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Spatial Based Zoning Plan for Sustainable Forest Management of Riam Sicangguran Village Forest

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ABSTRACT

Riam Sicangguran Village Forest has a high diversity of flora and fauna. Anticipating the increasing size of community gardens and the decline in the quality of environmental and ecosystem services as well as the decline in biodiversity, zoning management planning needs to provide. The purpose of this research was to find out which areas have the potential to become management zones and core zones based on the results of spatial analysis to make a map of the village forest management plan in the Riam Sicangguran Village Forest, Pangkalan Paket Village, Ketapang Regency, West Kalimantan Province. The spatial analysis method was used in measuring and analyzing orthoimages and survey methods in the ground check process. Overlap analysis on land cover classification map within the contour, slope class, and national forestry plan maps (RKTN) to determine zoning areas for forest management planning. The results showed that the total management area for the core block reached 195.41 hectares, while the utilization block reached 561.68 hectares. The comparison of the management zoning area was dominated by the utilization block by 74% of the total area in the Riam Sicangguran Village Forest management area and 26% in the core block. The primary land cover found in the village forest was determined to be plantations. The RSVF has significant potential for Non-Timber Forest Products (NTFPs) and environmental services.

1. INTRODUCTION

Forests play a crucial role in maintaining ecological balance by serving as carbon sinks, preserving biodiversity, and providing essential ecosystem services. Sustainable forest management (SFM) has become a global priority to mitigate deforestation, habitat loss, and climate change [1]. In Indonesia, village forests (hutan desa) have been increasingly recognized as a viable approach to balancing conservation and local livelihoods [2]. The Riam Sicangguran Village Forest (RSVF), located within the Gunung Raya Protected Forest (GRPF) in Ketapang Regency, West Kalimantan, is a critical conservation area that supports rich biodiversity while also sustaining local communities through traditional agroforestry practices.

GRPF is a crucial sanctuary for a diverse range of plant and animal species found in dryland forests. The forest also includes multiple settlements, each with its unique socio-cultural characteristics and established traditions for land usage, such as farming and oil palm production. The inclusion of the Riam Sicangguran Village Forest (RSVF) in the GRPF represents a significant step towards forest management that centered around the community. This approach holds great potential for the sustainable use of resources and the improvement of livelihoods [3, 4].

However, RSVF is facing mounting challenges due to the rapid expansion of community plantations, particularly oil palm and rubber cultivation. While these land-use changes provide short-term economic benefits, they pose significant threats to forest integrity, including biodiversity loss, soil degradation, and reduced ecosystem services [5]. The increasing demand for land has led to a land-use conflict between conservation priorities and community livelihood needs, necessitating an effective spatial zoning strategy to balance these competing interests. The attraction of varying economic benefits derived from palm oil, combined with a limited understanding of sustainable alternatives, has contributed to this incursion [5, 6].

The RSVF is essential for the Pangkalan Paket villagers as it provides vital resources including fruit trees and rubber through the traditional "dahas" or tembawang system. This highlights the complex interaction between the community and the forest [2, 7].

The main difficulty lies in achieving a careful equilibrium between meeting the community's demands for survival and maintaining the crucial goal of preserving the forest [8, 9]. The rapid expansion of community plantations, particularly those cultivating oil palm, has led to significant changes in land cover and widespread deforestation in the GRPF. These issues have raised worries over the decline of environmental services, the loss of biodiversity, and the possible disturbance of the delicate socio-ecological balance in the region [10]. There has been a clear and indisputable need for efficient zoning and management planning in the RSVF.

This work aimed to tackle this urgent issue by utilizing the capabilities of spatial analysis. The objective of the research was to determine and define certain regions within the RSVF that are appropriate for both management and core zones. This will ensure the responsible and long-term use of forest resources, while also protecting vital ecological services [11, 12]. The research also aimed to create a strong zoning plan and a highly comprehensive management map for the RSVF. These will serve as a guiding framework for future conservation and community development efforts, promoting peaceful coexistence between the community and the forest, ensuring that not only are livelihoods maintained, but also improved, and the priceless biodiversity of the RSVF was conserved for future generations [13, 14].

By providing a data-driven zoning framework, this study supports the implementation of Indonesia's national forest governance policies, particularly within the framework of social forestry programs (Peraturan Menteri LHK No. P.41/MENLHK/SETJEN/ KUM.1/7/2019). Additionally, the integration of community participation in the zoning process enhances the social legitimacy of the proposed management plan, increasing the likelihood of long-term adherence and sustainability.

2. MATERIALS AND METHODS

2.1 Location and time

The Riam Sicangguran Village Forest (RSVF) located in the GRPF, Ketapang Regency of the West Kalimantan Province, Indonesia. The forest has an area of around 757 hectares and is situated at a geographical position of 01°58'43.213" South latitude and 110°41'55.412" East longitude. Research location can be seen in Figure 1.

