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Coffee Land Mapping Using Unmanned Aerial Vehicles (UAVs) Multispectral Remote Sensing

Ade Astri Muliasari[1,*], Zainal Wassahua[2], Merry Gloria Meliala[1], Ika Sartika[3], Reza Septian[4]

[1]Technology and Management of Plantation, College of Vocational Studies, Bogor Agricultural University, Indonesia
[2]National Research and Innovation Agency, Republic of Indonesia, Indonesia
[3]Digital Communications and Media, College of Vocational Studies, Bogor Agricultural University, Indonesia
[4]Food Crops, Horticultural, and Plantation Office of Bogor Regency Government, Indonesia

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Abstract Remote sensing UAV technology, also known as drones, is a tool that is quite well-known today as a technological transformation for land mapping that can be done directly and inexpensively every day. Currently, the use of UAVs is growing because this technology is easy to operate for crop monitoring and land mapping. Although the resulting spectral pattern is quite varied to assess vegetation, especially in mixed vegetation. The use of UAV image data will be better for identifying plants, especially for coffee if they are not covered by other dominant vegetation. This study aims to map the distribution and number of Arabica coffee plants in Megamendung Village, Bogor Regency. A multispectral remote sensing UAV can be used to effectively map coffee fields and the number of coffee plants, even on land with steep contours, if they are not covered by denser vegetation or shade trees. Based on UAV Acquisitions process, it produces a wide multispectral image of 9.68 ha (69%) in the first and the second area of 8.91 ha (78%). Coffee planting can be differentiated into < 4 years, 4 – 15 years, and > 15 years. The number of coffee plants identified at the first location was 179 immature coffee trees. While the number of coffee plants identified at the second location was 69 immature coffee trees (3%), mature coffee 1 was 1329 trees (50%), and mature coffee 2 was 1269 trees (48%) of the total number of coffee plants of 2667 coffee trees.

Keywords Coffee, Land Mapping, Multispectral, Remote Sensing

1. Introduction

Coffee is one of the most consumed and marketed beverages in the world [1, 2]. Coffee is one of the leading commodities exported abroad after palm oil, rubber, and cocoa [3]. Indonesian coffee price was 76% influenced by international price changes [4]. Indonesian coffee products exported reach 639,900 tons in 2022 or 6% of the total world coffee production after Brazil (30%), Vietnam (26%) and Colombia (10%) [5, 6]. Meanwhile, domestic coffee productivity is 786,000 tons [7].

Bogor Regency is one of the coffee-producing areas in West Java Province, Indonesia. The area of coffee plants reached 6,407.70 ha in 2019. The potential production for robusta coffee per hectare can reach 3 tons and Arabica coffee can reach 2 tons, while coffee production in Bogor Regency is only able to produce 1 ton of coffee per hectare [8]. Therefore, it is necessary to make efforts to optimize production, including technical improvements in cultivation, the actual area of coffee plantations, and the level of suitability of land that is in accordance with the growing characteristics of coffee plants.

The level of suitability of coffee land in Bogor Regency is quite good, namely belonging to the fairly suitable (S2), marginally suitable (S3), and not suitable (N), with the main environmental limiting factors being rainfall, altitude, and slope [9]. Based on the parameters for coffee growing conditions, the area of Bogor Regency is divided into 56% suitable land and 44% unsuitable land for coffee growth. Megamendung District is one of the areas that has the potential to develop coffee plantations. After conducting a coffee land suitability analysis, the next step is to validate the data compared to the actual land area in the field, especially in Megamendung District, using high-resolution aerial photography technology. Validation research conducted by [10] produced information regarding gaps or deviations between maps resulting from the spatial analysis of land suitability and actual conditions in the field.

Coffee plantation land in Megamendung has been developing for a long time. More is used to grow Arabica coffee because this area is more suitable, especially based on the height above sea level (more than 1000 m). In detail, mapping of coffee fields in this area needs to be done, especially to detect the distribution of coffee plantations and the number of coffee plants. Detailed mapping is carried out using survey methods and the utilization of remote sensing unmanned aerial vehicles (UAVs) data. This method is more specific for detecting objects with higher spatial resolution and accuracy.

Remote sensing UAV technology, also known as drones, is a tool that is quite well-known today as a technological transformation for land mapping that can be done directly and inexpensively every day [11]. Currently, the use of UAVs is growing because this technology is easy to operate for crop monitoring and land mapping [12]. Although the resulting spectral pattern is quite varied to assess vegetation, especially in mixed vegetation. The spectral pattern of plants varies due to several factors, such as: stage of development, plant vegetative vigor, and management used [13]. The use of UAV image data will be better for identifying plants, especially for coffee if they are not covered by other dominant vegetation. This study aims to map the distribution and number of Arabica coffee plants in Megamendung Village, Bogor Regency.

2. Materials and Methods

2.1. Times and Location

The research was held from April to December 2022. The research location is in Megamendung Village, Megamendung District, Bogor Regency, West Java Province, Indonesia (Figure 1). Mapping with UAV drones was carried out at two locations, first in the Eagle hill block (-6.633178° and 106.937291°, -6.633279° and 106.939762°, -6.636346° and 106.938929°, -6.636319° and 106.936949°) and secondly in the Pase block tires (-6.640928° and 106.952935°, -6.640210° and 106.955068°, -6.643243° and 106.955373°, -6.643286° and 106.953046°). This plantation is planted with Arabica coffee according to the height of this area above sea level for coffee plants.

