BIODIVERSITAS
Volume 26, Number 9, September 2025
Pages: 4297-4308

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d260905

Estimation of vegetation cover percentage using visual on-screen classification in the Krueng Lagsa Watershed, Aceh Province, Indonesia

ISWAHYUDI[1,♥], RENI YUSNIAR[1], BOY RIZA JUANDA[1], MUHAMMAD RUSDI[2]
[1]Department of Agrotechnology, Faculty of Agriculture, Universitas Samudra. Jl. Prof. Dr. Syarief Thayeb-Meurandeh, Langsa 24416, Aceh, Indonesia.
Tel.: +62-641-426487, Fax.: +62-641-7445137, ♥email: iswahyudi@unsam.ac.id
[2]Departement of Soil Science, Faculty of Agriculture, Universitas Syiah Kuala. Jl. Teuku Nyak Arief-Darussalam, Banda Aceh 23111, Aceh, Indonesia

Manuscript received: 12 February 2025. Revision accepted: 4 September 2025.

Abstract. *Iswahyudi, Yusniar R, Juanda BR, Rusdi M. 2025. Estimation of vegetation cover percentage using visual on-screen classification in the Krueng Lagsa Watershed, Aceh Province, Indonesia. Biodiversitas 26: 4297-4308.* The research aims to identify land cover types contributing to the degradation of the Krueng Langsa Watershed in Aceh Province, Indonesia and analyze the Vegetation Cover Percentage (VCP). The analysis used Geographic Information System (GIS) techniques, including visual on-screen digitization of land cover classes based on RapidEye satellite imagery. The RapidEye imagery has a 5 m spatial resolution, allowing detailed classification of land cover types and accurate estimation of Vegetation Cover Percentage (VCP). The Indonesian Ministry of Forestry Regulation guided the study No. P.61/Menhut-II/2014, focusing on monitoring and evaluating watershed management. Based on image interpretation, 12 land cover classes were identified: primary dryland forest, secondary dryland forest, primary mangrove forest, secondary mangrove forest, open land, plantations, settlements, mixed dryland agriculture, rice fields, shrubs, fishponds, and water bodies. This classification highlights the dominance of vegetated land, which plays an important role in supporting biodiversity and ecosystem services in river basins. Conversely, 35.41% of the Krueng Langsa Watershed comprises non-vegetated land such as open land, settlements, fishponds, and water bodies. The fishpond land cover class occupies 14.00% of the total watershed area, potentially exerting additional environmental pressure if not managed sustainably. This information is essential for guiding watershed management strategies and biodiversity conservation planning. The VCP value of 64.59% suggests that permanent vegetation in the Krueng Langsa Watershed remains in good condition.

Keywords: Degradation, Geographic Information System (GIS), land cover, sustainably

INTRODUCTION

Watersheds play a crucial role in maintaining ecosystem balance and water availability. Rainfall that reaches the earth's surface is influenced by vegetation in the watershed, which in turn affects the hydrological cycle. A significant reduction or removal of vegetated land, such as forests, can lead to decreased watershed performance, such as increased surface runoff. The increase in water flow can also result from changes in vegetation from deep-rooted plants to shallow-rooted plants and from ground cover plants with high interception capacity to plant types with low interception capacity (Asdak 2022).

Land cover conditions can be identified using satellite imagery and visual on-screen classification methods in a Geographic Information System (GIS), allowing for quick, accurate, and comprehensive data (Tong et al. 2023). Various studies have examined watershed degradation using remote sensing techniques. For example, Singh et al. (2021) analyzed watershed performance in India and showed that deforestation and land conversion significantly impact the hydrological cycle. Similarly, research by Pramanta et al. (2020) in Indonesia found that vegetation loss leads to increased flooding and erosion. However, research conducted in the Krueng Langsa Watershed, Aceh Province, is still limited, especially regarding the assessment of Vegetation Cover Percentage (VCP). Land use and land cover change have been widely recognized as a major driver of ecosystem service loss, particularly in forest landscapes (Sharma et al. 2019). Visual on-screen classification involves interpreting satellite imagery using human observation of colors, shapes, dimensions, patterns, textures, shadows, sites, and spatial associations. The Krueng Langsa Watershed is part of the Tamiang-Langsa river basin, covering the administrative areas of Langsa City, East Aceh District, and Aceh Tamiang District, as stated in the Decree of the Minister of Forestry of the Republic of Indonesia Number: SK. 511/Menhut-V/2011 concerning the determination of watershed boundary maps (Watershed Management 2011). Vegetation cover plays an important role in supporting biodiversity and ecosystem services within river basins. However, ecological data on Vegetation Cover Percentage (VCP) in the Krueng Langsa River Basin is still limited, hindering comprehensive biodiversity assessment and management strategies. The absence of detailed VCP information also limits the design of effective conservation measures and watershed management planning in this region.

The Krueng Langsa Watershed spans 126 km² and receives an average annual rainfall of 2300 mm, classifying it as an area with relatively high precipitation. This level of rainfall contributes to erosion and sediment deposition in rivers, channels, and river mouths. Consequently, sedimentation leads to river silting, murky runoff, uncontrolled water flow, and great fluctuations in river water levels. Ecosystem damage in the Krueng Langsa

Watershed is primarily caused by deforestation and C-class excavation activities in the upstream area. During the rainy season, erosion transports the topsoil layer downstream, reducing the watershed's storage capacity. The conversion of forests into plantations, agricultural land, or settlements also contributes to land degradation (Muntazar and Ramli 2021).

The enactment of Government Regulation No. 37 of 2012 on watershed management provides a legal framework for monitoring and evaluating watershed performance (Directorate General of Water Resources 2014). This activity should be conducted continuously, at least once a year. The results of monitoring and evaluation can be used to improve the planning and implementation of watershed management. To assess the effectiveness of watershed management, monitoring should consider land conditions, water management, socioeconomic factors, infrastructure investment, and spatial use, as outlined in the Regulation of the Minister of Forestry of the Republic of Indonesia No. P.61/Menhut-II/2014 on Watershed Management Monitoring and Evaluation (Ministry of Environment and Forestry 2014). This research aimed to identify land cover changes contributing to the degradation of the Krueng Langsa Watershed and evaluate the Vegetation Cover Percentage (VCP) using 2024 RapidEye satellite imagery. The findings can support the development of watershed management strategies, including conservation measures to prevent erosion and maintain the watershed's optimal performance. This study seeks to fill a research gap by using the latest satellite data as a basis for sustainable watershed management planning.

Despite the growing body of research on watershed degradation in Indonesia, there remains a lack of specific data on the Vegetation Cover Percentage (VCP) in the Krueng Langsa Watershed. Most watershed studies in Indonesia rely on Landsat or Sentinel imagery, leaving a lack of high-resolution assessments of VCP. This limits site-specific conservation planning in Krueng Langsa. This study addresses that gap by utilizing high-resolution RapidEye satellite imagery to generate detailed and accurate land cover classifications. The use of this imagery distinguishes the research from prior studies that often relied on lower-resolution data. This study aims to quantify the Vegetation Cover Percentage (VCP), classify land cover types, and assess their implications for forest loss and biodiversity in the Krueng Langsa Watershed.

MATERIALS AND METHODS

Study area

This research was conducted in the Krueng Langsa Watershed, which spans Aceh Tamiang District, East Aceh District, and Langsa City, Aceh Province, Indonesia (Figure 1), as stipulated in the Decree of the Minister of Forestry of the Republic of Indonesia No. SK: Sk. 511/Menhut-V/2011 concerning the determination of watershed boundary maps (Watershed Management 2011). Data preparation and analysis were carried out the Remote Sensing and Cartography Laboratory, Faculty of Agriculture, Universitas Syiah Kuala, located in Banda Aceh City, Aceh Province, Indonesia. The research was conducted over a period of three months, from July to September 2024.

