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POTENTIAL AGRICULTURAL LAND SUITABILITY VISUALIZATION USING AUGMENTED REALITY GEOGRAPHIC INFORMATION SYSTEM (AR-GIS)

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Abstract

This study aims to visualize the potential agricultural land suitability using the Augmented Reality Geographical Information System (AR-GIS). AR-GIS can provide an immersive experience to users. Bandung Regency area was chosen as the study area because it has good potential for agriculture. The challenge that motivates the development of Augmented reality in the visualization of Land Suitability is that farmers can use GIS practically to assist in decision making. This study has three main stages. The first and second stages integrated the Multi-Criteria Decision Analysis (MCDA) with the Geographic Information System (GIS) method. The first stage aims to determine potential commodities using the MCDA method by considering economic, environmental, and plant characteristics factors. The second stage describes the land suitability evaluation process for each commodity using the GIS method. Based on the evaluation results, cabbage, potatoes, and onion are the most suitable plant to be cultivated in the study area. This result is consistent with statistical data that shows that these commodities have the highest productivity. The third stage of this study explains the process of map visualization using augmented reality. AR-GIS is expected to be able to provide a better map visualization display. With good map visualization, information on the GIS can be easy to understand by the user. Furthermore, it is hoped that the AR-GIS will have a high level of usability.

Keywords: Augmented reality, Augmented reality geographical information system, Commodities, Geographic information system, Multi-criteria decision analysis.

1. Introduction

Indonesia is a country that has a high population growth rate. Based on data taken from the Indonesian Central Statistics Agency (BPS), the Annual Population Growth Rate is 1.31%. In 2010 the total population of Indonesia was 238 million and then increased to 268 million in 2019. This increase in population causes food needs in Indonesia to be increased [1]. Indonesia is an agricultural country. Agriculture has a crucial role in meeting domestic food needs [2]. Unfortunately, the agricultural sector in Indonesia continues to decline [3]. One of the factors causing the decline in agricultural productivity in Indonesia is crop failure.

Augmented reality (AR) is a computational technology that has been applied in various fields. Currently, AR can integrate the Real World and the virtual world. Many game applications use AR to represent the real-world environment [4-6]. With the same map as the real world, users can have a similar exploration experience to the real-world explorations. Providing map visualization in 3D is a challenging task for GIS developers. Augmented reality can display 3D objects well without being limited to the screen area of the device. Augmented reality also provides a new way to interact with 3D Maps [7]. Researchers utilize the augmented reality to provide an immersive experience to users [4, 8]. Researchers also explain that augmented reality can improve the understanding of 3D maps. Unity3D is a game engine that is well known among software developers. Unity3D can develop Augmented reality applications. However, this game engine does not have a projection/ coordinate system. The projection/ coordinate system is the most critical element in creating a GIS. The Mapbox extension for unity can handle the lack of Unity3D in managing spatial data by providing a projection / coordinate system.

Land evaluation is a process for predicting the land suitability to specific land uses in an area (land). According to the Food and Agriculture Organization of the United Nations (FAO), climate, soil, and topography are three important factors in land evaluation. The Indonesian Ministry of Agriculture also provides guidelines for conducting land evaluations for commodities cultivated in Indonesian regions [9]. However, to conduct land evaluation, a large amount of spatial data is required [10-13]. Research on land evaluation has been conducted. Herzberg et.al., conducted land evaluation by combining science with local farmers' knowledge [13]. Similar researches are carried out in many developing countries and have high agricultural potential such as Vietnam, Thailand, and India [14, 15, 16]. In Indonesia, research on land suitability evaluation is designated for one specific crop [17, 18]. So, it is not easy to compare land suitability between commodities.