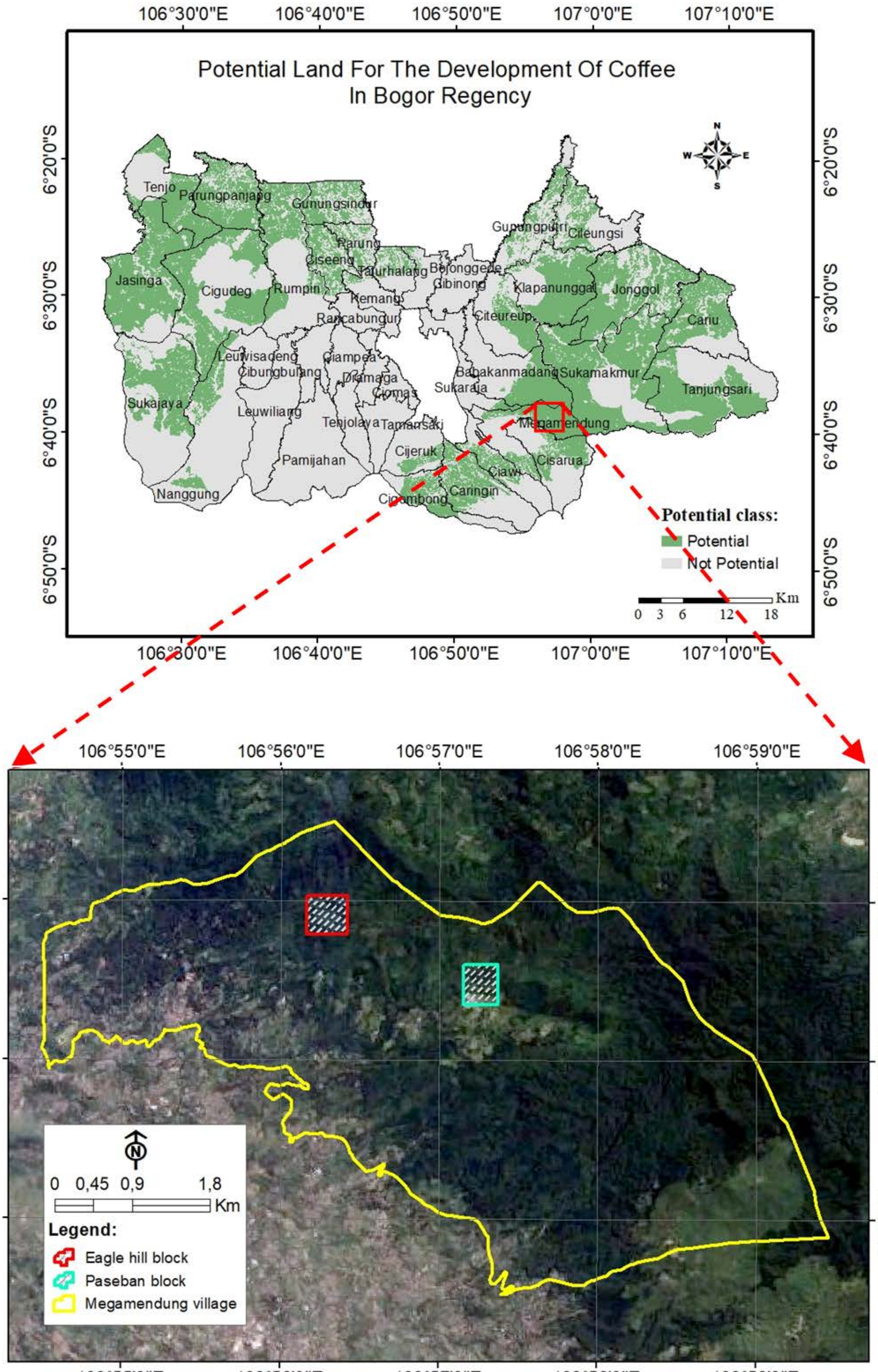

Figure 1. The Research Location Map of Megamendung Village, Megamendung District, Bogor Regency, West Java. It consists of Eagle Hill and Paseban Block

2.2. Data Collection

The important thing that must be done for UAV image collection before flying is calibration. UAV calibration is one way to ensure that sensors and various other devices are connected accurately. The calibration process involves adjusting or correcting errors that could allow inaccurate sensor measurements. Equipment used such as UAV, batteries, remote controller, and the computer, needs to be checked to determine whether it is working properly or not to avoid crashes and system failure due to malfunction. The DJI Mavic Enterprise Dual Thermal application is used for this calibration. It had an approximate sensor size of 24 x 48 mm, and a 48 mm F-adjustable lens.

M2ED visual and thermal camera with maximum image size 4056×3040 (4:3), 4056×2280 (16:9), video recording modes 4K Ultra HD 3840×2160 30p, 2.7K : 2688×1512 30p, FHD : 1920×1080 30p, the process of camera calibration also improves principal points, focal length, tangential lens distortions and radial lens distortion. These camera parameters must be included in digital image processing during the process of interior orientation. UAV's flying height is about 50-100 m above ground level and flying below clouds.

2.3. Pre-Processing

The UAV remote sensing data is obtained from an aerial photography process that produces multispectral images that can be directly used for mapping coffee fields. Before being processed to see land use, data preparation is carried out which consists of orthophoto, geoprocessing, and clip images (Figure 2). The data preparation process is carried out to ensure that the UAV data has been corrected. The orthophoto process is carried out to manage the resulting image from the shooting, which produces the initial 3D model. This process is also for processing dense point clouds, namely managing high point collections ranging from thousands to millions of points. The next process of orthophoto is building mesh and texture models to see a 3D model of the appearance in the coverage area [14].

Georeferencing, often known as rectification, provides a spatial reference (coordinate) for UAV data recorded from coffee grounds. This process also provides information on the position of the UAV on the earth's surface according to the coordinate system, for further use in a more specific land use analysis.

The resulting coverage image does not provide a perfect appearance of vegetation, especially at the edges of the image which tends to be imperfect and there are parts that are empty or have no data. To avoid parts that are not covered properly, a cutting or clipping process is carried out according to the area that has been determined. The clipping process can use a boundary map that has been prepared in shapefile or raster form. The results of the data preparation process has obtained UAV data that has been corrected and is ready for further processing for coffee land determination.

