	1. Seaweeds, **2. Rice**, 3. Cocoa
This Study	**General Indonesia**	**1. Sweet potatoes, 2. Casava, 3. Corn, 4. Rice and 5. Onions**

The final ranking shows that the AHP method with selection and classification extension on the criteria makes the commodity ranking more valid. All alternatives have balanced characteristics. The fact that in the 90s, Indonesia became the world's rice barn also supports this finding. This conclusion is also in line with the goal of the Indonesian Ministry of Agriculture to make Indonesia the world's rice barn[6], [67]. This goal proves that food crops have great potential to be cultivated in Indonesia. However, the land characteristics of each region affect the results of decision-making[42], [68]. That means that every agriculture region in Indonesia also has the potential to develop its potential agriculture commodities.

3.6 Conclusion

This chapter describes the process of selecting potential commodities using multi-criteria decision analysis. The AHP method is a method with the MCDM approach. This study complements the AHP method with alternative selection and classification. We conducted a rigorous selection of alternatives. It is because there are so many commodities that farmers can cultivate. Furthermore, these commodities have very different characteristics. We select agriculture commodities based on plant characteristics and the topology of Indonesian agricultural areas to make alternative comparisons equal. That way the ranking results have a high level of validity. The selection of agricultural commodities uses criteria that have a significant influence on plant growth. Data from the Indonesia ministry of agriculture, relevant literature, and suggestions from experts serve as a reference in selecting criteria and sub-criteria. Based on the calculation results, the land condition is the highest priority sub-criteria on environmental factors with a value of 0.185 or 18.5 percent. The land conditions also have the highest priority of all other priorities. The highest priority of the plant characteristics sub-criteria is the production age with a value of 0.1145 or 11.45%. Age of productivity is the third priority of all other priorities. Then Market demand is the sub-criteria with the highest priority from the economic criteria with a value of 0.1502 or 15.02%. Market demand is the second priority of all other priorities. This research takes food crops and vegetables as an alternative. The selected food crops and vegetables have the following requirements: (1) have a harvest period between 3-6 months, (2). can thrive at an altitude of 0-2500 meter above sea level, and (3). And plants that can thrive at temperatures of 15-30 degrees Celsius. This requirement is in line with the topography of agricultural areas in Indonesia. The findings in this chapter are that the most potential crops to be developed in Indonesian agriculture areas are food crops. These food crops include cassava, sweet potato, corn, and rice. Then, the most potential vegetable crops are onions, potatoes, and tomatoes. The overall weight indicates that food crops have a better ranking than vegetables. The final ranking shows that the AHP method with selection and classification extension on the criteria makes the commodity ranking more valid. All alternatives have balanced characteristics. We are confident that this result is universal because we use more alternative criteria and provide relevant consideration in selecting agricultural commodities. This ranking of agricultural commodities becomes a reference for making land suitability maps in the next chapter. Furthermore, it is hoped that the ranking results of agricultural commodities can be a reference for farmers in choosing agricultural commodities.

Chapter 4.

Integrating the Multi-Criteria Decision Making (MCDM) with Geographic Information System to evaluate land suitability

4.1 Introduction

Land evaluation is the process of predicting the suitability level of an area for specific crops [3], [22]. Farmers conduct land suitability assessments by analyzing the factors that affect plant growth. The Indonesian Ministry of Agriculture has developed guidelines for conducting land suitability assessment [69] . This guide should make it easier for farmers to do land suitability analysis. However, in practice, it is hard to conduct land suitability evaluations. To facilitate the land evaluation process, the Indonesian government uses a geographic information system. Geographic information systems can map land conditions, weather, and other factors for the land evaluation process. Furthermore, analyzing geospatial data make it easier for farmers to evaluate land suitability [3], [15], [23], [70].

The land suitability evaluation process requires a large amount of geospatial data. According to the Food and Agriculture Organization of the United Nations (FAO), soil, climate, and topography data are crucial for land suitability evaluation [10]. Herzberg et al. conducted a land evaluation by combining the knowledge of local farmers and scientific calculations [14]. In developing countries, researchers conduct land evaluations to increase agricultural productivity[14], [71]–[73]. Currently, the open data site provides the data needed for land evaluation. For example, NASA provides open access for those who need data. In Indonesia, some open data provider sites are the Indonesian Central Statistics Agency and Indonesia One Data. In addition to tabular data, several sites provide spatial data, such as Indonesia One Maps and the Indonesian Geospatial Agency. The Ministry of Agriculture also provides data openly to make it easier for related parties to obtain information. Unfortunately, it's hard to carry out the land evaluation process using open data[12], [74]. It is because data from open data sites have different formats.

This chapter describes the land evaluation process using Multi-Criteria Decision Analysis (MCDA) and Geographic Information System (GIS) methods. The land evaluation process uses soil, climate, and topography conditions as evaluation criteria. The output of this chapter is to create a land suitability map for potential agricultural commodities. The land evaluation process in this study has three main stages. The first stage is map data processing. This stage process data from open data sites using GIS software. The second stage is to create a thematic layer based on the decision-making criteria. The third stage is to determine the land suitability map using the weighted overlay method. It is hoped that integrating MCDM and GIS can produce more relevant land suitability maps. Land suitability can provide a reference for farmers in selecting and determining agricultural commodities.

4.2 Related Work

Agriculture is one of the crucial economic sectors that support the government to fulfill domestic food needs [14][47], [75]. Agriculture is closely related to the geographical factors of a region. Therefore, the role of Geographic Information Systems in the agricultural sector is significant [2], [8], [62]. GIS can visualize agriculture land mapping well. It can help farmers in the decision-making and land management process. One of the problems of farmers is crop failure. Farmers can use GIS to conduct land evaluation and commodity selection. It can reduce the risk of crop failure experienced by farmers. Herzberg et al. conduct a land evaluation to find suitable land for cultivating superior commodity cultivation in one of the districts in Vietnam [14]. This study combines multi-criteria decision analysis with Participatory Rural Appraisal (PRA). Other studies also use GIS to map land, irrigation canals, distribution of fertilizers, and distribution of agricultural commodities [23], [75][21], [76].

The Multi-Criteria Decision Analysis (MCDA) approach is the most appropriate method for the land evaluation process [8], [62], [77], [78][79]. Ostovari et al. conduct research that has a significant impact on land evaluation [23]. This study uses the MCDA approach with environmental factors and describes their effect on soil fertility. On the other hand, other studies also use MCDM to support sustainable farming systems by evaluating the land suitability for irrigation [80], [81]. The Analytical hierarchical process (AHP) method is a decision-making method using the MCDA approach. The drawback of this method is the possibility of the emergence of a rank reversal phenomenon[82]. Due to the phenomenon, many researchers criticize the AHP method in decision-making[58]. Wang et al. proves that the AHP method is still a good method for decision making[60]. That research also mentions that this phenomenon can occur in all decision-making methods. Many researchers also prove that combining the AHP method and other methods can strengthen decision-making results[70], [83].

Many researchers combine AHP with GIS to create land suitability maps[84]. These studies focus on one specific commodity like coffee, tea, seaweed, and specific vegetables [23], [61], [70], [85], [86]. In contrast, this study combines the Multicriteria decision-making method with the weighted overlay method to evaluate land and create land suitability maps for several types of potential commodities. In chapter three, this research makes commodity rankings. In this chapter, we propose a framework for conducting the land evaluation. We integrated the MCDA approach with the Weighted overlay method for land evaluation and making land suitability maps. This study uses data from an open data site, processes the data into a thematic map layer based on plant cultivation requirements, and then gives a weighting based on expert judgment. Similar to determining the ranking of commodities in chapter 3, we make limitations and classifications of alternative selection based on plant characteristics and the topology of Bandung District agricultural areas. The details of the original idea are explained in the research framework. This framework produces land suitability maps that are more relevant. Table 4.1 shows the comparison of this study with other studies

Table 4.1 The comparison of this study with other studies

Study	Criteria/ sub criteria used	Alternative Use	Classifi cation	Method
R. Herzberg, et., al. [14]	3/17	7	No	MCDM- Weighted Sum
Yalew, S.G., et al. [87]	1/10	Not Specified	No	AHP-Web Base Maps
Kazemi, H and Akinci, H [21]	1/5	Not Specified	No	AHP
Maddahi, Z., et., al. [70]	3/8	1(rice)	No	MCDM- Weighted Overlay (GIS)
Rahmawaty et, al. [68]	1/10	1(Palm)	No	Matching
Aflizar [88]	1/8	1(Cloves)	No	Matching
This Study	**3/11**	**11**	**Yes**	**MCDM-Weighted Overlay (GIS)**

4.3 Research Framework and Method

We integrated the MCDA approach with the Weighted overlay method for land evaluation and making land suitability maps. This study uses data from an open data site, processes the data into a thematic map layer based on plant cultivation requirements, and then gives a weighting based on expert judgment. This study proposed framework for land evaluation (see Figure 4.1). The first stage in the framework focuses on providing Georeferenced to the collected data. Stage two focuses on building the thematic maps layer. We convert all thematic maps into a raster format. We reclassify using the land suitability guidelines issued by the Indonesian government. The reclassification process aims to ensure that the land suitability map has an accurate class in accordance with the plant growth requirements. In the third stage, this study complements the AHP method with alternative selection and classification. We provide limitations and classifications of alternative selection based on plant characteristics and the topology of Bandung District agricultural areas. By adding alternative selection and alternative classification, it is hoped that the overlay process will produce a more accurate land suitability map.

4.3.1 Research Framework

Proposed framework for the land evaluation process in this study has three main stages. The first stage is collecting data from open data sites and then processing the data using GIS software. Data from the open-data sites have a different format. Therefore, this stage homogenizes the data format. The goal is to make the data easy to use at a later stage.

The second step is to create the Thematic map layer. The land evaluation process using the MCDA approach requires a thematic map layer that is in accordance with the criteria in decision making. This research creates a thematic map layer using the data from the first stage. These nine thematic layers match the decision-making criteria. These nine thematic layers consist of four layers of soil characteristics, two layers of climate characteristics, and four map layers of topography characteristics.

The last stage is the process of determining the land suitability map using the weighted overlay method. This stage converts all map layers into raster files. Then classify the raster data based on the guidelines for land evaluations for commodities cultivated in Indonesian regions. We carry out the weighting process using the online group discussions method with members of the Indonesian Agricultural Forum and experts from the Indonesian Computer University. This last step produces a map of the suitability of agricultural land in the study area. Similar to determining the ranking of commodities in chapter 3, this study provides limitations and classifications of alternative selection based on plant characteristics and the topology of Bandung District agricultural areas. Figure 4.1 describes the proposed research framework of this study.

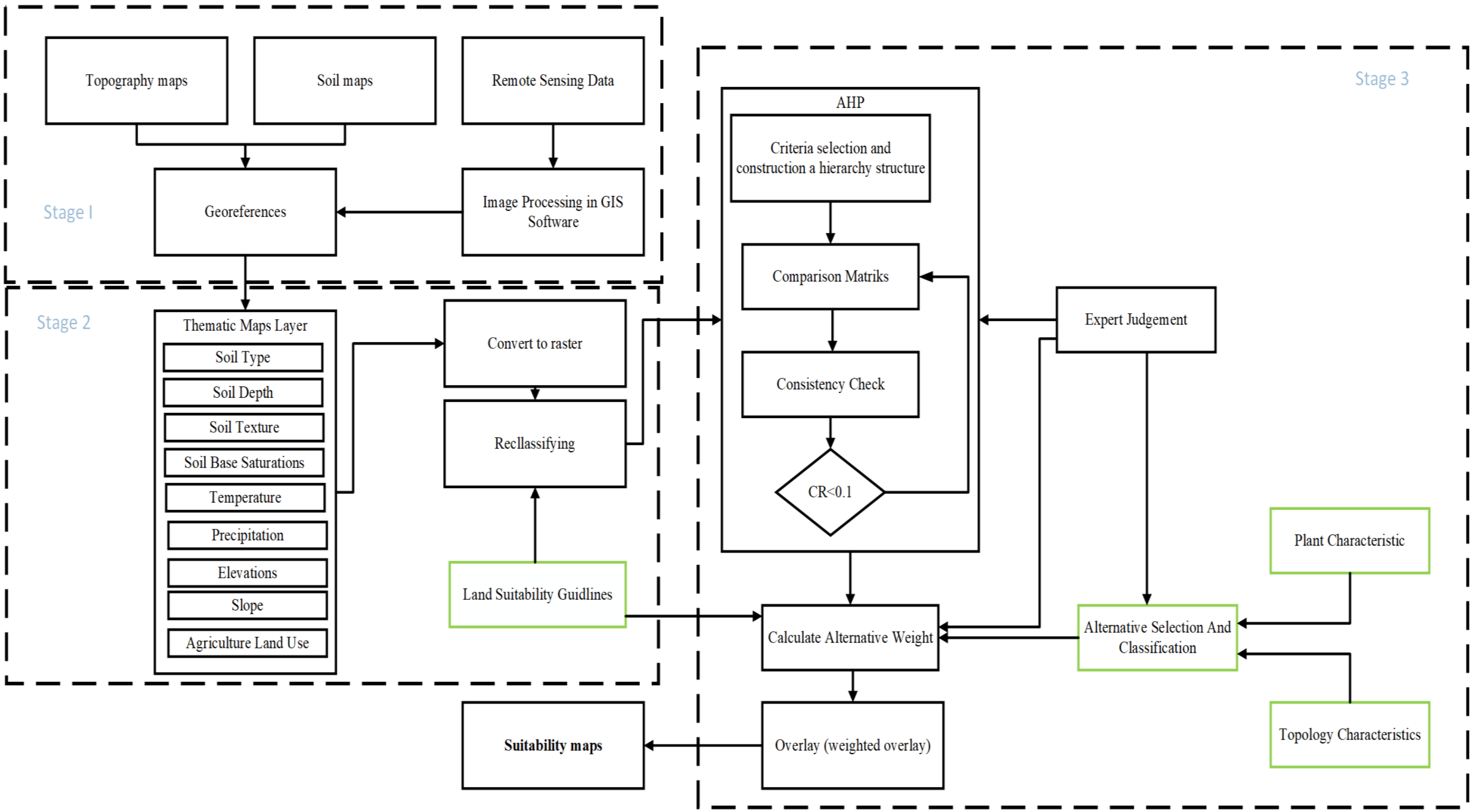

Figure 4.1 The proposed framework for land evaluation

4.3.2 Weighted Overlay Method

The Weighted Overlay method is one of the most frequently used approaches for overlay analysis [13]. Weighted Overlay can solve multi-criteria problems such as site selection and suitability models. Map analysis using a weighted overlay requires weights to determine the level of importance of the criteria [47]. Determining the criteria weights in this method uses the Analytical Hierarchy Process (AHP) approach [19],[22],[48]. The first step of the weighted overlay method is to classify the raster maps. The classification process aims to make all the layers have the appropriate value. All raster inputs must have an integer form. Equation (1) is applied to assemble the assessment criteria.

$$s = \frac{\sum w_i s_{ij}}{\sum w_i} \tag{11}$$

Where: W_i is the weight factor of criterion, S_{ij} Is the weight of the spatial map class, and S is the value of the spatial unit output. This overlay process produces a land suitability map. Figure 4.2 illustrates the weighted overlay method [21].

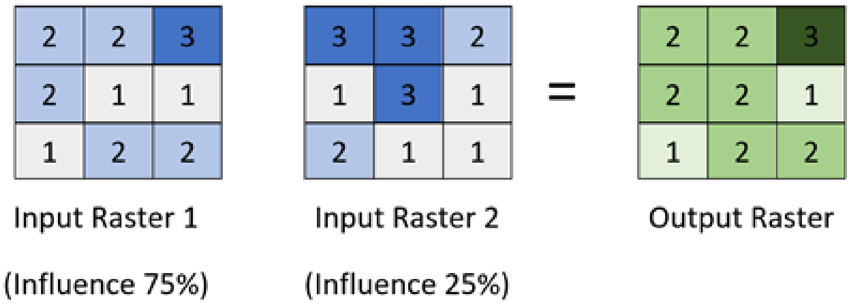

Figure 4.2 the weighted overlay method

4.4 Land Suitability Map Development

4.4.1 Study Area

Bandung Regency is one of the centers of agriculture in the province of West Java. The main agricultural product of this district is vegetable commodities, but the production of food crops is also one of the pillars of the fulfillment of food needs in Indonesia. Bandung has a total area of 176,238.67 hectares. More than 60% or around 110 hectares of the Bandung regency area is use for agriculture and plantations. It is located between latitude 107.14 N to 107.00 E. and longitude 6.49 N to 7.18 E. Mountains and highlands dominate the Bandung Regency Area with slopes between 0-8%, 8-15% to above 45%. Bandung Regency has a tropical climate with average rainfall between 1,500 mm to 4,000 mm per year. The air temperature ranges from 12° C to 24° C and has humidity between

78% in the rainy season and 70% in the dry season. Figure 4.3 describes the maps of the Bandung Regency and the agriculture areas.[89]

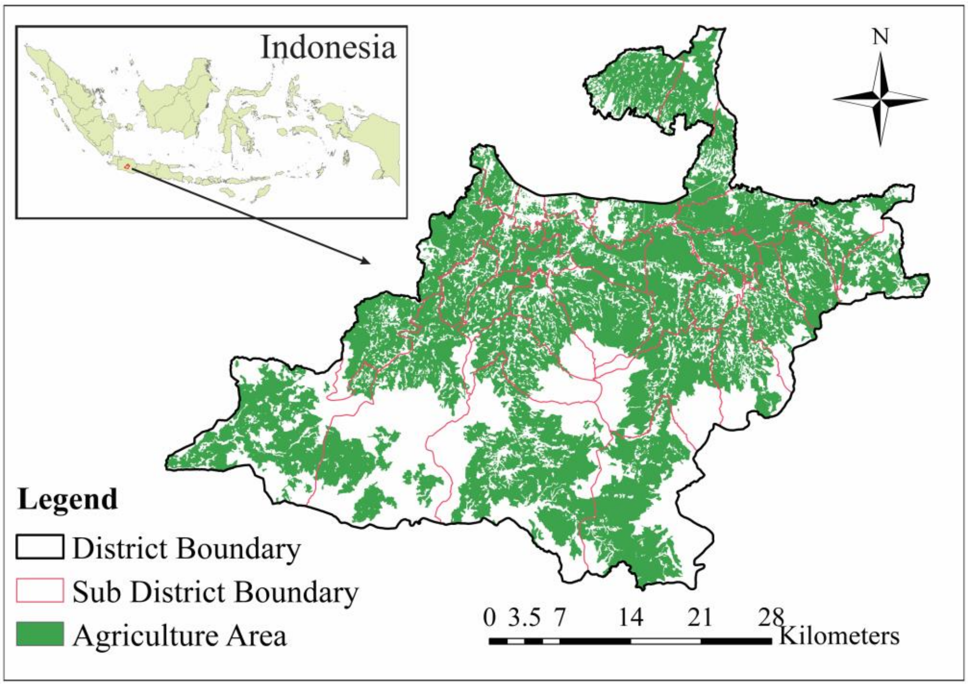

Figure 4.3 the Bandung Regency and the agriculture areas map.

4.4.2 Map Data Processing

Data is a crucial factor for the land evaluation process. Currently, there are open data open sites that provide various data. This open data sites provide both world scale and country scale data. One example of a data provider is NASA. NASA shares climate data from satellites. At the country level, each country has open data so that people in that country can take full advantage of the data. Indonesia is also promoting the era of data openness and one data policy. Open data means that the government provides reports and statistical data openly to the public. The one data policy aims to collect and integrate data from local governments into one data portal. This policy makes it easier for the public to obtain data. Indonesia's open data site provides both tabular and spatial data. Tabular data is usually is statistical data in text, CSV, or excel table formats. Spatial data is data that has spatial info mostly available in polygon data or raster data. The data is still in various data formats. So, it is hard to use without specific processing.

In this study, the land evaluation process uses several criteria that are the key to land suitability. The key is considered based on the guidelines issued by the Food and Agriculture Organization of the United Nations (FAO) and the land suitability guidelines issued by the Indonesian Government's Ministry of Agriculture[10], [69]. This study processes and converts the dataset into the same map format. It can make it easier to build a land suitability map. This study limits the criteria factors and uses three criteria factors. According to FAO, these three factors have a crucial role compared to other factors. The third factor is climate, soil, and topography.

Furthermore, these three factors have nine sub-criteria. This study collects data from open data sites based on the data needs of each criterion. Most of the data resources are from Indonesian open-data sites. Unfortunately, temperature data from the meteorological and geophysical agencies are incomplete. So this study uses Moderate Resolution Imaging Spectroradiometer (MODIS) data from The National Aeronautics and Space Administration (NASA). Table 4.1 describes a list of data sets, data sources, and original data formats used in the land evaluation process.

Table 4.2 List of data sets, data sources, and original data formats used in the land evaluation process

Criteria	Sub Criteria	Data Source	Map Method
Soil	Soil Depth Soil Texture Soil Base Saturation Soil Type	Soil map Scale 1: 50.000, Research and Development Center of Agricultural Land Resources, Ministry of Agriculture of the Republic Indonesia, 2016	Convert from MapInfo format (Tab) to Esri format (Shp)
Climate	Temperature	MODIS NASA LP DAAC at the USGS EROS Center 2018-2019(Satellite Image).	Original Data
	Precipitation	Annual rainfall from 5 climate stations in West Java,	Convert using Isohyet Method
Topography	Elevation Slope Agriculture Land Use Type	Indonesia Open Geospatial Data Research and Development Center of Agricultural Land Resources, Ministry of Agriculture	Original data

This study uses soil data derived from the Soil Map Scale 1: 50.000. This data is the most recent data issued by the Research and Development Center of Agricultural Land Resources, Ministry of Agriculture of Indonesia. Original data in the form of tabular data. Table 4.1 shows the example of original soil data.