Procedures

Data collection

This research used RapidEye satellite imagery (5 m spatial resolution) acquired in July 2024 from the Planet Team (2024) (https://www.planet.com), covering the entire Krueng Langsa Watershed. Additional spatial data, such as river networks, road networks, and administrative boundaries, were obtained from the Indonesian Geospatial Portal (https://tanahair.indonesia.go.id).

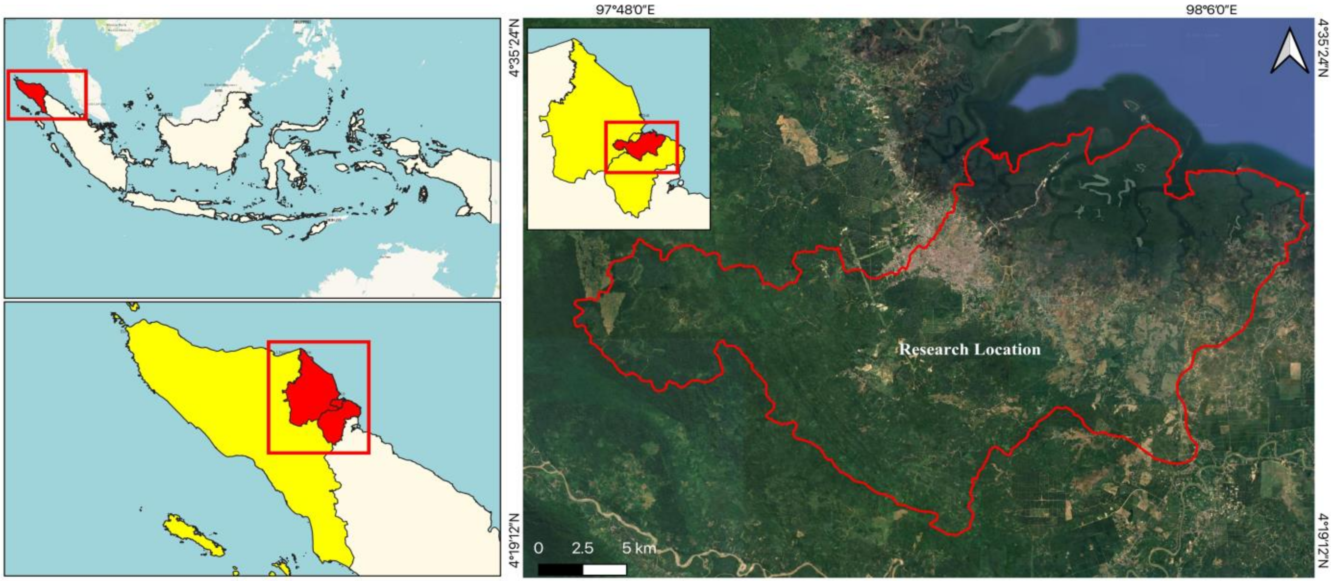

Figure 1. Map of the research location in Krueng Langsa Watershed, Aceh Province, Indonesia

Image interpretation

The image interpretation stage was carried out using ArcGIS 10.8 software and is conducted digitally through the On-Screen Visual Digitization method. Object identification on the imagery considered image elements and such as color/tone, shape, size, pattern, shadow, texture following the technical guidelines for image interpretation and land cover classification issued by the Ministry of Environment and Forestry (2020) in 2020. The Krueng Langsa River Basin has a highly heterogeneous land cover (e.g., mangrove forests, plantations, fish ponds, and mixed agriculture). Under such conditions, machine learning often requires extensive training data and can misclassify spectrally similar classes.

Ground check and field data collection

The ground check in this research was conducted to ensure that the results of the previous image interpretation align with actual field conditions. Field data verification was carried out using sampling techniques based on predetermined coordinate points representing each land cover class. According to Estok et al. (2002), the number of sample points can be calculated using the following cross-sectional equation:

$$n = \frac{Z^2(P(1\text{-}P)N}{Z^2(P(1\text{-}P)+(N\text{-}1)E^2} \quad [1]$$

Information: n: minimum number of samples required, Z: reliability coefficient or standard normal variable value, P (1-P): population variance, E: tolerated confidence level, N: population size.

During the fieldwork, coordinates were recorded using Global Positioning System (GPS) (Figure 2), along with capturing photos and gathering other relevant information about the observed land cover types. The accuracy assessment of the image interpretation results was performed based on the previously established coordinate points. In this study, RapidEye images (spatial resolution of 5 m) were processed using visual classification on-screen in ArcGIS 10.8. A total of 109 field validation points were collected with GPS for validation. Accuracy assessment was performed using a confusion matrix, which resulted in an overall accuracy of 87% and a Kappa coefficient of 0.85, indicating high classification reliability.

Accuracy test

To ensure mapping accuracy, an accuracy test was performed to examine the number of errors that occurred during the image interpretation stage. The visual accuracy of the image classification result was assessed a confusion matrix (Table 1). Mapping accuracy is analyzed with a confusion matrix involved comparing satellite imagery with field survey data (Hastoro and Yudinugroho 2023).