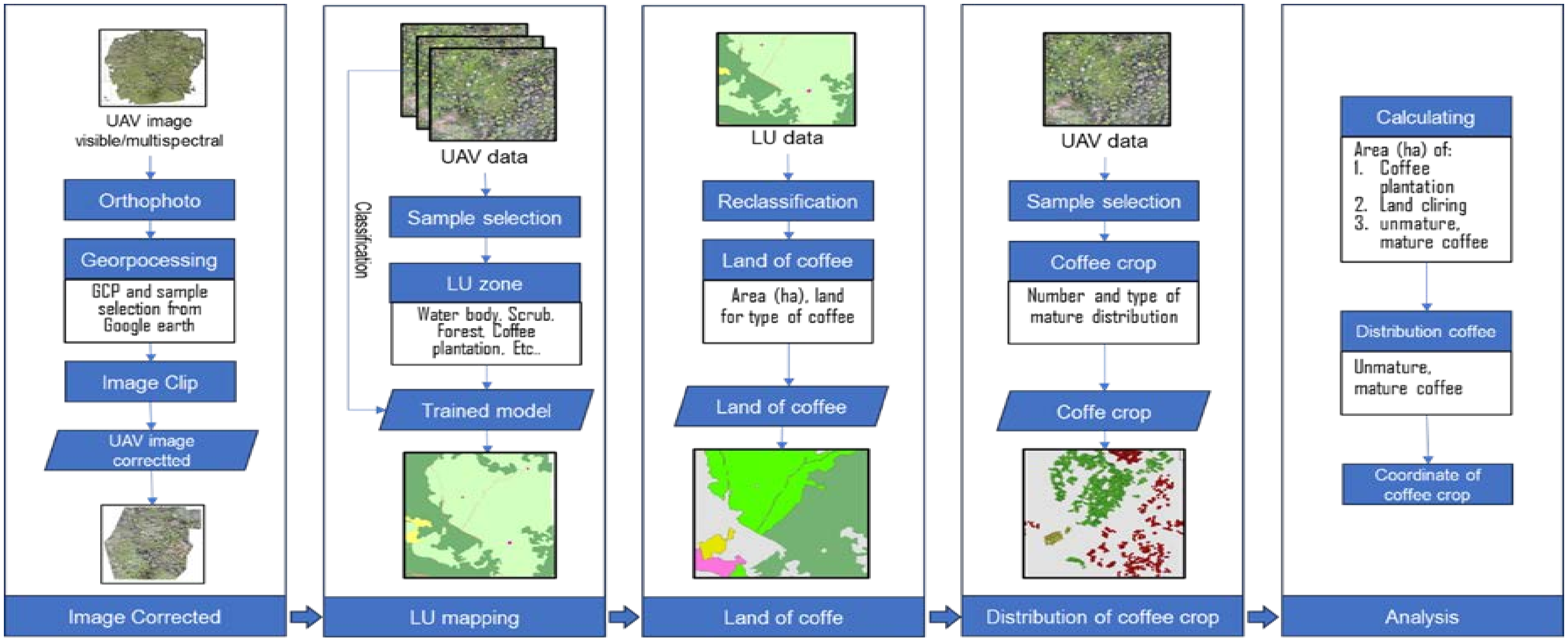

Figure 2. Diagram of processing and analysis UAV remote sensing data

2.4. Data Processing

The corrected image will enter the next stage of the process, namely land use classification based on field data such as water bodies, shrubs, forests, and coffee plantations. After obtaining coffee plantation land, the next stage is to reclassify the land based on the stage of coffee growth.

UAV image data can be used to analyze the spatial distribution of land use, coffee plantations, and coffee plants that are spread openly or covered by dense vegetation. The coffee land mapping process begins with the identification of land uses in coffee plantation areas that tend to mix to form one land cover vegetation. Land use analysis is carried out based on the visual classification of each object that is visible to the naked eye on the multispectral image. Classification is done by looking at hue, color, shape, and the area depicted as the object being observed. These objects are then categorized into land use classes such as forests, settlements/houses, roads, agricultural land, coffee plantations etc. Spatially grouping the land cover produces a land cover map in which the area (ha) can be calculated. Groups of unproductive land cover can be used for other more productive land use purposes, while productive land cover such as coffee land can be continued for distribution management based on the type of coffee growth and monitoring.

The monitoring process for coffee land and coffee plants is carried out based on land use maps and UAV data. The specific land use map can be further analyzed to see the grouping of coffee land use according to immature, mature coffee planting areas and land clearing for coffee planting. The coffee land classification process is based on spectral signature, color and size combined with ground checking or ground truth. This process is carried out by reclassifying the previously generated land use map. While the process of identifying the number of coffee plants was analyzed based on UAV image data. Coffee plants that can be identified are plants that are in open areas, both newly planted and mature plants, while coffee plants that are covered by other vegetation will be difficult to interpret visually, guided, or unguided. Coffee plants can be differentiated into < 4 years, 4 – 15 years, and > 15 years. The process of mapping the distribution of coffee plants is obtained by the number of coffee plants (principal) and the distribution of coffee plants (coordinates) per level of productivity.

3. Result and Discussion

3.1. UAV Acquisitions

UAV device recording produces high-resolution panchromatic images of certain areas that have been set at the beginning. The results of this panchromatic image recording include the targeted area or the specified study area and the boundaries of the study area. In addition to being able to show a representation of the condition of the original vegetation on the object, it is also densely packed with areas where the recording is not optimal (Figure 3). On the edges of the study area, the results of the recording are not optimal in the form of empty spots with no data and vegetation that does not represent actual conditions. The recorded UAV image is cropped to focus more on the study area and remove parts of the image that are not clearly defined.