Table 4.3 the example of original soil data.

Standard Penetration Test (SPT)	District	Soil 1	Slope	Soil Type	year
1	BANDUNG	Typic Endoaquepts	Plat (0-1)	Gleisol Eutrik	2016
2	BANDUNG	Aeric Endoaquepts	Choppy (3-8)	Gleisol Eutrik	2016
3	BANDUNG	Typic Endoaquepts	Plat (0-1)	Latosol Kromik	2016
4	BANDUNG	Typic Endoaquepts	Choppy (3-8)	Gleisol Eutrik	2016
5	BANDUNG	Typic Endoaquepts	plat (0-1)	Gleisol Eutrik	2016
6	BANDUNG	Typic Udorthents	Steep (25-40)	Kambisol Eutrik	2016
7	BANDUNG	Alfic Hapludands	Steep (25-40)	Andosol Eutrik	2016
8	BANDUNG	Alfic Hapludands	Very Steep (40-60)	Andosol Eutrik	2016
9	BANDUNG	Typic Hapludands	a little steep (8-15)	Andosol Eutrik	2016
10	BANDUNG	Typic Hapludands	Steep (25-40)	Andosol Eutrik	2016

The first step in processing soil data is to convert the original data into a Shape file (SHP). This process aims to visualize tabular data into spatial data. Figure 4.4 shows the converting process result of the original soil data into a shape file format.

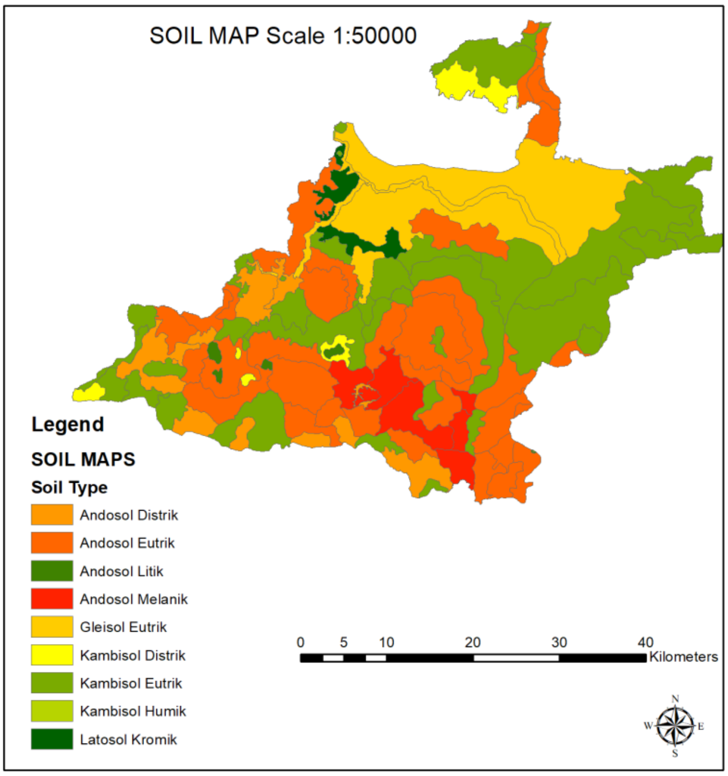

Figure 4.4 Soil Map

The second step in processing soil data is classifying and detailing soil data using soil taxonomic keys and national soil classifications. This process produces four layers of soil criteria. The third step in processing soil data is converting the shapefile into a raster format so that the map is in the same data format. The conversion aims to facilitate the overlay process. The last step is to intersect the map with a map of the agricultural area. The intersect process creates a map that only displays soil types in the agriculture area. This study took four sub-criteria for soil criteria. Soil type maps show the collection of soil types based on similarity in morphological, physical, chemical properties and characteristics, and mineralogy. It means soil maps contain more detailed information about soil properties, area, and distribution. The four soil characteristics are soil type, base saturation, soil texture, and soil depth. Soil map layers obtained from national soil data scale Figure 4.5 describes the layer of soil characteristics.

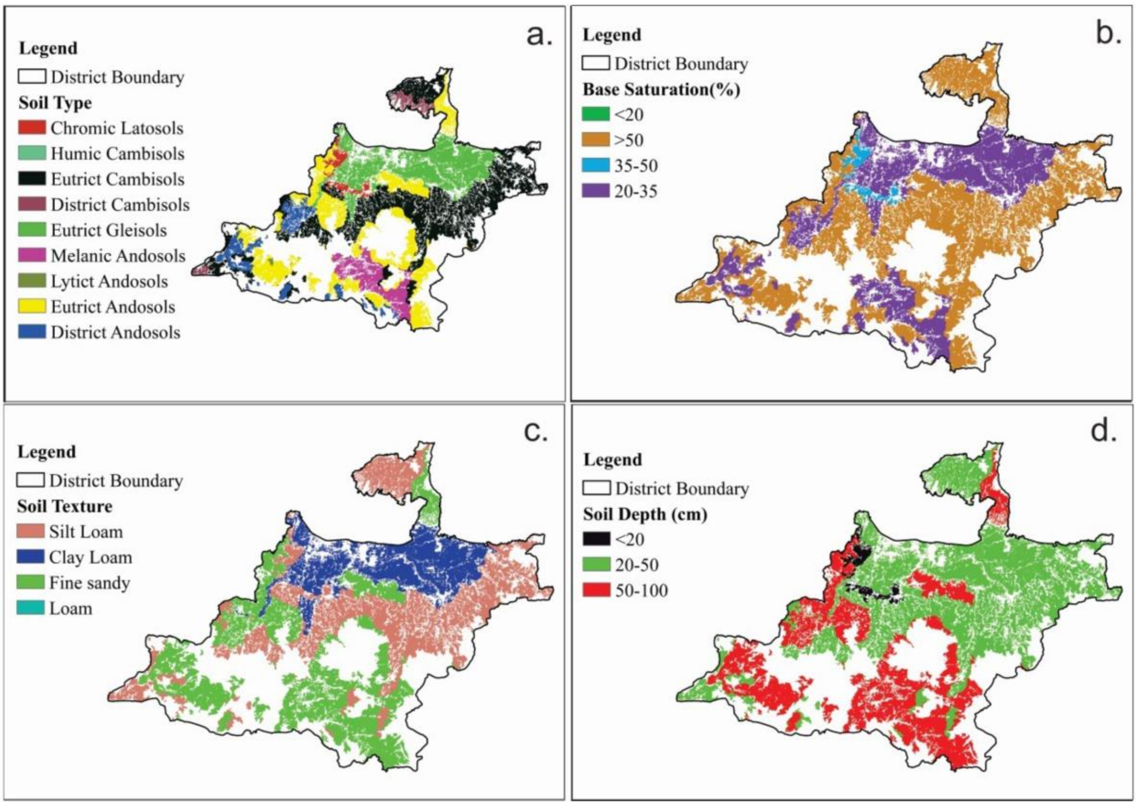

Figure 4.5 the layer of soil characteristics, a. Soil type layer, b. Base saturation layer, c. Soil texture layer and d. Soil depth layer

The climate criterion has two sub-criteria. The first sub-criteria are temperature and the second sub-criteria is rainfall. Weather data comes from two sources. The first source of data comes from the Indonesian geological and geophysical agency. Original data is tabular data. The first step in processing weather data is to visualize tabular data into map form. The process is similar to processing soil data. The second source is moderate resolution imaging spectroradiometer (MODIS) data by NASA. This data is a raster file format. So, it does not require a conversion process. We only need to intersect so that the map only shows the agricultural area of the Bandung district. Figure 4.6 describes the original MODIS Temperature data.

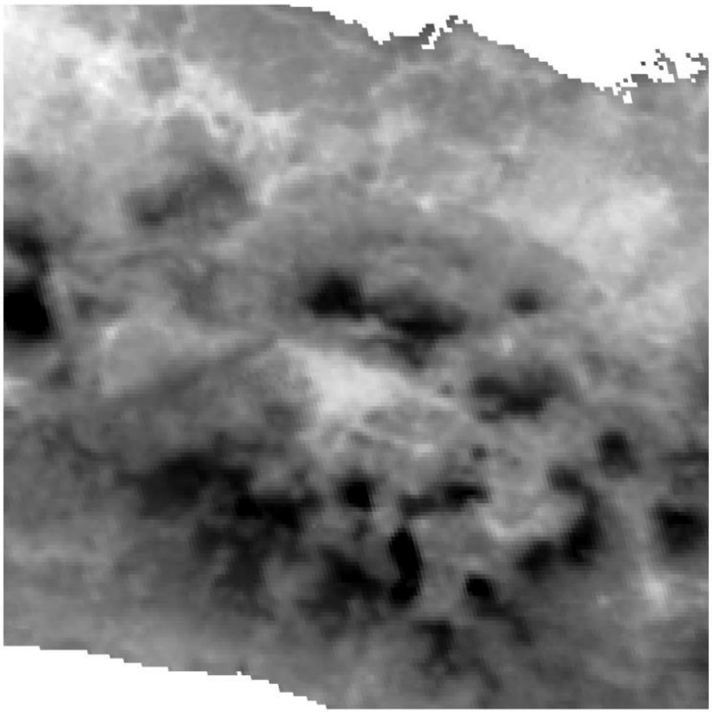

Figure 4.6 The original MODIS Temperature data

The rainfall data source is Annual rainfall from five climate stations in West Java, 2019. We converted the data into maps using the Isohyet method. Isohyet is a line that connects points with the same rain depth. The Isohyet method is the most accurate way to calculate the average rainfall depth in an area. In this method, the rain stations must be numerous and evenly distributed. The isohyet method requires more work and attention than the other two methods. Figure 6 describes the climate criteria characteristic.

The Isohyet method is the most accurate way to calculate the average rainfall depth in an area. In this method, the rain stations must be numerous and evenly distributed. The Isohyet method requires more work and attention than the other two methods. Figure 4.7 illustrates the climate characteristic criterion.

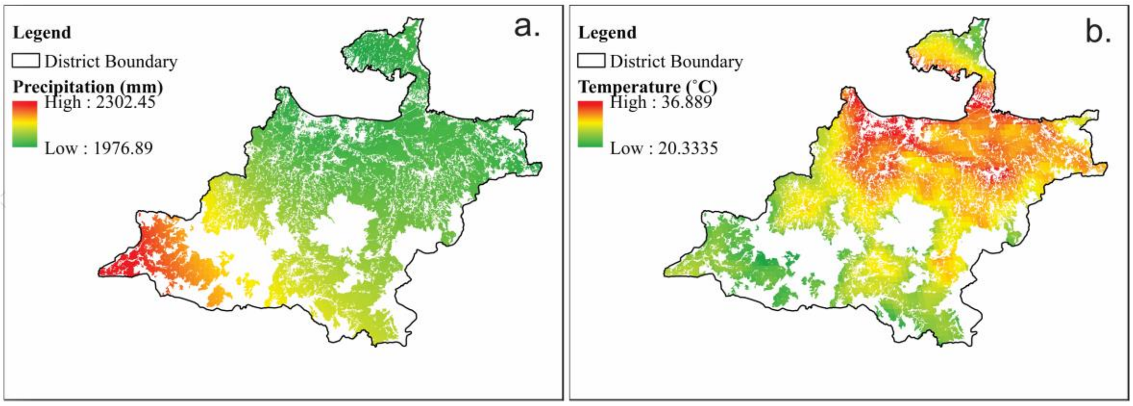

Figure 4.7 the climate characteristics criteria; a precipitation layer; b. Temperature layer

Topographic criteria have three sub-criteria. The first sub-criteria are the elevation layer, the second is the slope layer, and the third is the current agricultural land use. Elevation and slope data is the result of extraction from digital elevation data (DEM). This study downloads DEM data from the Indonesian geospatial data site. The Indonesian government provides DEM data through the Indonesia Geoportal (https://tanahair.indonesia.go.id/demnas/#/demnas). DEM data from Indonesia Geoportal is in Tiff file format. Figure 10 shows the Indonesian geoportal site. DEM file size is relatively large. This portal divides the DEM file into smaller pieces to make it easier to download data.

This study downloads the DEM file that intersects with the Bandung regency area. Seven raster files make up the Bandung regency area. QGIS software processes the seven DEM files to be merged and cropped according to the study area. QGIS software is open source-based software. Figure 4.8 describes the seven raster files that make up the Bandung district. The red line in the figure shows the boundaries of the Bandung district. The code in the right corner of each image is the file name by the Indonesian geoportal site.

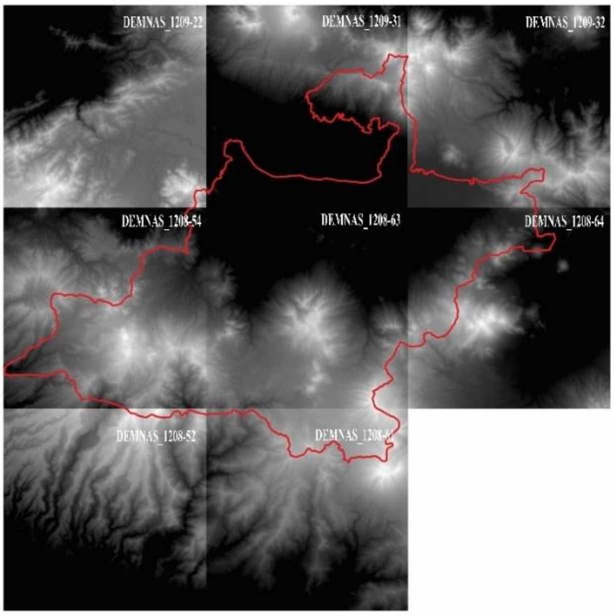

Figure 4.8 The original seven raster files that make up the Bandung district

After combining the raster data, the second step is to clip the raster data according to the Bandung district. In QGIS Software, there is a clipping by mask feature. This feature allows map users to cut maps based on area/region using polygons. This study clipped the combined raster files from the DEM file using the shape file for the Bandung district boundaries. Figure 4.9 A describes the clipping process using QGIS, and Figure 4.9 B is the raster map clipping results.

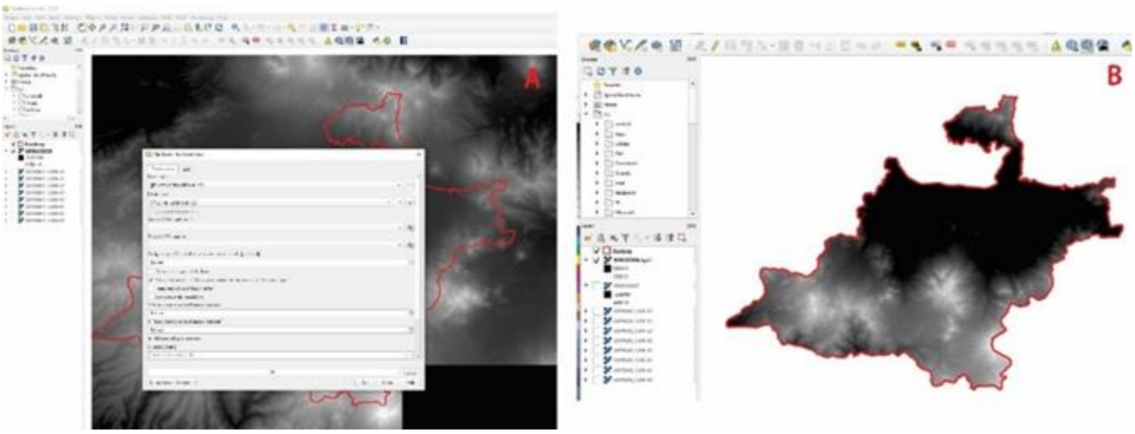

Figure 4.9 Raster file processing; A describes the clipping process using QGIS, and B is the raster map clipping results.

Most of the area of Bandung Regency is in the hills and mountains. The morphology of mountain areas has an average slope between 0-8%, 8-15%, and above 45%. Meanwhile, the last sub-criteria use agricultural vegetation data (Agriculture land use) from The Research and Development Center of Agricultural Land Resources, Ministry of Agriculture. Figure 4.10 describes the topographic criteria.

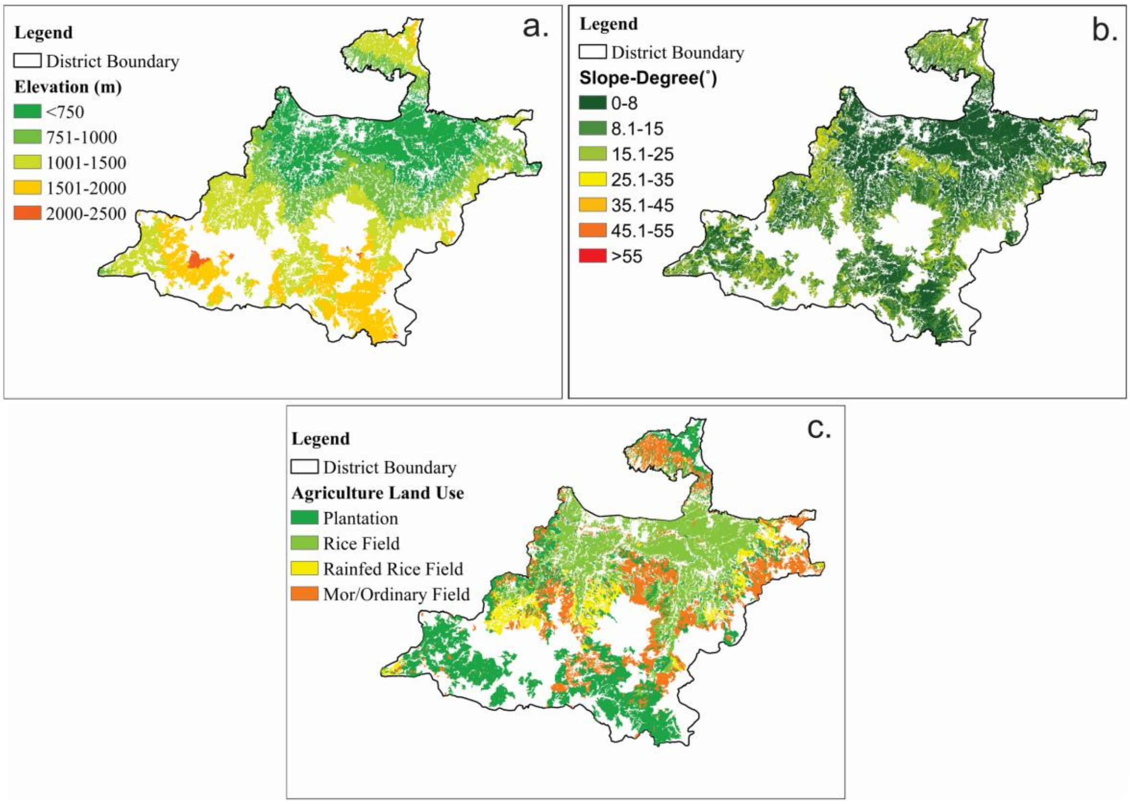

Figure 4.10 The topographic criteria; a. Elevation map layer; b. Slope; c. Agriculture land use

4.4.3 Land Suitability Map Development

Accurate data is essential in the land evaluation process. This research converts all maps into a raster file format. Raster data has the smallest data unit in the form of pixels[19]. It can make the overlay process more accurate. Furthermore, the classification process assigns weights to raster files based on their class. This study determines the criterion weights using multi-criteria decision analysis (MCDA). Decision-making uses topography, climate, and soil factors as decision criteria. Similar to potential commodities, determining criteria use a combination of farmer knowledge, the Indonesian Ministry of Agriculture, and literature review. Figure 4.11 describes the land suitability evaluation process hierarchical structure. In the hierarchy there are nine sub-criteria based on the land suitability guidelines of the Indonesian Ministry of Agriculture

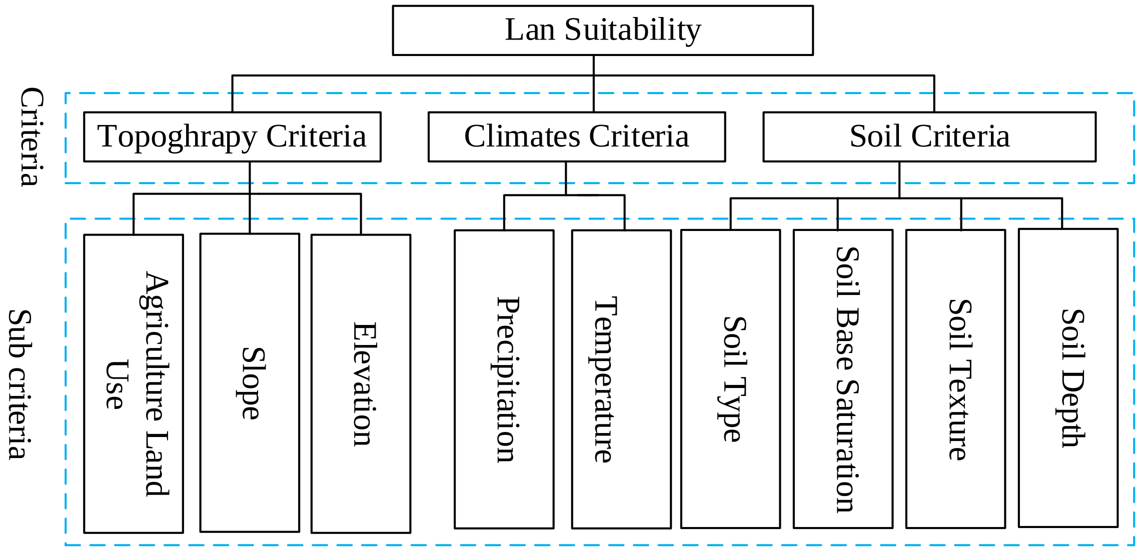

Figure 4.11 The land suitability evaluation process hierarchical structure.

