Jurnal Belantara Vol. 8, No.1, March (1-18) E-ISSN 2614-3453
DOI: 10.29303/jbl.v8i1.1109 P-ISSN 2614-7238

RELATIONSHIP BETWEEN LAND COVER CHANGES AND THE SURFACE AREA OF LAKE RANAU

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Received: 10/01/2025, Revised: 06/02/2025, Approved: 10/02/2025

ABSTRACT

Ranau Lake is one of Indonesia's 30 national priority lakes facing pressures from climate change and human activities, negatively impacting its water quality and ecosystem. This study aims to analyze land cover changes in the catchment area, measure the changes in the lake's surface area, and examine the relationship between land cover changes and Ranau Lake's surface area from 2016–2022. The data includes Sentinel-1A IW GRDH imagery, ESRI land cover maps, and Google Earth images. The analysis employed Support Vector Machine (SVM) classification, spatial analysis, and linear regression. The results reveal that water bodies, vegetation, and built-up land categories experienced an increase of 36.78 hectares, 33.96 hectares, and 9.1 hectares, respectively, while bare land decreased by 80.03 hectares. Ranau Lake's surface area increased by 28.3 hectares, showing a significant relationship between land cover changes in water bodies (R^2 = 99.88%), bare land (R^2 = 94.92%), vegetation (R^2 = 66.06%), and built-up land (R^2 = 56.85%) and the lake's surface area. These findings highlight the critical role of land cover changes in influencing the dynamics of lake surface area, an essential indicator of ecosystem health. This study emphasizes the importance of sustainable land cover management in supporting Ranau Lake's conservation. Continuous use of SAR-based remote sensing technology is recommended for land cover monitoring, enabling data-driven decision-making in water resource management.

Keywords: *Land Cover Change; Ranau Lake; Support Vector Machine; Water Surface Area*

INTRODUCTION

Lakes are vital resources that serve various strategic functions, including providing clean water, irrigation, hydroelectric power generation, and recreational opportunities. However, the challenges of environmental degradation driven by climate change and human activities have made lake conservation a top priority in water resource management (Ministry of Public Works and Housing, 2020). The Indonesian government, through the Ministerial Decree of the Ministry of Public Works and Housing No. 283/KPTS/M/2020, has designated 30 national priority lakes, including Ranau Lake in South Sumatra, which has experienced significant degradation and requires urgent conservation interventions (Ministry of Public Works and Housing, 2020). One effective approach to support these efforts is remote sensing technology, which provides precise spatial data for monitoring regional conditions and analyzing land cover changes (Puspitaningrum & Murti, 2020). When integrated with geographic information systems (GIS), this technology enables data-driven management strategies to ensure the sustainability of lake ecosystems.

Ranau Lake, located at the border of South Sumatra and Lampung Provinces, is one of Indonesia's largest lakes, and it is currently facing severe environmental challenges. The degradation of its ecosystem is driven by accelerated sedimentation due to heightened soil erosion, land-use changes in the catchment area, and pressures from human activities, such as intensive agriculture, infrastructure development, and deforestation (Haryani et al., 2019; Yulianto et al., 2021). Water pollution from domestic waste and chemical fertilizers used in agricultural activities has further compromised water quality, reducing biodiversity and ecosystem productivity (Fadli et al., 2020).

Global climate change, characterized by extreme rainfall fluctuations, has exacerbated sedimentation rates and disrupted water flow dynamics, aggravating the lake's degradation (Wijaya et al., 2018). To address these challenges, remote sensing technologies, such as Sentinel-1A data, have proven to be effective tools for real-time monitoring of land cover changes and hydrological conditions. Integrating remote sensing with geographic information systems (GIS) facilitates accurate data-driven decision-making, thereby supporting sustainable conservation and restoration efforts for the Ranau Lake ecosystem (Puspitaningrum & Murti, 2020; Medina & Atehortúa, 2019).

Synthetic Aperture Radar (SAR) technology is an effective tool for regional monitoring, particularly in land cover analysis, due to its ability to penetrate clouds and remain unaffected by weather conditions. SAR employs longer microwave wavelengths than optical bands, enabling consistent and accurate data acquisition. One of the most advanced SAR applications is Sentinel-1 imagery, which delivers high-resolution data with rapid acquisition frequencies. This study utilized Sentinel-1A imagery in the Interferometric Wide Swath (IW) Ground Range Doppler High-resolution (GRDH) mode. The IW mode is designed for standard surface observations, making it ideal for interferometric applications (Yulyta, 2018). Meanwhile, the GRDH mode captures ground-range reflections, enabling more detailed land cover analyses. After undergoing classification processes, Sentinel-1A IW GRDH imagery provided highly precise mapping results. The study employed the Support Vector Machine (SVM) classification method, which has been proven superior to the Maximum Likelihood Classification (MLC) method due to its hyperplane capability, which separates objects with higher clarity and accuracy (Ariyantoni & Rokhmana, 2020)..