This study conducted a land evaluation by combining MCDA with GIS techniques. In the first stage, the Analytical Hierarchy Process (AHP) method is used to select commodities that have the most significant potential for cultivation in the study area. The second stage is an evaluation of agricultural land by considering the physical conditions of the land. The physical conditions of the evaluated land are climate data, land topography, and soil conditions. The GIS method used to analyse the land is the weighted overlay method. By combining the MCDA and GIS methods, the land evaluation results will be more accurate and relevant. In addition, we can compare the suitability of land between commodities. So, farmers have reasonable consideration when deciding which commodities should be planted. The last stage describes the visualization process of maps by utilizing augmented reality technology. The processed map is then uploaded to the

Mapbox cloud and converted into Mapbox tile set format. Unity3D scene integrates the map in the Mapbox cloud into an AR-Map. AR Maps is expected to help farmers in the decision-making process regarding the selection of agricultural commodities. With the land suitability map, it is also expected to reduce the risk of crop failure.

2. Related Work

Agriculture has a significant influence on the food needs of a region. To meet food needs, farmers do various ways to increase agricultural productivity and reduce the risk of crop failure. Various studies use the decision-making system to assist farmers in increasing productivity and reducing the risk of crop failure. Land suitability assessment is one alternative. The geographical factor's role is significant in decision-making in the agricultural sector. Therefore, the role of geographic information systems (GIS) in agriculture is very crucial [19, 20]. Land suitability evaluation helps farmers in land management. Furthermore, good land management can create a sustainable agricultural system [21].

The land evaluation process often uses various methods. One of the most appropriate methods is the Multi-Criteria Decision Analysis (MCDA) method [10-14]. Ostovari et al. [22] used the MCDA for land evaluation by considering the effects of the environment on fertile land [21]. Other studies also apply MCDA to assist in decision-making to support agricultural processes such as land suitability evaluation for irrigation [23, 24]. One method that uses the MCDA approach is the Analytical Hierarchical Process (AHP) method. Criticism of the use of the AHP method in decision-making often occurs. It is because AHP tends to have problems such as rank reversal phenomena [25, 26]. However, combining AHP with one of the GIS methods can provide an appropriate decision [27, 28]. The weighted Overlay method is a GIS method that uses AHP weighting in overlaying map layers [26]. Researchers integrated this method for land suitability assessment for various crops such as tea, coffee, rapeseed, and even seaweed [21, 22, 29, 30]. This research proves that the integration of MCDA and GIS methods is an appropriate method for land suitability.

GIS can visualize maps very well. Unfortunately, the implementation of GIS is less than optimal [3]. It is because very few farmers can operate GIS directly. GIS is generally computer-based, but farmers are not familiar with computer systems [4]. There are various ways to improve GIS usability. One of them is enriching the GIS with better visualization and interaction [5-8]. In addition, many researchers are developing mobile-based GIS to improve familiarity aspects [30, 31]. The researchers concluded that the ease-of-use GIS and good map visualization makes it easier for users to understand the map [4-8].

GIS Interaction Development is a challenging topic. Researchers use the game engine's capabilities to enrich interactions. Merging the real-world environment and the virtual world can create an immersive experience for the user. Carera et.al. [32], using Augmented reality to improve understanding of spatial data. Researchers take advantage of the visualization and interaction capabilities of the game engine to display geospatial data [6-8]. However, game engines still have limitations. The limitation is that the game engine does not yet have a projection/coordinate system, so it is still relatively difficult to develop a complete GIS.

Unity 3D is one of the well-known game engines. Researchers take advantage of Unity 3D's ability to visualize geospatial data with Augmented reality [32, 33]. This game engine supports adding extensions to develop various applications. Mapbox SDK extension is one of the extensions that allow Unity3d to process geospatial data. With this Mapbox extension, Unity 3D has a Projection system to manage spatial data. Laksono et al. [8] used Mapbox SDK extension in Unity to visualize topographic data. This SDK allows unity3D to develop GIS. With the addition of the Mapbox Unity SDK, Unity 3D game engine can have a coordinate system like other GIS Builder software.

3. Method

This research is divided into three stages. The first stage is to determine the commodities that have the best potential to be cultivated in the research area. This stage uses the AHP method to select potential commodities. The second stage is to evaluate the land suitability using GIS method. This evaluation process is based on the physical land characteristics, such as climate, soil, and topography factors. The last stage is visualizing the map using augmented reality technology. The map is processed and saved into the cloud database. The map is then accessed to be integrated with the scene in unity3D.