Aerial photography was taken at an altitude of 100 m from the ground surface where data was collected at both the first and second location to obtain multispectral imagery with a spatial resolution of 3.8 cm per pixel. The UAV image is analyzed using a clip process to separate the study area which is the maximum area for image recording. Recording at the first location produces a wide multispectral image of 14.09 ha, an area that is not maximal for image recording is 4.41 ha (31%), and a maximum area for image recording is 9.68 ha (69%). While the first location produces a multispectral image with a recording area of 11.46 ha, an area with no maximum coverage of 2.55 ha (22%), and an area with a maximum coverage of 8.91 ha (78%). Recording from UAV drones tends not to reach 100% of the maximum coverage. On average, from the two coverages, around 27% of the recording area cannot be used for the interpretation process. Even though there are coffee plantations in areas where coverage is not optimal, they cannot be used to detect them.

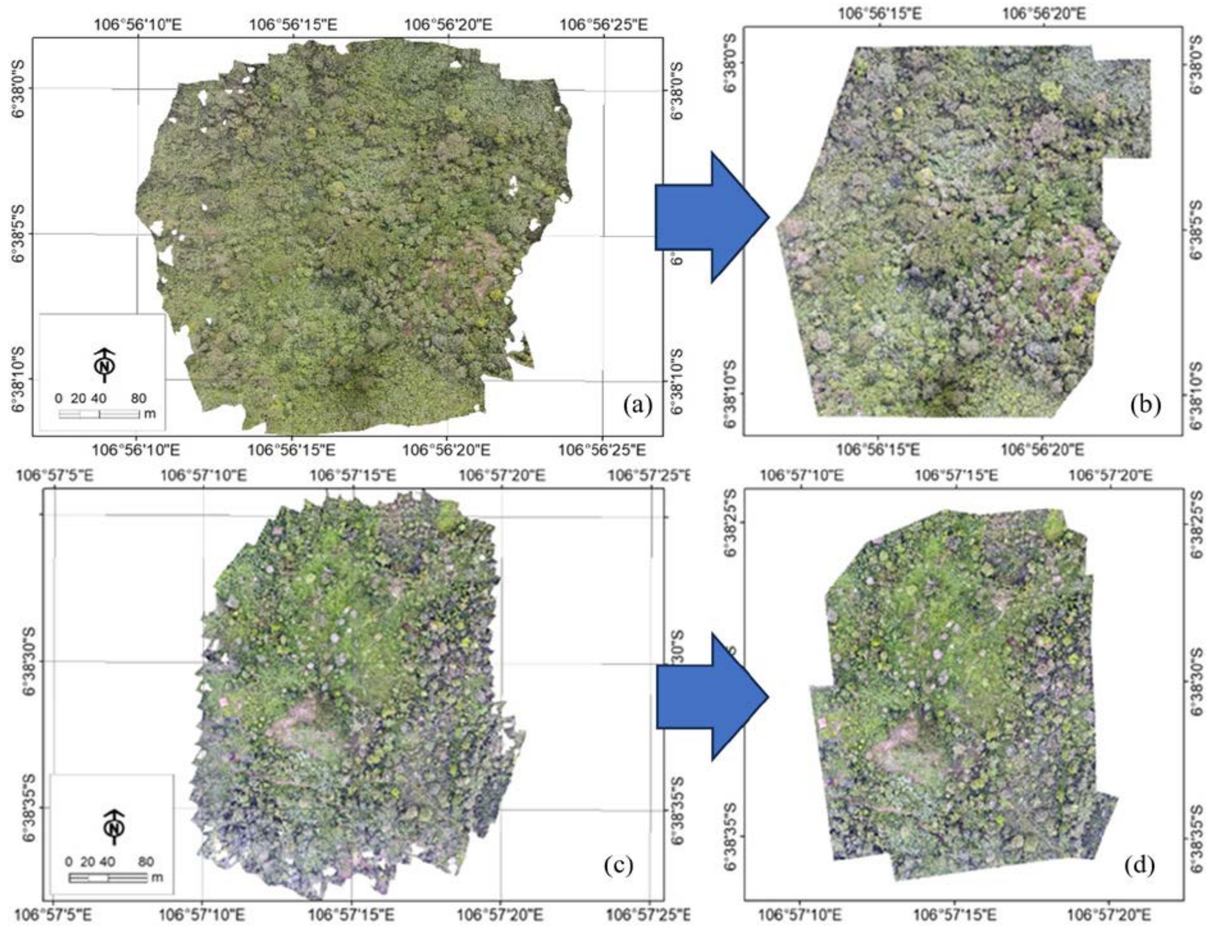

Figure 3. Image from UAV coverage (a) UAV image of location 1 (Eagle Hill), (b) UAV image of location 1 after clipping to the study area, (c) UAV image of location 2 (Paseban) and (d) UAV image of location 2 after clipping to study area

3.2. Land Use Identification

Identification of land cover from multispectral images obtained from UAV drone recording obtained several land cover classes. Interpretation of land cover classes based on image data and conversion into vector data in the form of polygons. There are 4 groups of land use at the monitoring location at Eagle Hill, namely scrub, forest, coffee, and residence/houses. Meanwhile, at the recording location in Paseban, 8 groups were found, namely water body, scrub, forest, roads, coffee, agriculture, residence/houses, and savanna (Figure 4).

In both the first and second locations, the forest area was found to be more dominant, specifically for the coffee area, it was found less in the first location and more in the forest area.

Vegetation conditions in the first monitoring location were denser than in the second location. This has an impact on the different interpretations of coffee vegetation between the two. The first monitoring location shows only a small proportion of coffee that can be monitored from other use classes. The location of the coffee is in an open area that can be identified directly from the UAV image by means of visual interpretation. Even though on the ground there are already productive coffee plants spreading under the forest vegetation. Whereas in the second observation location, most of the coffee plantations are in open areas so coffee plants can be identified through visual interpretation. Visual interpretation can be used to identify and map different types of land use classes [15, 16].