This study gives aliases to the decision criteria names to make simple the matrix table. Alphabet symbols use the characters "A" to "I" successively according to the order of the hierarchical position from right to left (figure 4.11). Table 4.4. shows the recapitulation result of the expert responses contained in the research instrument.

Table 4.4 Recapitulation result of expert response

	A	B	C	D	E	F	G	H	I
A	1	1/3	1	1	1/3	1/7	1/3	1	1/3
B	3	1	3	1/3	1/3	1/5	1/3	1	1/3
C	1	1/3	1	1	1/5	1/7	1/3	1	1/3
D	1	3	1	1	1/3	1/3	1	1	1
E	3	3	5	3	1	1	3	2	3
F	7	5	7	3	1	1	3	5	3
G	3	3	3	1	1/3	1/3	1	3	1
H	1	1	1	1	1/2	1/5	1/3	1	3
I	3	3	3	1	1/3	1/3	1	1/3	1

The calculation of the weight value of each criterion starts by converting the value in the recapitulation table (Table 4.4) to a decimal value. The conversion process can make it easier to calculate the weight of each criterion. After turning it into decimal, the next step is to add up each column of decision criteria. Table 4.5 describes the decimal value pairwise matrix between decision criteria.

Table 4.5 The decimal value pairwise matrix

	A	B	C	D	E	F	G	H	I
A	1	0.333	1	1	0.333	0.143	0.333	1	0.333

	A	B	C	D	E	F	G	H	I
B	3	1	3	0.333	0.333	0.2	0.333	1	0.333
C	1	0.333	1	1	0.2	0.143	0.333	1	0.333
D	1	3	1	1	0.333	0.333	1	1	1
E	3	3	5	3	1	1	3	2	3
F	7	5	7	3	1	1	3	5	3
G	3	3	3	1	0.3333	0.333	1	3	1
H	1	1	1	1	0.5	0.2	0.333	1	3
I	3	3	3	1	0.333	0.333	1	0.333	1

After calculating the sum of each column, the next stage is the calculation process is to normalize the matrix by dividing each cell by the sum value of each column. This calculation process uses equation 5. Table 4.6 describes the normalization matrix of the paired matrix.

Table 4.6 The normalization matrix

	A	B	C	D	E	F	G	H	I
A	0.04	0.02	0.04	0.08	0.08	0.04	0.03	0.07	0.03
B	0.13	0.05	0.12	0.03	0.08	0.05	0.03	0.07	0.03
C	0.04	0.02	0.04	0.08	0.05	0.04	0.03	0.07	0.03
D	0.04	0.15	0.04	0.08	0.08	0.09	0.10	0.07	0.08
E	0.13	0.15	0.20	0.24	0.23	0.27	0.29	0.13	0.23
F	0.30	0.25	0.28	0.24	0.23	0.27	0.29	0.33	0.23
G	0.13	0.15	0.12	0.08	0.08	0.09	0.10	0.20	0.08
H	0.04	0.05	0.04	0.08	0.11	0.05	0.03	0.07	0.23
I	0.13	0.15	0.12	0.08	0.08	0.09	0.10	0.02	0.08

The next stage is the calculation process adds up each row of criteria $\sum_{x=1}^{n} C_{xy}$ then divides that number by the number of decision criteria (n) to calculate the weight of the decision criteria. This calculation uses equation 5. The calculation process produces a final ranking for each sub-criterion. Table 4. 7 shows the final ranking for each sub-criterion.

Table 4.7 The final ranking for each sub-criterion.

Criterion	Sub Criterion	Weight	Ranking
Soil	Soil Depth	0.047	8
	Soil Texture	0.065	7
	Soil Base Saturation	0.043	9
	Soil Type	0.080	5
Climate	Temperature	0.209	2
	Precipitation	0.270	1
Topography	Elevation	0.113	3
	Slope	0.079	6
	Agriculture Land Use	0.094	4

The calculation process of the maximum eigenvalue using the order matrix value of 9(n=9). It's because there are eleven criteria in the matrix. The calculation results show that the maximum eigenvalue is 9.8988. After defining the maximum eigenvalue, the next stage is calculation is to determine the Consistency Index (CI) using equation (9). CI value for this matrix is 0.1123. The Random Index (RI) for n = 9 is 1.45. The calculation of the consistency ratio using equation (8) produces a CR value of 0.077. According to Saaty, if CR ≤ 0.1, the pairwise comparison matrix for decision criteria is consistent.

This study uses online group discussions to make the comparison matrix for each criterion. Participants consist of 10 Farmers as Agricultural experts. The experts have more than ten years of experience in agriculture. Table 4.8 show the farmer list data.

Table 4.8 Expert list

No	Nama	Age	Experience As Farmer (years)
1	Udjed Sujana	65	43
2	Ayat	65	38
3	Aang Suhendi	63	37
4	Uteng	39	15
5	Dayat	43	25
6	Budi Hidayat	39	14
7	H. Asep	38	15
8	Eleng	48	16
9	Ano Hartono	40	15
10	Ujang Warman	38	27

Chapter 3 describes the process of selecting potential agricultural commodities in the territory of Indonesia. The selecting commodities process produces agriculture commodity ranking. This ranking can be a reference for farmers in plant selection. Chapter 3 states that food crops have great potential to be cultivated in Indonesia. However, the land characteristics of each region affect the results of decision-making. That means that every agriculture region in Indonesia also has the potential to develop its potential agriculture commodities. This chapter describes the land suitability evaluation process for one of the central agricultural areas in Indonesia. The area is Bandung Regency. The Bandung Regency area has a morphology in the form of Mountains and highlands that dominate the Bandung Regency area with slopes between 0-8%, 8-15%, to above 45%. Bandung Regency has a tropical climate with average rainfall between 1,500 mm to 4,000 mm per year. The average air temperature is between 12° C to 24° C and has humidity around 78% in the rainy season and 70% in the dry season. This morphology becomes a reference in the selection of alternative plants. This chapter selects three food crops and three vegetable crops. According to commodity ranking in the previous chapter, these plants rank highest for each category. Crops from the food crop category are sweet potatoes, cassava, and rice/paddy. Corn has a higher rank than rice. However, based on land suitability guidelines, corn is more suitable for cultivation in the lowlands [69]. Selected plants from the vegetable crop category are onions, cabbage, and potatoes. Tomatoes have a higher rank than cabbage, but the rainfall intensity in the Bandung district causes tomato production to be less than optimal. Rainfall suitable for tomato cultivation is around 750-1,250 mm/year[69].

For each commodity, the classification parameter has a different value. GIS can make it easier for farmers to select areas that match the criteria and parameters for plant growth and development. In Indonesia, experts, agency/institutional/ministry experts, and universities make land suitability guidelines for farmers to evaluate land. FAO (1976) classifies land suitability into four classes[10].

The classes are:

1. S1 (Very suitable)
2. S2 (Suitable)
3. S3 (Marginally Suitable), and
4. N (Not Suitable)

Land evaluation is a process of identifying parameters and analyzing suitability criteria for certain types of land. Each commodity has different suitability criteria. For example, potato is suitable for cultivation in areas with an average temperature between 16-18 (°C) [69]. Cabbage has better temperature resistance, which is between 13-24 (°C) [65]. Table 4.9 describes the classification of parameters for the potato commodity. While table 4.10

is a classification of parameters for cabbage commodity.

Table 4.9 The classification of parameters for the potato.

Criteria	Parameter/sub criteria	Class category	Suitability Level
Soil	Soil Depth (cm)	>75	S1
		50-75	S2
		30-49.99	S3
		<30	N
	Soil Texture	Sandy Loam	S1
		Clay loam, Silt loam	S2
		Silt, Loam	S3
		Sand	N
	Soil Base Saturation (%)	>35	S1
		<35	S2
	Soil Type	Andosols	S1
		Cambisols	S2
		Latosols	S3
		Gleisols	S3
Climate	Temperature (˚C)	16-18	S1
		14-15.9 and 18.1-19.9	S2
		12-13.9 and 20-23	S3
		<12 and >23	N
	Precipitation (mm)	1000-1500	S1
		700-999 and 1501-2500	S2
		<700 and >2500	S3
Topography	Elevation	1000-1300	S1
		700-999 and 1301-1500	S2
		300-699 and 1501-2000	S3
		<300 and >2000	N
	Slope	<7	S1
		8-16	S2
		16.1-30	S3
		>30	N
	Agriculture Land use	Moor/Ordinary Field	S1
		Plantation	S2
		Non-Cultivated Vegetation	S3

Criteria	Parameter/sub criteria	Class category	Suitability Level
		Rice Field	N

Table 4.10 the classification of parameters for the Cabbage

Criteria	Parameter/sub criteria	Class category	Suitability Level
Soil	Soil Depth (cm)	>12 and <50	S1
		-	S2
		25-50	S3
		<25	N
	Soil Texture	Clay loam, Silt loam	S1
		Sandy Loam	S2
		Silt, Loam	S3
		Sand	N
	Soil Base Saturation (%)	>50	S1
		35-50	S2
		<35	S3
	Soil Type	Andosols	S1
		Cambisols	S2
		Latosols	S3
		Gleisols	S3
Climate	Temperature (˚C)	13-24	S1
		14-16 and 18-20	S2
		12-14 and 20-23	S3
		>12 and <23	N
	Precipitation (mm)	350-800	S1
		300-350 and 800-100	S2
		<700 and >2500	S3
Topography	Elevation	1000-1300	S1
		700-999 and 1301-1500	S2
		300-699 and 1501-2000	S3
		230-500 and >1000	N
	Slope	<8	S1
		15-20	S2
		20-25	S3
		>25	N
	Agriculture Land use	Moor/Ordinary Field	S1

Criteria	Parameter/sub criteria	Class category	Suitability Level
		Plantation	S2
		Non-Cultivated Vegetation	S3
		Rice Field	N

Table 4.4 and 4.5 describe the difference between suitability parameters between potato and cabbage plants based on land suitability criteria issued by the Indonesian Ministry of Agriculture. Furthermore, to facilitate the processing of the suitability level map layer, it is converted into weights. Experts' knowledge and related literature help the process of converting suitability levels into weights. Table 4.11 describes the parameter classification for the land suitability map layer of potatoes.

Table 4.11 The parameter classification for the land suitability map layer of potatoes

Criteria	Parameter/sub criteria	Class category	Class Score
Soil	Soil Depth (cm)	>75	5
		50-75	4
		30-49.99	3
		<30	1
	Soil Texture	Sandy Loam	5
		Clay loam, Silt loam	4
		Silt, Loam	3
		Sand	1
	Soil Base Saturation (%)	>35	5
		<35	1
	Soil Type	Andosols	5
		Cambisols	4
		Latosols	3
		Gleisols	2
Climate	Temperature (˚C)	16-18	5
		14-15.9 and 18.1-19.9	4
		12-13.9 and 20-23	3
		<12 and >23	1
	Precipitation (mm)	1000-1500	5
		700-999 and 1501-2500	4
		<700 and >2500	1
Topography	Elevation	1000-1300	5
		700-999 and 1301-1500	4

Criteria	Parameter/sub criteria	Class category	Class Score
		300-699 and 1501-2000	3
		<300 and >2000	1
	Slope	<7	5
		8-16	4
		16.1-30	3
		>30	1
	Agriculture Land use	Moor/Ordinary Field	5
		Plantation	4
		Non-Cultivated Vegetation	3
		Rice Field	1

The land suitability analysis using the weighted overlay method requires weighting for each criterion. The weighted overlay method uses the Analytical Hierarchical Process (AHP) method to determine the weight of each decision criterion. The purpose of using the AHP method is to assign a priority scale to each maps layer. This study uses online discussions with farmers and experts to determine the effect of each decision criteria on alternative commodities. Based on the discussion result, the soil factor has a more significant influence than other factors for food crop commodities that have tubers. But for vegetable crops, the climate factor is more important than other factors. Table 4.12 describes the final weights for each agriculture commodity.

Table 4.12 The final weights for each agriculture commodity

Criteria	Sub Criteria	Final weight for commodity					
		Rice	Onion	Cassava	Potatoes	Cabbage	Sweet Potatoes
Soil	Soil Depth	0.08	0.09	0.17	0.10	0.10	0.15
	Soil Texture	0.10	0.11	0.16	0.12	0.10	0.15
	Soil Base Saturation	0.09	0.09	0.11	0.09	0.13	0.11
	Soil Type	0.11	0.15	0.17	0.13	0.13	0.15
Climate	Temperature	0.12	0.11	0.07	0.15	0.12	0.09
	Precipitation	0.15	0.15	0.06	0.13	0.13	0.07
Topography	Elevation	0.11	0.09	0.10	0.13	0.11	0.10
	Slope	0.09	0.08	0.09	0.09	0.9	0.08
	Agriculture land use	0.15	0.13	0.07	0.06	0.9	0.10

The integration of the weighted map layers produces a land suitability map. This integration process uses nine thematic layers. Table 4.7 explains the weight of the influence of each selected characteristic layer. The weighted overlay method is accurate because it uses raster data as input. Raster data has the smallest unit in pixels. Each pixel can have a weight and score. It makes for an excellent level of accuracy when overlaying the map. This study overlays each map layer using equation 11. Different from other methods, as described earlier, this method performs classification on each map layer. This classification process makes the output of the weighted overlay method more accurate than other methods. Figure 4.12 to 4.17 describes the resulting land suitability map visualization.