Land cover changes around lakes can significantly impact environmental conditions and aquatic ecosystems, requiring serious attention in their management. Several studies have contributed valuable insights into the dynamics of land cover changes. For example, Febianti et al. (2023) investigated land cover changes in Semarang City using Landsat 8 imagery from 2016 to 2022 and the Support Vector Machine (SVM) classification method. Their findings revealed substantial land cover changes within a relatively short period. Another study by Jupiardi et al. (2022) examined land use changes in the catchment area of Kerinci Lake using Landsat 5 and Landsat 8 imagery, reporting significant changes with high accuracy levels (78.67% in 2009 and 85.33% in 2019). Similarly, Dede (2021) explored the dynamics of land area and cover around Kerinci Lake using Landsat 7 and 8 imageries for the 2000–2020 period, highlighting notable variations in land cover changes over time. Medina and Atehortúa (2019) provided critical insights into satellite image classification methods, demonstrating that SVM is more effective in distinguishing objects and avoiding classification confusion than other methods such as Maximum Likelihood Classification (MLC) and Decision Tree. Additionally, Umar et al. (2018) analyzed land use changes around Limboto Lake using Landsat imagery from 1991 to 2017, revealing that changes over a 26-year period significantly impacted the lake's conditions. These studies form an essential foundation for understanding land cover changes around Ranau Lake, offering deeper insights into the effects of such changes on lake ecosystems and emphasizing the importance of continuous monitoring.

As one of Indonesia's 30 national priority lakes, Ranau Lake faces significant challenges due to ecosystem degradation caused by land-use changes, sedimentation, and anthropogenic activities. Although several studies have investigated land cover changes in major Indonesian lakes such as Kerinci Lake and Limboto Lake, research specifically examining the relationship between land cover changes in the catchment area and the surface area of Ranau Lake remains limited. This is despite Ranau Lake's strategic role as a source of clean water, hydroelectric power, and a vital ecosystem buffer. In this context, applying remote sensing technology, such as Sentinel-1A with the Support Vector Machine (SVM) classification method, represents an innovative step toward providing high-quality multitemporal data. This study broadens the understanding of land cover dynamics and surface area changes and offers a technology-driven solution to support sustainable conservation and lake management efforts. Thus, this research is critically important to fill knowledge gaps and introduce a novel approach to managing the Ranau Lake ecosystem. The study aims to assess how land cover changes in the Ranau Lake catchment area influence its surface area using multitemporal Sentinel-1A imagery.

METHOD

Research Location and Timeframe

This study was conducted from January to March 2023. The area analyzed includes the catchment area of Lake Ranau, located in West Lampung Regency, Lampung Province, and South Ogan Komering Ulu Regency (OKU Selatan), South Sumatra Province (**Figure 1**).

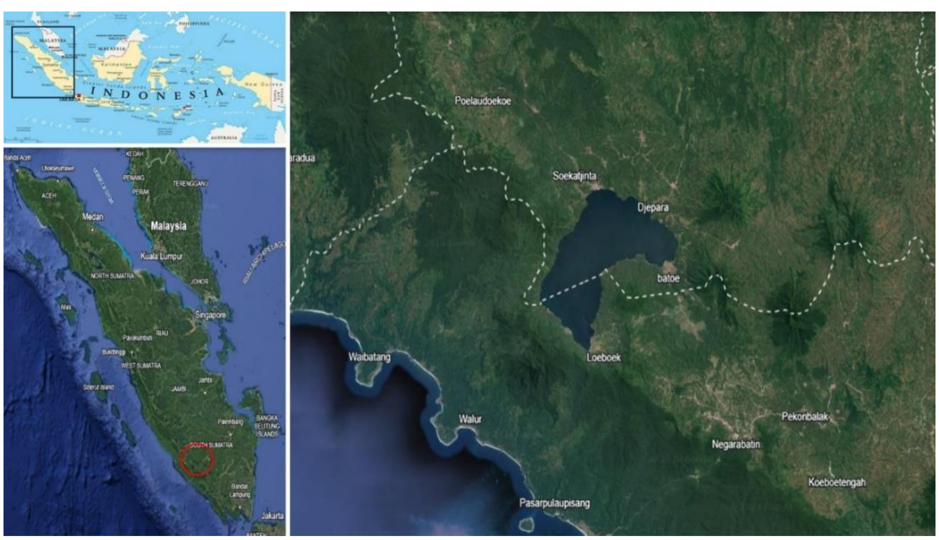

Figure 1. Research Location: West Lampung Regency, Lampung Province, and South Ogan Komering Ulu Regency (*OKU Selatan*), South Sumatra Province

Data and Parameters

The data used in this research consists of Sentinel-1A IW GRDH imagery, which is an Interferometric Wide-swath Ground Range Doppler High-resolution product with a spatial resolution of 10.21 x 9.93 m, C-band frequency (middle frequency: 5.405 GHz), and polarization (VV+VH), with a processed spatial resolution of 5 x 5 m. The Sentinel-1A IW GRDH images were acquired at two-year intervals, specifically in May. The processed imagery was subjected to RGB composition using the Dual Pol Ratio (Gamma) in decibels (dB), where the Red channel corresponds to Gamma_VV_dB, the Green channel to Gamma_VH_dB, and the Blue channel is derived from the ratio of Gamma_VV_dB to Gamma_VH_dB. This RGB composition utilized the VV and VH bands, which were converted into decibels (dB) to enhance amplitude and facilitate interpretation. Additionally, the software tools used in this study include SNAP–S1Tbx (Sentinel-1 Toolbox) for processing the Sentinel-1A IW GRDH images, ENVI for image classification using the Support Vector Machine method, ArcGIS for spatial analysis of land cover and the surface area of Lake Ranau, Google Earth Pro for validation imagery, and Microsoft Office 2019 for attribute data analysis and regression.