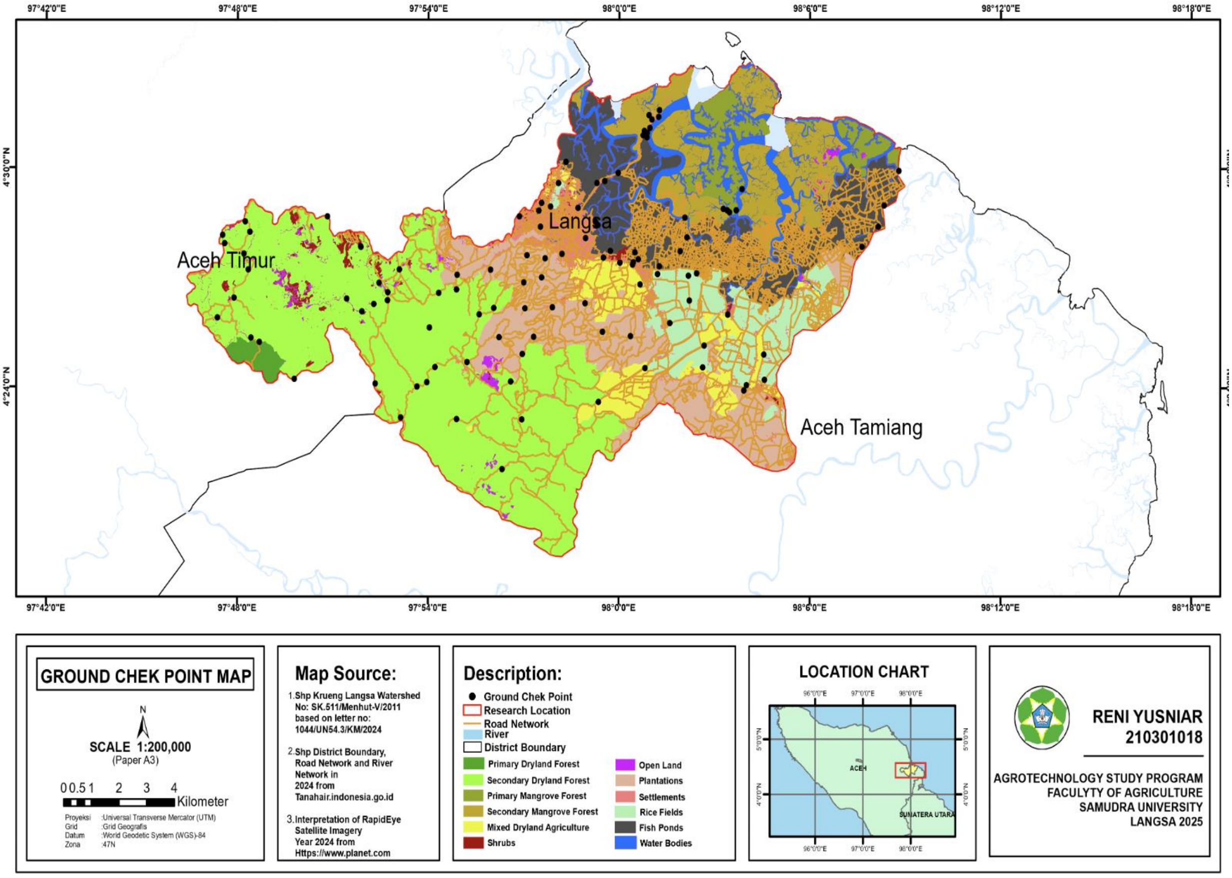

Figure 2. Ground check point map

Table 1. Confusion matrix

		Interpretation data			Total rows	Producer's accuracy
		A	B	C		
Reference data	A	X_{ii}			X_{i+}	Xii/Xi_{+}
	B		X_{ii}			
	C			X_{ii}		
Total columns		X_{+1}			N	
User's accuracy		Xii/X+i				

Source: Hastoro and Yudinugroho (2023)

$$\text{User's Accuracy} = \frac{X_{ii}}{X_{+i}} \text{ x } 100\% \quad [2]$$

$$\text{Producer's Accuracy} = \frac{X_{ii}}{X_{i+}} \text{ x } 100\% \quad [3]$$

$$\text{Overall Accuracy} = \frac{\sum_i^r X_{ii}}{X_{+1}} \text{ x } 100\% \quad [4]$$

$$\text{Kappa Accuracy} = \frac{N \sum X_n - \sum X_{n+} X_{+n}}{N^2 - \sum X_{n+} X_{+n}} \times 100\% \quad [5]$$

Information: Xii: Diagonal value of the contingency matrix for the i-th row and i-th column, X+: Total number of pixels in the i-th row, X+i: Total number of pixels in the i-th column, N: Total number of pixels in the sample, X: Diagonal value of the contingency matrix for row i and column i, Xii: Number of pixels in row i, Xi+: Number of pixels in the i-th column, Xn: Data being tested, ∑Xn: Count of each reference data/image classification.

In 2015, according to the National Aviation and Space Agency (2015) stated that image classification is deemed accurate if the tolerated value in the confusion matrix yields results of 75% or higher. The purpose of the accuracy test is to evaluate the correctness of mapping during the classification process. To evaluate the accuracy of land classification, tests are performed for each land category. One effective method for accuracy assessment involves comparing classification results with verified field data using a confusion matrix. Key metrics used in accuracy testing include overall accuracy, producer's accuracy, user's accuracy, and Kappa accuracy (K) (Johnson and Jozdani 2018). To validate the effectiveness of the selected method, accuracy tests of land cover classification using remote sensing data are essential throughout the classification process. A contingency matrix, or square matrix, that includes categorized land cover classes serves as a valuable tool for evaluating classification accuracy (National Aviation and Space Agency 2015).

Calculation of Vegetation Cover Percentage (VCP)

The VCP is a reliable indicator for watershed sustainability. The VCP classification is detailed in Table 2, along with the evaluation of watershed management using the following equation:

$$\text{VCP} = \frac{\text{Area of permanent vegetation}}{\text{Watershed area}} \times 100\% \quad [6]$$

Table 2. Vegetation cover percentage class

Sub criteria	Weight (%)	Mark	Class
Vegetation Cover Percentage	10	VCP>80%	Very Good
		60<VCP≤80 %	Good
		40<VCP≤60 %	Medium
		20<VCP≤40 %	Bad
		VCP≤20%	Very Bad

Source: Regulation of the Minister of Forestry of the Republic of Indonesia No. P.61/Menhut-II/2014

Data analysis

This research was conducted based on the Guidelines of the Minister of Forestry Regulation of the Republic of Indonesia (No. P.61/Menhut-II/2014) on Monitoring and Evaluation of Watershed Management (Ministry of Environment and Forestry 2014). The research methodology involved several steps: collecting both primary and secondary data, defining the study area's boundaries, conducting image interpretation, analyzing land cover classes, performing ground checks and field data collection, conducting accuracy tests, and finally calculating the Vegetation Cover Percentage (VCP) in the area using a scoring method.

RESULTS AND DISCUSSION

Results

General condition of research location

The Krueng Langsa Watershed, as outlined in the Decree of the Minister of Forestry of the Republic of Indonesia (No.: SK. 511/Menhut-V/2011) on regarding the Determination of Watershed Maps, which is located administratively within parts of Aceh Tamiang District, East Aceh District, and Langsa City (Watershed Management 2011). The geographical coordinates for the upstream section of the Krueng Langsa Watershed are 97°51'46.8"E, 4°25'8.4"N and 97°58'26.4"E, 4°19'30"N, while the downstream section is marked by 98°01'58.8"E, 4°32'38.4"N and 98°03'7.2"E, 4°31'26.4"N. Based on spatial analysis, the total area of the Krueng Langsa Watershed is 49,712.04 hectares, as presented in Table 3.

Table 3 shows that the Krueng Langsa Watershed is the largest in Aceh Tamiang District, covering an area of 17,422.23 hectares, which contribute to the 35.05% of the total watershed area. The administrative boundaries of the Krueng Langsa Watershed as illustrated in Figure 3.

Land cover

After analyzing the RapidEye satellite imagery using the visual on-screen classification method, 12 (twelve) land cover classes were identified in the Krueng Langsa Watershed. These classes include: primary dryland forest, secondary dryland forest, primary mangrove forest, secondary mangrove forest, open land, plantations, settlements, mixed dryland agriculture, rice fields, shrubs, ponds, and water bodies. The data that has been analyzed shows the different characteristics of the various land cover types. Further details as shown in Table 4.

Table 3. Area of Krueng Langsa Watershed in Aceh Province, Indonesia based on administrative regions

District/City	**Sub-district**	**Area of Sub-district in Krueng Langsa Watershed**			
		Area (Ha)	**%**	**Total area (Ha)**	**%**
Aceh Tamian	Banda Mulia	569,31	1.15	17,422.23	35.05
	Karang Baru	390,92	0.79		
	Manyak Payed	15,563,37	31.31		
	Sekerak	89,63	1.81		
Aceh Timur	Birem Bayeun	15,963.04	32.11	15,973.05	32.13
	Simpang Jernih	10.01	0.02		
Langsa	Langsa Barat	4,253.85	8.56	16,316.76	32.82
	Langsa Baro	1,557.05	3.13		
	Langsa Kota	669.73	1.35		
	Langsa Lama	2,947.89	5.93		
	Langsa Timur	6,888.24	13.86		
Total		49,712.04	100	49,712.04	100

Table 4. Land cover classification based on color, pattern, and texture

Land cover classes	**Color**	**Pattern**	**Texture**	**Environmental association**
Primary dryland forest	Dark green	Dense canopy	Coarse	Diverse vegetation, complex shadows
Secondary dryland forest	Yellowish-green	Uneven shape	Fine to coarse	Road networks, signs of fire/logging
Primary mangrove forest	Dark green, uniform	Dense canopy	Coarse	Undisturbed, healthy vegetation
Secondary mangrove forest	Bright green	Many gaps	Fine	Lower vegetation, human disturbance
Open land	Bright reddish-purple	Irregular	Fine	Ranges from lowlands to steep topography
Plantations	Green	Neat, parallel rows	Fine	Road access, irrigation
Settlements	Pink	Consistent	Somewhat coarse	Associated with road networks
Mixed dryland agriculture	Darker hue	Not specified	Softer	Connected to residential areas, road networks
Rice fields	Bright to dark, blue with green spots	Homogeneous	Fine	Near water sources, populated areas
Shrubs	Light green	Irregular	Coarse	Associated with open land, forest, agriculture
Fish ponds	Dark blue, almost black	Regular plots	Fine	Associated with tidal, mangrove areas
Water bodies	Dark brown	Irregular	Fine	Not specified