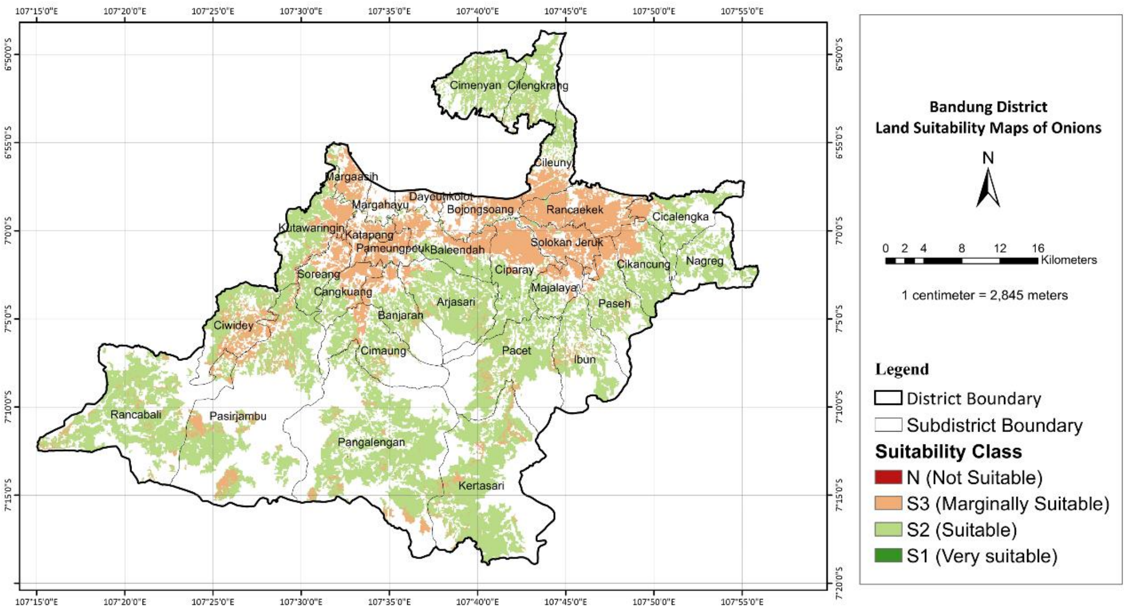

Figure 4.12 The land suitability maps of onions

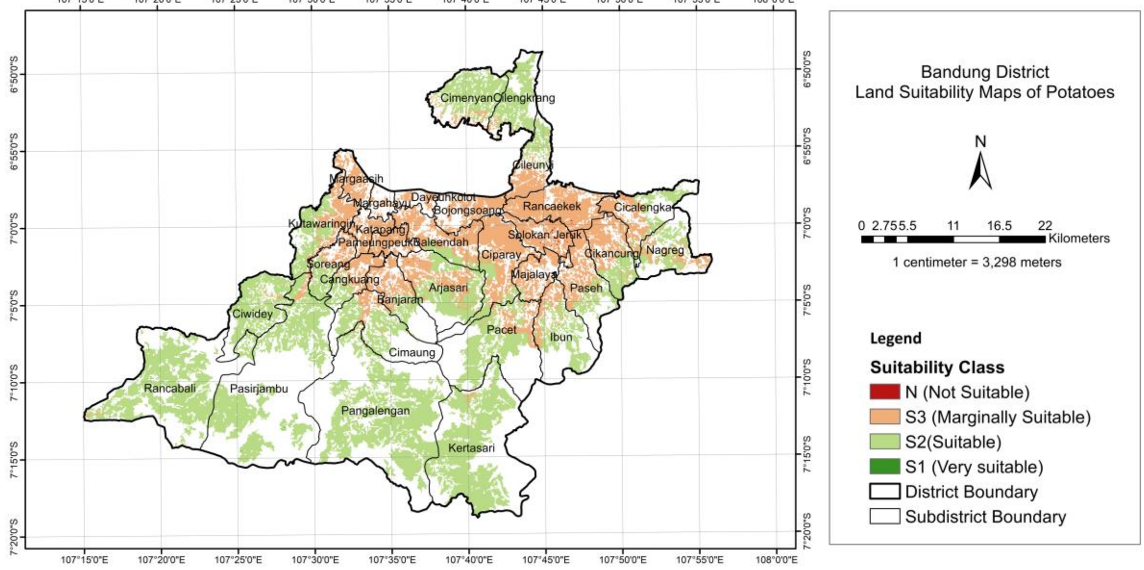

Figure 4.13 The land suitability maps of potatoes

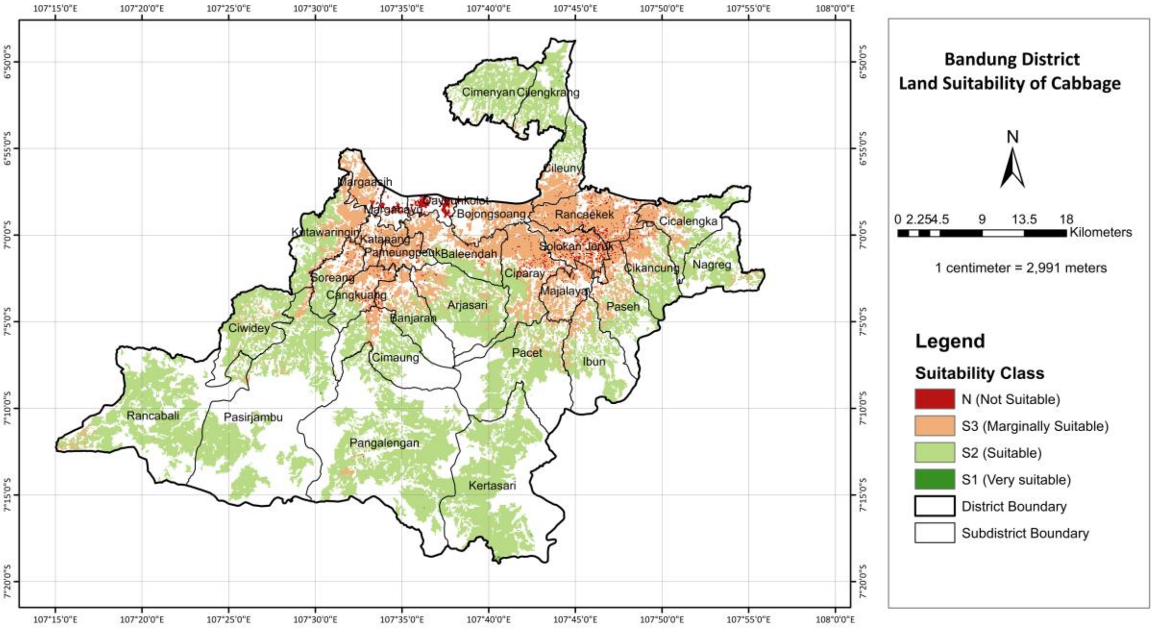

Figure 4.14 The land suitability maps of cabbage

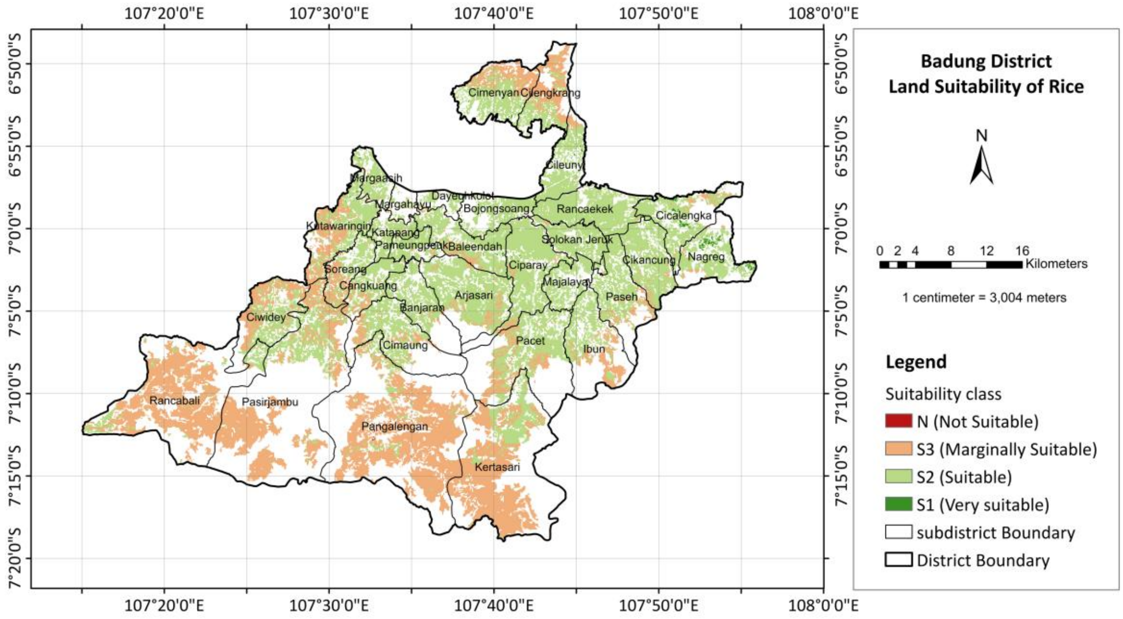

Figure 4.15 The land Suitability maps of rice

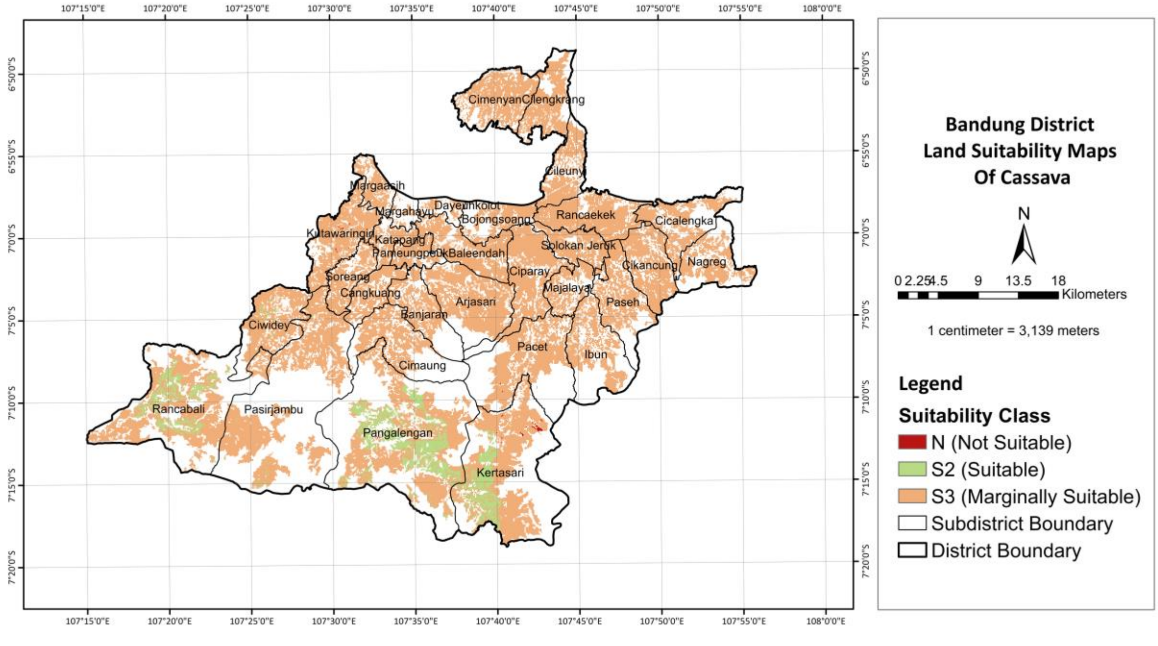

Figure 4.16 The land suitability maps of cassava

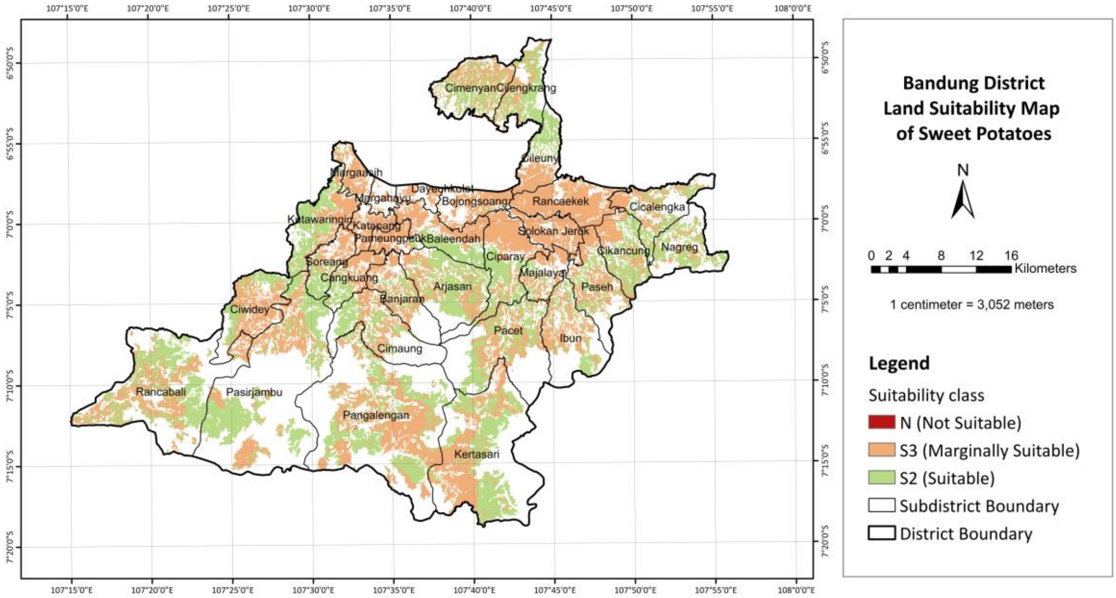

Figure 4.17 The land suitability maps of sweet potatoes

4.5 Discussion

This chapter describes the process of making land suitability maps by combining MCDA with GIS methods. The land evaluation process uses the Weighted overlay method. This method is very suitable for the land evaluation process with raster data as input [38]. This method integrates the thematic map layer using the Multicriteria Decision Making (MCDM) approach. The weighted overlay method uses the MCDM approach by giving priority weights to the raster map using the AHP method. This study uses online group discussions with farmers to determine the influence weight of the criteria. These nine thematic layers match the decision-making criteria. These nine thematic layers consist of four layers of soil characteristics, two layers of climate characteristics, and four map layers of topography characteristics. The output of the weighted overlay method is a land suitability map. There are four classes of conformity according to FAO [12]; Highly Suitable (S1), Suitable (S2), Marginally Suitable (S3), and Not Suitable (N) [5]. In general, the study area has a good level of suitability(S2) for cultivating onions, cabbage, and potatoes. Figure 4.18 shows the overall percentage class area of land suitability based on the overlay results.

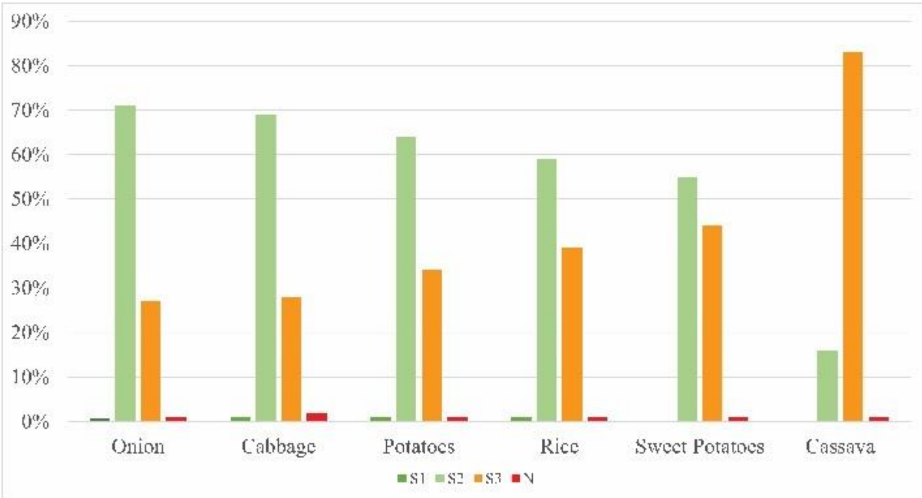

Figure 4.18 The overall percentage class area of land suitability

Based on the graph in Figure 4.18, almost seventy percent of the agricultural area of Bandung Regency has suitable conditions (S2) for cultivating onions. Bandung district agriculture area also has suitability conditions (S2) for cabbage, potato, and rice cultivation.

The statistical data strengthen this result. According to the statistical data, these three commodities are the leading commodities in the study area [89]. Table 4.13 describes Production of Seasonal Vegetables 2018-2020 from the statistical data from the Central Statistics Agency for Bandung Regency.

Table 4.13 Production of seasonal vegetables 2018-2020

Vegetables	Production of Seasonal Vegetables 2018-2020(Ton)		
	2018	2019	2020
Onions/shallots	645858	621001	609361
Garlic	11573	29091	7691
Chili/ big chili	496546	434261	586656
Chili Cayanne pepper	188911	210446	212583
Potatoes	857834	816543	652152
Cabbage	917671	978130	823645
Mushrooms (kg)	799932	1138311	1563408
Chinese Cabbage	967501	789066	876973

Based on table 4.8, cabbage, potatoes, and onions have high productivity every year. But the production of mushrooms and Chinese cabbage also has good productivity. This study does not include mushrooms and Chinese cabbage in the calculation of decision-making.

It's because the two plants did not meet the specified criteria. To cultivate mushrooms, farmers use indoor cultivation. Farmers can manipulate the parameters of the place of cultivation. Chinese cabbage has a short and varied harvest period. Chinese cabbage growing period only ranges from 25-65 days (depending on the variety). Vegetable production data by sub-district strengthens the resulting land suitability map[69]. Table 4.14 is the production data of cabbage, potatoes, and onions by sub-district [89].

Table 4.14 The production data of cabbage, potatoes, and onions by sub-district

Sub district	Onions/Shallot	Cabbage	Potatoes
Ciwidey	780	19678	-
Rancabali	4731	12173	5447
Pasirjambu	3677	18678	9099
Cimaung	93220	6434	204
Pangalengan	70453	628047	516249
Kertasari	552	52707	57218
Pacet	85095	2758	2019
Ibun	84062	9396	2018
Paseh	16461	18239	21880
Cikancung	4170	10767	1494
Cicalengka	1073	6238	4643
Nagreg	1058	719	-
Rancaekek	-	-	-
Majalaya	-	1904	-
Solokanjeruk	111	-	-
Ciparay	1971	-	-
Baleendah	-	-	-
Arjasari	49817	4853	-
Banjaran	3281	-	-
Cangkuang	2124	-	-
Pameungpeuk	-	-	-
Katapang	-	-	-
Soreang	8023	924	1171
Kutawaringin	-	-	-
Margaasih	-	-	-
Margahayu	209	-	-
Dayeuhkolot	-	-	-
Bojongsoang	-	-	-

Sub district	Onions/Shallot	Cabbage	Potatoes
Cileunyi	474	1624	-
Cilengkrang	2040	5344	8751
Cimenyan	175889	23172	21959

Table 4.14 represents vegetable production by sub-district. We perform analysis and compare data with maps. We found many similarities between land suitability and statistical data. In addition, several sub-districts have the promising potential to increase the production of agricultural products. Table 4.15 describes the comparison of production data with land suitability area with the suitable level (S2)

Table 4.15 The comparison of production data with land suitability area with the suitable level (S2)

Sub district	Onions/Shallot		Cabbage		Potatoes	
	Production data (Ton)	Suitable land area (S2)	Production data (Ton)	Suitable land area (S2)	Production data (Ton)	Suitable land area (S2)
Arjasari	49817	3881.98 ha/ 90%	4853	3496.08 ha/ 78%	-	2642.28 ha/ 60%
Baleendah	-	1234.33 ha/ 45%	-	999.58 ha/ 34%	-	597.79 ha/ 20 %
Banjaran	3281	1211.6 ha/ 66 %	-	1019 ha/ 52%	-	629.64 ha/ 32%
Bojongsoang	-	94.33 ha/ 7 %	-	0 ha/ 0%	-	0 ha/ 0%
Cangkuang	2124	775.59 ha/ 47 %	-	619.84 ha/ 37%	-	636.99 ha/ 38%
Cicalengka	1073	1832.09 ha/ 81 %	6238	1832.1 ha/ 81%	4643	994.68 ha/ 42%
Cikancung	4170	2138.16 ha/ 75 %	10767	1776 ha/ 62%	1494	1195.58 ha/ 42%
Cilengkrang	2040	2288.8 ha/ 97%	5344	2355.63 ha/ 97%	8751	2271.11 ha/ 40%
Cileunyi	474	856.37 ha/ 46%	1624	935.88 ha/ 46%	-	808.49 ha/ 40%
Cimaung	93220	2067.9 ha/ 79%	6434	2184.13 ha/ 82%	204	2061.64 ha/ 78%
Cimenyan	175889	2943.5 ha/ 98%	23172	3040.39 ha/ 98%	21959	2778.25 ha/ 90%
Ciparay	1971	1957.34 ha/ 50%	-	1212.73 ha/ 30%	-	858.71 ha/ 21%
Ciwidey	780	1852.93ha/ 59%	19678	2961 ha/ 92%	-	3143.3 ha/ 97%
Dayeuhkolot	-	19.60 ha/ 5%	-	0 ha/ 0%	-	0 ha/ 0%
Ibun	84062	2183.40 ha/ 89 %	9396	2083.68 ha/ 78%	2018	1821.54 ha/ 68%
Katapang	-	71.07 ha/ 7%	-	0 ha/ 0%	-	0 ha/ 0%
Kertasari	552	7175.3 ha/ 91%	52707	7920.69 ha/ 99%	57218	7865.59 ha/ 99%

Sub district	Onions/Shallot		Cabbage		Potatoes	
	Production data (Ton)	Suitable land area (S2)	Production data (Ton)	Suitable land area (S2)	Production data (Ton)	Suitable land area (S2)
Kutawaringin	-	2306.4ha/ 66%	-	2008.96 ha/58%	-	1910.97 ha /55%
Majalaya	-	726.29 ha/ 52%	1904	52.67 ha/ 3.5%	-	71.05 ha/ 5%
Margaasih	-	221.8 ha/ 21%	-	17.15 ha/ 2%	-	4.9 ha/ 0.5%
Margahayu	209	62.49 ha/ 31%	-	0 ha/ 0%	-	0 ha/ 0%
Nagreg	1058	1846.55 ha/ 99%	719	1799.49 ha/ 94%	-	1201.7 ha/ 62%
Pacet	85095	3786.78 ha/ 92%	2758	3802.32 ha/ 89%	2019	3312.34 ha/77%
Pameungpeuk	-	116.39 ha/ 11%	-	60.02 ha/ 6%	-	6.12 ha/ 0.6%
Pangalengan	70453	9203.12 ha/ 92%	628047	9905.15 ha/ 98%	516249	9995.83 ha/ 99 %
Paseh	16461	1806.30 ha/ 71%	18239	1397.7 ha/ 52%	21880	897.91 ha/ 34%
Pasirjambu	3677	5992.53 ha/ 79%	18678	7360.87 ha/ 96%	9099	7455.22 ha/ 97%
Rancabali	4731	6675.28 ha/ 91%	12173	6658.8 ha/ 90%	5447	7457.67 ha/ 99%
Rancaekek	-	72.2 ha/ 2 %	-	0 ha/ 0%	-	0 ha/ 0%
Solokanjeruk	111	60.02 ha/ 3%	-	0 ha/ 0%	-	0 ha/ 0%
Soreang	8023	991.31 ha/ 58%	924	868.51 ha/ 51%	1171	870.96 ha/ 51%

Based on table 4.1**5**, eleven sub-districts have a good level of land suitability. The sub-districts are Arjasari, Banjaran, Cimaung, Cimenyan, Ibun, Kertasari, Pacet, Pangalengan, Paseh, Pasirjambu and Rancabali. This sub-district has a suitability level (S2) for growing vegetables with a percentage of the area above 75%. The results are in line with vegetable production data per sub-district which shows that these eleven sub-districts are the most productive areas. However, based on the results of the land analysis, we found that several sub-districts that currently have low production even though they have a good level of suitability (S2). Table 4.1**6** shows the sub-districts that have low vegetable production but have a good level of land suitability (S2). That means this sub-district has the potential to produce related crops.

Table 4.16 The sub-districts that have low vegetable production but have a good level of land suitability (S2)

Commodity Name	Subdistrict
Onion	Kertasari, Kutawaringin, and Cwidey
Cabbage	Nagreg, Soreang, Ciparay, and Banjaran
Potatoes	Arjasari, Cimaung, Ciwidey, and Kutawaringin

For food crops, the comparison data used is data from the Central Statistics Agency for West Java. The reason for using this data is because there is no food crops data on the Bandung Regency open data site. The data shows that the Bandung Regency area is more suitable for growing rice. Because rice production every year is better than other food crops. It is because cassava and sweet potato are not stapling foods in the study area. Table 4.17 Shows the production of food crop 2018-2020 in Bandung district

Table 4.17 Production of food crop 2018-2020

Food Crops	Production of food crop 2018-2020(Ton)		
	2018	2019	2020
Rice	588386	765863	277156
Cassava	99451	56667	Not update yet
Sweet Potatoes	11729	33248	Not update yet
Soybeans	1592	3215	Not update yet

The amount of commodity production in this statistical data indicates that the land suitability map is in accordance with current agricultural conditions. Based on the distribution of land suitability areas, then comparing with the statistical data of the current situation, we conclude that the integration between MCDM and GIS methods can produce valid and relevant land suitability maps. We are confident that the land suitability map produced is in accordance with the conditions of the agricultural area in the current study area. The contribution of this study is to provide land suitability maps. Farmers can get an overview of land suitability in the study area. Land suitability maps can be taken into consideration when choosing commodities. Farmers also have considerable information about what plants are suitable to cultivate on their land. Furthermore, it is hoped that a land suitability map can reduce the risk of crop failure in the future.

4.6 Conclusion

This chapter explains the process of making land suitability maps for agricultural commodities in the Bandung Regency. This study proposed framework for land suitability evaluation. The first stage is collecting data from open data sites and then processing the data using GIS software. Data original from The Open data sites has different formats and forms. Therefore, this stage uniforms the data format to make it is easy to use data. The second stage is to create the Thematic map layer. The land evaluation process using the MCDA approach requires a thematic map layer that is in accordance with the criteria for decision making. This research creates a thematic map layer using the resulting map from the first stage. These nine thematic layers are in accordance with the decision-making criteria. The last stage is the process of determining the land suitability map using the weighted overlay method. this study complements the AHP method with alternative selection and classification. We provide limitations and classifications of alternative selection based on plant characteristics and the topology of Bandung District agricultural areas. This study contributes to providing land suitability maps. From the resulting land suitability map, we summarize the findings that agricultural land in the Bandung district is more suitable for vegetable cultivation. However, the study area also has a good level of land suitability for rice cultivation. This finding proves the conclusion in chapter three, which states that food crops are suitable for cultivation in general in Indonesia. Statistical data support this finding. According to the statistical data, these three vegetables and food crop commodities are the leading commodities in the study area. Based on the distribution of land suitability areas, then comparing with the statistical data of the current situation, we conclude that the integration between MCDM and GIS methods can produce valid and relevant land suitability maps. We are confident that the land suitability map produced is in accordance with the conditions of the agricultural area in the current study area. Farmers can get an overview of land suitability in the study area. Land suitability maps can be taken into consideration when choosing commodities. Farmers also have considerable information about what plants are suitable to cultivate on their land. Furthermore, it is hoped that a land suitability map can reduce the risk of crop failure in the future.

Chapter 5.

Potential Agricultural Land Suitability Visualization Using Augmented Reality Geographic Information System (AR-GIS).

5.1 Introductions

One of the crucial aspects that influence success in agriculture is geographical conditions [10]. Geographical conditions are also one of the factors that have a significant influence on decision-making in agriculture. Currently, data regarding geographic conditions are widely available in various open data sites. Unfortunately, the data is still not ready for the decision-making process[24]. In addition, the decision-making process requires large amounts of data[14]. A geographic information system (GIS) can handle a large amount of geospatial data effectively[15], [85][59]. The Indonesian government utilizes GIS capabilities for various fields such as mining, agriculture, regional planning, and others[90]. In the agriculture field, the agriculture office uses GIS for many purposes, for example, mapping irrigation distributions, land suitability maps, mapping vegetation, fertilizer distribution, and others[18], [91].