Research Implementation

The study employs remote sensing technology and geographic information systems (GIS). The Sentinel-1A IW GRDH imagery data were processed using the SNAP-ESA S1Tbx software. The data used include multitemporal Sentinel-1A images from 2016, 2018, 2020, and 2022, with a two-year interval and consistent acquisition periods. Image classification was performed using the Support Vector Machine algorithm, which has been demonstrated to offer higher accuracy than Maximum Likelihood (Ariyantoni and Rokhmana, 2020). The processed output consists of multitemporal land cover maps for the Lake Ranau Catchment Area, which were subsequently analyzed in relation to the surface area of Lake Ranau.

This research comprises several analytical stages. The first stage, image pre-classification, involves processing the imagery data obtained from ESA Copernicus using the SNAP-S1Tbx software. The image pre-classification process, utilizing the Support Vector Machine method, is conducted through the following steps:

1. Image Cropping

Image cropping is used to perform lighter data processing. Figure 2. a presents the display showing the raw data before the image cropping (subset image), while Figure 2. b shows the Sentinel-1A IW GRDH image after the cropping process (subset image).

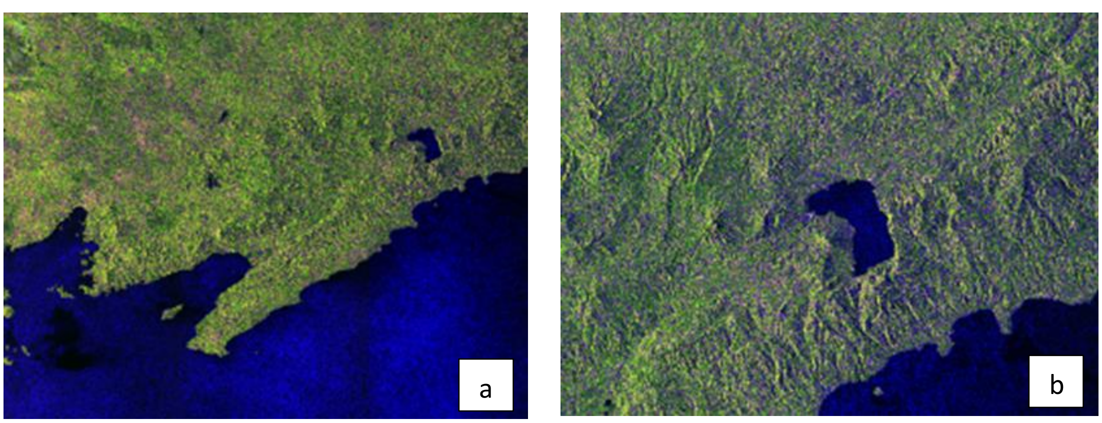

Figure 2. Sentinel-1A IW GRDH image before cropping (a) and after cropping (b).

2. Multilooking

Multilooking is a process aimed at reducing speckles in SAR images by transforming the slant range into the ground range based on speckle reduction values (Moreira, 1990). Before multilooking, the image still exhibits the presence of a speckle (Figure 3.a), while after the multilooking process, the speckle appears reduced (Figure 3.b). The multilooking technique is commonly used for minimizing the speckle effect in SAR imagery.

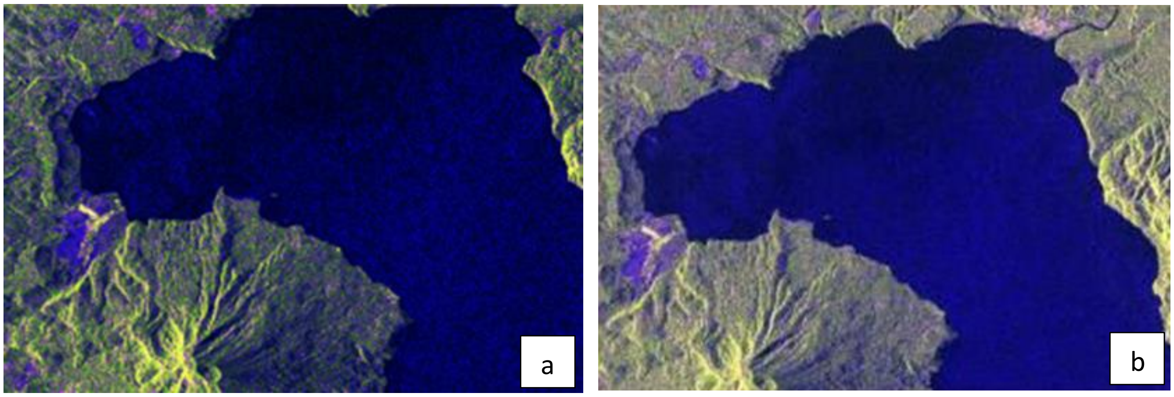

Figure 3. Sentinel-1A IW GRDH image before multilooking (a) and after multilooking (b)

3. Radiometric Calibration

Radiometric calibration of SAR imagery is performed to correct disturbances in the raw data and obtain pixel values that accurately reflect the actual surface conditions. This process uses the radiometric calibration function in SNAP-S1Tbx (Sentinel-1 Toolbox), which yields sigma nought (σ0) values. The Sentinel-1A IW GRDH image before radiometric calibration is shown in Figure 4.a, while the post-calibration result is displayed in Figure 4.b.