The average yearly temperature ranges from 27.2 to 27.8°C. The average annual rainfall between 2011 and 2020 was 2985 mm, with the lowest recorded at 2016 mm and the highest at 3970 mm. The number of days with precipitation varied from 134 to 265 [15]. Usually, the months of July and August are drier, although in certain years this dry period can extend until September [16].

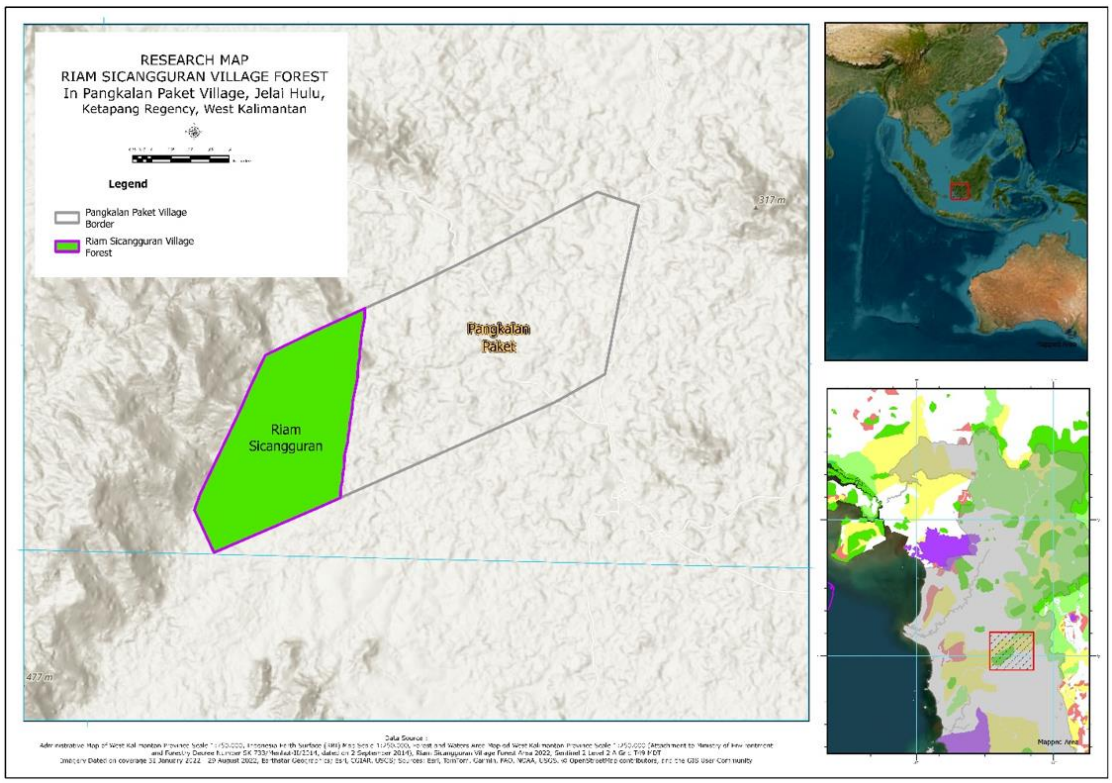


Figure 1. Research location map

The nature reserve has a wide range of plant life, including several ecosystems such as lowland forest, heath forest, swamp forest, and mangrove [17]. Based on the Geological Map Sheet Ketapang, Kalimantan 1:250,000, the geological composition of the area consists of Granite, Andesite, Basalt, and Schist rocks and the prevailing soil type is red-yellow podzolic soil, classified as Dystropupis (https://geologi.esdm.go.id/geomap/pages/preview/peta-geologi-lembar-ketapang-kalimantan).

2.2 Data collection

Data collection in this study was carried out by involving several stages carried out simultaneously in the form of Aerial Photography and Image Processing, Land Cover Classification and Ground-truthing and Data Verification. DJI Phantom 4 Pro drone was used, equipped with a 1-inch 20-megapixel (MP) CMOS sensor. The flight missions were pre-programmed with the following parameters to ensure optimal coverage and image quality using parameters:

- Flight altitude: 120 meters above ground level (AGL)
- Overlap: 80%
- Ground Sampling Distance (GSD): 5 cm per pixel
- Camera settings: Shutter priority mode, fixed at 1/2000 sec to minimize motion blur
- GPS correction: Real-Time Kinematic (RTK) GNSS for high-precision georeferencing

Aerial Photography and Image Processing

- High-resolution aerial photographs were captured using a DJI Phantom 4 Pro drone, following pre-programmed flight paths and camera settings to ensure optimal image quality and coverage [18-20].
- The captured images were processed using Metashape software to generate an orthomosaic image of the RSVF, correcting for geometric distortions and ensuring uniform scale and resolution [21-23].
- The orthomosaic image was then analyzed using ERDAS Imagine software to enhance visual clarity and facilitate accurate land cover classification [24, 25].