Until now, the use of GIS technology in Indonesia is still not optimal. The use of GIS is limited to large-scale agriculture or plantations and government agencies, whereas small-scale agriculture dominates the agriculture sector in Indonesia[8]. Farmers have not been able to use GIS directly. That's because farmers still have difficulty operating GIS. Besides, not all farmers can read maps well. Spatial thinking skills are crucial in understanding maps especially topographic maps[92], [93]. Furthermore, GIS in Indonesia still has several weaknesses. (1) Most Agricultural GIS is a Computer-Base System. Meanwhile, farmers in Indonesia are novices. Besides that, it's not like a mobile base system. A computer-based system limits the use of GIS. (2) GIS has a Complex User interface. It requires a user with a high level of usage. farmers prefer simple operations to facilitate the use of GIS. (3) The main focus of GIS is to provide information. Where to improve usability, information, visualization, and interactive point are equally important.

There are many options to optimize the use of GIS for Novice users. One solution is to enrich the GIS with a better map visualization. Then, the presentation of information needs to be limited so that the GIS only provides appropriate information and isn't confusing. The addition of an interactive interaction can also make GIS more attractive. In addition, selecting the appropriate device can increase the familiarity aspect.

This research aims to visualize land suitability using Augmented reality Geographic Information systems. Then to enrich the usability aspect, this study adds the augmented reality feature on GIS. This study takes advantage of unity3D's capabilities in customizing virtual environments. However, the use of game engines to build GIS is not uncommon[50], [77]. Although it has a powerful ability to simulate the real world, the game engine does not have a projection/coordinate system[78]. We use the Mapbox extension to cover this shortcoming. The processed map is then uploaded to the Mapbox cloud and converted into Mapbox tileset format. Unity3D scene visualizes the map layers in the Mapbox cloud into an AR-GIS. This research also explores Unity3D's ability to provide spatial data. We hope that the use of Augmented Reality can enrich GIS with a better visualization. Furthermore, we expect that the proposed system can improve GIS Usability by farmers.

5.2 Related Works

A geographic information system (GIS) has an outstanding ability to visualize maps. Agriculture uses maps for its operations. Currently, the implementation of GIS in agriculture is still not optimal [12]. It is because not every farmer can operate GIS [49]. GIS is generally computer-based. Therefore, the use of GIS is only limited to agencies and large-scale agriculture. Most of the small and medium-scale farmers are a novice in using computers. There are many ways that farmers can take advantage of GIS. one way is to enrich the GIS content to make GIS more interactive[77], [80], [50], [94]. Besides, choosing the right and familiar device can increase the familiarity aspect [61]. Many researchers state that users better understand GIS which is easy to use and prioritizes the familiarity aspect [49], [78].

The development of GIS for various purposes is a hot topic. Researchers use many methods to create interactive GIS. one way is to use the Game engine. Game engines can combine the real world with the virtual world and provide an immersive experience to the user. Carrera et al. use augmented reality to improve user understanding of spatial data [84]. Many researchers took advantage of the game engine's capabilities to display real-world topography [50], [78], [94]. Unfortunately, there are some weaknesses in the game engine. The most crucial deficiency is that the game engine does not have a projection/coordinate system. This projection/coordinate system is an absolute requirement for processing Spatial data.

Visualizing geospatial data in 3D is a challenge for cartographers and GIS developers [80], [94]. Researchers concluded that 3D maps provide better information than 2D maps [15], [50], [78]. Furthermore, 3D maps can reduce the cognitive load of map readers [95].

Currently, Game engines can import real-world topography and insert it into the game scene. Game engines also have the advantage of providing attractive interactions[86]. Research on utilizing game engines to visualize maps has become a challenging topic in recent years. Researchers compete to take advantage of the game engine's ability to display 3D maps for various disciplines related to maps[50], [78], [86]. one example is the application of augmented reality and virtual reality to display maps [81], [82], [84], [94], [96]. This technology can provide an immersive experience to the user.

Unity3D is one of the most commonly used game engines. Unity3D can create various assets into the scene. Then the game logic, user interaction, and other algorithms are managed using C# scripts [50]. Unity3D is usually used to create simulations of the real world. However, the visualization of the real-world maps in a game scene does not have a projection/coordinate system. Virtual environments without a coordinate system only have value as virtual objects or ordinary game assets.

Unity3D supports adding extensions to build various applications [90], [97], [98]. Mapbox SDK extension is the only extension that can allow Unity 3D to have a projection and coordinate system similar to GIS software. Laksono et al. use Mapbox SDK extension in UNITY3D to visualize the Kanjuruhan Malang University topography[94]. In contrast, we further explore the capabilities of game engines to create GIS applications. We propose a dynamic GIS where the user can customize the map visualizations and choose the map layer according to their needs. We develop a GIS to visualize land suitability using a mobile-based system. Then to enrich the usability aspect, we equip the system with augmented reality features. We take advantage of unity3D's capabilities in customizing virtual environments. We use the Mapbox Unity extension so that the Map has a true coordinate system. That means the map we make, represents the actual geographical situation. By using the Game engine, we hope that the system can increase the usability of the GIS. Table 5.1 shows comparison between this research with another research.

Table 5.1 Comparison between this research with another research.

Study	Map Dimension	Layer management	Coordinate system	Output Maps
Buyuksalih et al [77].	3D	No	No	3D Model of City
Laksono & Aditya [50]	3D	No	Yes	Topographic maps
Ruzinoor Che & Mohd Hafiz [94].	3D	No	No	3D Model of palm plantation
Nigam et al.[99]	3D	No	No	3D Maps Using head-mounted display
Bazlan et al., [49]	2D	Yes	No	Web-Based AR-GIS for Disease Prevention and Control Program
This Study	**3D**	**Yes**	**Yes**	**Mobile Base AR-GIS land Suitability Maps**

5.3 Research Framework

This study proposes a framework for making GIS applications. This framework modifies the User-Centered Design (UCD) method for the specific purpose of building GIS. The UCD method focuses on what the user will see and do with the user interface elements. We apply these principles in creating the Map User interface. The proposed framework consists of 5 main stages. The first stage of this framework is requirement analysis. This stage aims to determine user requirements for the system. We use user personas to describe users, create software specifications, and design use cases.

The second stage is data gathering and integration. This stage unifies and integrates map layers in the form of raster data and vector data. Then save the resulting map integration data in Mapbox Cloud. This stage also describes the integration process of the map layer in the UNITY3D scene.

The third stage of the framework is Map and Attributes Visualization. The rendering of 3D maps is a bit more complicated than 2D maps. At this stage, we analyze the 3D map components. Two-dimensional GIS represents data in the form of textual content and geospatial content. Meanwhile, building a 3D map environment requires complete data representation than 2D.

The fourth stage is interaction design. This stage aims to design an interaction method based on the potential user's action on the map. This stage also describes the interaction model in AR-GIS.

The last stage is prototype development and evaluation. The first evaluation is evaluating user requirements. The evaluation stage aims to ensure that the software requirements specifications include everything the user needs. The second and third evaluations are prototype evaluations. This study evaluates the prototype using several methods. The first method is performance testing. Performance test aims to test the limits of the toughness and stability of the system. Then we use a qualitative test using a questionnaire to know the user's response to the system. Figure 5.1 describes the proposed framework

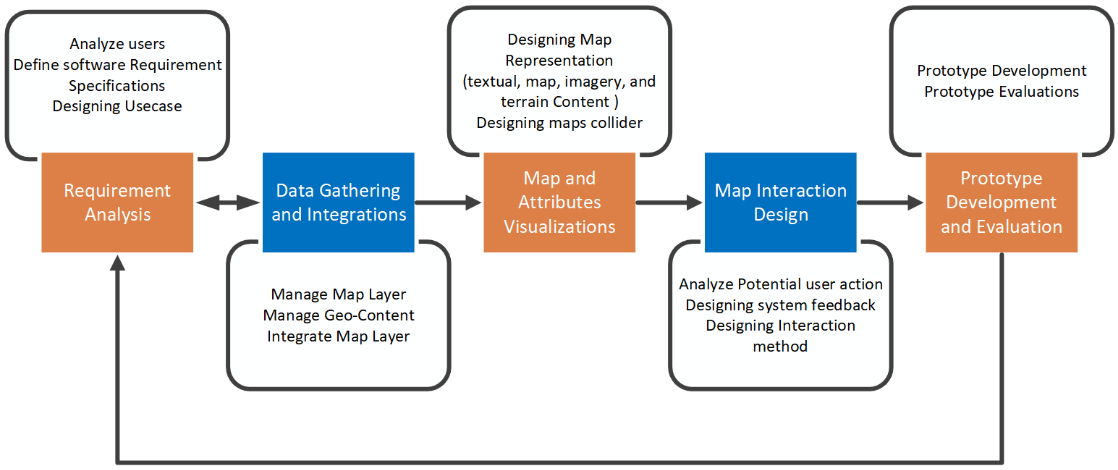

Figure 5.1 Proposed Framework

5.4 Augmented Reality Geographic Information System (AR-GIS).

5.4.1 Requirement Analysis

Requirement Analysis aims to determine user requirements for the system. At this stage, we analyze the user and the problems related to GIS that they face. Then we analyze user needs as a reference in making use cases.

5.4.1.1 User Analysis

The users of this AR-GIS are farmers. Based on data from the Bandung Regency Agriculture department, most farmers in the Bandung district are sharecroppers. They do not cultivate on their agricultural land. One example is a farmer in Tarumajaya Village, Kertasari District. In this area, only 97.7 Ha or 3.6% of the total agricultural area is the land of individual farmers. Meanwhile, almost 60% of its citizens are farmers. Most farmers cultivate crops on government-owned land. The government allows the residents of Bandung Regency to manage part of the forest area for agriculture. Sometimes some of them work on forests located in other sub-districts. Therefore, it is necessary to know the suitability of the land for a large area. The large scope of maps can help farmers get information about land suitability. It is not only in the sub-district where they live but also in other sub-districts.

One of the crucial factors in system development is user characteristics. This study uses a questionnaire and literature study to determine the characteristics of farmers as users. We use Persona to understand the expectations, hopes, concerns, and motivations of the target user of AR-GIS. To increase the validity of the user analysis results, we use in-depth and repeated questions. This method can reduce the pressure on the farmers so that the data have a high level of validity. Many researchers consider that this is an effective way to define user needs. A total of 10 farmers are involved in determining user needs. User persona describes information about the user such as personal data, motivation, device use, and farmer expectations related to the agricultural land mapping system. Figure 5.2 is the user persona format in this study. Based on user analysis, farmers in the Bandung district are generally do not use computer systems in daily activity. They are more accustomed to using smartphones for communication and social media needs.

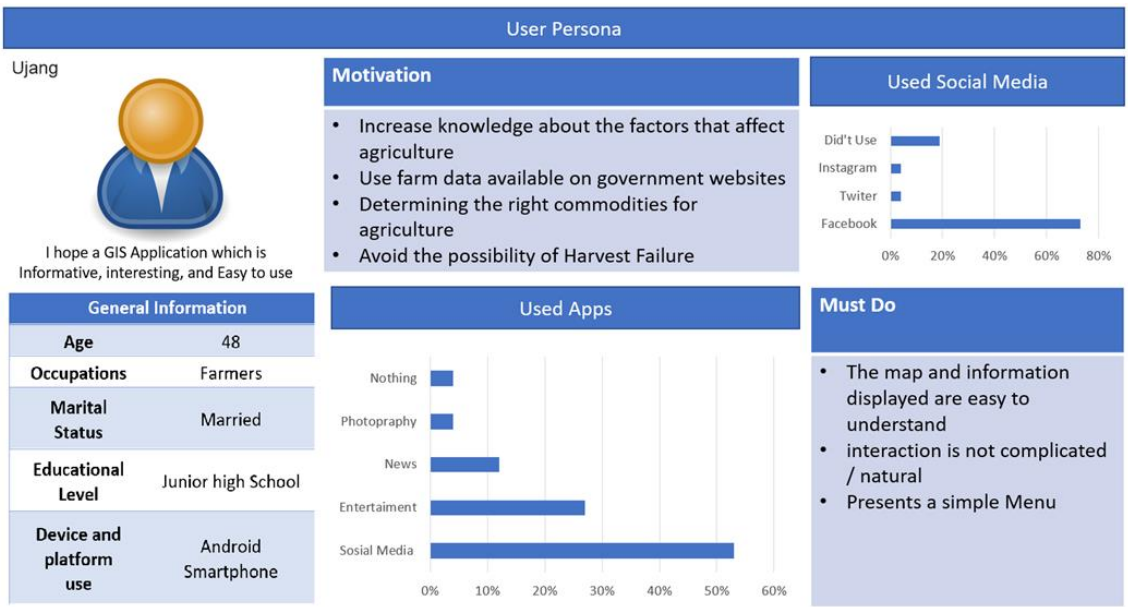

Figure 5.2 Example of User Persona

5.4.1.2 System Requirement Analysis

System Requirement analysis aims to identify and evaluate problems, opportunities, obstacles that occur, and expected needs. Currently, farmers have the following problems related to GIS:

First is still difficult for the farmer to find land suitability maps that can be used directly by farmers. Until now, Bandung District used Land suitability maps are only for agricultural planning and other analysis. In addition, the existing land suitability maps are still paper-based maps that are easily damaged and difficult to carry. Second, Indonesia has implemented GIS for agriculture since the 1970s when the REPELITA II Program. However, until now, most agricultural GIS is still computer-based.

The Indonesian Agriculture Service is currently developing a web-based system via http://sig.pertanian.go.id:8081/portalsig/. This GIS only provides one map layer, namely a rice field map. Based on the results of user analysis in the previous stage, farmers in Indonesia are a novice in using computers. This GIS makes it difficult for farmers to access the available GIS. In addition, the information and map layers produced still do not meet the needs of farmers. Figure 5.3 shows a GIS developed by the Indonesian ministry of agriculture.

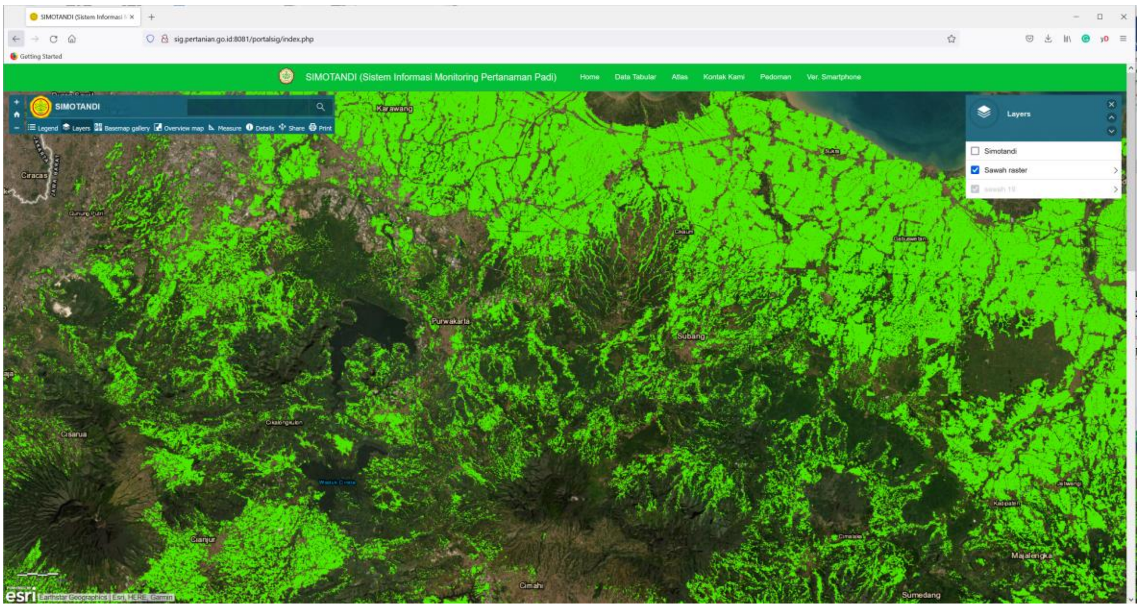

Figure 5.3 GIS developed by the Indonesian ministry of agriculture

Third, most GIS has a complex user interface. It requires a user with a high level of ability. The GIS menu (see figure 5.3) is designed for high expertise GIS Users. On the other hand, novice users need a simple menu and interface to make GIS operation easy.

Fourth, it's hard for farmers to understand GIS information. That's because not all farmers can digest the information on a 2D map. In contrast with 3D maps, reading 2D maps requires good spatial thinking skills to analogize maps.

5.4.1.3 Software Requirements Specifications

We define the requirement specification of GIS application software based on user analysis. Then we divide it into functional requirements specifications and non-functional requirements specifications. Table 5.2 describes the Functional Requirement Specifications, and table 5.3 describes Non-Functional Requirements Specifications.

Table 5.2 Functional Requirement Spesifications

Requirement code	Functional Requirement Specifications
SRS-F-001	User can choose the Base map
SRS-F-002	User can choose overlay imagery layer
SRS-F-003	User can adjust map visualization
SRS-F-004	Provides mini maps
SRS-F-005	Do a location search
SRS-F-006	Control map layer
SRS-F-007	Display the land characteristic map layer (soil, Climate, and topography)
SRS-F-008	Display Land Suitability map layer
SRS-F-009	Display Map information
SRS-F-010	Provide Augmented Maps

Table 5.3 Non-Functional Requirement Specifications

Requirement code	Non-Functional Requirement Specifications
SRS-NF-001	Required high performance of GPU to display map on 3D
SRS-NF-002	System users is farmer
SRS-NF-003	Required high-speed internet access
SRS-NF-004	The system must be built on a platform that is familiar to farmers

Based on the functional requirements specifications in table 1, we illustrate the functions that exist in the system using a use case diagram. The main function of the use case diagram is to describe the interaction between the user (actor) and the AR-GIS. Figure 5.4 Illustrates the use-case of an AR-GIS prototype.

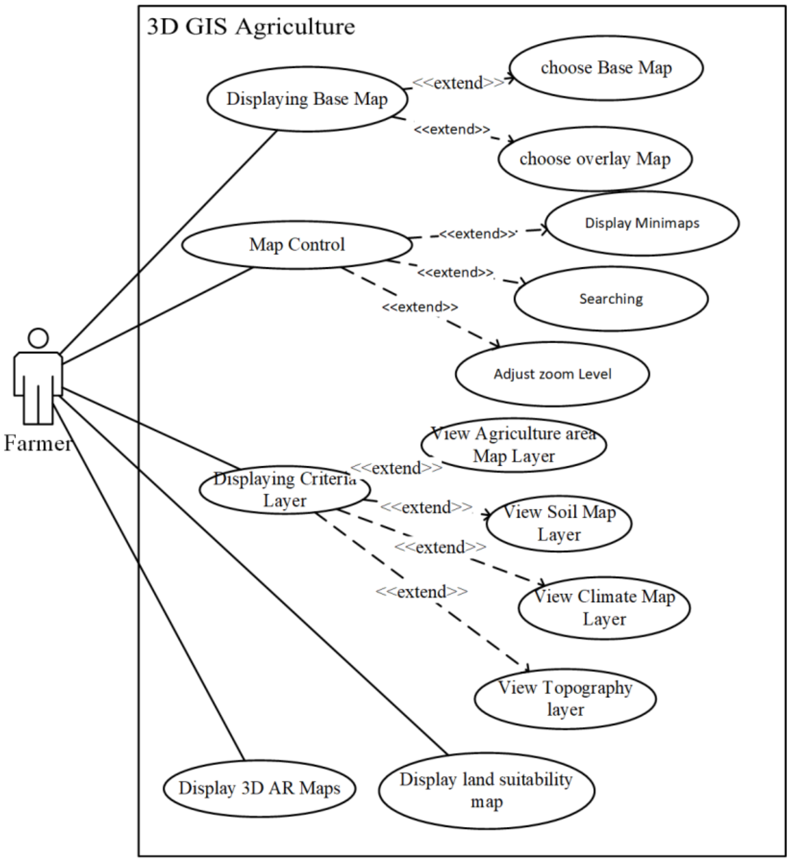

Figure 5.4 Use case diagrams

5.4.2 Data gathering and Integrations

The previous chapter describes the collecting data and developing land suitability by combining multi-criteria decision analysis (MCDA) with (GIS) methods. The first step in building a Mobile GIS is data collection and integration. This stage unifies and integrates map layers in the form of raster data and vector data. Then save the resulting map integration data in Mapbox Cloud. Mapbox is an online database platform that provides map and location services[50], [100]. We convert map layers to Mapbox tileset format. Mapbox also provides a platform for processing maps on the Mapbox cloud through Mapbox studio. This platform allows map developers to customize the layers stored in the Mapbox cloud. These customizations aim to improve map visualization, such as setting map color, setting lines, and customizing the symbols on the map. In addition, Mapbox studio also allows the organization of map layers based on the zoom level. Each layer Mapbox tileset has a unique map ID. Figure 5.5 shows the process of managing map styles on Mapbox cloud.