3.1. Analytical hierarchical process

The process of determining the potential commodity consists of four main steps. The first step is to select the criteria and sub-criteria. The second step is to construct a hierarchical structure. The third step is to create pairwise comparison matrix based on the value of each criterion's relative importance. The final step is to calculate the matrix and check it is consistency. Figure 1 describes the steps of the process of determining potential commodities using the AHP method

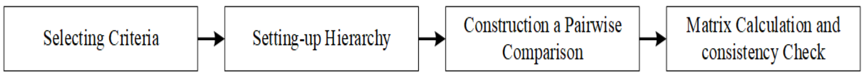

Fig. 1. The steps for determining potential commodities use the AHP method.

In implementing the AHP method, consistency checking is crucial. The value of the Consistency Ratio (CR) shows the level of consistency in the paired matrix. If CR> = 0.1, then there is no random scoring in the matrix. Its means that the pairwise comparison matrix is acceptable. CR value is calculated using Eq. (1)

$$CR = \frac{CI}{RI} \quad (1)$$

where CR is Consistency Ratio, RI is Random index value defined by Saaty [34], and CI is consistency index calculated using Eq. (2).

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad (2)$$

where *n* is total number of compared criteria. For calculation of $\lambda_{\max}$ which is the matrix largest eigenvalue used Eq. (3).

$$\lambda_{\max} = \frac{\sum \frac{\sum_{y=1}^{n} w_x * C_{xy}}{w_x}}{n} \quad (3)$$

where w_x is weight of criteria x and C_{xy} is level of importance of each criterion.

3.2. GIS base evaluation

The land evaluation process using the GIS technique consists of four main steps. The first step is data collection. Land characteristics data are collected from an open data portal. The second step is pre-processing data by clipping and reclassifying the map layer. The third step is the map overlay process. The reclassification process on the map is based on literature studies and land suitability assessment guidelines issued by the Indonesian Ministry of Agriculture. In the final step, a land suitability map is obtained for each commodity. Figure 2 illustrates the process of land evaluation using GIS techniques.

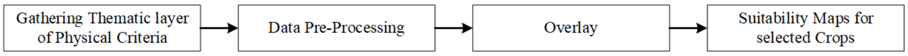

Fig. 2. Land evaluation using GIS techniques.

The thematic layer is overlaid using the weighted overlay method to provide the land suitability map. The weighted overlay method is the most often used method for evaluating land suitability. This method is an effective method for managing raster data. It can integrate the layer according to the criteria in the AHP method. Equation (4) is applied to overlay each thematic layer

$$s = \frac{\sum w_i s_{ij}}{\sum w_i} \tag{4}$$

Where, W_i is the factor of criterion weight, S_{ij} is the spatial map class weight, and s is the spatial unit output value.

3.3. Augmented reality GIS

The augmented reality development process begins with editing raster and vector data. The Mapbox cloud stores the map layer data and covers it as tile sets of data. Unity3D integrates these layers into a scene [8]. The custom C # script is combined with other game assets to interact with objects on the map. This research uses the marker less augmented reality method. Figure 3 describes the map processing process in AR-GIS.

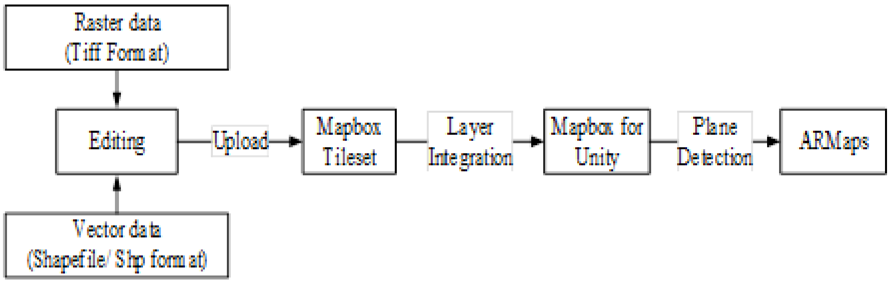

Fig.3. The map processing process in AR-GIS.

The marker less method increases the reusability of using AR. Users do not need specific markers to display digital elements. First, the camera will detect the plane/surface then the user will provide the interaction to position the map. Then the map is visualized based on the anchor point defined by the user. Figure 4 describes the AR GIS concepts.