Land Cover Classification

- The orthomosaic image was classified into distinct land cover types based on visual interpretation of spectral characteristics and vegetation patterns according to Land Cover Classification of Indonesian National Standardization Agency SNI 7645:1:2014 [26].
- The classification of land cover was performed using a combination of spectral analysis and supervised classification in ERDAS Imagine 2015. The Maximum Likelihood Classification (MLC) method was employed to classify the orthomosaic imagery into distinct land cover types. The classification process followed the Indonesian National Standard for Land Cover Classification (SNI 7645:1:2014) and was refined using machine learning algorithms in ArcGIS 10.4.
- Raster Calculator: Used to overlay multiple spatial datasets, including land cover, slope, and elevation.
- Accuracy assessment: Conducted using confusion matrix analysis, with overall accuracy exceeding 85% [27].

Ground-truthing and Data Verification

- Ground checks were conducted to verify the accuracy of the land cover classification and collect additional data on land use and vegetation characteristics [28].
- GPS coordinates of ground checkpoints were recorded and compared with the classified image to assess accuracy and make necessary adjustments.

2.3 Data analysis

The classified land cover map was overlaid with contour and slope maps generated from topographic data to identify areas suitable for management and core zones [29].

The land cover map was also overlaid with the National Forestry Plan map to ensure compliance with national land-use guidelines from The Regulation of the Minister of Environment and Forestry No.: P.41/MENLHK/SETJEN/KUM.1/7/2019 [30].

The final zoning plan was developed by integrating the results of the spatial analysis with ground-truthing data and considering the socio-economic and cultural context of the RSVF community [31]. Research process and workflow sequentially can be seen in Figure 2.

Although the spatial zoning analysis provided valuable insights, several limitations should be considered the spectral similarity between land cover types may introduce misclassification errors. Seasonal variations in vegetation cover could affect classification accuracy. Drone flight constraints, such as cloud cover and terrain elevation, may lead to minor distortions in the final orthomosaic map. Community land-use dynamics require continuous monitoring to ensure zoning effectiveness. Future studies should incorporate higher-resolution LiDAR data and time-series analysis to enhance the accuracy of forest management planning.

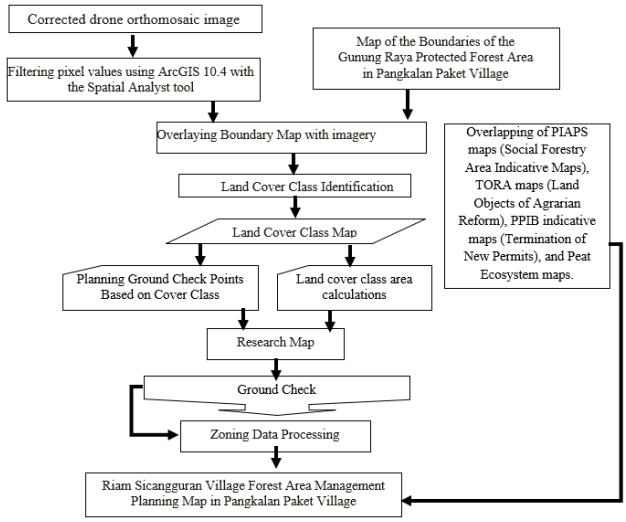


Figure 2. Research workflow

3. RESULTS AND DISCUSSION

3.1 Land cover classification

The spatial analysis of the forest area in RSFV resulted in the classification of land cover types into six distinct canopy cover classes. The primary dryland forest had the largest canopy cover, spanning 259.60 hectares. It was followed by the secondary dryland forest canopy, which covered 233.78 hectares. Plantations covered 193.31 hectares, old shrubs covered 49.41 hectares, young shrubs covered 17.50 hectares, and there were 3.49 hectares of open land. The classification of land cover in the research area based on spatial analysis can be shown in Table 1.

Based on the Table 1 of the land cover classification carried out in the village forest of Riam Sicangguran, more dominated by primary dryland forest cover types. The data that has been generated from the initial stages of this research then followed by a ground check process to determine the correctness of the land cover classification results carried out on the desk.

The results of ground checks in the field and information from the local Chief Customary on the land cover classification map that has been made, there are land covers that are primary dryland forest types and secondary dryland forests which are identified as old Pedahasan belonging to the Pangkalan Paket village community [32]. So that the identified land cover was classified as plantation land cover. The change in land cover classification aims to be taken into consideration when determining the zoning of village forest management areas. Changes in land cover classification can be seen in Table 2.

The results of the ground inspection were compared to the land cover classification map, revealing a significant change in the type of land cover. The changed land cover was secondary dryland forest and primary dryland forest. Where the cover was identified as Pedahasan or plantation owned by the community. Changes in land cover classification resulting from a comparison of land cover classification adjustments based on Ground check results can be seen in the following Figures 3.