The results of the analysis show that the presence of land cover in the two areas is quite diverse based on the identified area. The first observation location found that the forest area was more dominant by 7.96 ha (89.61%), the second largest scrub was 0.67 ha (7.58%), and other land uses such as coffee and residence were smaller, each only 2.73 % and 0.08 % respectively (Figure 5).

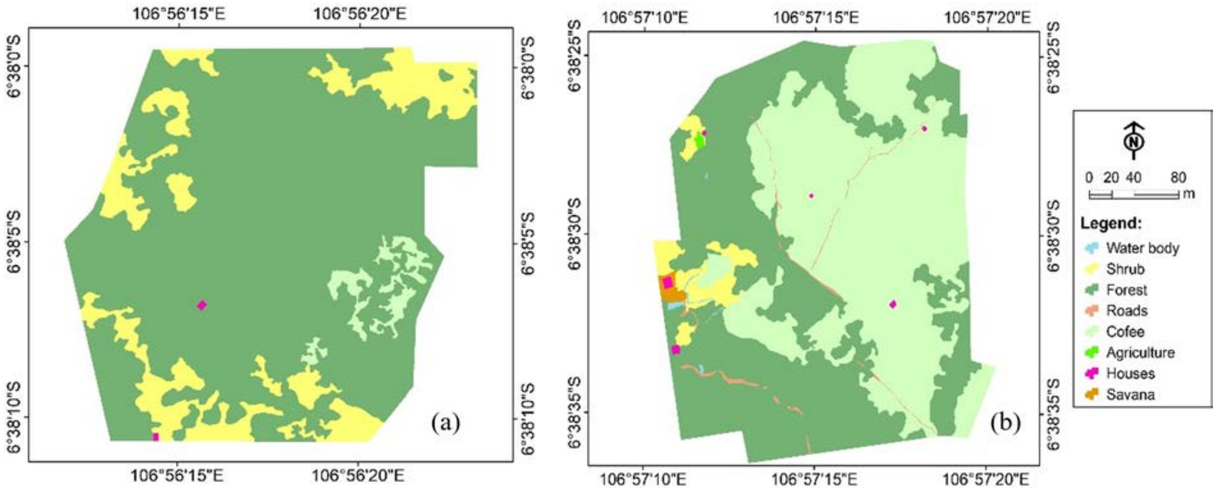

Figure 4. Land use map visual classification results from UAV image data (a. Eagle Hill Block, b. Paseban Block)

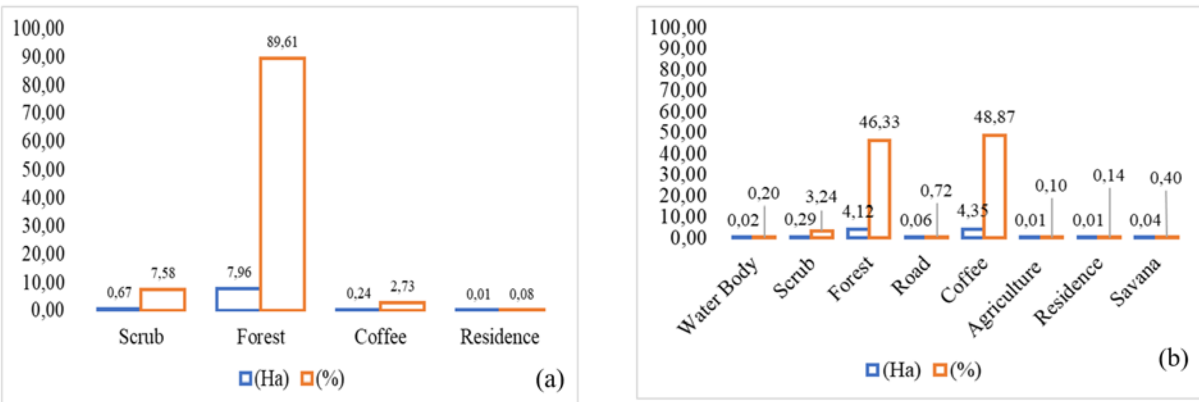

Figure 5. Land cover area resulting from the interpretation of the UAV image (a) Eagle hill Block, and (b) Paseban Block

3.3. Coffee Land Mapping

The spatial distribution of coffee grounds shows that there are differences between the first and second recording locations (Figure 6). There are fewer coffee fields that can be identified from the UAV imagery in the first location than the coffee fields in the second location. Coffee land in the first location is very small because in that area land is still being cleared for coffee cultivation. Observations from the air using multispectral imagery found that there were only two categories of coffee land, namely open land preparation for coffee planting which is called land clearing and immature coffee plants. This condition is proven by the actual situation on the ground which tends to be in a higher area than the entire area recorded by drones. Meanwhile, coffee land in the second location found 4 coffee land categories consisting of land clearing for coffee, immature coffee, mature coffee 1, and mature coffee 2. The coffee land in this second location is larger than other land uses.

Coffee planting activities in the second location have been longer so the age of plants with varying levels of productivity can be found in this location. At least the age of coffee planting in this location can be differentiated into < 4 years, 4 – 15 years, and > 15 years. Visual appearance of multispectral UAV images can also be distinguished based on the three planting categories. The appearance of immature coffee aged <4 years is in the form of single vegetation and in the form of small dots or spots that line up neatly between open land or new land clearing.

Coffee aged 4 – 15 years has started producing single fruit vegetation that is round, slightly purplish green in neat rows, and tends to mix with shrubs and savanna. Coffee aged > 15 years is already produced and tends to become lush vegetation mixed with purplish coffee plants, and if it is aged, the plants start to show white veins in the middle, indicating the branches are starting to run out of leaves. Coffee plants are lush shrubs that are well-known by the wider community.