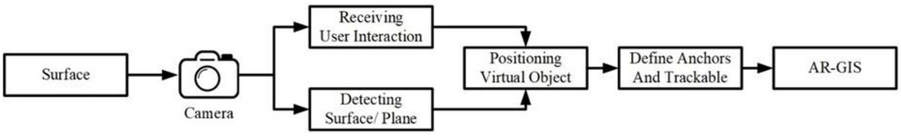

Fig. 4. The AR GIS concepts.

4. Result and Discussion

To obtain right criteria, a hierarchy is arranged into three levels. The goals to be achieved are used as the foundation of the hierarchy. After determining the goals, the next step is to develop criteria and sub-criteria. The criteria chosen are economical, plant characteristics, and environmental characteristics. Figure 5 describes the hierarchical structure used for commodity selection using the AHP method. These factors were selected because they have a significant influence on the process of cultivating agricultural commodities. To determine the sub-criteria used a combination of data taken from the knowledge of farmers, the Indonesian Ministry of Agriculture as well as relevant literature [13, 18-20]. A pairwise comparison matrix is used to determine the priority order of each criterion [13, 21, 22]. The importance level of each criterion is compared and given a decimal value according to the defined provisions. Then the matrix is normalized. The result of this normalization stage is the weight value of each criterion. The results were validated by calculating the consistency ratio value. The consistency ratio obtained is 0.0819. This value ≤ 0.1 means that the CR values are consistent [21].

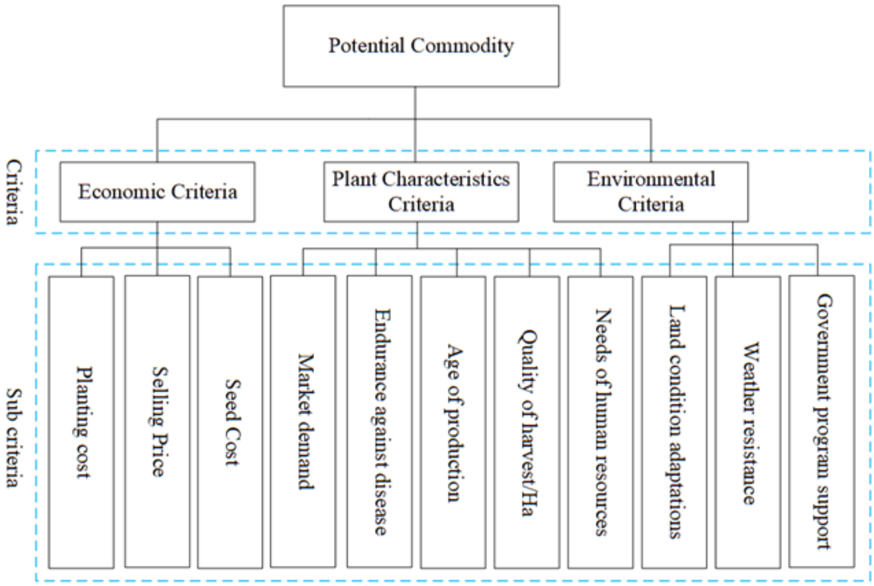

Fig. 5. Hierarchy of criteria for potential commodity selections.

The weighting process is not only for the criteria but also for each alternative. This weighting process is carried out to calculate the final ranking of each alternative. Based on the final ranking calculation, cassava, sweet potato, onion, potato, and paddy are the most potential commodities cultivated in the study area. The next step is the land evaluation process using GIS Method. Bandung Regency was chosen as the study area because it has a large agricultural area. Figure 6 shows a map of the study area and the existing agricultural land in the study area.

Data Sets that are openly available on several open data sites are used to carry out the land evaluation process. Three criteria were selected as input layers for the land evaluation process. Then nine thematic layers were created as the basis for evaluating land suitability. Figure 7 describes the nine thematic layers that illustrate the general land conditions in the study area. Each thematic layer is reclassified and given a weight based on land suitability evaluation guidelines for the agricultural commodities conduct by the Indonesian Ministry of Agriculture's agricultural research and development agency [9]. Each commodity has different suitability parameters from other ones.