The findings from the interpretation of RapidEye satellite imagery using ArcGIS 10.8 editor tools based on on-screen visual classification are presented in Table 5, showing the distribution of land cover classes within the Krueng Langsa Watershed. Additionally, the land cover map for 2024 is illustrated in Figure 3. The spatial distribution of land cover in the Krueng Langsa River Basin (DAS) is shown in Figure 3. Forest areas are mainly concentrated in the upstream zone, while agricultural and plantation areas dominate the middle zone. Settlements and aquaculture areas are concentrated in the downstream zone, especially along the riverbanks. Although only 2024 imagery was analyzed, the results are consistent with previous studies in the region. For example, Pramanta et al. (2020) and Muntazar and Ramli (2021) also reported a decline in vegetation associated with agricultural expansion and settlement growth. The 2024 VCP value of 64.59% indicates relatively stable permanent vegetation, but increasing anthropogenic pressure in the downstream zone may signal the risk of future forest loss or fragmentation.

The accuracy of the 2024 land cover interpretation was verified by comparing the classification findings with field data collected from ground surveys. A total of 109 coordinate points representing land cover classes were selected based on accessibility during field data collection. The confusion matrix table is shown in Table 6. The results of the observations for each of the twelve land cover classes are illustrated in Figure 4.

These results suggest that the on-screen visual classification method produced very good results in interpreting the 2024 RapidEye satellite imagery. A strong indicator of the classification process's reliability is the Kappa accuracy, which reached 85%. The Kappa statistic is a measure that compares observed accuracy with the accuracy expected by random chance. A Kappa value of 85% indicates a significant improvement over random classification, demonstrating a very strong agreement between the classified data and the reference data. The Kappa value affirms the validity of the visual classification technique use in this study.

Additionally, the overall classification accuracy reached 87%, further supporting the reliability of the image interpretation. Overall accuracy is calculated by dividing the number of correctly classified pixels by the total number of pixels. An 87% accuracy rate indicates that the vast majority of pixels were correctly classified an excellent outcome for land cover analysis. Such a high level of accuracy is essential for ensuring that land cover and vegetation assessments are credible and capable of supporting further analysis and decision-making. According to National Aviation and Space Agency (2015), minimum acceptable accuracy for image interpretation is 75%. This standard ensures that the interpretations results are dependable for practical use. In this study, both Kappa accuracy significantly easily exceeds this threshold, indicating that the classification results are not only acceptable but exceptionally reliable. The degree of accuracy is essential for making informed decisions about land cover and vegetation management within the Krueng Langsa Watershed.

Discussion

Accuracy and reliability of classification

The results of this analysis were satisfactory in many respects and carry important implications for the management of the Krueng Langsa Watershed. The high accuracy of land cover classification also provides a reliable basis for tracking changes in the watershed over time. Detecting trends such as deforestation, urbanization, and changes in vegetation health is critical for ensuring the sustainability of the watershed. Accurate and up-to-date information enables stakeholders to make informed decisions regarding conservation and management strategies.

The Vegetation Cover Percentage (VCP) of 64.59% indicates that the Krueng Langsa Watershed (DAS) still maintains a relatively high level of permanent vegetation, particularly in the upstream forest areas (Table 7). However, the increasing dominance of plantations and agricultural land suggests an ongoing shift in land-use patterns, which could accelerate fragmentation and reduce ecological stability. This trend is consistent with findings in other river basins in Indonesia, where agricultural expansion and settlement growth are the main factors causing forest loss and river basin degradation (Fitmawati et al. 2022).

Table 5. Area of the Krueng Langsa Watershed in Aceh Province, Indonesia based on land cover classes using the visual on-screen classification method in 2024

Land cover classes	Area	
	Ha	%
Vegetation cover		
Primary dryland forest	411.48	0.83
Secondary dryland forest	5,822.95	11.71
Primary mangrove forest	1,931.24	3.88
Secondary mangrove forest	4,294.66	8.64
Plantations	19,289,18	38,80
Shrubs	359.18	0.73
Sub total	32,108.69	64.59
Non vegetation cover		
Settlements	2,784.16	5.60
Mixed dryland agriculture	1,417.67	2.85
Rice fields	3,585.01	7.21
Open land	638.47	1.28
Fish ponds	6,952.91	14.00
Water bodies	2,225.13	4.48
Sub total	17,603.35	35.41
Total	49,712.04	100

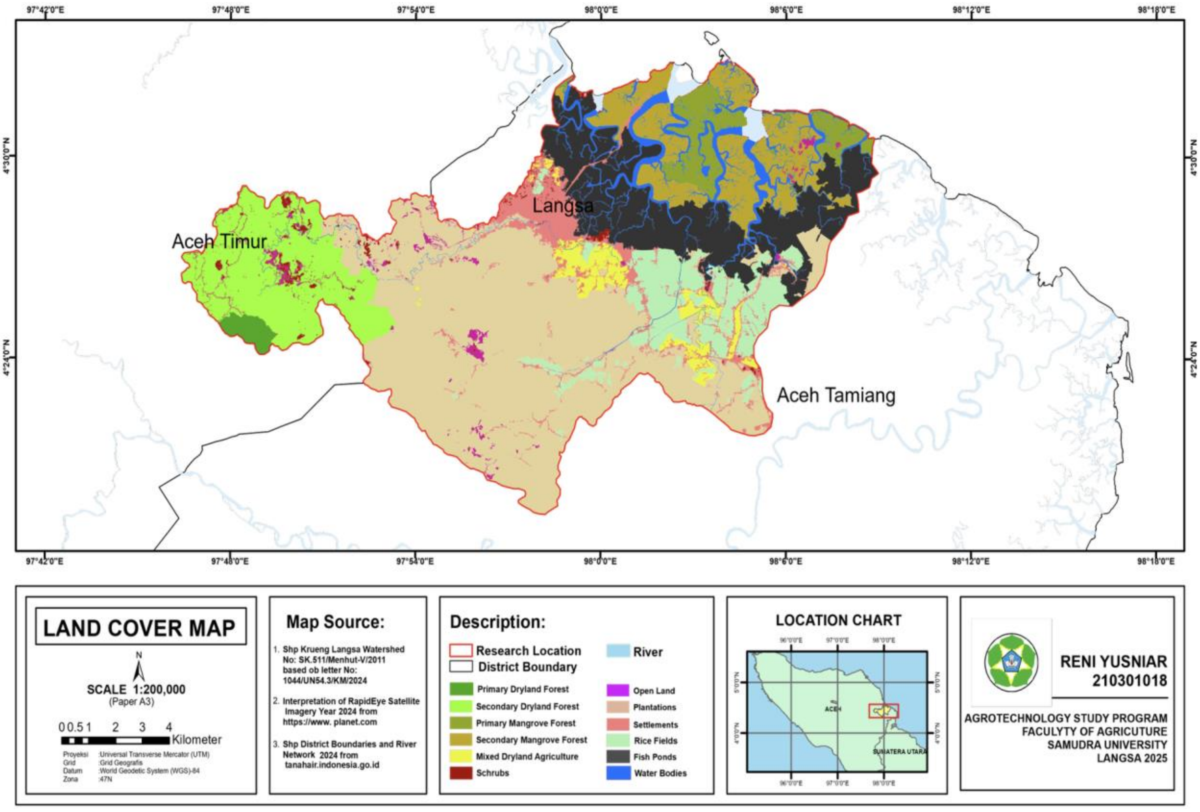

Figure 3. The 2024 land cover map of the Krueng Langsa Watershed in Aceh Province, Indonesia from the 2024 RapidEye satellite image using the on-screen visual classification method