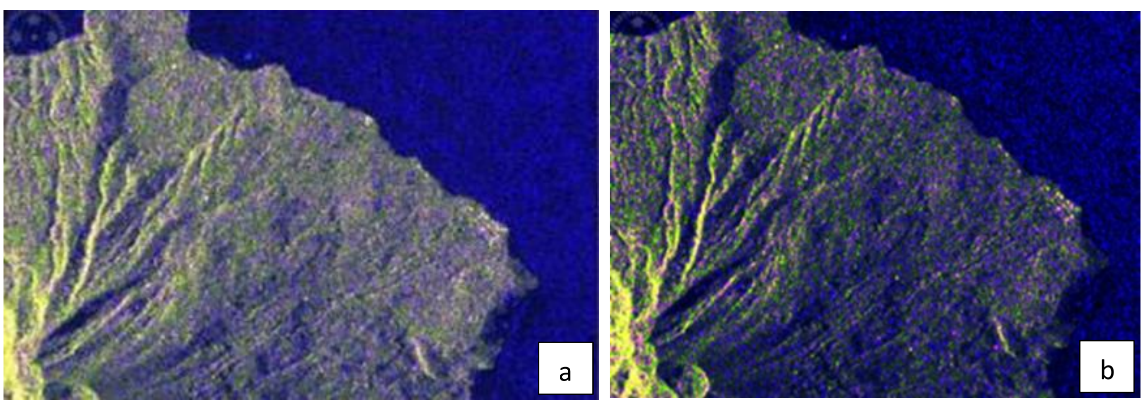

Figure 4. Sentinel-1A IW GRDH image before Radiometric Calibration (a) and after Radiometric Calibration (b).

4. Geometric Correction

Geometric correction is a step to eliminate spatial distortions in SAR images, resulting in an image that accurately represents the actual geographic conditions. This process uses the geometric function in SNAP-S1Tbx (Sentinel-1 Toolbox) with the Range Doppler Terrain Correction method. This method involves DEM data and orbit files, which are automatically obtained by the SNAP-S1Tbx software to correct geometric errors in the image. The Sentinel-1A IW GRDH image before geometric correction is shown in Figure 5.a, while the post-correction result is displayed in Figure 5.b.

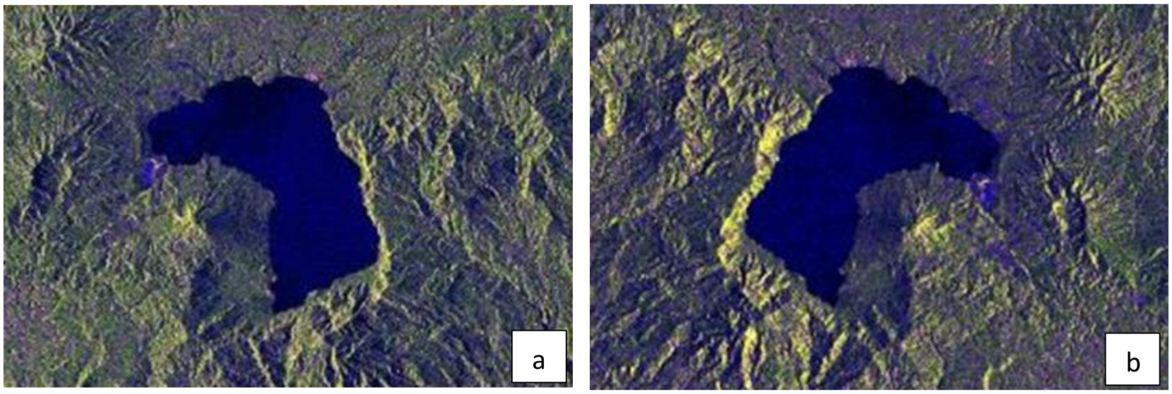

Figure 5. Sentinel-1A IW GRDH image before geometric correction (a) and after geometric correction (b).

5. Speckle Filtering

Speckle filtering was performed using the Gamma Map filter with a pixel window size of 5 x 5. This process aims to reduce speckles in the image before interpretation. The speckle filtering stage allows for the speckle in the image to be effectively filtered and removed (Hatwar, 2015). The Sentinel-1A IW GRDH image before speckle removal is shown in Figure 6.a, while the image after speckle removal is presented in Figure 6.b.