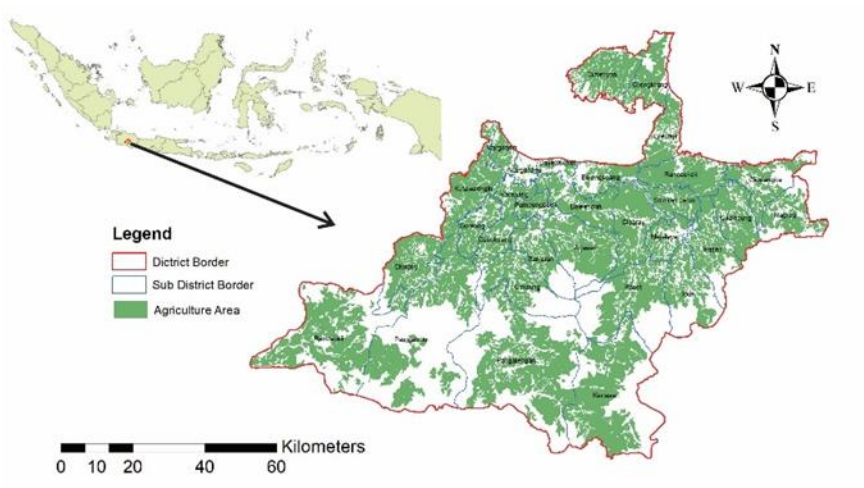

Fig. 6. Study area.

Data Sets that are openly available on several open data sites are used to carry out the land evaluation process. Three criteria were selected as input layers for the land evaluation process. Then nine thematic layers were created as the basis for evaluating land suitability. Figure 7 describes the nine thematic layers that illustrate the general land conditions in the study area. Each thematic layer is reclassified and given a weight based on land suitability evaluation guidelines for the agricultural commodities conduct by the Indonesian Ministry of Agriculture's agricultural research and development agency [9]. Each commodity has different suitability parameters from other ones.

To overlay the map, it is necessary to assign weights to each layer's criteria [11-14]. This weight value shows the difference in the importance level of each criterion for each commodity. The method for determining each parameter weight is the same as the method for determining the weight when selecting potential commodities. The process of determining the weights uses two methods, namely online group discussion, and online questionnaire. Thirty farmers participated in the weighting process. Table 1 describes the overall weight criteria for each commodity.

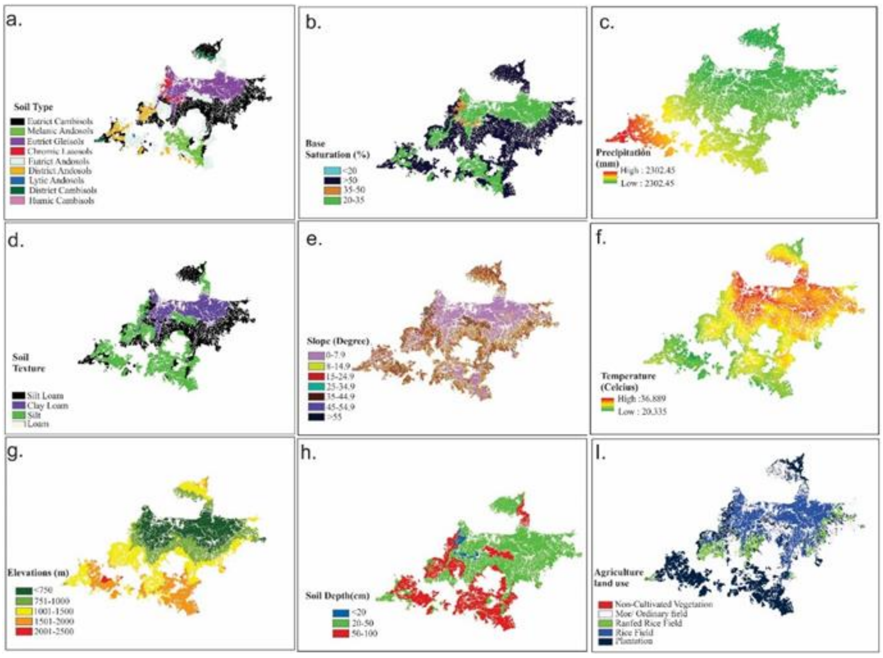

Fig. 7. The thematic layer of physical criteria in the study area: a. soil type; b. Base Saturation; c. Precipitation; d. Soil texture; e. Slope; f. Temperature; g. Elevations; h. Soil depth; i. Agriculture land use.