Table 6. Confusion matrix of land cover sample points

Classification research	**Survey**												**Rows total**	**User accuracy**
	HP	**HS**	**HMP**	**HMS**	**T**	**PK**	**PM**	**PC**	**SW**	**B**	**TM**	**A**		
HP	1												1	100%
HS		18				10		3					31	58%
HMP			5										5	100%
HMS				10									10	100%
T					2								2	100%
PK						16							16	100%
PM							7						7	100%
PC					1			5					6	83%
SW									9				9	100%
B										1			1	100%
TM											16		16	100%
A												5	5	100%
Clumn Total	1	18	5	10	3	26	7	8	9	1	16	5	**109**	
Producer (%)	100	100	100	100	67	62	100	63	100	100	100	100		
Overall Accuracy (%)			87											
Kappa Accuracy (%)			85											

Note: ▨ : Number of points corresponding to the field check, HP: Primary Dryland Forest, HS: Secondary Dryland Forest, HMP: Primary Mangrove Forest, HMS: Secondary Mangrove Forest, T: Open Land, PK: Plantations, PM: Settlements, PC: Mixed Dryland Agriculture, SW: Rice Fields, B: Shrubs, TM: Fish Ponds, A: Water Bodies

Table 7. Vegetation Cover Percentage (VCP) in the Krueng Langsa Watershed in Aceh Province, Indonesia

Permanent of vegetation cover	**Area of vegetation permanent (Ha)**	**Area of watershed (Ha)**	**Mark VCP (%)**	**Class**
Primary dryland forest	411.48	49,712.04	64.59	Good
Secondary dryland forest	5,822.95			
Primary mangrove forest	1,931.24			
Secondary mangrove forest	4,294.66			
Plantations	19,289.18			
Shrubs	359.18			
Total	32,108.69			

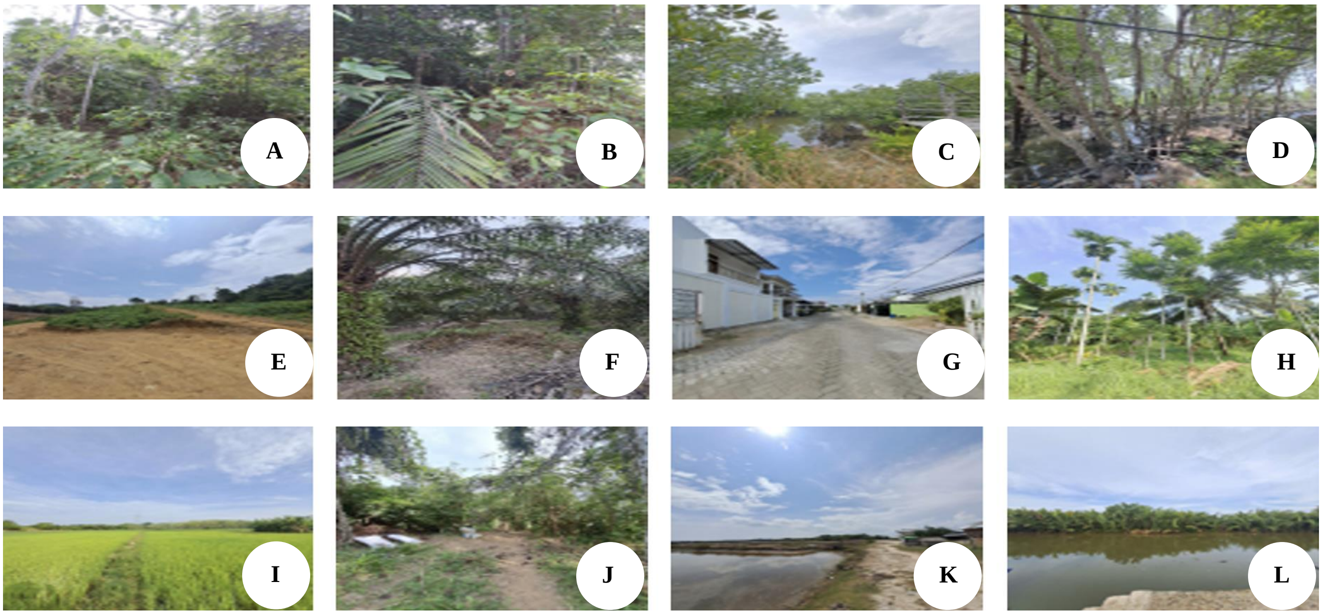

Figure 4. The result of the observations for each of the twelve land cover classes. A: Primary Dryland Forest (HP), B: Secondary Dryland Forest (HS), C: Primary Mangrove Forest (HMP), D: Secondary Mangrove Forest (HMS), E: Open Land (T), F: Plantations, G: Settlements (PM), H: Mixed Dryland Agriculture (PC), I: Rice Fields (SW), J: Shrubs (B), K: Fish Ponds (TM), L: Water Bodies (A)

The impact of human activities on the watershed can be effectively assessed using reliable classification results. By capturing land cover data over different periods of time, it becomes possible to identify areas affected by human activities such as agricultural expansion or urban encroachment into natural habitats. These data help pinpoint areas at risk and contrast them with those that may benefit from improved land use practices.

Moreover, the high accuracy of image interpretation at once increases trustworthiness and credibility of the study and its findings. Gaining the trust and support of stakeholders, including local communities, government agencies, and conservation organizations, is vital. Reliable data not only support the justification for necessary conservation actions but also help in securing funding and resources for watershed management initiatives. Finally, the Kappa accuracy of 85% and overall accuracy of 87% demonstrate the effectiveness of the 2024 RapidEye satellite images interpretation using the on-screen visual classification method. These results also exceed the minimum accuracy threshold set by the National Aviation and Space Agency (2015), underscoring the reliability of the analysis. The high accuracy levels provide a dependable baseline dataset for ongoing monitoring and watershed management activities, providing a solid foundation for data-driven decision-making.

Land use change and driving factors

According to Table 5, the most dominant land cover class was plantations (38.80%), mainly oil palm and rubber. According to Mawardati et al. (2022), the rapid expansion of oil palm plantations in Aceh has significantly altered land use, contributing to deforestation and biodiversity loss. This transformation reduces the land's capacity to absorb water and accelerates sedimentation, particularly in high rainfall areas like Krueng Langsa. Permanent vegetation, such as forests, plantations, and shrubs, plays a crucial role in maintaining the hydrological balance. In the Krueng Langsa Watershed, forested areas located in the upstream region are essential for reducing surface runoff, preventing erosion, and stabilizing soil. Supangat et al. (2021) emphasized that upstream watersheds with steep topography require dominant perennial vegetation to sustain ecological functions. Distinguishing between primary and secondary dryland forests can be challenging, particularly in mountainous terrain with varying elevations. A key difference is that secondary forests exhibit signs of logging activity, such as visible patches or tracks (Noviar and Kartika 2017). The conversion of forest areas into plantations, agricultural land, or other uses has made the watershed susceptible to various issues, such as flooding, erosion, drought during dry seasons, and overall degradation of environmental quality. Achmad et al. (2022) emphasizes that managing the watershed as a single, integrated unit promotes a more logical and objective understanding that any activities conducted in the upstream watershed impact downstream conditions, and vice versa.