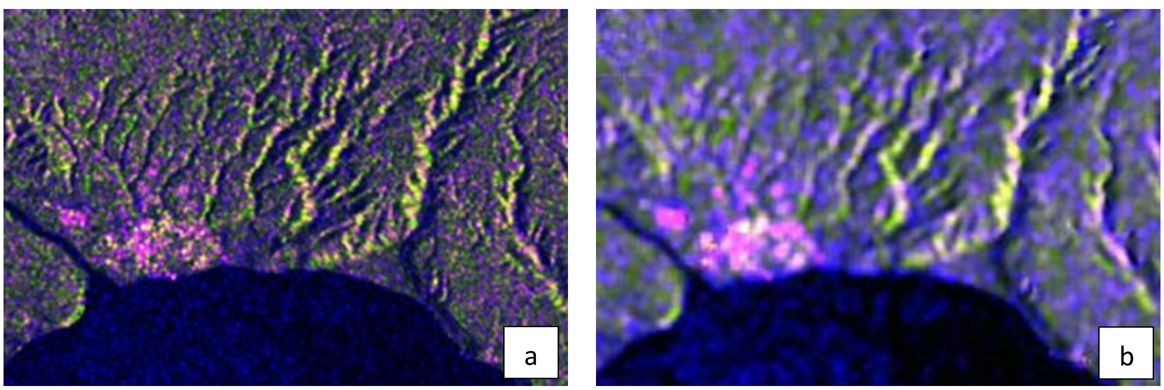

Figure 6. Sentinel-1A IW GRDH image before speckle filtering (a) and after speckle filtering (b).

6. Image Classification

SAR (Synthetic Aperture Radar) image classification is performed to identify and map land cover objects based on recorded pixel appearances. SAR image classification differs from optical imagery because SAR uses microwave waves to form images, while optical images rely on visible light. Therefore, further testing is required to interpret objects in Sentinel-1A imagery. The following image displays pixel appearances representing land cover objects, compared with the ESRI map and images from Google Earth. After classification, bare land is marked in red, vegetation in green, water bodies in blue, and built-up land in yellow (Figure 7).

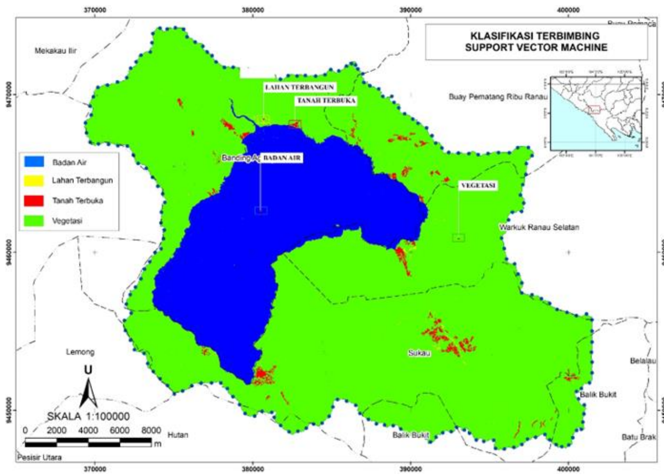

Figure 7. Supervised Classification using Support Vector Machine

7. Accuracy Assessment

The accuracy assessment determines the visual accuracy of the classification results for a specific area. The mapping accuracy is evaluated by creating a confusion matrix, and land cover is considered valid when the Overall Accuracy is ≥ 85% (Ministry of Environment and Forestry et al., 2020). The data used for validation include imagery from Google Earth and the ESRI land cover map. The steps for processing the accuracy test of Sentinel-1A IW GRDH images, along with the Google Earth source imagery and ESRI land cover map, which are considered as ground truth data, are presented in Figure 8.

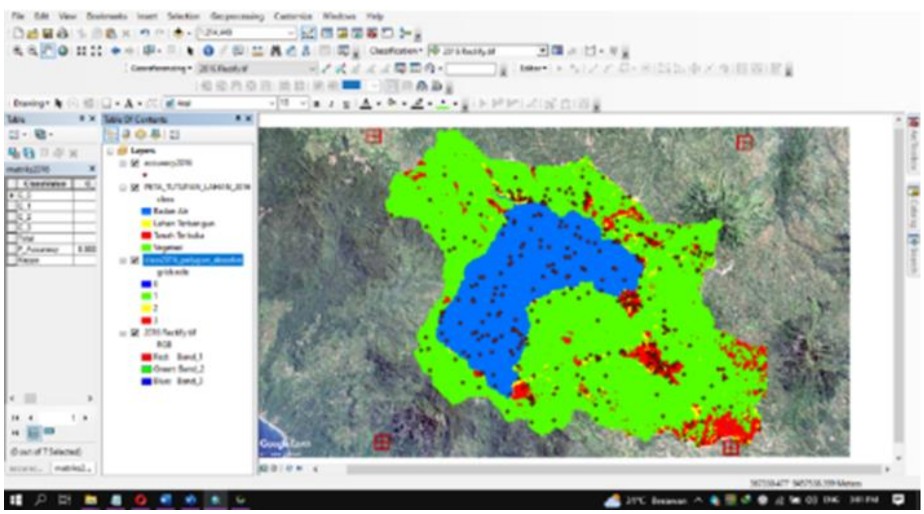

Figure 8. Accuracy Assessment of Sentinel-1A IW GRDH imagery using Google Earth imagery and ESRI land cover map

8. Correlation and Regression Testing

Correlation and linear regression tests were conducted to analyze the relationship between land cover change area and the surface area of Lake Ranau during the period from 2016 to 2022. The data used include land cover change area and surface area of Lake Ranau within this timeframe. The correlation value measures the strength of the relationship between these two variables. Furthermore, multiple linear regression analysis was performed to examine the impact of land cover change area on the surface area of Lake Ranau. This test provides more detailed and accurate information about the relationship between the two variables and other factors influencing the surface area of Lake Ranau.