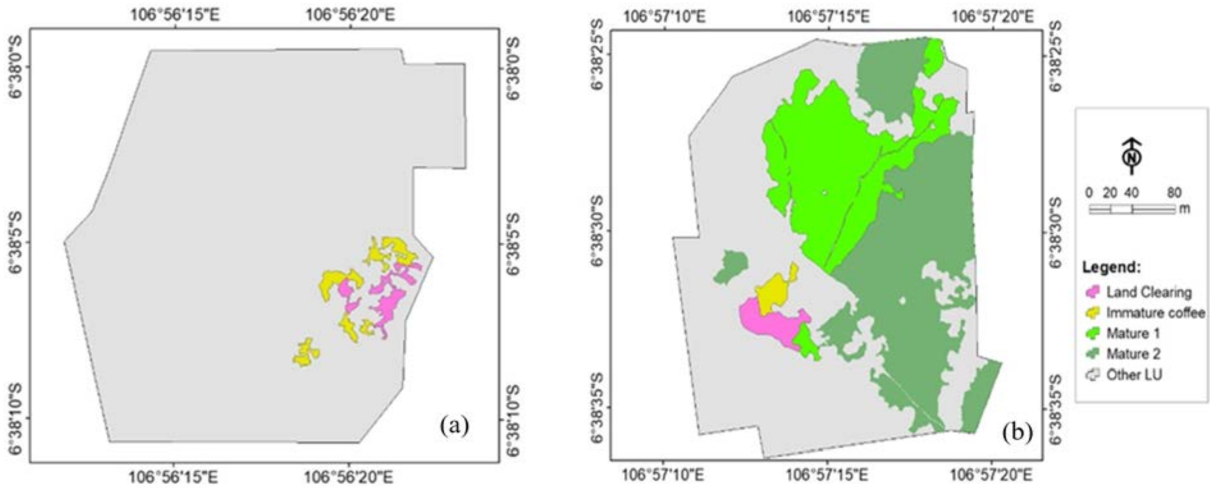

Figure 6. The distribution of coffee fields consists of land clearing, immature coffee, mature 1 (4 – 15 years of coffee) and mature 2 (> 15 years of coffee). (a) Eagle hill Block, and (b) Paseban Block

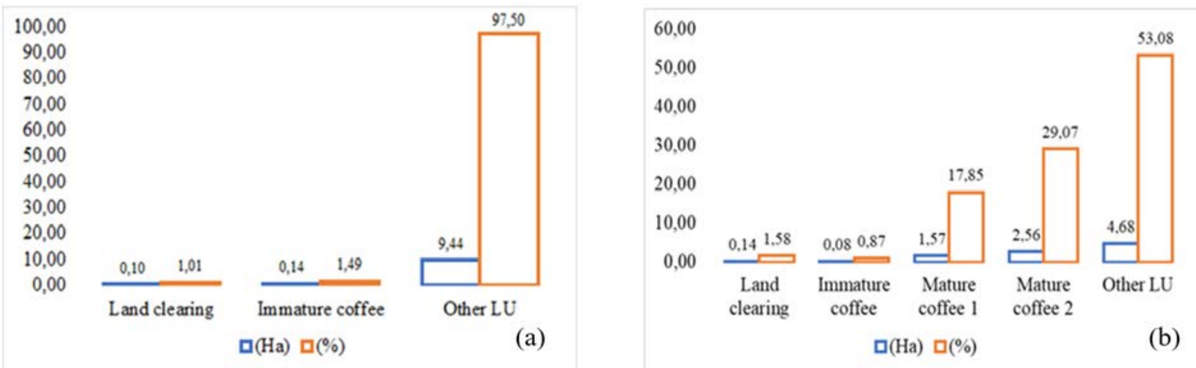

Figure 7. The area of coffee land based on the level of productivity (a) Eagle hill Block, and (b) Paseban Block

The visual interpretation results show that the area of coffee land in the first location is very small compared to the area of other land uses. The area of coffee land identified was divided into land cleared for coffee and land already planted with coffee. The area of newly cleared land is 1.10 ha (1.01%) and the area of newly planted coffee plants is 0.14 ha (1.49%) of the total study area of 9.68 ha. Meanwhile, the area of coffee plantations in the second location was found to vary. The area of land cleared for coffee planting was 0.14 ha (1.58%), newly planted coffee plants were 0.08 ha (0.87%), coffee plants aged 4-15 years were 1.57 ha (17 .85%), and coffee plants aged > 15 years amounted to 2.56 ha (29.07%) of the total study area of 8.81 ha (Figure 7).

In general, the existence of coffee plantations in these two regions is in accordance with the ideal conditions for land for coffee, especially Arabica coffee. The two study locations are in Megamendung Village, Megamendung District, Bogor Regency, which are the areas with great potential for coffee cultivation (Figure 1) [9]. Therefore, geographically the two coffee plantations as aerial photography locations with UAV drones are suitable for growing coffee both based on environmental parameters and coffee productivity in this area which has been running for a long time.

3.4. Identification of Coffee Plants

Multispectral UAV technology is further utilized to map the distribution and identify the number of coffee plants. The distribution of coffee plants that can be identified at the first study location is coffee that has just been planted and has not been productive. Its distribution is very small, and the pattern is spread unevenly because part of the land is covered by dense forest vegetation. In addition to dense vegetation, the contours of the land which tend to be uneven also cause the coffee plants to not be identified properly. Vegetation index is recommended for estimating coffee maturity using aerial imagery [17]. Identification of coffee trees starts by filtering and segmentation. Filtering uses a white mask-matched filter. Matched filter emphasizes the edges of the inner leaf set canopy of each tree. Segmentation is used to differentiate tree canopies from non-tree objects. Identify trees using features: shape, size, and intensity neighbourhood. In this identification, we chose the disk shape because the leaf clusters tend to be small solid circles like a disk. The image segmentation results are compared with the ground truth. We evaluated this tropical tree identification method using F-Score. Meanwhile, the distribution of coffee plants in the second study location can be identified based on the age at which they were planted. Coffee plants in this location are very easy to identify because the vegetation cover is not dense. Besides the vegetation that is not dense, this location also has land contours that tend to be flat, so the visualization of coffee plants on UAV imagery is clear enough to identify. The distribution of coffee plants identified from the UAV imagery can be mapped as shown in Figure 8.