Based on the field survey results, primary mangrove forests are located far from residential areas and form a regular pattern on each side of the estuary meeting the sea. In addition to serving as a barrier against sea water abrasion, these primary mangrove ecosystems also provide critical habitats for fish. This is consistent with Getzner and Islam (2020), who stated that mangrove forests and aquatic environments are inherently interconnected, forming an ecosystem community with numerous irreplaceable benefits. Modern mangrove ecosystems have also started to function as recreational areas. For example, the Kuala Langsa mangrove forest nature tourism is a protected forest that has been developed into a tourist destination, supervised jointly by the government and the surrounding community. Agroforestry systems have been proposed as a sustainable management alternative, offering significant biodiversity potential. However, poor planning can negatively impact surrounding ecosystems, including coastal ecologies that support the region's tourism sector (Natsir et al. 2022). For environmental protection and biodiversity conservation, trees are essential. To achieve self-sufficiency and sustainability, agroforestry is considered the backbone of marginal agriculture, as emphasized by Subedi et al. (2022), and contributes not only to environmental security but also to food security. It provides benefits to tribal and rural communities by offering diversified income sources, helping to alleviate poverty. Proper land use planning, based on the capacity of the landscape to support both trees and crops, is crucial, and lawmakers must consider this information when developing future policies to ensure long-term sustainability.

Ecological implications

Human activities have significantly altered the natural landscape, leaving most vegetation in a state of secondary succession, a transitional phase in ecological recovery following disturbances like logging and land conversion. In many parts of Indonesia, these ecosystems have not yet reached a climax condition, the final stage of ecological succession characterized by a stable and self-sustaining ecosystem (Setyawan et al. 2008). These dynamic ecosystems require ongoing monitoring and research. Remote sensing technologies such as satellite imaging can be used to obtain key information on land cover and land cover change, vegetation health and other environmental parameters. Such data can guide evidence-based decision-making for ecosystem protection and recovery of these ecosystems. The Central Java vegetation has been significantly disturbed by human activities, leaving room for recovery. While Central Java's vegetation has been heavily disturbed, the resilience of young plants, including mangroves, offers hope, provided that efforts in sustainable land management, conservation, and community involvement continue. The challenge lies in balancing regional development with ecological preservation to ensure a sustainable future.

Field survey findings indicate that a large portion of open land results from logging of secondary dryland forest, moving old plantation crops to new plants, or turning the forests into plantations. Globally, plantation expansion, particularly of oil palm in Southeast Asia, is rapidly replacing natural forests to meet growing food and oil demands (Wang et al. 2021). This transition has reduced the land's capacity to absorb water, resulting in greater surface runoff, sedimentation, and flooding due to the erosion of exposed soil. In the Krueng Langsa Watershed, high rainfall intensifies this process, transporting sediment downstream and contributing to river silting and estuary sedimentation. The field survey revealed two primary types of plantation crops: oil palm and rubber. Tarigan et al. (2018) recommends establishing a minimum forest cover percentage to maintain an adequate amount of ecosystem services, particularly as plantations of *Elaeis guineensis* (oil palm) and *Hevea brasiliensis* (rubber) continue to expand. Furthermore, palm oil production introduces challenges such as toxic by-products that hinder biogas production and are sensitive to temperature changes.

The central region of Krueng Langsa Watershed experiences severe erosion particularly within plantation areas. This supports Elaloui et al. (2017) finding that the middle and lower reaches of river basins are often the most vulnerable to erosion. Due to close proximity to the river estuary, eroded materials from these areas are quickly deposited into watershed reservoirs. Langsa City, positioned in the central part of the Krueng Langsa Watershed, exhibits settlement patterns that align with the river network. Iswahyudi et al. (2023) observed that the central location of Krueng Langsa within the city, along with Langsa City's rapid development, significantly influences the ecological system of the watershed. This includes extensive residential construction that often neglects environmental considerations. There has been a noticeable shift from agricultural land to residential and urban use in Langsa City. The concentration of settlements is primarily in the central area of Langsa City, which serves as the economic and administrative hub (Urfan et al. 2022).

Field survey results also found that mixed dryland agriculture includes areca nut, cocoa, durian, rice, oil palm, rubber, along with seasonal crops such as chili, eggplant, pineapple, spinach, water spinach, long beans, tubers, and lime. The local community indirectly implements agroforestry practices in the Krueng Langsa Watershed. Diah et al. (2022) stated that traditional mixed farming and green open spaces play an important role in regulating river flow. These agroforestry systems are characterized by an irregular distribution of dominant plants, creating a vegetation structure similar to natural forests. Based on field survey results, rice fields are located in the downstream part of the Krueng Langsa Watershed, which is a cultivation area. Rice field land cover is associated with irrigation networks and found at lower topography compared to the upstream and middle parts. Urfan and Ningrum (2022) stated that the cultivation areas in the Krueng Langsa Watershed have a high potential for river siltation. This is because the cultivation areas in the downstream region have flat and homogeneous land morphology, causing the river flow speed to decrease.

The land cover classified as shrubs consists of low vegetation on dry land that dominates the overall appearance of the area. Based on field survey results, shrubs are associated with forests, rivers, open land, and agricultural land, functioning as a transition zone between land cover classes. Shrubs support high biodiversity in both flora and fauna, including annual weed class of Senggani (*Melastoma malabathricum*) and wire fern (*Dicranopteris linearis*). This is consistent with Fitmawati et al. (2022), who stated that bamboo plants can adapt well to various habitat conditions, making them highly recommended for use in watershed conservation and rehabilitation. As Liu et al. (2023) pointed out, shrub vegetation also contributes to water infiltration. Our results of 0.72% shrubs support this finding, although the area is still relatively small.

Based on field survey results, fishponds in the Krueng Langsa Watershed are located with water networks, allowing them to easily access water directly or through channels. Fishponds in the Aceh Tamiang District and Langsa City generally cultivate grouper, crabs, and shrimp. However, the decline of mangrove-associated plants, such as the casuarina tree, is notable. Mangrove-associated plants are those that can adapt and adjust to extreme ecological changes, particularly high salinity in coastal areas. In many areas, mangrove clusters have been converted into shrimp farms, even though mangroves serve as windbreaks. Shrimp farming has become one major causes of significant mangrove forest deforestation worldwide. Historical data indicate that 35% of mangrove cover has been lost, with over 50% of that loss attributed to conversion for aquaculture (Afsholnissa et al. 2019). This aligns with Samad et al. (2023) noted that the soil and water quality in both regions are generally favorable to aquaculture development.

The middle and lower part of the Krueng Langsa Watershed face increasing siltation due to sedimentation and erosion, a problem visible in satellite imagery as brown-colored river flow. Additionally, field surveys revealed that some communities are building residential areas directly on the riverbanks. This observation is supported by Urfan and Ningrum (2022) who reported that the buffer zone of the Krueng Langsa Watershed in its middle section has a river width of 17 meters and an uneven depth resulting from variations in flow velocity, sedimentation, and erosion processes. The cultivation areas in the lower part of the Krueng Langsa Watershed have a high potential for river siltation, as sediment deposition tends to increase over time, reducing the river’s capacity to hold high-intensity rainwater, especially during the rainy season, leading to natural disasters such as flooding in the lower watershed.

According to Table 7, out of the total area of the Krueng Langsa Watershed, 32,108.69 hectares or 64.59% is covered by annual crops or permanent vegetation such as forests, shrubs, and plantations. This permanent vegetation plays a crucial role in maintaining the ecological balance, particularly in water retention, soil stabilization, and providing habitats for various species. Forests and shrubs also, acts as a-carbon sinks, helping to combat the impacts of climate change by absorbing carbon dioxide from the atmosphere.