9. Analysis

At this stage, an analysis was conducted on the Sentinel-1A IW GRDH imagery classification results for the Lake Ranau catchment area during 2016, 2018, 2020, and 2022. This analysis includes correlation and regression tests, which provide data and information regarding the area and changes in land cover. Based on the classification results and the correlation and regression analysis, information was obtained regarding the extent of land cover change, changes in the surface area of Lake Ranau, and the impact of land cover changes on the surface area of Lake Ranau during the 2016-2022 period.

RESULT AND DISCUSSION

1. Land Cover Changes for the Period 2016-2022

Changes in land cover are evident in the Sentinel-1A IW GRDH imagery from 2016 to 2022 based on the interpretation of objects. The land cover classification analysis results using the Support Vector Machine (SVM) method are presented in Figure 9 below.

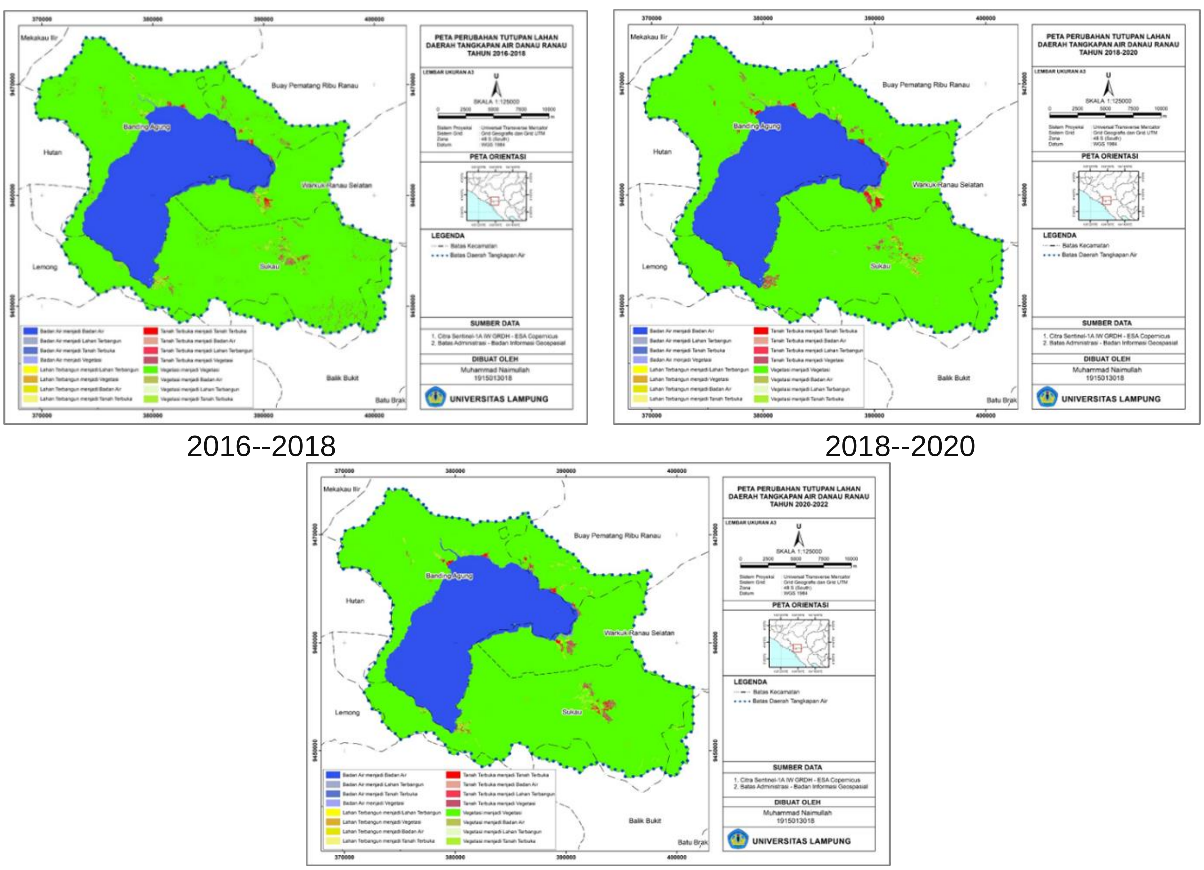

Figure 9. Land cover changes in the Lake Ranau catchment area

The analysis results show changes occurred in each land cover class from 2016 to 2022. The area of water bodies, built-up land, and vegetation generally increased yearly throughout 2016-2022. In contrast, bare land experienced a decline during the same period. Figure 10. presents a complete overview of the land cover area changes for each class and period.