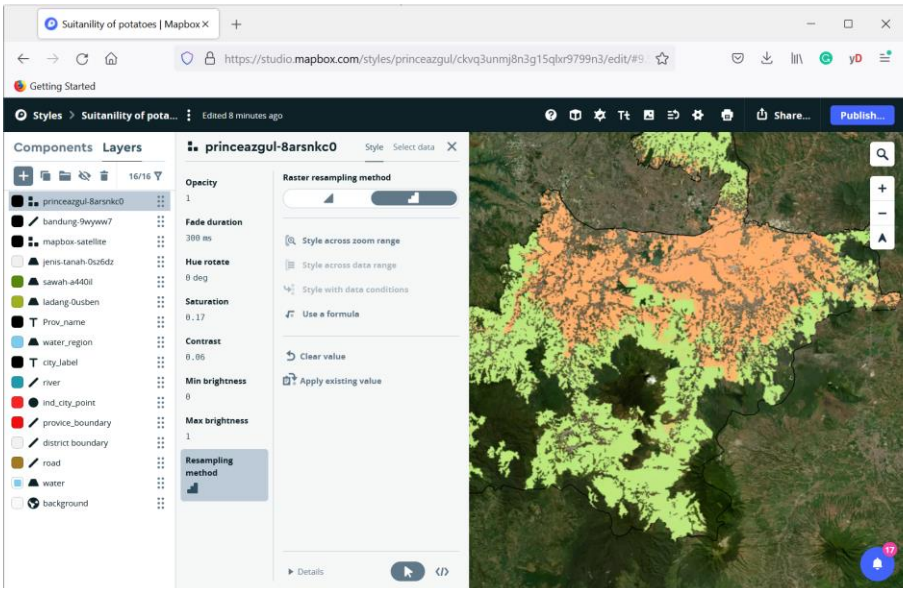

Figure 5.5 The process of managing map styles on Mapbox cloud

Mapbox for Unity3D uses map layers in the Mapbox cloud and translates each ID into Unity Game Components. Unity3D adds a map layer to the scene in the form of Mapbox tilesets. Figure 5.6 describes the data integration workflow on AR maps.

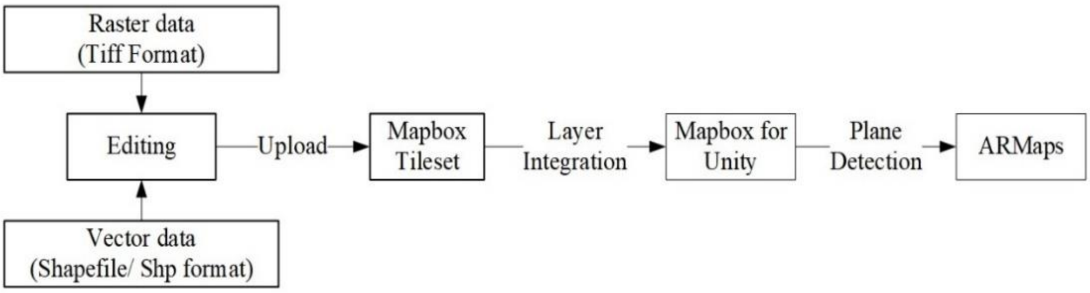

Figure 5.6 The data integration workflow on AR maps

To increase the use of GIS, we use the marker less augmented reality method. This method allows the user to display digital elements without a specific marker. This study uses the plane detection algorithm to analyze the user's environment. The system will search for a flat plane through the camera then wait for the user to confirm the position to display the map. After that, the system will display a map in the form of digital objects. Plane detection allows the user to display a map on a table or floor. Figure 5.7 illustrates the AR GIS plane detection features.

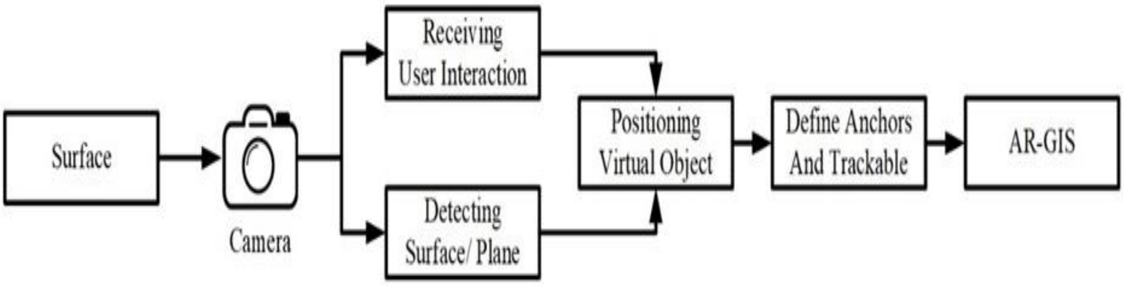

Figure 5.7 The AR GIS plane detection features.

5.4.3 Map and Attributes Visualization

This study uses data from various open data sources. GIS divides data into two types; textual data is tabular data, and Geo content is spatial data that contains geographic references. Then, we highlight the data to make interactive maps. Figure 5.8 Illustrates the data transformation process on the prototype.

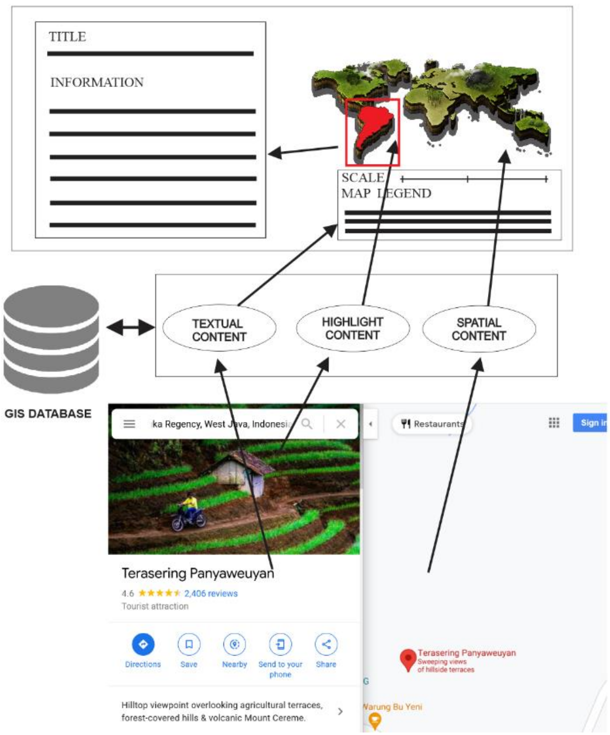

Figure 5.8 The data transformation illustration

This study proposes an interface model based on the illustration in Figure 5.8. The interface model describes the components in the user interface. 2D maps Interface component consists of spatial and non-spatial data, while 3D maps require more complex data representations. 3D maps also need an Image Representation to wrap the topography maps. 3D maps also require a terrain representation which will be given a collider for map interaction reference. Figure 5.9 is the interface model on the prototype 3D maps.

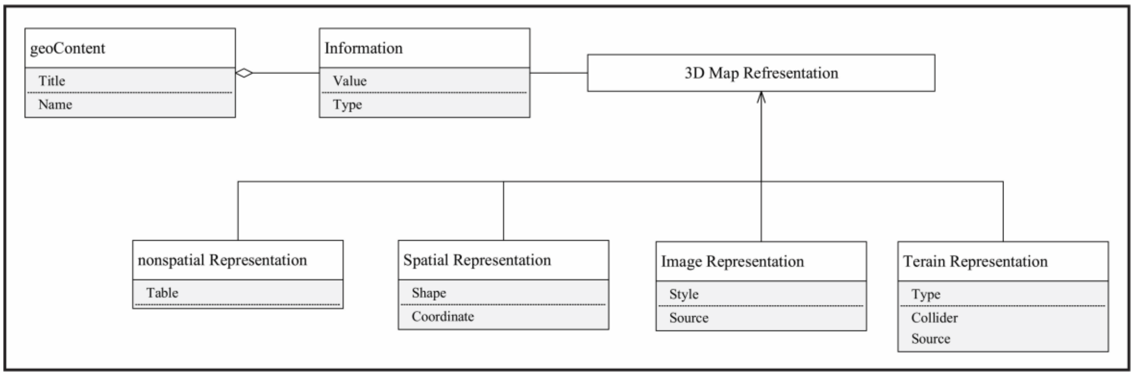

Figure 5.9 The interface model on the prototype 3D maps

Map Visualization in the Unity 3D Mapbox has three main layer structures. The first structure is the terrain layer that has the altitude property to display a 3D map. With this property, users can also enable and disable the 3D map view. The second structure of Mapbox for Unity is the imagery layer. This layer structure is above the terrain layer. The imagery layer on the Mapbox standard feature using Open street maps tileset [100]. The imagery layer wraps the terrain layer with tileset data. Mapbox also allows users to create and publish their imagery layers via Mapbox studio. With this feature, the map developer can customize a suitable base map and share it with others. The last layer structure is a vector layer. Mapbox uses vector layers to present information on the map[50]. In general, GIS vector layers usually contain information. The information such as buildings, roads, rivers, and other information. This study arranges vector layers based on layer requirements for the land evaluation process.

This study uses Custom C# (I.e., "Modifier") to display map information and interact with the map. This study applies a modifier to each layer to display the map attribute. Figure 5.10 describes the map layer structure of the AR-GIS and modifier.

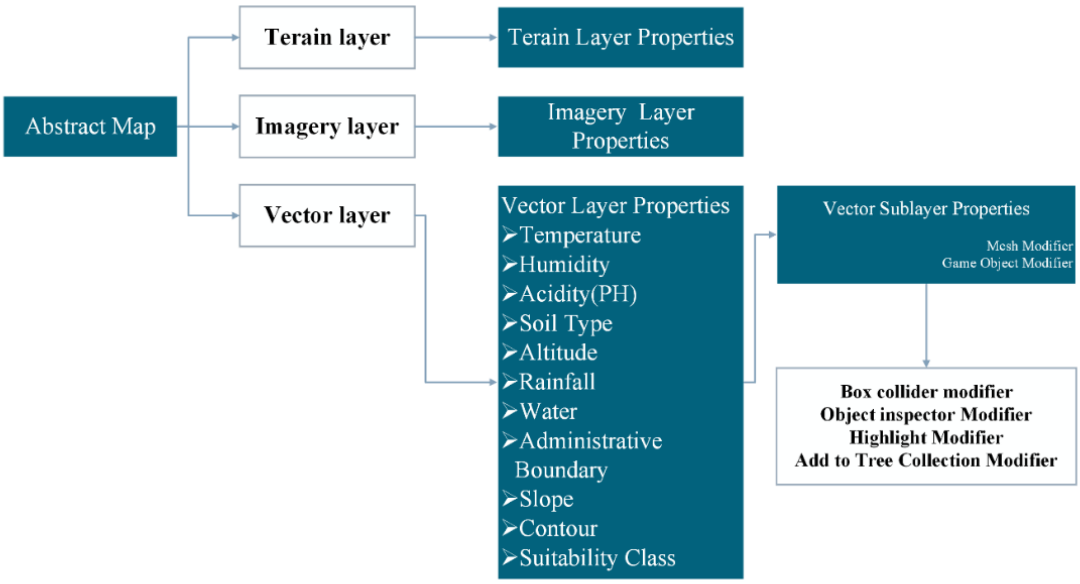

Figure 5.10 The map layer structure of the AR-GIS and modifier.

5.4.4 Map Interactions

Game engines such as Unity3D provide standard features for displaying data and interacting with objects in each scene. However, providing better interaction requires minor modifications to these features. We use a custom C# script to display information and manage camera movement. With all map data stored on Mapbox, this research uses Unity 3D to build the user interface and interaction logic. This study uses two camera navigation. (1) Bird's Eye View. The system allows the user to control camera movement on maps. examples of this movement are zooming, panning, and rotating the maps. (2) First Person View (FPV). AR-GIS uses this view so that the user can control camera movement directly through the device. This research uses the ray casting method to produce bird-eye view navigation. This method deduces the camera position based on the intersection of the rays with the ground surface. We assign different functions on the touchscreen using custom C#. Figure 5.11 shows the assignment of interaction functions on the touchscreen.

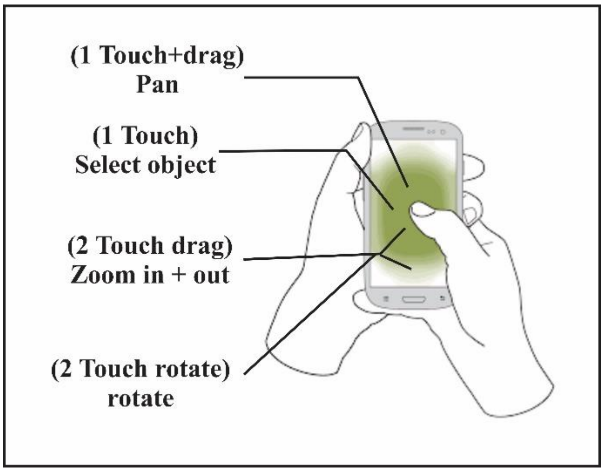

Figure 5.11 Interaction functions on the touchscreen.

The user interface provides buttons to access each function. The menu contains mini maps and buttons for bringing up layers and manipulating layers. Mini map provides a visual cue to assist in map navigation while in Birds Eye View. This study creates menus using the Unity3D user interface component. Figure 5.12 describe the Logical Flow design of the user interface.

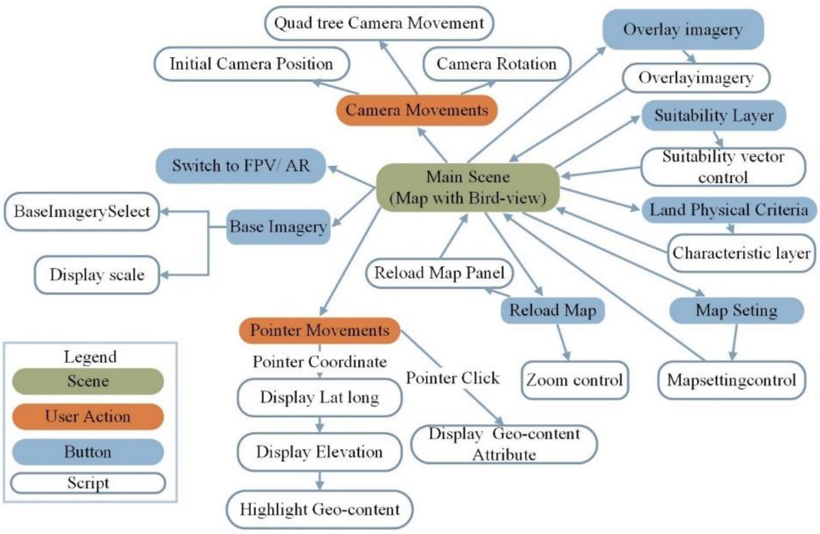

Figure 5.12 The logical Flow design of the user interface

AR-GIS combines several scripts with game components and assets to control the User Interface. The interaction script captures user interaction and provides a response based on user input. This script controls pointer movement, enables/disables layer visualization, and displays information based on User Interaction. The combination between scripts and user interface components allows interactions to adapt to various visualizations when exploring maps. Figure 5.13 is an Example Script to interact with the map.

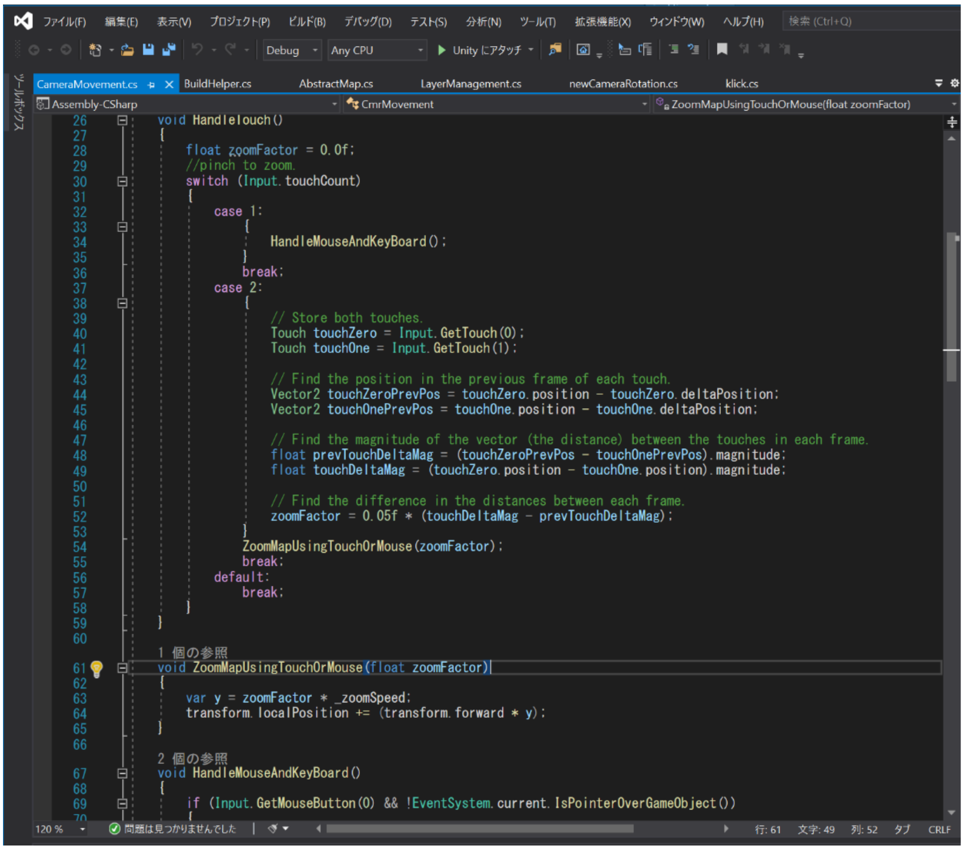

Figure 5.13 Example Script to interact with the map

5.4.5 Mobile Base AR-GIS Prototype

This study proposes Mobile Base AR-GIS Prototype to support Land suitability map Visualization using the Unity3D Game engine. AR-GIS has two scene concepts to facilitate the user exploring the maps. The first concept uses a bird's eye view, and the second concept uses first-person views. Figure 5.14 describes the main interface of the system.

Figure 5.14 The main interface of the system

The main menu contains functions to help manage layers on the map. Mini Maps facilitates and becomes the user's reference in navigating the map. This system has two ways to set the zoom level. The first is to use the slide bar in the menu, and the other way is to use two touches and swipe outward to zoom in or move inward to zoom out. In the AR-GIS prototype, there is also a menu to configure the map display. The user can configure the map view using the imagery layer menu to change the base map to the desired map's view. In the main interface, there are also buttons to control the map layer. Then information about the longitude and latitude center point of the map is displayed at the bottom left of the interface. The system uses custom highlight modifiers and objects inspector modifiers to display vector layer Attributes. Figure 5.15 describes the use of custom modifiers to display vector soil type data.

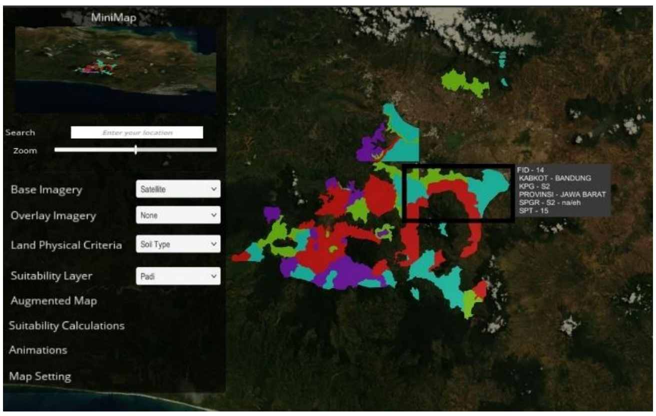

Figure 5.15 The use of custom modifiers to display vector data

This research uses Augmented Reality to display maps in larger areas. We build AR-GIS using marker less method. This method increases the use of AR-GIS because the user does not need a specific marker to display digital objects. The system uses a plane detection algorithm to detect flat areas such as tables or floors. Figure 5.16 a show the process of plane detection and map initialization on a flat plane.

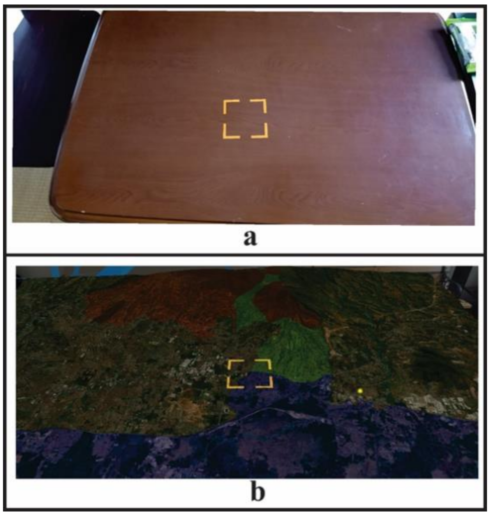

Figure 5.16 Plane detection and map initialization

AR-GIS can visualize maps well. First-person view (FPV) in AR GIS supports Responsive and interactive Map visualization. The interactive User interface allows the user to navigate freely on the map. AR-GIS also produces topographic views that are similar to the original. It can help the user in inspecting the land suitability map. Figure 5.17 shows the FPV mode of AR-GIS.