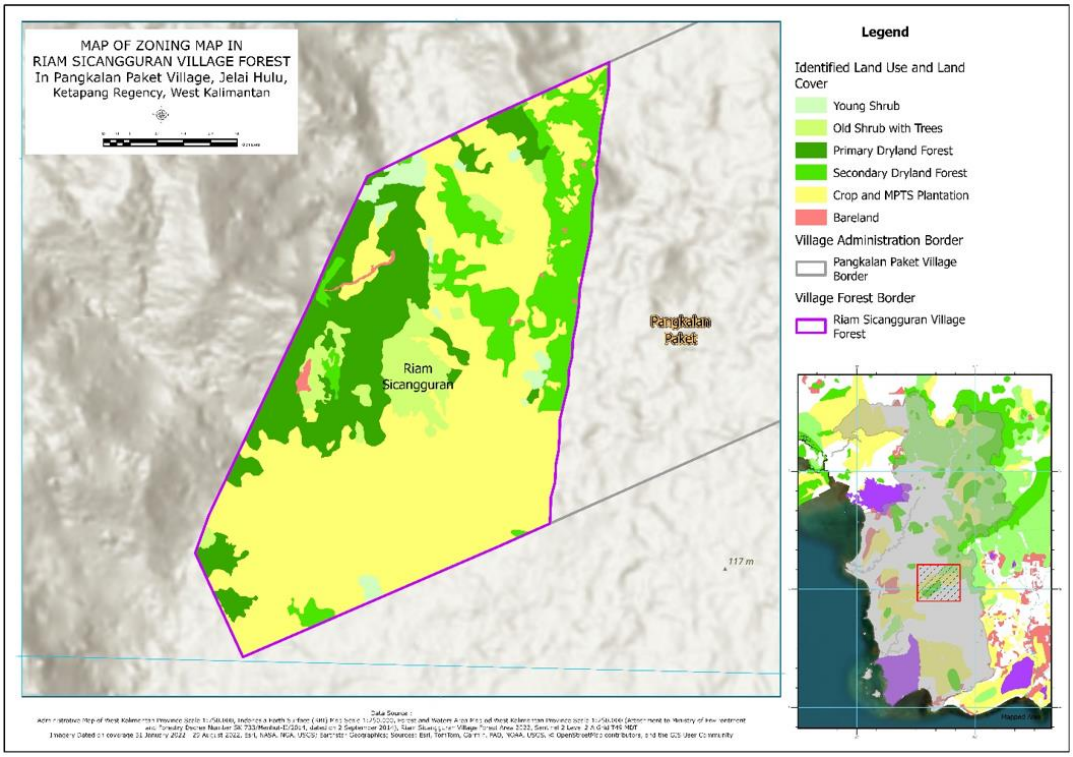


Figure 3. Map of land cover classification in Riam Sicangguran Village Forest based on ground check results

Table 1. Classification of land cover in Riam Ricangguran village forest

Land Cover Types	Spatial Analysis		Ground Check	
	Area (ha)	Coverage (%)	Area (ha)	Coverage (%)
Young Shrub	17.5	2.31%	17.5	2.31%
Old Shrub	49,41	6.53%	49,41	6.53%
Primary Dryland Forest	259.6	34.29%	143.74	18.99%
Secondary Dryland Forest	233.78	30.88%	106.05	14.01%
Plantation	193,31	25.53%	436.9	57.71%
Open Land	3.49	0.46%	3.49	0.46%
Totals	757.09	100.00%	757.09	100.00%

One of the primary challenges in land cover classification is the spectral similarity between different vegetation types, which can lead to misclassification errors [33]. In this study, secondary dryland forests were often spectrally similar to community plantations (Pedahasan), resulting in an overestimation of forested areas in the initial classification. Comparison of land use types, image taken from the aerial photograph and ground survey can be seen in Figure 4.

The Maximum Likelihood Classification (MLC) method, while effective, may not fully differentiate mixed land-use patterns, especially when tree canopy cover is continuous. To mitigate these errors, ground-truthing surveys were conducted at 30 sample points, improving classification accuracy from 85% to 92%. However, certain seasonal variations in vegetation reflectance could still affect classification reliability, particularly for distinguishing between old and young shrub formations [24].

3.2 Zoning and management framework

According to the regulations set by the Indonesian Minister of Environment and Forestry. These regulations include Regulation Number 8 of 2021, which focuses on The Regulation of the Minister of Environment and Forestry Number: P.41/MENLHK/SETJEN/ KUM.1/7/2019, which outlines the National Forestry Plan from 2011 to 2030. The zoning procedure adopted a comprehensive approach, taking into account many aspects such as land cover, topography, slope, current land use, and the specific requirements of the community. The use of spatial analysis tools, specifically ArcGIS 10.4 and ERDAS Imagine, along with on-site data verification and input from local stakeholders, enabled the division of the RSVF into two main zones:

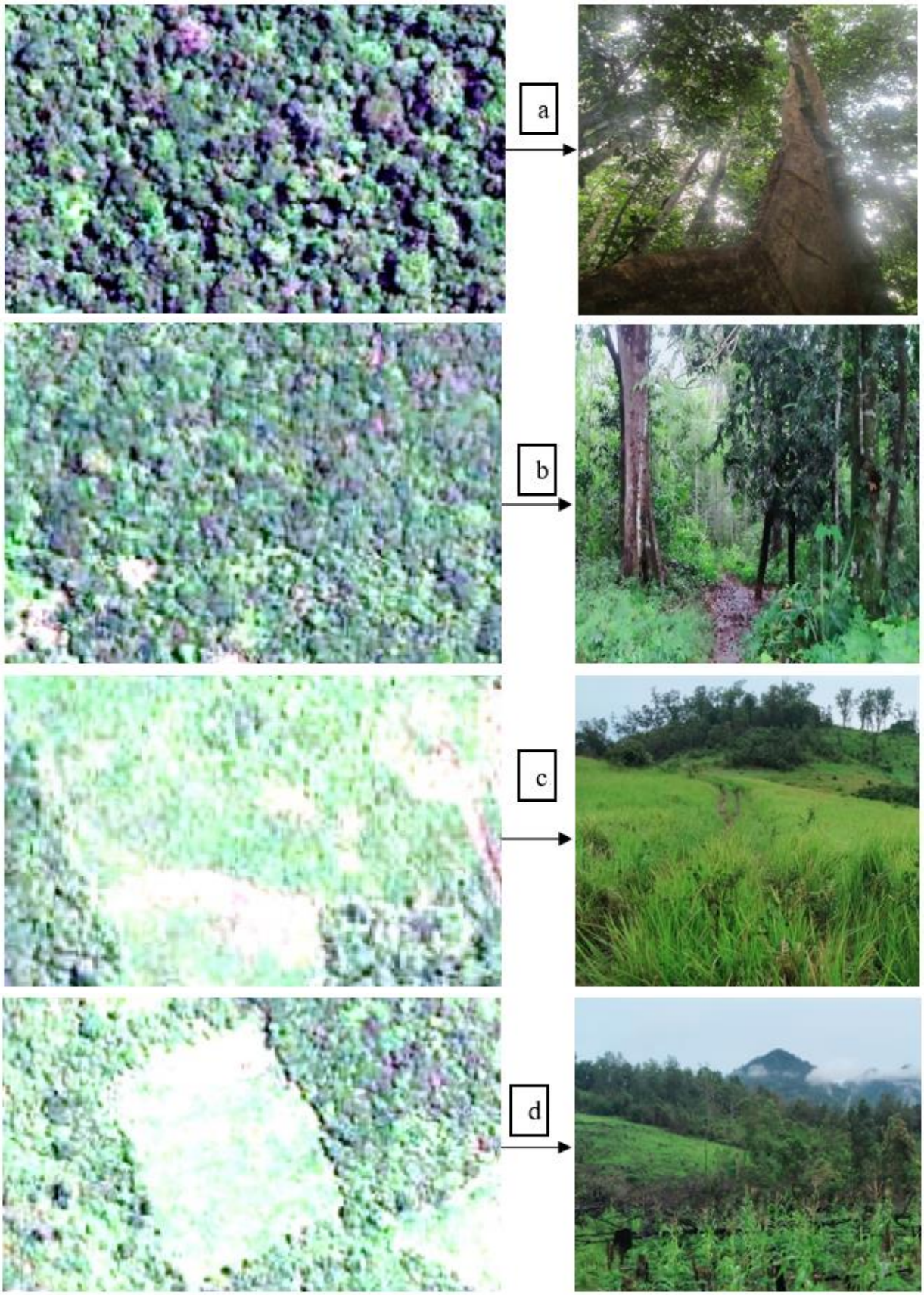
- Core Block which covers 26% of the total area, which mainly designated for the preservation and rehabilitation of the ecosystem. The area includes regions with primary dryland forests and locations that play a crucial role in providing essential environmental services, such as water sources. The decision to prioritize the protection of primary dryland forests highlighted the crucial significance of these forests in terms of carbon sequestration and biodiversity preservation [34, 35].
- The Utilization Block, which covers 74% of the total area, which designated for the sustainable exploitation of forest resources and the advancement of community development. It includes regions with established community plantations, secondary woods, and easily accessible places appropriate for livelihood activities. The zoning map of Riam Sicangguran Village Forest management (RSVF) can be seen in Figure 5. The incorporation of community plantations into the utilization block recognizes the current land-use patterns and economic goals of the local population [36, 37].

The high prevalence of the use block (74%) demonstrates the importance of achieving a balance between conservation goals and the socioeconomic welfare of the community. Nevertheless, the incorporation of specific secondary forest and plantation regions inside the central area emphasizes the crucial need to protect biodiversity and ecosystem services, especially in places that have undergone previous human

intervention [38].

The management plan for the RSVF was based on the ideals of sustainable resource usage, biodiversity preservation, and community empowerment. The utilization block was designed to facilitate a wide range of livelihood activities, including the development and harvesting of Non-Timber Forest Products (NTFPs), agroforestry, and the growing potential of ecotourism.