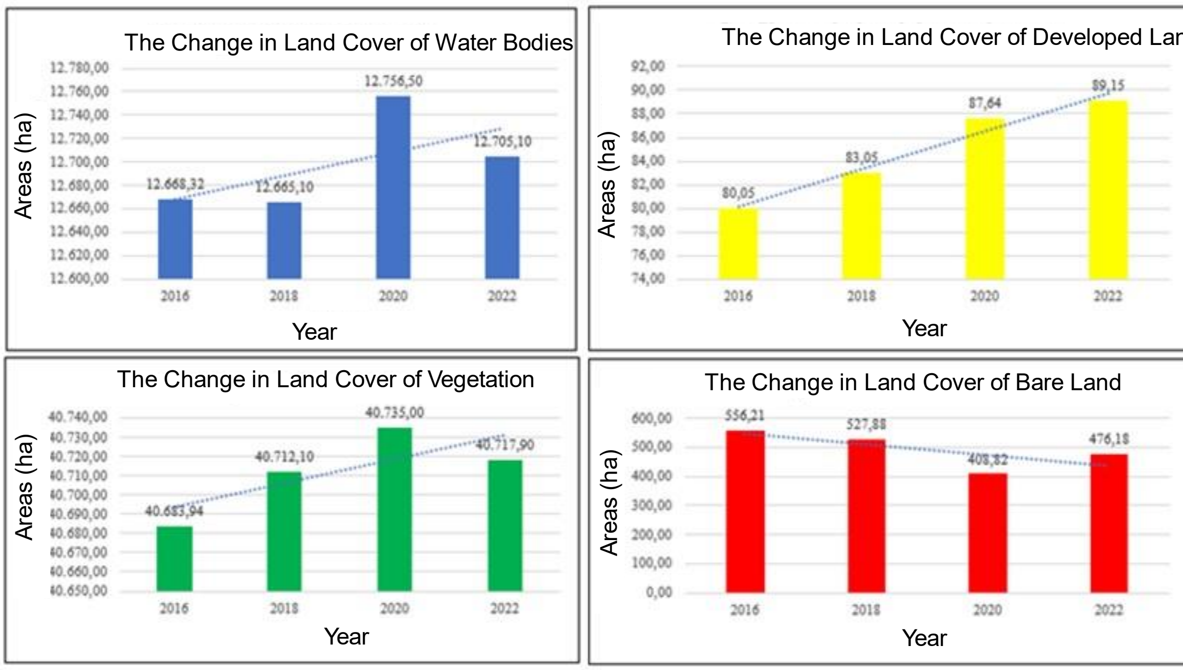

Figure 10. Changes in land cover area for each land cover class during the period from 2016 to 2022

2. Land Cover Change 2016-2018

The land cover change matrix is an effective method for analyzing land use dynamics over time. Table 1. presents the land cover change data for the Catchment Area of Lake Ranau between 2016 and 2018. This analysis includes four main categories of land cover: water bodies, built-up areas, bare land, and vegetation. The data provides a detailed view of the transitions between land cover types during this period, which can be used to evaluate ecosystem changes, human activities, and land management in the area.

Table 1. Land Cover Change Matrix of the Catchment Area of Lake Ranau from 2016 to 2018.

Land Cover 2016	**Land Cover 2018**				
	Water Body	built-up area	Bare Land	Vegetation	Total
Water Body	12.600,60	0,31	11,38	56,04	12.668,33
built-up area	0,09	35,90	1,59	42,45	80,03
Bare Land	1,46	1,34	125,92	427,47	556,19
Vegetation	63	45,47	388,99	40.182,40	40.679,86
Total	12.665,15	83,02	527,88	40.708,36	53.984,41

Source: Primary data (2023)

The land cover change matrix results in the Ranau Lake Catchment Area show significant dynamics between 2016 and 2018. The largest change occurred in the vegetation category, which was converted into 388.99 hectares of bare land and 45.47 hectares of built-up land. This change can be associated with human activities such as land clearing for agriculture, settlement, or infrastructure development (Umar et al., 2018). These activities are often driven by the increasing demand for land due to population growth or local economic pressures (Jupiardi et al., 2022). A significant recovery was observed in the bare land category, with 427.47 hectares changing into vegetation. This reflects efforts in reforestation or natural regeneration in the area. According to Dede (2021), natural regeneration often occurs in previously abandoned areas after temporary land use, such as shifting cultivation. Water bodies also experienced minor changes, with 56.04 hectares converting into vegetation. Due to soil erosion in bare lands, this phenomenon may be caused by sedimentation or vegetation invasion around water bodies, often in watershed areas (Medina & Atehortúa, 2019). The built-up land category saw an increase of 42.45 hectares, previously covered by vegetation. This increase indicates urbanization and development around Ranau Lake, potentially disrupting the long-term ecosystem balance (Febianti et al., 2023).

3. Land Cover Change 2018-2020

To support the analysis of recent land cover changes in the Ranau Lake catchment area, data from 2018 to 2020 were processed. The results of this analysis are presented in the form of a land cover change matrix, which illustrates the dynamics between land cover categories over the two-year period. The distribution of land cover changes, which provides insights into the extent of land conversion and shifts in land use patterns in the study area, is presented in Table 2.

Table 2. Land Cover Change Matrix for the Ranau Lake Catchment Area from 2018 to 2020

Land Cover 2018	**Land Cover 2020**				
	Water Body	built-up area	Bare Land	Vegetation	Total
Water Body	12.609	0,26	9,29	99,00	12.756,55
built-up area	0,34	47,76	0,21	39,62	87,59
Bare Land	18,20	0,13	110,24	293,09	408,82
Vegetation	128,98	40,94	356,44	40.280,70	40.729,78
Total	12.756,52	89,09	476,18	40.712,40	53.982,74

Source: Primary data (2023)