Utilization of multispectral UAV technology makes it easier to identify the number of coffee plants and their productivity level. The number of coffee plants identified at the first location was 179 immature coffee trees and no mature coffee 1 and 2 were found at this location. While the number of coffee plants identified at the second location was 69 immature coffee trees (3%), mature coffee 1 was 1329 trees (50%), and mature coffee 2 was 1269 trees (48%) of the total number of coffee plants of 2667 coffee trees identified at the second location (Figure 9).

Coffee planting in the first location will only start in 2022 when the UAV imagery data is collected in this study. This is evidenced by the results of the imagery in the form of open land among lush forest vegetation. Initial land clearing for coffee cultivation tends to be followed by planting in installments, especially in areas with steep land contours. In contrast to that, the second location is plantation land that has developed for a long time and has produced quite a lot of coffee. The second location is more suitable for coffee cultivation because the contours of the land are not steep. Coffee at the first location is planted in rows at a certain distance following the steep contour of the land. Meanwhile, coffee at the second location is planted more neatly in straight row formations following a certain direction and distance and was distinguished between immature and mature. Commercial coffee plantations plant coffee trees in rows along certain directions to increase production yields and management efficiency [18].

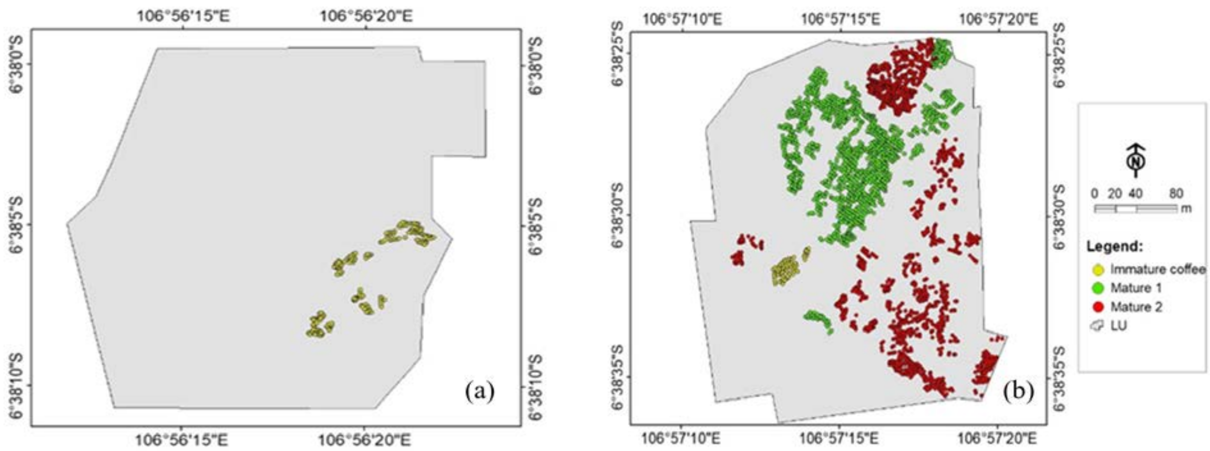

Figure 8. Distribution of coffee plants in (a) Location 1 Eagle hill block, and (b) Location 2 Paseban block

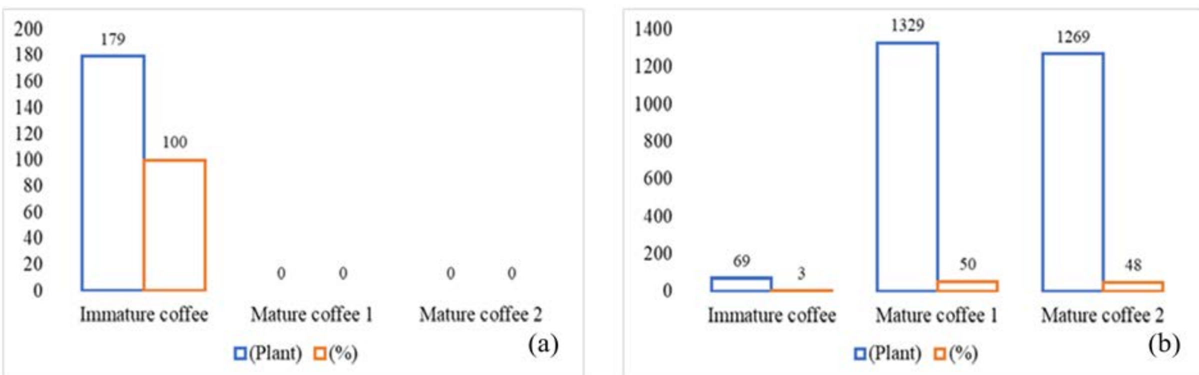

Figure 9. Identification of the number of coffee plants based on their productivity level (a) Eagle hill block, and (b) Paseban block

4. Conclusions

This study concluded that the multispectral remote sensing UAV can be used to effectively map coffee fields and the number of coffee plants, even on land with steep contours, if they are not covered by dense vegetation or shade trees especially at coffee plantations in Megamendung, Bogor Regency, West Java, Indonesia. Based on UAV Acquisitions produces, a wide multispectral image of 14.09 ha, an area that is not maximal for image recording is 4.41 ha (31%), and a maximum area for image recording is 9.68 ha (69%) in the first location and the second area of 11.46 ha, an area with no maximum coverage of 2.55 ha (22%), and an area with a maximum coverage of 8.91 ha (78%). Coffee planting can be differentiated into < 4 years, 4 – 15 years, and > 15 years. The number of coffee plants identified at the first location was 179 immature coffee trees and no mature coffee 1 and 2 were found at this location. While the number of coffee plants identified at the second location was 69 immature coffee trees (3%), mature coffee 1 was 1329 trees (50%), and mature coffee 2 was 1269 trees (48%) of the total number of coffee plants of 2667 coffee trees.