The emphasis on Non-Timber Forest Products (NTFPs) underscores its importance in the context of forest management planning and livelihood diversification [39].



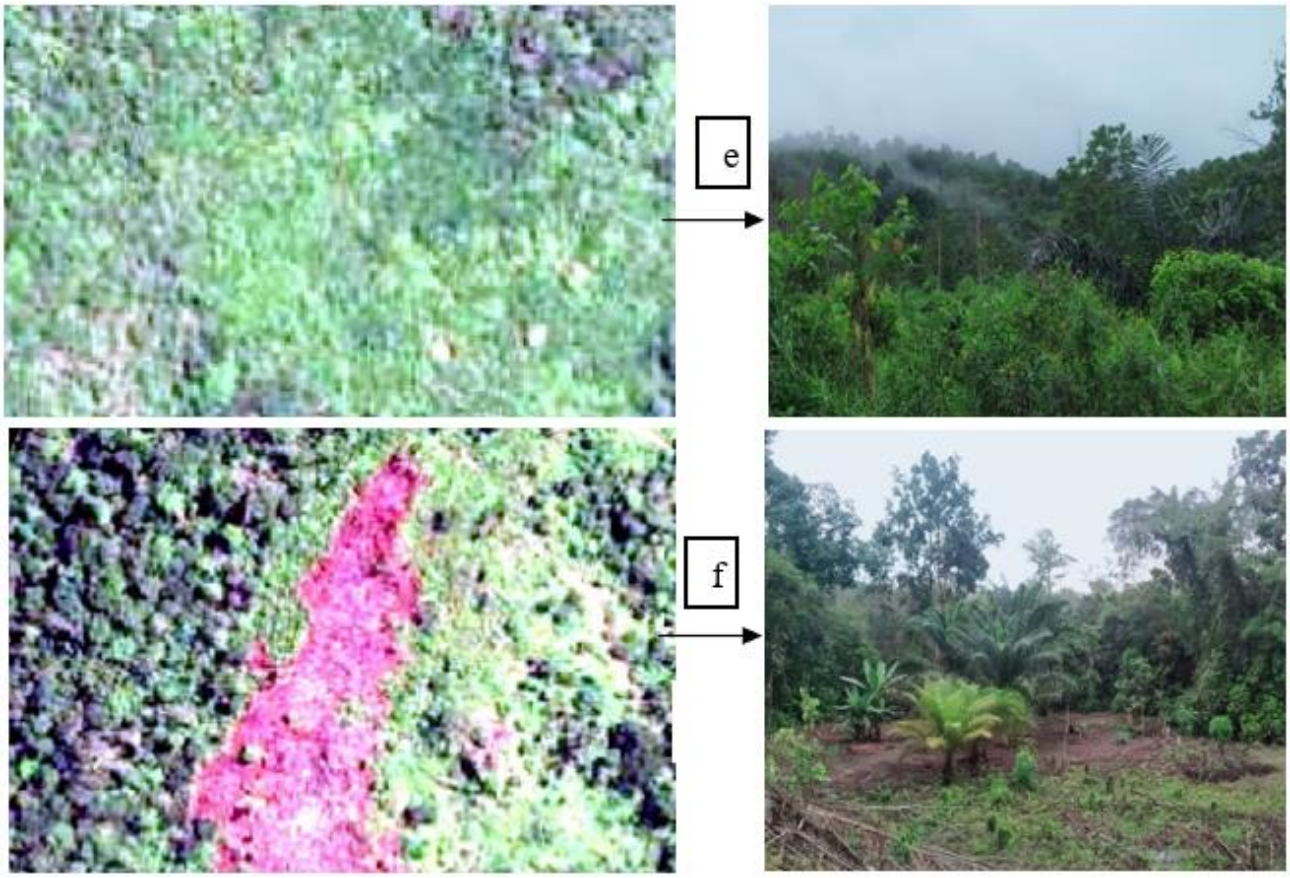


Figure 4. Comparison of the aerial photograph with ground survey for (a) Primary Dryland Forest; (b) Secondary Dryland Forest/Pedahasan; (c) Young Shrub; (d) Plantation; (e) Old Shrub; (f) Bareland