Table 1. Overall weight criteria for each commodity.

Sub Criteria	Rice	Onion	Cassava	Potatoes	Sweet Potatoes
Soil Depth	0.08	0.09	0.17	0.10	0.15
Soil Texture	0.10	0.11	0.16	0.12	0.15
Soil Base Saturation	0.09	0.09	0.11	0.09	0.11
Soil Type	0.11	0.15	0.17	0.13	0.15
Temperature	0.12	0.11	0.07	0.15	0.09
Precipitation	0.15	0.15	0.06	0.13	0.07
Elevation	0.11	0.09	0.10	0.13	0.10
Slope	0.09	0.08	0.09	0.09	0.08
Agriculture land use	0.15	0.13	0.07	0.06	0.10

The overlay process for each thematic layer produces land suitability classes for potential commodities in the study area. Land suitability is grouped into four classes; very suitable (S1), suitable (S2). marginally matched (S3) and not suitable (N) [9, 10, 16]. Figure 8 shows the agricultural land suitability for the five potential commodities to be cultivated in the study area.

The agricultural land in the study area has suitable conditions (S2) to cultivate onions covering 71% of the total agricultural area. Covering 70% of the agriculture area has suitable conditions (S2) to cultivate cabbage and covering 64% of the agriculture area has suitable conditions (S2) to cultivate potatoes. This result is in accordance with the data obtained from the Bandung Regency Agriculture Office. That data shows that the production of these tree commodities is better than other commodities [23]. The overlay method produces a land suitability map (Fig. 8). This map is expected to give an overview of the potential of agricultural land in the study area. This map can also be used when selecting commodities. With the land suitability map, it is hoped that the risk of crop failure experienced by farmers can be minimized.

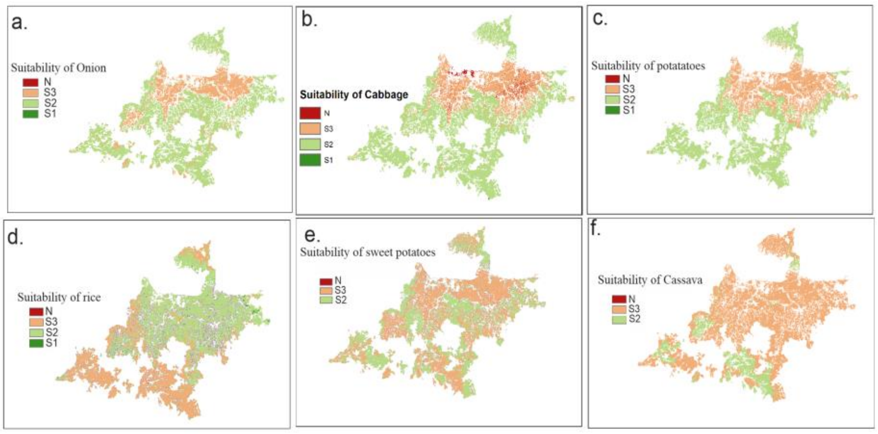

Fig. 8. Land suitability map for each commodity, a. land suitability of onion, b. land suitability of cabbage, c. land suitability of potatoes, d. land suitability of rice, e. land suitability of sweet potatoes, f. land suitability of cassava.

This study visualizes a map using augmented reality technology. Mapbox cloud stores each thematic layer. Each thematic layer is converted into a tile set layer. each tile set has a unique ID to call in the unity3D scene. The layers that are stored in the Mapbox are then called and imported into the unity3D scene using the Mapbox for unity extension. The map abstraction on the Mapbox Unity consists of three main structure layers. The first layer structure is the terrain layer. This layer is used to create 3-dimensional topographic maps.