Management and policy implications

This assessment of the Vegetation Cover Percentage (VCP) was based on the 2024 land cover data, serving as a key metric ecosystem service, such as erosion reduction, water quality maintenance, and biodiversity conservation. This analysis was conducted in accordance with Ministerial Regulation Number 61 of 2014 regarding Watershed Management Monitoring and Evaluation. In this regard, the regulation provides a standardized basis for assessing watershed sustainability through scientifically sound methods. It ensures consistency and comparability in measuring land cover, water quality, vegetation health, and the impact of human activities. The procedures and criteria for assessing the health and sustainability of watersheds are specified in the specific in Ministerial Regulation Number 61 of 2014. This includes determining factors such as water quality, land cover, and the health of vegetation and of human activities. It stresses that the accumulated findings should be based on the use of scientifically sound methods and comparable data collection techniques.

In the Krueng Langsa Watershed, satellite imagery interpretation classified several land cover classes, including primary and secondary dryland forests, mangroves, open land, plantations, and shrubs. Guided by regulatory standards, the analysis successfully identified and quantified this land cover classes, allowing for accurate monitoring and change detection. The regulation emphasizes not only the current condition but also long-term sustainability of the watershed by evaluating the effectiveness of conservation and restoration efforts. When following this regulation, the analysis can help furnish the information concerning the level at which different kinds of conservation and restoration efforts are effective. This is particularly important in the Krueng Langsa Watershed wherein human activities, including deforestation, agriculture and urbanization can destroy the environment rapidly.

This standardization further enhances the credibility of the analysis given the nature of the regulation. This also makes the results both reliable and comparable to other studies that were conducted under the same framework. It is critical to this comparability in decision making at any watershed management scale, local or national. The regulation acts as a consistent basis for the evaluation of management practices and helps ensure that they are based on sound scientific evidence, and monitorable and adjustable as necessary. Furthermore, it emphasizes how stakeholders can play a vital role in the process of monitoring and evaluation, including engaging getting local communities, government agencies and any other relevant parties involved in assessment and decision-making processes. The regulation that supports collaboration and transparency promotes development of trust and support for watershed management activities. This approach ensures that management strategies are not only technically sound but also socially acceptable and sustainable.

In summary, the analysis of Krueng Langsa Watershed is framed within Ministerial Regulation Number 61 of 2014 which provides a solid foundation for evaluating watershed health and sustainability evaluation. These guidelines ensure the use of standardized and reliable methodologies enabling credible findings to support informed decision-makings. The regulation is essential for enhancing watershed management practices that are sustainable and ensuring the proper conservation and use of natural resources for both present and future generations.

The Land Cover class interpretation through the on-screen visual classification technique in the Krueng Langsa Watershed has been analyzed with utilization of some classes in the permanent vegetation. They include primary dryland forest, secondary dryland forest, primary mangrove forest, secondary mangrove forest, plantations and shrubs. Each of these classes contributes uniquely to the ecosystem by, enhancing biodiversity, promoting carbon sequestration and supporting overall watershed health. Primary dryland forests, for example are home to many of the endemic species, and act as natural buffer against climate change. Meanwhile, mangrove forests are critical for protecting coastal areas from erosion and serve as essential habitats for marine life.

Table 7 presents the calculated Vegetation Cover Percentage (VCP) for the Krueng Langsa Watershed. Permanent vegetation covers 64.59% of the total watershed area, serving as a key indicator of the watershed's ecological health. This proportion reflects the extent to which the existing vegetation performs vital ecological functions such as reducing erosion, maintaining water quality, and providing habitat for various flora and fauna. In addition, Table 7 shows that the VCP in 2024 was 64.59%, which classifies the condition of the Krueng Langsa Watershed as "good". Thise high percentage indicates a significant portion of the watershed is covered by vegetation, which is essential for maintaining an ecosystem healthy, minimizing erosion and protecting biodiversity. Besides, there is adequate vegetation cover to filter pollutants and diminish the surface runoff. Overall vegetation cover plays a crucial role in stabilizing the soil, preventing sedimentation in nearby water bodies, supporting the hydrological cycle, and delivering essential ecosystem services.

The results showed that the VCP in the Krueng Langsa Watershed in 2024 reached 64.59%, based on the permanent vegetation area of 32,108.68 ha out of a total watershed area of 49,712.04 ha. This indicates a "good" classification according to the official regulation. The remaining 35.41% consists of non-vegetated land such as open areas, settlements, ponds, and water bodies (Table 5). The results of this study provided important implications for the management of the Krueng Langsa Watershed, particularly in land conservation and rehabilitation strategies aimed at preventing erosion and maintaining water quality. The utilization of satellite imagery in VCP evaluation has been an effective and accurate method, offering a solid basis for planning land degradation mitigation efforts. Further studies are needed to monitor VCP changes over time to support more sustainable watershed management policies.

In conclusion, the Krueng Langsa Watershed currently has a good level of vegetation cover, with a VCP of

64.59% based on permanent vegetation classes. This condition highlights the crucial role of vegetation in maintaining the function of watersheds, particularly in reducing erosion, stabilizing soil, and maintaining water quality. However, the dominance of plantation land cover reflects a shift in land use that could accelerate fragmentation and reduce ecological resilience if not managed properly. These findings underscore the importance of sustainable land-use planning and conservation measures. Preserving upstream forests, conserving mangroves in coastal zones, and promoting agroforestry practices are essential strategies for protecting biodiversity and hydrological stability. Preventing further conversion of forests into plantations or settlements is also necessary to avoid long-term degradation of the watershed. The use of RapidEye imagery has proven effective for accurate land cover classification and serves as a reliable basis for vegetation cover monitoring. Future research should integrate multi-year high-resolution satellite data with hydrological and ecological assessments to detect temporal changes and better understand the factors driving land degradation. This approach will support evidence-based and adaptive watershed management strategies that balance integrity

ACKNOWLEDGEMENTS

The author sincere extends gratitude and appreciation to the Dean of the Faculty of Agriculture, Universitas Samudra, Indonesia, for who has supported the research article through the Merdeka Learning Campus Merdeka Research activities in 2024. This article has also benefited from valuable guidance and technical support from colleagues from the Remote Sensing and Cartography Laboratory, Faculty of Agriculture, Universitas Syiah Kuala, Indonesia. Special thanks are extended to the Forest Management Unit Region III Aceh, Indonesia, for their assistance and guidance during field data collection. The author also acknowledges the contributions of journal editors, reviewers, research teams, and partners from Universitas Andalas, Indonesia, for their support in the publication of this article.

REFERENCES

Achmad E, Fazriyas, Irawan B, Kusuma AK. 2022. Forest cover changes analysis using Landsat Imageries over Pengabuan Watershed in Jambi Province. IOP Conf Ser Earth Environ Sci 1095 (1): 01202. DOI: 10.1088/1755-1315/1095/1/01202.

Afsholnissa S, Hernawan E, Lastini T. 2019. Land cover change and land use suitability analyses of coastal area in Bantul District, Yogyakarta, Indonesia. Biodiversitas 20 (5): 1475-1481. DOI: 10.13057/biodiv/d200541.

Asdak C. 2022. Hydrology and Watershed Management. Universitas Gadjah Mada, Yogyakarta.

Diah YI, Purba JH, Sasmita N, Komara LL, Olviana T, Kartika IM. 2022. Balinese traditional agroforestry as base of watershed conservation. J Appl Agric Sci Technol 6 (1): 49-60. DOI: 10.55043/jaast.v6i1.54.

Directorate General of Water Resources. 2024. Government Regulation of the Republic of Indonesia Number 37 of 2012 on Watershed Management. https://sda.pu.go.id/assets/files/PP%2037%20Tahun%202012%20ttg%20Pengelolaan%20DAS.pdf. [Indonesian]

Elaloui A, Marrakchi C, Fekri A, Maimouni S, Aradi M. 2017. USLE-based assessment of soil erosion by water in the watershed upstream Tessaoute (Central High Atlas, Morocco). Model Earth Sys Environ 3 (1): 873-885. DOI: 10.1007/s40808-017-0340-x.