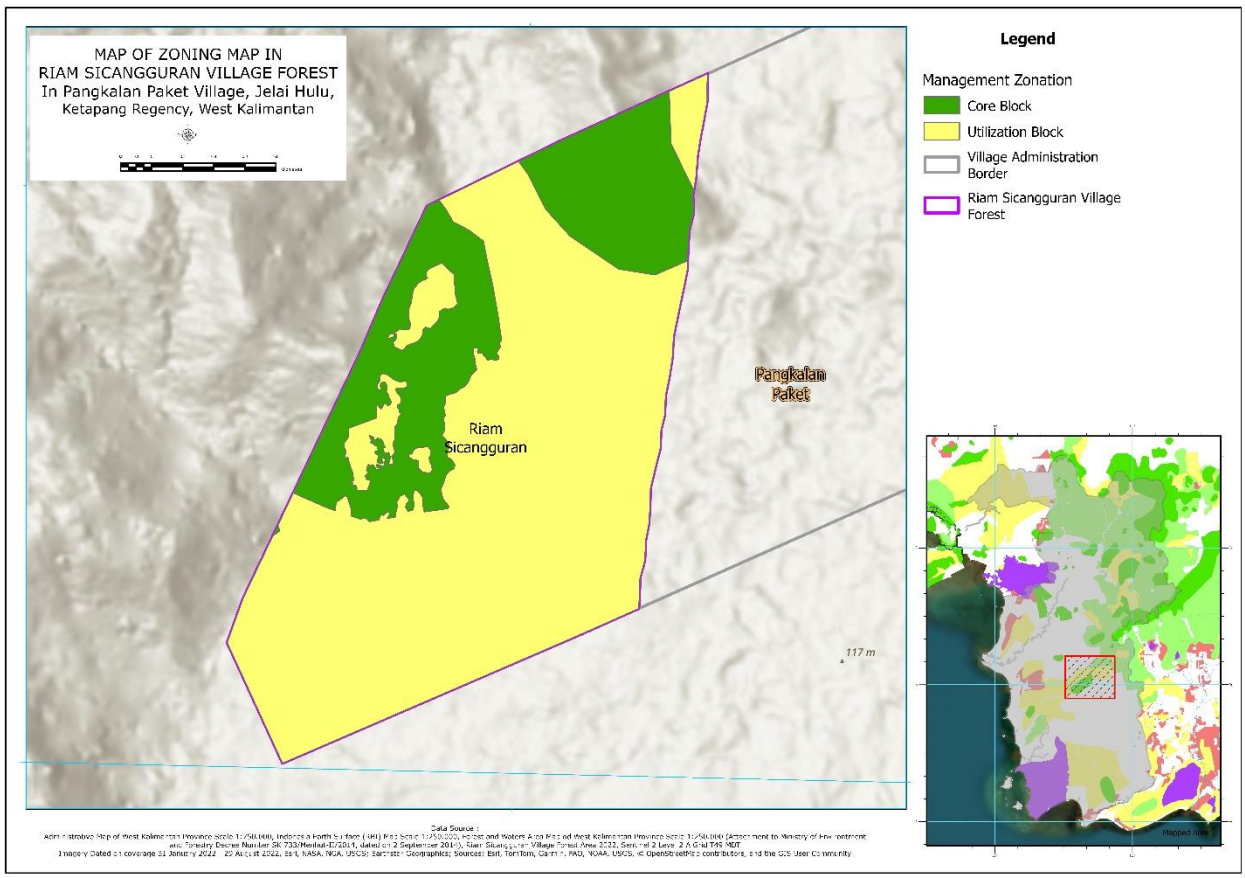


Figure 5. Zoning map of Riam Sicangguran Village Forest management (RSVF)

The most significant change was observed in primary and secondary dryland forests, which were overestimated in the spatial analysis by 115.86 ha and 127.73 ha, respectively. Conversely, the ground-truthing results showed a substantial increase in plantation areas (243.59 ha). The primary cause of this misclassification was the spectral similarity between secondary dryland forests and community-managed agroforestry plantations (locally known as Pedahasan), which were mistakenly classified as forested areas. This finding underscores the importance of field validation in land cover mapping, as remote sensing alone may fail to capture fine-scale land-use dynamics [40].

Table 2. Zoning analysis of Riam Sicangguran Village Forest (RSVF) management for land cover types

Management Zoning	Land Cover Types						Grand Totals
	Young Shrub	Old Shrub	Primary Dryland Forest	Secondary Dryland Forest	Plantation	Open Land	
Core Block	4.73	3.67	116.83	26.79	42.87	0.52	195,41
Utilization Block	12.77	45,74	26,92	79,26	394.03	2.97	561.68
Grand Totals	17.50	49,41	143.74	106.05	436.90	3.49	757.09

3.3 Implications for sustainable forest management

The spatial analysis carried out in this research establishes a strong basis for making decisions based on evidence and for the sustainable management of the RSVF. The carefully designed zoning plan and management map are essential tools for the Village Forest Management Institution (LPHD) and the community. They guide their actions and promote a peaceful balance between resource exploitation and conservation. The distinct separation between core and usage zones enables the effective application of focused management techniques, guaranteeing the protection of vital ecosystems while still permitting sustainable livelihood activities. By using spatial data on terrain, slope, and land cover, the plan becomes more successful as it takes into consideration the physical limitations and possibilities [41, 42].

The zoning process highlights the significance of acknowledging and valuing local expertise and ambitions in forest management. By actively engaging the community in the process of making decisions, the plan acquires social legitimacy and promotes a feeling of ownership, which essential for its successful execution and long-term viability [43]. The participatory method enhances the incorporation of traditional ecological knowledge alongside scientific data, resulting in more sophisticated and contextually appropriate management solutions [44].