The second layer structure is the Imagery layer. The imagery layer is overlaid into the terrain layer to create the appearance of the earth's surface that the user wants. Imagery layer using open street map tile. The developer map can also customize the imagery layer using Mapbox studio.
The third layer is the vector layer. GIS uses vector layers to provide information on the map. In the AR-GIS the factor layers are arranged based on the data requirements of the land evaluation process. This study uses a Custom C# script (i.e., "Modifier") to interact with map objects. Modifiers are applied to each layer to display the map attributes and information on the map. Figure 9 shows the map abstraction from AR-GIS.

Unity3D provides standard features for interacting with game objects in the scene. However, providing user-oriented interaction requires adjustments to the interaction algorithm. In the AR-GIS the interaction functions are assigned to the touchscreen using Custom C# Scripts. Figures 10(a) and (b) show the interaction functions applied to touchscreen and examples of interaction algorithms.

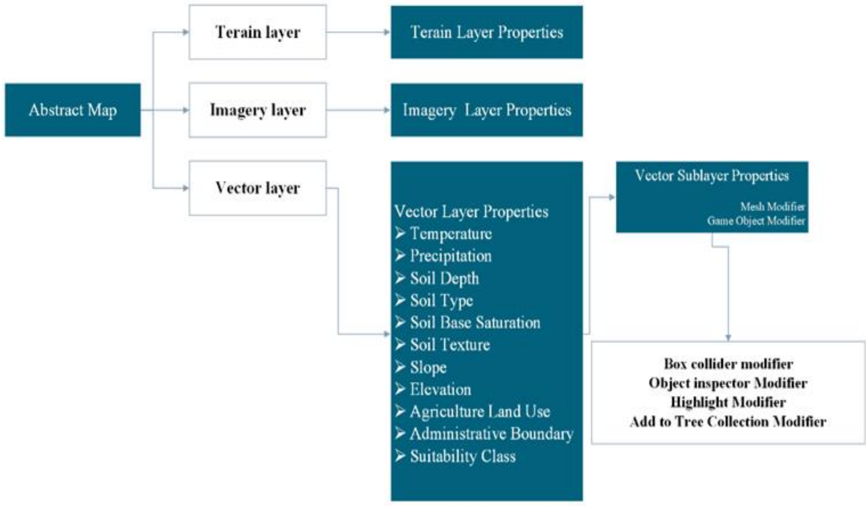

Fig. 9. The map abstraction from AR-GIS.

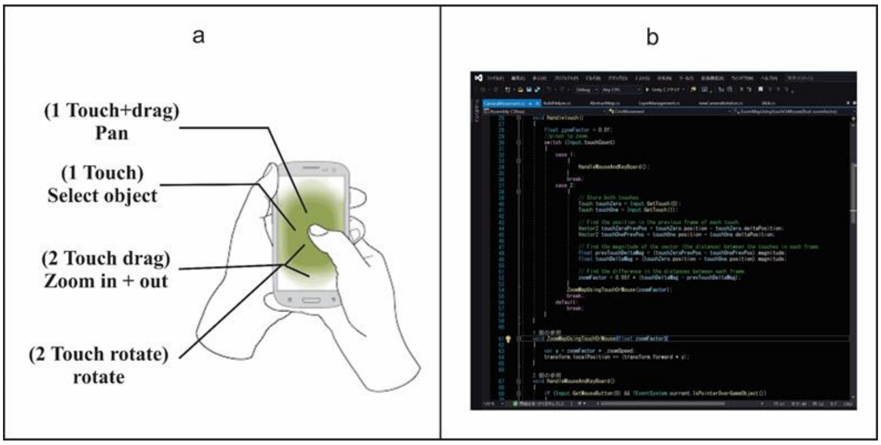

Fig. 10. Map Interaction a. The interaction functions applied to touchscreen, b. examples of interaction algorithms.

AR-GIS was built using the marker less augmented reality method. This method is used to increase the usability level of AR-GIS. Systems built using Plan detection algorithms to generate digital elements in AR-GIS. With this algorithm, the user can display the map on a flat area such as a table or floor. Figures 11(a) and (b) show the resulting plane detection and Augmented Reality Map (AR-Map).