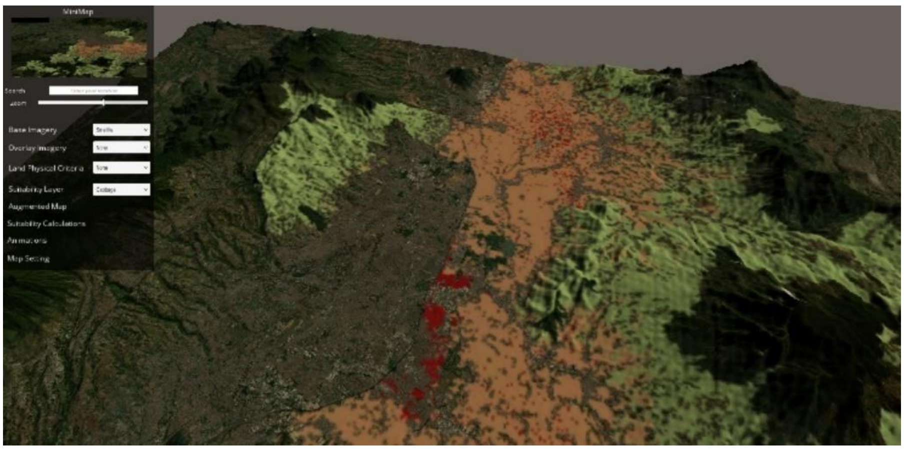

Figure 5.17 FPV mode of AR-GIS

5.5 System Testing and Evaluation

This study evaluates the system using several methods. The first method is performance testing. Performance test aims to test the limits of the toughness and stability of the system. The study installs the system on two mobile devices with different specifications. Then analyze the response time on each device. Table 5.4 describes the device specifications for system testing.

Table 5.4 The device specifications for system testing

Specification Category		OPPO F11 Pro (Device 1)	Xiaomi POCO X3 Pro (Device 2)
Network	Technology	GSM / HSPA / LTE	GSM / HSPA / LTE
	Speed	HSPA 42.2/5.76 Mbps, LTE-A (2CA) Cat7 300/50 Mbps	HSPA 42.2/5.76 Mbps, LTE-A (CA)
	Status	Available. Released 2019, March	Available. Released 2021, March 24
Body	Dimensions	161.3 x 76.1 x 8.8 mm (6.35 x 3.00 x 0.35 in)	165.3 x 76.8 x 9.4 mm (6.51 x 3.02 x 0.37 in)
	Weight	190 g (6.70 oz)	215 g (7.58 oz)
	Build	Glass front, plastic back, plastic frame	Glass front (Gorilla Glass 6), plastic back
	SIM	Hybrid Dual SIM (Nano-SIM, dual stand-by)	Hybrid Dual SIM (Nano-SIM, dual stand-by) IP53, dust and splash protection
	Size	6.53 inches, 103.6 cm^2 (~84.4% screen-to-body ratio)	6.67 inches, 107.4 cm^2 (~84.6% screen-to-body ratio)
	Resolution	1080 x 2340 pixels, 19.5:9 ratio (~397 ppi density)	1080 x 2400 pixels, 20:9 ratio (~395 ppi density)
Platform	OS	Android 9.0 (Pie), ColorOS 6	Android 11, MIUI 12.5 for POCO
	Chipset	Mediatek MT6771 Helio P70 (12nm)	Qualcomm Snapdragon 860 (7 nm)
	CPU	Octa-core (4x2.1 GHz Cortex-A73 & 4x2.0 GHz Cortex-A53)	Octa-core (1x2.96 GHz Kryo 485 Gold & 3x2.42 GHz Kryo 485 Gold & 4x1.78 GHz Kryo 485 Silver)
	GPU	Mali-G72 MP3	Adreno 640
Memory	Card slot	microSDXC (uses shared SIM slot)	microSDXC (uses shared SIM slot)

Specification Category		OPPO F11 Pro (Device 1)	Xiaomi POCO X3 Pro (Device 2)
	Internal	64GB 6GB RAM	256GB 8GB RAM
Main Camera	Modules	48 MP, f/1.8, (wide), 1/2.25", 0.8µm, PDAF 5 MP, f/2.4, (depth)	48 MP, f/1.8, (wide), 1/2.0", 0.8µm, PDAF 8 MP, f/2.2, 119˚ (ultrawide), 1.0µm 2 MP, f/2.4, (macro) 2 MP, f/2.4, (depth)
	Features	LED flash, HDR, panorama	Dual-LED flash, HDR, panorama
	Video	1080p@30fps	4K@30fps, 1080p@30/60/120/240fps, 1080p@960fps, gyro-EIS
Battery	Type	Li-Po 4000 mAh, non-removable	Li-Po 5160 mAh, non-removable
	Charging	Fast charging 20W VOOC 3.0	Fast charging 33W, 59% in 30 min, 100% in 59 min (advertised)
Comms	WLAN	Wi-Fi 802.11 a/b/g/n/ac, dual-band, Wi-Fi Direct, hotspot	Wi-Fi 802.11 a/b/g/n/ac, dual-band, Wi-Fi Direct, hotspot

This study stores all map layers in the Mapbox cloud. Therefore, we also tested the influence of network quality on the system. This study conducted a test using different internet speeds. Table 5.4 describes the differences in the hardware specifications of the two devices. Even so, both devices have the same network and Wi-Fi hardware specifications. It makes the network quality testing is relevant and has high validity. The speed of Wi-Fi connections and cellular networks test is using speed test to the same server. The server is the Nison server in Osaka. Table 5.5 describes the results of network testing using a speed test.

Table 5.5 The results of network testing using a speed test

No	Network	Ping (millisecond)	Speeds (Mbps)
1	WI-FI network	18	156.71
2	Cellular network	73	4.81

Table 5.5 describes the optimal speed provided by a network connection. Based on the table Wi-Fi network is better than a cellular network.

After performing the performance test, we conducted a qualitative test using a questionnaire to know the user's response to the system. We make demonstration video of the systems then designed a questionnaire to find out the user's view of the system. System users are farmers, but we also involve GIS experts' insight into the GIS system. GIS expert comes from the Indonesian Computer University. Total respondents are 30 people consisting of 5 GIS experts, 25 farmers in the Bandung district. To ensure that those who fill out the questionnaire are the relevant respondents, we spread the questionnaire hyperlink only to the target group as the focus group. We divided the questionnaire into three sections. This test divides the questionnaire into three sections. The first section of the questionnaire aims to analyze the user's response to statements regarding the visualization of the criteria map and land suitability in the system. The first section of questioner consists of five statements sentences that related to map layer visualizations. The second section focuses on the User interface in AR-GIS. This section has ten statements sentences about information visualization and system interactions. The last questioner section aims to determine the user's response to the system as a whole. This section contains five related to the whole system. Table 5.6 describes the statements and response choices in the questionnaire.

Table 5.6 The statements and response choices in the questionnaire

	Statement	Item
S1	The system provides an initial overview of the agricultural area in Bandung district	Strongly Agree Agree Neutral Disagree Strongly Disagree
S2	The system visualizes four layers of soil Characteristics, the soil condition map provides an understandable visualization of the soil conditions in the study area	Same as above
S3	The system visualizes two layers of weather characteristics, weather characteristics maps provide an understandable visualization of the weather conditions in the study area	Same as above
S4	The system visualizes tree layers of	Same as above

	Statement	Item
	Topography characteristics, Topography characteristics maps provide an understandable visualization of the topographic conditions in the study area	
S5	We calculated the land evaluation using the Weighted Overlay Method. The overlay process produces a land suitability map. There are four land suitability classes, namely: Very Suitable (S1), Suitable (S2), Marginal Suitable (S3), and not suitable (N). The resulting map can visualize the suitability of agricultural land in the Bandung Regency area.	Same as above
S6	The main display of the system is understandable and provides sufficient information.	Strongly Agree Agree Neutral Disagree Strongly Disagree
S7	The attributes on the menu provide sufficient information	Same as Above
S8	Map Information visualization can be understood well and meet user needs	Same as Above
S9	Interaction methods can be understood and meet user needs	Same as Above
S10	The interaction method is suitable for map navigation	Same as Above
S11	The First-person view in AR-GIS can better visualize topographic maps	Same as Above
S12	3D land suitability maps provide better visualization than 2D	Same as Above
S13	The use of AR GIS increases the system Usability	Same as Above
S14	Use of AR GIS Makes it easy for users to visualize maps	Same as Above
S15	AR GIS is an alternative for farmers to	Same as Above

	Statement	Item
	reduce the need of using computer-based GIS	
S16	Overall, Features in Systems help users in getting information from maps	Strongly Agree Agree Neutral Disagree Strongly Disagree
S17	Visualization of information and interactions on the system to meet user needs	Same as Above
S18	The use of the system can improve understanding of the land suitability map	Same as Above
S19	Data visualization through maps helps users in understanding land suitability maps	Same as Above
S20	Overall, Augmented reality can increase the usability level of the system	Same as Above

5.6 Data Analysis and Discussions

We tested the system performance using two devices that have specifications in table 5.4. This performance test is to determine the system's response to several tasks. The task starts when starting the system (initializing maps), performing navigation, until displaying information. Table 5.7 describes the results of system performance test.

Table 5.7 The results of system performance test

No	Task	Response times (second)			
		Device 1 (Wi-Fi)	Device 2 (Wi-Fi)	Device 1 (Cellular Network)	Device 2 (Cellular Network)
1	Starting system	0.071	0.053	0.080	0.076
2	Plane detection time	0.036	0.027	0.036	0.027
3	Change Base Layer	0.040	0.020	0.080	0.020
4	Add Map layers	0.020	0.017	0.021	0.017
5	Show Information	0.020	0.010	0.020	0.010
6	Panning and rotating in 8 Zoom Level	0.010	0.010	0.020	0.010

No	Task	Response times (second)			
		Device 1 (Wi-Fi)	Device 2 (Wi-Fi)	Device 1 (Cellular Network)	Device 2 (Cellular Network)
	(default)				
7	Zoom from 8 to 10	0.034	0.027	0.130	0.030
8	Panning and rotating in 10 Zoom Level	0.020	0.010	0.020	0.010
9	Zoom from 10 to 12	0.150	0.059	0.340	0.101
10	Panning and rotating in 12 zoom level	0.030	0.010	0.130	0.020
11	Zoom from 12 to 15	0.180	0.035	0.560	0.050
12	Panning and rotating in 15 zoom level	0.070	0.020	0.100	0.030

Table 5.7 shows the results of application testing using two devices with different hardware specifications. Table 5.7 also shows the test results with similar hardware specifications but uses different networks speeds. We convert table data into graphs to make data analysis easier. Figure 5.18 A explains the results of the performance test on two devices that have different hardware specifications. Figure 5.18 B describes the comparison of task time between the two devices.

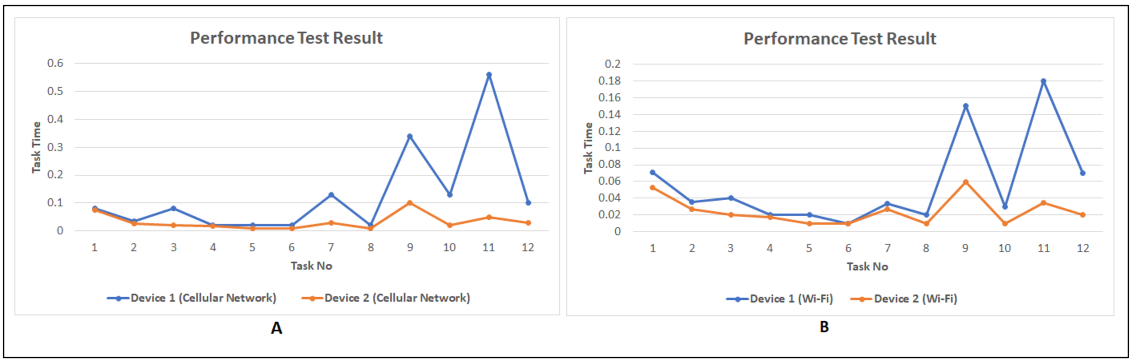

Figure 5.18 The comparison of task time between the two devices; A. Using cellular network, B Using Wi-Fi network

This study also compares the effect of differences in internet network speed on system response time. Figure 5.19 describes the comparison of response time based on the network speed.

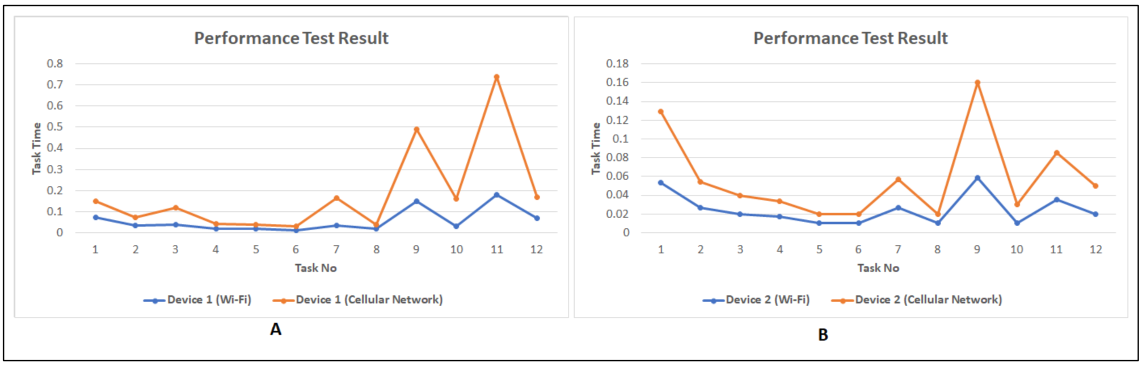

Figure 5.19 The comparison of task time based on the network speed; A. device 1, B device 2

Based on the two-device response time, we draw the following conclusions: First, it is clear that hardware specifications affect AR-GIS performance. The second device has a higher hardware specification. The response system in displaying the map is shorter than the first device. Then panning and the rotating map does not give too much burden to the hardware. The map load consumes more resources when zooming maps. It is because the zoom process changes the map scale. If the map scale changes, the map will load a new tilesets and update the map information. Second, Mapbox stores all maps in cloud storage media. Therefore, internet speed affects map loading time. It is getting longer on poor internet connection. As we see in Figure 5.12, there are differences in task times on the same device but using different internet speeds. Finally, the tasks that require the longest response time are tasks 1, 2, 7, 9, and 11. These five tasks are tasks that require the system to load tilesets from the cloud. These two conclusions are in line with other studies[50], [82], [92], [101]. Other study result state that hardware capabilities and internet networks have a significant influence on system performance. However, based on the performance testing result in table 5.4, the maximum response time on the system is 0.180 seconds. This value is still categorized as a Short Response Time so that it does not affect the user's activity on the application[102].

Meanwhile, we summarize result of qualitative testing method in table 5.8 and table 5.9. table 5.8 shows the recapitulation response of farmers to the system.

Table 5.8 The recapitulation response of farmers to the system

	Participant Response				
	A	B	C	D	E
S1	4	21	0	0	0
S2	5	19	1	0	0
S3	7	17	1	0	0
S4	6	19	0	0	0
S5	6	17	2	0	0

	Participant Response				
	A	B	C	D	E
S6	7	17	1	0	0
S7	5	18	2	0	0
S8	6	17	2	0	0
S9	10	15	0	0	0
S10	6	19	0	0	0
S11	9	13	3	0	0
S12	13	12	0	0	0
S13	10	14	1	0	0
S14	9	14	2	0	0
S15	7	13	5	0	0
S16	9	16	0	0	0
S17	5	20	0	0	0
S18	7	18	0	0	0
S19	7	16	2	0	0
S20	8	17	0	0	0

Then we recapitulate the answers from GIS Experts. Table 5.9 shows a recap of the questionnaire results based on the expert response.

Table 5.9 The questionnaire results based on the expert response

	Participant Response				
	A	B	C	D	E
S1	1	4	0	0	0
S2	0	5	0	0	0
S3	2	3	0	0	0
S4	1	4	0	0	0
S5	2	3	0	0	0
S6	2	3	0	0	0
S7	2	3	0	0	0
S8	2	2	1	0	0
S9	3	2	0	0	0
S10	2	3	0	0	0
S11	3	2	0	0	0
S12	2	3	0	0	0
S13	3	2	0	0	0
S14	3	2	0	0	0

	Participant Response				
	A	B	C	D	E
S15	2	2	1	0	0
S16	2	3	0	0	0
S17	1	4	0	0	0
S18	2	3	0	0	0
S19	1	4	0	0	0
S20	2	3	0	0	0

Based on the questionnaire recapitulation result, we draw the following conclusions: first, the overall response from the user shows a positive approval with the evaluation statement in the instrument. There are no respondents who disagree or highly disagree with evaluation statements on the test instrument. We convert the questionnaire result into a graph to make it easier to analyze the evaluation result. Figure 5.20 explains the graph of questionnaire recapitulation results.

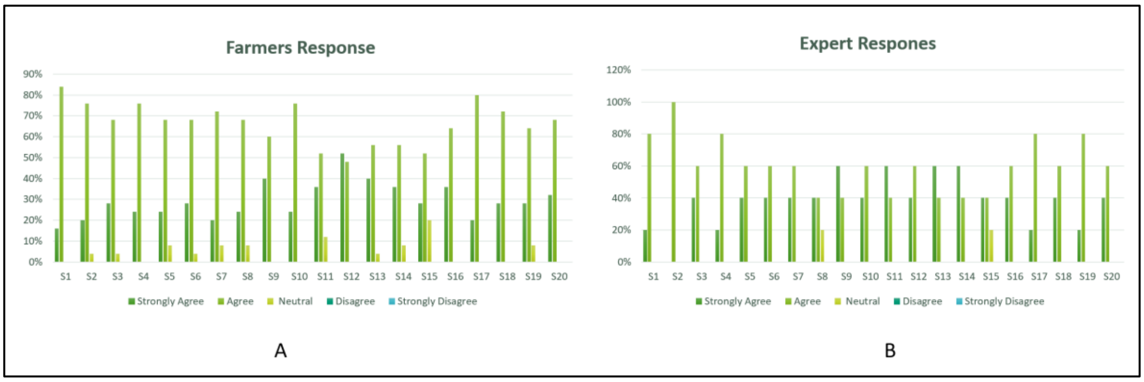

Figure 5.20 The graph of questionnaire recapitulation results

Second, the most positive response from farmers is in a statement no 12, 13 participants or 52% from total participants strongly agree that the visualization of 3D land suitability maps provides better visualization than 2D. Then 12 participants, or 48%, agree with the statement. The expert also gave a positive response to statement no. 12. It further strengthened the response from farmers. Based on this response, we conclude that the visualization of land suitability maps based on 3D is better than 2D. The results of previous studies strengthen this conclusion[103], [104]. The previous research stated that it was easier for users to understand 3D maps than 2D maps.

Third, statements no. 8 and no. 15. have the most varied response distributions. Both farmers and experts gave neutral answers. First, Statement no. 8 is: Map information visualization can be understood well and meet user needs. Based on graph A, 24% of respondents gave answers strongly agree, 68% agree, and 8% gave neutral answers. Then based on graph B, 40% of respondents choose strongly agree or agree to the statement, and others 20% choose neutral. Based on these results, we conclude that the visualization of information on maps still needs improvement. Second, the varied response distributions are statement no 15. Evaluation statement no 15 is "AR GIS is an alternative for farmers to reduce the need of using computer-based GIS." Based on graph A, 28% of respondents choose strongly agree, 52% of respondents agree, and 20% choose neutral. Then similar to statement no 8, based on graph B, 40% of respondents choose strongly agree or agree to the statement, and others 20% choose neutral. Based on the distribution of respondents' answers, we conclude that most respondents agree that AR-GIS can be an alternative to reduce the need for using computer-based GIS. We assume that the neutral response to the S15 statement is due to the unfamiliarity with applying Augmented Reality technology to GIS. Then the field of agriculture, especially those on a large scale, prefer to use computer-based GIS.

Fourth, the user's response to the whole system is in section three. The user's response to the overall AR-GIS shows positive results. Almost all users give a positive response to the statement in evaluation instruments. Statement 19 ("Data visualization through maps helps users understand the land suitability maps") has a neutral answer. There are two respondents from farmers' respondents chose neutral on the statement. However, all users choose strongly agree and agree on statement no 17 ("Visualization of information and interactions on the system to meet user needs"). This result becomes a reference for system development in future research. We conclude, the AR-GIS can visualize the data and information well. But some farmers still have difficulties in understanding the land suitability map.

Finally, Unity3D is a game engine that has the ability to visualize a virtual environment. Unity3D also produces many applications that take advantage of real-world topographic conditions and location-based applications. Even so, the use of unity3D to create a GIS is challenging. It's because Unity3D initially did not provide a projection/coordinate system to manage the actual layer maps. The Mapbox makes additional extensions for unity. With this extension, Mapbox makes unity3D can process spatial data. The Mapbox unity extension provides features for manipulating map objects and assets in the scene. Mapbox also makes it possible to overlay vector layers in the same way as GIS software. Many researchers create 3D maps using Unity3D, but it will still be in the form of static maps [32], [50], [104]. Statics map shows all the information at once on one map. Contras with other this study uses Unity3D to display a dynamic land suitability map using the Mapbox extension. We use Augmented reality to visualize land suitability maps. Users can modify the visualization of map layers. Statement no. 20 ("Overall, Augmented reality can increase the usability level of the system gets a positive response from the user.") The response from farmers is as follows: 32% of respondents stated strongly agree while the remaining 68% state agrees with statements. Then 40% of respondents from the expert strongly agree with the evaluation statement in the instrument, and the other 60% agree. We conclude by managing the map visualization, farmers can get the information in a better way. This result is in line with the research conducted by Herman et., al. [37]. According to Herman et al., users better understand the information presented on dynamic land suitability maps than static maps. It is because the user can choose to display the required information. A good understanding of land suitability maps can help farmers in considering commodities and land selection[14], [22], [105].