The capacity of the RSVF to make a substantial contribution to Indonesia's Nationally Determined Contribution (NDC) commitments by serving as a carbon sink and a refuge for biodiversity. The effective stewardship of the RSVF, including the safeguarding and rejuvenation of primary arid forests, can have a crucial impact in alleviating climate change and promoting ecological sustainability [45, 46]. The forest's ability to capture and store carbon and protect biodiversity highlights its significance in the worldwide effort to combat climate change and save natural ecosystems [47, 48].

The emphasis on Non-Timber Forest Products (NTFPs) in the usage sector corresponds to the increasing acknowledgment of their importance in fostering livelihood diversification and sustainable forest management [49]. The RSVF possesses a diverse selection of Non-Timber Forest Products (NTFPs), including rattan, bamboo, and medicinal plants, which have favorable prospects for generating revenue and reducing poverty among residents. Nevertheless, to guarantee the long-term sustainability of livelihoods based on non-timber forest products (NTFPs), it is crucial to implement sustainable harvesting methods and focus on developing the value chain [50, 51].

The findings also have implications for addressing the challenges posed by the growth of oil palm plantations within the RSVF. To effectively manage the environmental impact of plantation lands in both the core and usage blocks, it was essential to identify them and implement measures that encourage their sustainable management. Agroforestry systems, including the integration of multi-purpose tree species (MPTS) with oil palm, present a promising option as they enhance biodiversity, improve soil health, and offer supplementary income opportunities for farmers [52, 53].

The zoning plan and management map could be utilized as a significant model for future conservation and community development endeavors in the RSVF [54, 55]. The plan's focus on sustainable resource utilization, biodiversity conservation, and community empowerment is in line with the ideas of social forestry and sustainable development [56, 57].

The successful implementation and monitoring of the plan will depend heavily on the active participation of the LPHD and the community [58, 59]. The effectiveness of spatial analysis and participative approaches in creating successful zoning and management plans for village forests. It was also important to guide policy and implementation in community-based forest management, promoting a more sustainable and fair approach to the use and preservation of forest resources [53].

The implementation of the zoning plan depends on the alignment with national forestry policies, including Regulation No. P.41/MENLHK/SETJEN/KUM.1 /7/2019, which governs village forest management in Indonesia. However, legal ambiguities regarding customary land rights and social forestry concessions may pose barriers to enforcement [53]. Moreover, stakeholder conflicts between conservation agencies and local communities could hinder the adoption of sustainable forest management practices. Addressing these issues requires:

Incentives for agroforestry-based land management, such as payment for ecosystem services (PES) programs. Strengthening local governance structures to enhance compliance with zoning regulations. Capacity-building initiatives for communities to adopt sustainable land-use alternatives instead of expanding monoculture plantations [52].

The rapid increase in plantation areas (Pedahasan) highlights the growing dependence of local communities on agroforestry systems for their livelihoods. Agroforestry, particularly the cultivation of rubber, fruit trees, and oil palm, provides economic benefits but also raises long-term sustainability concerns [52].

4. CONCLUSIONS

With a total management area of 757.09 ha, the spatial analysis conducted in this research has produced the successful identification of management zones inside the RSVF. Thoughtfully split into a core block mostly used for conservation and spanning 195.41 hectares and a utilization block meant for sustainable resource use and community development 561.68 ha in total. The predominance of plantations inside the RSVF emphasizes the complex interaction between the local inhabitants and their surroundings, therefore stressing the need for sustainable land-use policies promoting both economic well-being and ecological integrity.

Rich possibilities for Non-Timber Forest Products (NTFPs) and environmental services presented by the RSVF provide means of enhancing sustainable livelihoods and reducing poverty. Utilizing their identification and mapping inside the use block, these resources offer a useful framework for their sustainable maintenance and application. Dedicated to protection and restoration, the core block provides a vital defense for the biodiversity and ecological processes of the forest, therefore ensuring the long-term survival and resilience of the ecosystem.

The offered research results provide a strong basis for wise decision-making and environmentally friendly RSVF maintenance. Designed by a collaborative process combining scientific data with local knowledge, the zoning plan and management map offer the Village Forest Management Institution (LPHD) and the community a useful road map. The emphasis of the plan on sustainable resource use, biodiversity protection, and community empowerment fits very well with the ideas of social forestry and sustainable development, so opening the path for a future in which the RSVF thrives as a model of harmonic coexistence between people and nature.

This research highlights the need for more research to fully utilize the forest even while it provides insightful analysis of the management of the RSVF. Future studies could probe the RSVF's capacity for carbon sequestration more thoroughly and pinpoint High Conservation Value (HCV) areas, therefore offering vital data to improve its contribution to national and worldwide climate change mitigating efforts. The dynamic character of socio-ecological systems makes constant monitoring and adaptive management necessary to guarantee the long-term resilience of the zoning plan against changing environmental and socioeconomic circumstances.

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