The system was tested using the functional testing method. This test is an initial test by a developer. The testing process aims to make sure all functionality on the map can work properly. The test results show that the system has all the required functionality. However, there are still some weaknesses in building AR-GIS using Mapbox Unity. The first weakness is related to the performance of AR-Maps. AR-Map presentation performance still depends on hardware capabilities. So that, it needed further testing process to analyse the system performance in displaying the map. This condition is in line with the results of research conducted by other researchers [24, 25]. It states that hardware capabilities affect system performance. The second weakness is that because the tile set is stored in the Mapbox cloud, the map loading time depends on internet speed. Overall, the use of AR technology provides a new way of maps visualizing and interacting with GIS. Another advantage is that the AR map visualization is not limited to a small screen. In the future research, with AR, it is possible to create GIS that supports collaborative work between users. The presentation of information visualization needs to be explored more deeply. Unity 3D can describe topographic conditions in an attractive way. The addition of animation and automatic camera movement can also enrich interactions in AR-GIS.

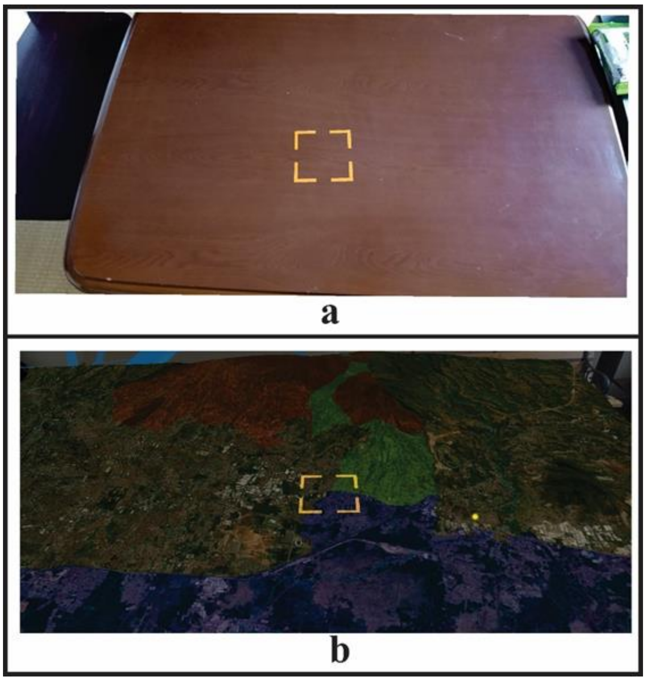

Fig. 11. AR-GIS output; a. Plane detection b. Augmented reality map.

5. Conclusion

This study describes the process of visualizing the potential agricultural land suitability using the Augmented Reality Geographical Information System. The first and second stages describe the land evaluation process by combining the multi-criteria decision analysis method with the overlay technique using GIS. The method used is the AHP method using tree main criteria and 11 sub-criteria. Based on the calculation results, there are five plants with the most potential to be developed in the study area. After selecting the most potential commodity, the land suitability is evaluated by overlaying nine thematic layers of criteria as input. The nine thematic layers of criteria consist of topography, soil and climate factors. The classification of each land suitability parameter is assessed based on the land suitability assessment guidelines issued by the research and development agency of the Indonesian Ministry of Agriculture. The overlay of nine selected thematic layers produces a land suitability map for potential commodities in the study area. The overlay process results shows that most agricultural land in study area is suitable for cultivating onion, Cabbage and potatoes commodities. By conducting a land evaluation process using a combination of these methods, more accurate and relevant results can be obtained. This result is also can be one of the consideration factors for selecting commodities. By selecting the right commodity for fair agricultural land use, it is hoped that the risk of crop failure can be reduced. The final stage of this research is visualizing the map using augmented reality technology. This stage describes the map processing process and visualizes it with augmented reality. Based on the test results the map can provide all the functionality required by the user. AR-GIS allows users to use maps more freely without being limited by the screen. The resulting map is also easier for the user to understand. The system is also enriched with interactive interaction methods. AR technology provides a new way of maps visualizing and interacting with GIS. It makes it easier for farmers to understand the information provided by GIS. With AR-GIS, it is hoped that the level of map usability level can be increased.

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