5.7 Conclusions

This chapter describes the process of visualizing potential agricultural land suitability using augmented reality geographic information systems. We propose a GIS to visualize land suitability using a mobile-based system. Then to enrich the usability aspect, we equip the system with augmented reality features. We take advantage of unity3D's capabilities in customizing virtual environments. Although it has a powerful ability to simulate the real world, the game engine does not have a projection/coordinate system. We use the Mapbox extension to cover the weakness. The processed map is then uploaded to the Mapbox cloud and converted into Mapbox tileset format. Unity3D scene integrates the map in the Mapbox cloud into an AR-GIS. This research also explores Unity3D's ability to provide spatial data. We take advantage of unity3D's capabilities in customizing virtual environments. We use the Mapbox Unity extension so that the Map has a true coordinate system. That means the map we make, represents the actual geographical conditions. This study evaluates the system with two testing methods. The first method is performance testing. We tested the system using two mobile devices with different specifications. Then this study tested performance using two network networks with different speeds. Based on the test results, we found that hardware and network specifications influence the system's performance. However, the resulting response time on evaluation is still within the scope of the short response time. It does not interfere with the usability of the system. The performance test result also means that the use of Uity3D to make GIS gives positive results. Then we conducted a qualitative test using a questionnaire to determine the user's response to the system. Based on the test results, we can conclude that overall, AR-GIS can provide good information visualization. AR technology can provide a new way of maps visualizing and interacting with GIS. Even so, this research requires development to maximize user understanding. In future research, we will add collaboration features to AR. This feature allows map users to do collaborative work. Collaborative AR can also facilitate the knowledge exchange between farmers, GIS experts, and other stakeholders. With the exchange of knowledge between stakeholders, farmers' understanding of GIS land suitability is getting better

Chapter 6.
Conclusion, Contributions and Future Research

6.1 Conclusion

This study proposes a framework of the Geographic Information System (GIS) to assist farmers in the decision-making process in agriculture. First, this study determines potential commodities that are suitable for the agriculture area in Indonesia. We rank commodities by determining factors that have a significant influence on the land selection process. Then choose the criteria according to the actual conditions of Indonesian agriculture. Second, we made a land suitability map by combining Multi-Criteria Decision Analysis with GIS methods. Third, we propose a system to visualize land suitability using a mobile-based system. Then to enrich the usability aspect, we equip the system with augmented reality features. We divide the explanation of the framework into three Chapters. Chapters 3, 4, and 5 are as follows:

- Chapter 3 Multi-Criteria Decision Analysis for Determining Potential Agriculture Commodities

  This chapter describes the process of determining the potential for agricultural commodities in Indonesia. This chapter aims to select the agriculture commodity with the most potential and most suitable to cultivate in Indonesia. First, we analyze and determine the factors that have a crucial influence on agricultural commodities selections. Then evaluate the weights between the criteria by involving farmers and experts. This study complements the AHP method with alternative selection and classification. We select agriculture commodities based on plant characteristics and the topology of Indonesian agricultural areas to make alternative comparisons equal. The determination of commodity ranking using multi-criteria decision making (MCDM) shows that food crops have better potential to be cultivated in Indonesia. The final ranking shows that the AHP method with selection and classification extension on the criteria makes the commodity ranking more valid. It's because all alternatives have equal characteristics. We are confident that these results are generally relevant for the Indonesian region. That's because we use more alternative criteria and provide limits when selecting alternatives. Even so, every agriculture region has unique potential commodities. It's because the morphology of each agriculture region has significant influences on agriculture commodities determination. Commodity ranking a result is expected to be a reference for farmers in choosing criteria.

- ❖ Chapter 4 Integrating the Multi-Criteria Decision Making (MCDM) with Geographic Information System to evaluate land suitability.

  This chapter describes the land evaluation process by integrating Multicriteria Decision Analysis (MCDA) and Geographic Information System (GIS) methods. This study aims to create a land suitability map for potential agricultural commodities. This study proposed framework for land suitability evaluation. The first stage in the framework focuses on providing Georeferenced to the collected data. Stage two focuses on building the thematic maps layer. We convert all thematic maps into a raster format. We reclassify using the land suitability guidelines issued by the Indonesian government. The reclassification process aims to ensure that the land suitability map has an accurate class in accordance with the plant growth requirements. In the third stage, this study complements the AHP method with alternative selection and classification. We provide limitations and classifications of alternative selection based on plant characteristics and the topology of Bandung District agricultural areas. Based on land suitability maps, we summarize the findings that the study area agriculture land is more suitable for growing vegetables. However, the study area also has a good level of land suitability for rice cultivation. With the land suitability map, Farmers can get an overview of land suitability in the study area. Land suitability maps can be taken into consideration when choosing commodities. Farmers also have considerable information about what plants are suitable to cultivate on their land.

- ❖ Chapter 5 Potential Agricultural Land Suitability Visualization Using Augmented Reality Geographic Information System (AR-GIS).

  In this chapter, we analyze the weaknesses in GIS agriculture. Then we propose a system to visualize land suitability using a mobile-based system to increase familiarity. Then to enrich the usability aspect, we equip the system with augmented reality features. We take advantage of unity3D's capabilities in customizing virtual environments. We use the Mapbox Unity extension so that the Map has a true coordinate system. That means the map we make, represents the actual geographical conditions. This study evaluates the system with two testing methods. The first testing method is the performance test, and the second is a qualitative test using a questionnaire that aims to find out the user's response to the system. This study concludes that overall; AR-GIS can provide good information visualization. AR technology also provides a new way of maps visualizing and interacting with maps. AR-GIS can make it easier for farmers to extract information from land suitability maps.

Speak in general, the original contribution of this research is the proposed framework of a Geographic information system (GIS) to assist farms in the decision-making process regarding agriculture commodity selection. Many aspects of GIS to assist decision-making in agriculture have not been deeply explored previously. This document describes some of the details of contributions to this area.

1. Provide insight on decision-making to select potential commodities in the study area. We conduct analysis and determine the factors that have a significant influence on the potential of the agriculture commodity. Then provide appropriate limits on selecting alternative agriculture commodities. We are confident that determining potential agriculture commodities produces relevant rankings and can be one of the factors that farmers consider in choosing agriculture commodities. This ranking is also a reference for the effectiveness of the land suitability evaluation process.
2. Integrate of GIS with multi-criteria decision analysis (MCDA) to conduct the land evaluation. This integration produces an accurate land suitability map and can provide an overview of land suitability in the study area. Land suitability maps are one of the considerations factors when selecting commodities. Farmers also have insight into what kinds of plants are suitable to cultivate on their land.
3. Provide a new way to visualize land suitability maps to make it easier for farmers to get information on land suitability maps. The proposed system does not only focus on presenting information but also on visual and interaction aspects. Overall, AR-GIS can provide good information visualization. AR technology enhances maps visualization and interaction on GIS.

Although AR-GIS provides sufficient information, farmers still find it hard to understand the map. Therefore, this research needs improvement to maximize user understanding of the land suitability map in the future.

6.2 Future Research

In future research, it is necessary to increase the farmers' understanding of land suitability maps. Farmers must receive education on how to understand land suitability maps properly. Multi-user was one of the limitations of using the early AR platform. Currently, Cloud-based anchor points on the AR platform can connect users via the web. Cloud anchors allow multiple devices to see, interact, and synchronize the same digital context at the time. We will add collaboration features to AR by utilizing cloud anchors. This feature allows map users to do collaborative work. Collaborative AR also enables the exchange of knowledge between farmers, GIS experts, and other stakeholders. With the exchange of knowledge between stakeholders, farmers understanding of GIS land suitability will increase. Another advantage of using collaborative-AR GIS is that users can keep their distance when interacting with maps. This advantage is significant to overcome the difficulties of doing collaboration work in the COVID-19 pandemic situation. The system with Collaborative AR-GIS is expected to enhance the farmer's understanding of the land suitability map. We consider that the system will have a high level of usability to help farmers in the decision-making. Furthermore, with good insight on the land suitability map, it is hoped that it will reduce the risk of crop failure and increase the productivity of the agricultural sector in the future.

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Publications

1. H Maulana, R Andriana, H Kanai; Development of the 3-Dimensional Map in the Bandung Regency Government Complex; International Conference on Informatics Engineering, Science & technology; INCITEST 2019; July 18, 2019; Bandung Indonesia
2. Maulana H and Kanai H, Multi-Criteria Decision Analysis for Determining Potential Agriculture Commodities in Indonesia J. Eng. Sci. Technol. 15 33–40, 2020.
3. Maulana H and Kanai H, Development of Precision Agriculture Models for Medium and Small-scale Agriculture in Indonesia IOP Conf. Ser.: Mater. Sci. Eng. 879 (1) 01208, 2020.
4. Maulana H and Kanai H, Designing Human-Centered 3D GIS Interface and Interaction Model to Support Agriculture Commodity Selection AWIST 2020. 3 29, 2020.
5. H Maulana and H Kanai, Potential Agricultural Land Suitability Evaluation using Multi-Criteria Decision Analysis (MCDA) and Geographical Information Systems (GIS), The 4th International Conference on Informatics, Engineering, Science, and Technology (INCITEST 2021), March 2021, Bandung, Indonesia (oral Presentations)
6. Maulana, Hanhan, and Hideaki Kanai. "Land Suitability Evaluation by Integrating Multi-Criteria Decision-Making (MCDM), Geographic Information System (GIS) Method, and Augmented Reality-GIS." In Intelligent Decision Technologies, pp. 309-320. Springer, Singapore, 2021.
7. Maulana H and Kanai H, Potential Agricultural Land Suitability Visualization Using Augmented reality Geographic Information System (AR-GIS), International Engineering and Computing Research Conference; EURECA 2021, June 2021, Selangor Malaysia (Accepted)
8. Maulana H and Kanai H, Utilizing Game Engine for Development Interactive 3-Dimensional Geographic Information System (GIS) Agriculture Commodity Selection and Land Evaluation; IEEE International Conference on Systems, Man, and Cybernetics; October, 2021. Melbourne, Australia. (Accepted)
9. Maulana H and Kanai H, Designing Human Centered 3D GIS Interface and

Interaction Model to Support Agriculture Commodity Selection; Asia-Pacific Journal of Information Technology and Multimedia; pp 1-14, UKM PRESS, Singapore 2021.

Awards:

1. The Best Presenter, In The 3 International Conference on Informatics Engineering, Science & Technology (INCITEST) held in Universitas Komputer Indonesia, Bandung, West Java, Indonesia, on June 11, 2020.
2. Best Research Paper Presentation, during 15th EURECA International Engineering & Computing Research Conference, held in Taylor's University Lakeside Campus on June 30, 2021.

Appendix A

Research Instrument for Criterion Comparison matrices

Comparative judgement Instrument

Government Support												Government Support				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Government Support												Weather Resistance				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Government Support												Land condition Adaptations				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Government Support												Needs of human resources				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Government Support												Quality of harvest/Ha				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Government Support												Age of Productions				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Government Support												Endurance against disease				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Government Support												Market demand				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Government Support												Seeds cost				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Government Support												Selling price				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Government Support												Planting Cost				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Weather Resistance												Government Support				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Weather Resistance												Weather Resistance				

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Weather Resistance	Land condition Adaptations
Weather Resistance	Needs of human resources
Weather Resistance	Quality of harvest/Ha
Weather Resistance	Age of Productions
Weather Resistance	Endurance against disease
Weather Resistance	Market demand
Weather Resistance	Seeds cost
Weather Resistance	Selling price
Weather Resistance	Planting Cost
Land condition Adaptations	Government Support
Land condition Adaptations	Weather Resistance
Land condition Adaptations	Land condition Adaptations
Land condition Adaptations	Needs of human resources

Each pair above is followed on the page by the scale row:

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Land condition Adaptations												Quality of harvest/Ha				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Land condition Adaptations												Age of Productions				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Land condition Adaptations												Endurance against disease				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Land condition Adaptations												Market demand				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Land condition Adaptations												Seeds cost				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Land condition Adaptations												Selling price				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Land condition Adaptations												Planting Cost				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Needs of human resources												Government Support				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Needs of human resources												Weather Resistance				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Needs of human resources												Land condition Adaptations				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Needs of human resources												Needs of human resources				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Needs of human												Quality of harvest/Ha				

resources	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Needs of human resources	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Age of Productions
Needs of human resources	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Endurance against disease
Needs of human resources	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Market demand
Needs of human resources	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Seeds cost
Needs of human resources	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Selling price
Needs of human resources	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Planting Cost
Quality of harvest/Ha	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Government Support
Quality of harvest/Ha	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Weather Resistance
Quality of harvest/Ha	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Land condition Adaptations
Quality of harvest/Ha	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Needs of human resources
Quality of harvest/Ha	9	8	7	6	5	4	3	2	[redacted]	2	3	4	5	6	7	8	9	Quality of harvest/Ha
Quality of harvest/Ha	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Age of Productions

Quality of harvest/Ha — Endurance against disease

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Quality of harvest/Ha — Market demand

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Quality of harvest/Ha — Seeds cost

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Quality of harvest/Ha — Selling price

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Quality of harvest/Ha — Planting Cost

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Age of Productions — Government Support

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Age of Productions — Weather Resistance

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Age of Productions — Land condition Adaptations

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Government Support — Needs of human resources

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Age of Productions — Quality of harvest/Ha

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Age of Productions — Age of Productions

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Age of Productions — Endurance against disease

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Age of Productions — Market demand

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Age of Productions — Seeds cost

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Age of Productions — Selling price

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Age of Productions												Planting Cost				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Government Support												Government Support				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Endurance against disease												Weather Resistance				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Endurance against disease												Land condition Adaptations				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Endurance against disease												Needs of human resources				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Endurance against disease												Quality of harvest/Ha				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Endurance against disease												Age of Productions				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Endurance against disease												Endurance against disease				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Endurance against disease												Market demand				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Endurance against disease												Seeds cost				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Endurance against disease												Selling price				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Endurance against disease												Planting Cost				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Market demand												Government Support				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Market demand												Weather Resistance				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Market demand												Land condition Adaptations				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Government Support												Needs of human resources				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Market demand												Quality of harvest/Ha				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Market demand												Age of Productions				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Market demand												Endurance against disease				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Market demand												Market demand				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Market demand												Seeds cost				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Market demand												Selling price				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Market demand												Planting Cost				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Seeds cost												Government Support				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Seeds cost												Weather Resistance				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Seeds cost												Land condition Adaptations				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Seeds cost												Needs of human				

												resources				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Seeds cost												Quality of harvest/Ha				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Seeds cost												Age of Productions				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Seeds cost												Endurance against disease				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Seeds cost												Market demand				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Seeds cost												Seeds cost				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Seeds cost												Selling price				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Seeds cost												Planting Cost				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selling price												Government Support				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selling price												Weather Resistance				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selling price												Land condition Adaptations				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selling price												Needs of human resources				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selling price												Quality of harvest/Ha				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selling price												Age of Productions				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selling price												Endurance against disease				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Selling price												Market demand				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selling price												Seeds cost				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selling price												Selling price				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Selling price												Planting Cost				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Planting Cost												Government Support				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Planting Cost												Weather Resistance				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Planting Cost												Land condition Adaptations				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Planting Cost												Needs of human resources				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Planting Cost												Quality of harvest/Ha				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Planting Cost												Age of Productions				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Planting Cost												Endurance against disease				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Planting Cost												Market demand				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Planting Cost												Seeds cost				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Planting Cost												Selling price				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Planting Cost												Planting Cost				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Research Instrument for alternative comparison

Comparative judgement Instrument

Rice												Rice				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Rice												Soybeans				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Rice												Corn				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Rice												Peanut				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Rice												Cassava				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Rice												Sweet Potatoes				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Rice												Potatoes				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Rice												Onions				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Rice												Cabbage				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Rice												Chili				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Rice												Tomato				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Soybeans												Rice				
9	8	7	9	8	7	9	8	7	9	8	7	9	8	7	9	8
Soybeans												Soybeans				
9	8	7	9	8	7	9	8	7	9	8	7	9	8	7	9	8
Soybeans												Corn				
9	8	7	9	8	7	9	8	7	9	8	7	9	8	7	9	8
Soybeans												Peanut				
9	8	7	9	8	7	9	8	7	9	8	7	9	8	7	9	8
Soybeans												Cassava				

9	8	7	9	8	7	9	8	7	9	8	7	9	8	7	9	8
Soybeans												Sweet Potatoes				
9	8	7	9	8	7	9	8	7	9	8	7	9	8	7	9	8
Soybeans												Potatoes				
9	8	7	9	8	7	9	8	7	9	8	7	9	8	7	9	8
Soybeans												Onions				
9	8	7	9	8	7	9	8	7	9	8	7	9	8	7	9	8
Soybeans												Cabbage				
9	8	7	9	8	7	9	8	7	9	8	7	9	8	7	9	8
Soybeans												Chili				
9	8	7	9	8	7	9	8	7	9	8	7	9	8	7	9	8
Soybeans												Tomato				
9	8	7	9	8	7	9	8	7	9	8	7	9	8	7	9	8
Corn												Rice				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Corn												Soybeans				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Corn												Corn				
9	8	7	6	5	4	3	2	[redacted]	2	3	4	5	6	7	8	9
Corn												Peanut				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Corn												Cassava				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Corn												Sweet Potatoes				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Corn												Potatoes				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Corn												Onions				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Corn												Cabbage				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Corn												Chili				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Corn												Tomato				

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Peanut — Rice

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Peanut — Soybeans

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Peanut — Corn

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Peanut — Peanut

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Peanut — Cassava

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Peanut — Sweet Potatoes

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Peanut — Potatoes

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Peanut — Onions

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Peanut — Cabbage

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Peanut — Chili

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Peanut — Tomato

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Cassava — Rice

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Cassava — Soybeans

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Cassava — Corn

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Cassava — Peanut

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Cassava — Cassava

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Cassava												Sweet Potatoes				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Cassava												Potatoes				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Cassava												Onions				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Cassava												Cabbage				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Cassava												Chili				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Cassava												Tomato				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Sweet Potatoes												Rice				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Sweet Potatoes												Soybeans				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Sweet Potatoes												Corn				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Sweet Potatoes												Peanut				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Sweet Potatoes												Cassava				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Sweet Potatoes												Sweet Potatoes				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Sweet Potatoes												Potatoes				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Sweet Potatoes												Onions				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Sweet Potatoes												Cabbage				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Sweet Potatoes												Chili				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Sweet Potatoes												Tomato				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Potatoes												Rice				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Potatoes												Soybeans				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Potatoes												Corn				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Potatoes												Peanut				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Potatoes												Cassava				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Potatoes												Sweet Potatoes				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Potatoes												Potatoes				
9	8	7	6	5	4	3	2	[redacted]	2	3	4	5	6	7	8	9
Potatoes												Onions				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Potatoes												Cabbage				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Potatoes												Chili				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Potatoes												Tomato				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Onions												Rice				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Onions												Soybeans				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Onions												Corn				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Onions												Peanut				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Onions												Cassava				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Onions												Sweet Potatoes				

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Onions												Potatoes				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Onions												Onions				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Onions												Cabbage				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Onions												Chili				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Onions												Tomato				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Cabbage												Rice				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Cabbage												Soybeans				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Cabbage												Corn				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Cabbage												Peanut				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Cabbage												Cassava				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Cabbage												Sweet Potatoes				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Cabbage												Potatoes				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Cabbage												Onions				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Cabbage												Cabbage				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Cabbage												Chili				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
Cabbage												Tomato				
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Chili Rice

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Chili Soybeans

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Chili Corn

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Chili Peanut

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Chili Cassava

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Chili Sweet Potatoes

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Chili Potatoes

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Chili Onions

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Chili Cabbage

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Chili Chili

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Chili Tomato

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Tomato Rice

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Tomato Soybeans

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Tomato Corn

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Tomato Peanut

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Tomato Cassava

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Tomato Sweet Potatoes

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Tomato Potatoes

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Tomato Onions

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Tomato Cabbage

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Tomato Chili

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Tomato Tomato

9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9

Appendix B

Questioner for system evaluation

Please mark only one option for each statement

1. Highly disagree
2. Disagree
3. Neutral
4. Agree
5. Highly agree

No	Statement	Option				
		1	2	3	4	5
1	The system provides an initial overview of the agricultural area in Bandung district					
2	The system visualizes four layers of soil Characteristics, the soil condition map provides an understandable visualization of the soil conditions in the study area					
3	The system visualizes two layers of weather characteristics, weather characteristics maps provide an understandable visualization of the weather conditions in the study area					
4	The system visualizes tree layers of Topography characteristics, Topography characteristics maps provide an understandable visualization of the topographic conditions in the study area					
5	We calculated the land evaluation using the Weighted Overlay Method. The overlay process produces a land suitability map. There are four land suitability classes, namely: Very Suitable (S1), Suitable (S2), Marginal Suitable (S3), and not suitable (N). The resulting map can visualize the suitability of agricultural land in the Bandung Regency area.					
6	The main display of the system is understandable and provides sufficient information.					
7	The attributes on the menu provide sufficient information					
8	Map Information visualization can be understood well and meet user needs					
9	Interaction methods can be understood and meet user needs					

No	Statement	Option				
		1	2	3	4	5
10	The interaction method is suitable for map navigation					
11	The First-person view in AR-GIS can better visualize topographic maps					
12	3D land suitability maps provide better visualization than 2D					
13	The use of AR GIS increases the system Usability					
14	Use of AR GIS Makes it easy for users to visualize maps					
15	AR GIS is an alternative for farmers to reduce the need of using computer-based GIS					
16	Overall, Features in Systems help users in getting information from maps					
17	Visualization of information and interactions on the system to meet user needs					
18	The use of the system can improve understanding of the land suitability map					
19	Data visualization through maps helps users in understanding land suitability maps					
20	Overall, Augmented reality can increase the usability level of the system					