Estok M, Nevitte N, Cowan G. 2002. The Quick Count and Election Observation: An NDI Handbook for Civic Organizations and Political Parties. National Democratic Institute for International Affairs, USA.

Fitmawati, Pranata S, Juliantari E, Yahya VJ, Aldafi A. 2022. Bamboo spreading impacts as a watershed conservation strategy in upstream areas of three big rivers of Sumatra. J Bamboo Rattan 21 (3): 125-137. DOI: 10.55899/09734449/jbr021304.

Getzner M, Islam MS. 2020. Ecosystem services of mangrove forests: Results of a meta-analysis of economic values. Intl J Environ Res Public Health 17 (16): 5830. DOI: 10.3390/ijerph17165830.

Hastoro MDA, Yudinugroho M. 2023. Land cover classification analysis using Sentinel 1A imagery with polarimetric decomposition method in Yogyakarta Province. J Geomat Sci 3 (2): 58-67. DOI: 10.31315/imagi.v3i2.10778.

Iswahyudi, Rosmaiti, Fitriyani, Fauzia A. 2023. Analysis of the carrying capacity of the Krueng Langsa River Basin based on water management criteria. IOP Conf Ser Earth Environ Sci 1182 (1): 1-11. DOI: 10.1088/1755-1315/1182/1/012043.

Johnson BA, Jozdani SE. 2018. Identifying generalizable image segmentation parameters for urban land cover mapping through meta-analysis and regression tree modeling. Remote Sens 10 (1): 73. DOI: 10.3390/rs10010073.

Liu J, Chen W, Fang W, Zhang B. 2023. Sub-shrub components change the soil water storage response to daily precipitation and air temperature in the Loess Plateau. Water 15 (23): 4157. DOI: 10.3390/w15234157.

Mawardati M, Dewi R, Khalsiah K, Afriliia Y, Ramadhan G, Munanda A. 2022. The role of women in increasing oil palm production in Aceh Province. Proceeding of 3rd Malikussaleh International Conference on Multidisciplinary Studies (MICOMS). Aceh, 31 November 2022. DOI: 10.29103/micoms.v3i.44.

Ministry of Environment and Forestry. 2014. Minister of Forestry Regulation No. P.61/Menhut-II/2014 on Watershed Management Monitoring and Evaluation. https://jdih.menlhk.go.id/new2/home/portfolioDetails/61/2014/5. [Indonesian]

Ministry of Environment and Forestry. 2020. Technical Guidelines for Interpreting Medium-Resolution Satellite Imagery for Updating National Land Cover Data. Directorate of Forest Resources Inventory and Monitoring. Directorate General of Forestry Planning and Environmental Management. https://sigap.menlhk.go.id › sigap-trial › files › download. [Indonesian]

Muntazar J, Ramli I. 2021. Erosion and sedimentation analysis due to land use changes in the Krueng Pase watershed. IOP Conf Ser Earth Environ Sci 922 (1): 012040. DOI: 10.1088/1755-1315/922/1/012040.

National Aviation and Space Agency. 2015. Digital Multispectral Satellite Data Processing Guidelines for Supervised Classification. National Institute of Aeronautics and Space Utilization Center, Indonesia. [Indonesian]

Natsir M, Ulya Z, Fitriani R. 2022. Mangrove forest utilization policies reconceptualized with a view to improving the regional economy in Aceh Tamiang District, Indonesia. Biodiversitas 23 (12): 6570-6578. DOI: 10.13057/biodiv/d231256.

Noviar H, Kartika T. 2017. Identification and classification of forest types using landsat 8 data in Karo, Dairi, and Samosir Districts, North Sumatra. Intl J Remote Sens Earth Sci 13 (2): 139-150. DOI: 10.30536/j.ijreses.2016.v13.a2477.

Planet Team. 2024. Planet Imagery Product Specifications. Https://www.planet.com. Accessed on March 10, 2024.

Pramanta R F, Moulana R, Rusdi M. 2020. On-screen visual classification of satellite imagery for pine mapping in Blangjerango District. JIMFP 5 (1): 615-622. DOI: 10.17969/jimfp.v5i1.13726.

Samad APA, Junita, Baihaqi B. 2023. Is it possible to use idle shrimp ponds for grouper farming? (A case study for Langsa and Aceh Tamiang). IOP Conf Ser Earth Environ Sci 1221 (1): 1-6. DOI: 10.1088/1755-1315/1221/1/012005.

Setyawan AD, Winarno K, Indrowuryatno, Wiryanto, Susilowati A. 2008. Mangrove plants in coastal area of Central Java: 3. Horizontal and vertical diagram of vegetation profile. Biodiversitas 9 (4): 315-321. DOI: 10.13057/biodiv/d090416.

Sharma R, Rimal B, Baral H, Nehren U, Paudyal K, Kandel P. 2019. Impact of land cover change on ecosystem services in a tropical forested landscape. Resources 8 (1): 1-13. DOI: 10.3390/resources8010018.

Singh WR, Barman S, Tirkey G. 2021. Morphometric analysis and watershed prioritization in relation to soil erosion in Dudhnai Watershed. Appl Water Sci 11 (9): 1-12. DOI: 10.1007/s13201-021-01483-5.

Subedi PB, Mahara S, Paudel S, Bhandari J, Thagunn RS. 2022. Agroforestry potential of Kanchanpur District, Nepal using remote sensing and geographic information system. Asian J For 6 (2): 65-74. DOI: 10.13057/asianjfor/r060202.

Supangat AB, Agus C, Wahyuningrum N, Indrawati DR, Purwanto. 2021. Soil and water conservation planning toward sustainable management of upstream watershed in Indonesia. Sustain Nat Resour Manag Land Plan 914 (1): 77-91. DOI: 10.1007/978-3-030-76624-5_6.

Tarigan S, Wiegand K, Slamet B. 2018. Minimum forest cover required for sustainable water flow regulation of a watershed: A case study in Jambi Province, Indonesia. Hydrol Earth Syst Sci 22 (1): 581-594. DOI: 10.5194/hess-22-581-2018.

Tong XY, Xia GS, Zhu XX. 2023. Enabling country-scale land cover mapping with meter-resolution satellite imagery. ISPRS J Photogram Remote Sens 196 (1): 178-196. DOI: 10.1016/j.isprsjprs.2022.12.011.

Urfan F, Ningrum AS. 2022. Conservation zone delimitation based on physical properties in Langsa Watershed, Aceh Province. Geosfera Indonesia 7 (2): 180-193. DOI: 10.19184/geosi.v7i2.31624.

Urfan F, Sihotang Z, Arrasyid R. 2022. Analysis of land use change in Langsa City, Aceh Province in 2013-2021. Jurnal Pendidikan Ilmu Sosial 31 (2): 213-226. DOI: 10.17509/jpis.v31i2.52971.

Wang Y, Chen L, Xiang W, Ouyang S, Zhang T, Zhang X, Zeng Y, Hu Y, Luo G, Kuzyakov Y. 2021. Forest conversion to plantations: A meta-analysis of consequences for soil and microbial properties and functions. Glob Chang Biol 27 (21): 5643-5656. DOI: 10.1111/gcb.15835.

Watershed Management. 2011. Decision of the Minister of Forestry of the Republic of Indonesia Number: SK. 511/Menhut-V/2011 Concerning the Determination of the Watershed Map. Directorate General of Watershed and Social Forestry. https://muspera.menlhk.go.id/Perpus_search/detail/20424. [Indonesian]