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REFERENCES

[1] Pena A. G., L. V. Hernandez, A. B. Galindo, V. M Ramos. Chemical analysis and NIR spectroscopy in the determination of the origin, variety, and roast time of Mexico coffee. Heliyon vol. 9. 8 e18675. 2023. DOI:10.1016/j.heliyon. 2023.e18675

[2] Gomes A. P. A., D. M. de Queiroz, D. S. M. Valente, F. de A. de C. Pinto, J. T. F. Rosas. Comparing A Single-Sensor Camera with A Multisensor Camera for Monitoring Coffee Crop Using Unmanned Aerial Vehicles. Engenharia Agrícola, Jaboticabal, vol. 41, no. 1, pp. 87-97, 2021. DOI: 10.1590/1809-4430-Eng.Agric.v41n1p87-97/2021

[3] Alfianur. Efforts of the International Coffee Organization (ICO) in Encouraging Indonesian Coffee Products to Compete in the International Market. eJournal of International Relations, Volume 7, no. 4, pp. 1793-1804, 2019. https://ejournal.hi.fisip-unmul.ac.id/site/?p=3166

[4] Fitriani, B. Arifin, H. Ismono. Indonesian coffee exports and its relation to global market integration. Journal of Socioeconomics and Development. Vol. 4 (1): 120-133, 2021. DOI: 10.31328/jsed. v4i1.2115

[5] International Coffee Organization [ICO]. Total Production Coffee by Exporting Countries. 2022. Online available from https://www.ico.org/trade_statistics.asp

[6] Jaya R., Y. Yusriana, R. Ardiansyah. Sustainable Production and Processing System of Coffee: State of the Art. Journal Agrotechnology, vol. 13 no. 02, 2019. DOI:10.19184/j-agt. v13i02.14651

[7] BPS-Statistics Indonesia, "Indonesian Coffee Statistics", BPS-Statistics Indonesia, 2021, pp.1-101

[8] Setiadi D. "Potency Development Economics of Coffee Farmers in Bogor Regency", Radar deplantation.com, vol. 2. No. 1 pp. 1-7https://deplantation.com/wp- content/uploads/2021/03/RADAR-Vol02-No01-Maret-2021.pdf (accessed Oct 1, 2022)

[9] Muliasari A. A., H. Dewi, Suwarto. "Spatial analysis for land suitability of Arabica coffee (*Coffea arabica* L.) in Bogor District". The 2nd International Conference on Sustainable Plantation, Bogor, INA, September 2021, IOP Conf. Ser.: Earth Environ. Sci. 974 012096, DOI: 10.1088/1755-1315/974/1/012096

[10] Ellyanti, A. Karim, H. Basri. Analysis of the geographical indications of Gayo Arabica coffee in terms of the district spatial plan. Journal Agrista, vol. 16, no. 2, pp. 46-61, 2012. https://jurnal.usk.ac.id/agrista/article/view/230

[11] Bernie J. A., P. J. Zarco-Tejada, L. Suárez, E. Fereres. Thermal and narrowband multispectral remote sensing for vegetation monitoring from an unmanned aerial vehicle. IEEE Trans. Geosci. Remote Sens, vol. 47, issue 3, pp 722–738, 2009. DOI: 10.1109/TGRS.2008.2010457

[12] Barbosa B. D.S., G.A.S. Ferraz, L.M. dos Santos, L. S. Santana, D.B. Marin, G. Rossi, L. Conti. Application of RGB Images Obtained by UAV in Coffee Farming. Remote Sensing, vol. 13, no. 12 2397, 2021. DOI:10.3390/rs13122397

[13] Hatfield J. L., J. H. Prueger. Value of Using Different Vegetative Indices to Quantify Agricultural Crop Characteristics at Different Growth Stages under Varying Management Practices. Remote Sens, vol. 2, no.2, pp. 562–578, 2010. DOI: 10.3390/rs2020562

[14] Fahmi F., D. Trianda, U. Andayani, B. Siregar. "Image processing analysis of geospatial UAV orthophotos for palm oil plantation monitoring". The 2nd International Conference on Computing and Applied Informatics. Medan, INA, November 2017. Journal of Physics: Conference Series, 978 012064. DOI:10.1088/1742- 6596/978/1/012064

[15] Govindaraj V., C. Lakshumanan, P. Ramki. Visual Interpretation Methods of Land Use/Land Cover Changes & Analysis Using Gis & Remote Sensing Technology: A Case Study of Gomukhi River Basin of Tamilnadu, India. International Journal of Advanced Research, vol. 5, no. 8, pp. 638-649, 2017. DOI: 10.21474/IJAR01/5101

[16] Wassahua Z. "The Use of Markov Cellular Automata Technique for Predicting Forest Cover Change in Rokan Hulu, Riau Province, Indonesia". IPB Repository, https://repository.ipb.ac.id/handle/123456789/41349 (accessed September 1, 2023)

[17] Martins R. N., F.A.C Pinto, D.M. de Queiroz, D. S. M Valente, and J. T. F. Rosas. A Novel Vegetation Index for Coffee Ripeness Monitoring Using Aerial Imagery. Remote Sensing, vol. 13 no. 2, 263, 2021. DOI: 10.3390/rs13020263.

[18] D. M. Tsai, W. L. Chen. Coffee plantation area recognition in satellite images using Fourier transform. Computers and Electronics in Agriculture. Vol. 135, pp. 115-127, 2017. DOI: 10.1016/j.compag.2016.12.020