Table 2. shows significant land cover changes over the past two years. The water body land cover class increased by 147.55 hectares, from 12,609 hectares in 2018 to 12,756.55 hectares in 2020. This increase is likely related to the inundation of surrounding areas due to hydrological changes or seasonal variations, often associated with rainfall fluctuations (Arifin et al., 2019). Meanwhile, the built-up land class showed an increase of 7.56 hectares, from 80.03 hectares to 87.59 hectares. This could indicate ongoing development activities, such as expanding settlements or infrastructure, major drivers of land cover conversion in watershed areas (Seto et al., 2012). The bare land class experienced a decrease in area from 556.19 hectares in 2018 to 408.82 hectares in 2020, possibly due to natural revegetation or greening efforts that increased vegetation cover in the area (Pranoto et al., 2021). Conversely, the vegetation land cover class significantly increased from 40,679.86 hectares to 40,729.78 hectares, indicating land recovery or increased forest cover at a certain scale (Rahmawati et al., 2020). In addition to changes within land cover classes, the matrix shows transition patterns, such as converting bare land to vegetation (293.09 hectares) and water bodies to vegetation (99.00 hectares). These conversions reflect a complex

environmental dynamic, including interactions between natural and anthropogenic factors (Turner et al., 2021).

4. Land Cover Change 2018-2020

The land cover changes in the Lake Ranau Catchment Area between 2020 and 2022 show the dynamics of land cover during this period. Table 3 presents the distribution of land cover changes, which provides insights into the level of land conversion and shifting land use patterns in the study area.

Table 3. Land Cover Change Matrix for the Ranau Lake Catchment Area from 2020 to 2022

Land Cover 2018	Land Cover 2020				
	Water Body	Built-up area	Bare Land	Vegetation	Total
Water Body	12.648	0,26	9,29	99,00	12.756,55
Built-up area	0,002	47,76	0,21	39,62	87,59
Bare Land	5,37	0,13	110,24	293,09	408,82
Vegetation	51,70	40,94	356,44	40.280,70	40.729,78
Total	12.705,07	89,09	476,18	40.712,40	53.982,74

Source: Primary data (2023)

The analysis of land cover changes in the Lake Ranau Catchment Area between 2020 and 2022 reveals significant dynamics in several land cover classes. The area of water bodies remained relatively stable with slight fluctuations, decreasing from 12,756.55 hectares in 2020 to 12,648 hectares in 2022. This decline may indicate sedimentation or decreased water quality due to anthropogenic activities around the lake (Umar et al., 2018). Built-up land also underwent slight changes, remaining around 87.59 hectares, reflecting relatively controlled development activities in the area. However, the increased presence of built-up land compared to the previous period suggests potential pressure on natural vegetation areas (Jupiardi et al., 2022).

Bare land decreased in area from 408.82 hectares in 2020 to 293.09 hectares in 2022. This decline is associated with the shift from bare land to vegetation, as evidenced by the increase in vegetation area to 40,280.70 hectares in 2022. This trend suggests potential ecosystem recovery in the region, although its sustainability still requires further monitoring (Medina and Atehortúa, 2019). Significant changes also occurred in the vegetation land cover, which remains the dominant land cover with consistent growth. Vegetation now covers more than 75% of the total area of the watershed, indicating a relatively strong potential for ecosystem protection. However, the dynamics of land cover changes highlight the importance of integrated management to minimize negative environmental impacts and ensure ecosystem sustainability (Dede, 2021).

5. Land Cover Accuracy Test for 2016-2022

The land cover classification accuracy test was conducted using a confusion matrix. A total of 86 sample points were used for the accuracy test. Based on the classification by the Ministry of Environment and Forestry (2020), the minimum land cover accuracy value is 85% or ≥ 85%, so the classification results are deemed acceptable. The accuracy value of the classification results using the Support Vector Machine method was validated with Google Earth imagery and supplemented with a land cover reference map sourced from ESRI (Environmental Systems Research Institute) for the same years: 2016, 2018, 2020, and 2022. The accuracy test results for 2016-2022 are presented in Table 4. below.

Table 4. Land Cover Accuracy Test for 2016-2022

Bare Land (ha)	Vegetation (ha)	Water Body (ha)	Built-up area (ha)	Lake Area (ha)
556,21	40.683,94	12.668,32	80,05	12644,30
527,88	40.712,10	12.665,10	83,05	12640,90
408,82	40.73	12.756,50	87,64	12708,20
476,18	40.717,90	12.705,10	89,15	12672,60

Source: Primary data (2023)

The land cover classification accuracy test using the confusion matrix showed results consistent with the Ministry of Environment and Forestry et al. (2020) standards, with a minimum accuracy of 85%. This accuracy was calculated using 86 sample points from satellite imagery and reference maps sourced from Google Earth and ESRI. The classification method used was Support Vector Machine (SVM), which effectively classifies images with high dimensionality and complex variables (Mountrakis et al., 2011). The classification results indicate that land cover experienced significant changes between 2016 and 2022, with a decrease in bare land area from 556.21 ha in 2016 to 476.18 ha in 2022, while the vegetation category remained relatively stable (Liu et al., 2020). Based on the accuracy test results, the SVM method is acceptable for mapping land cover in the study area with an accuracy greater than 85%, meaning these classification results can be relied upon to support land use planning and conservation policy decisions (Foody, 2002). Thus, this classification provides a clear picture of land cover dynamics and can be used for long-term monitoring in natural resource management.

6. Water Surface Area of Lake Ranau

The map's analysis results indicate that the lake's surface area fluctuated from 2016 to 2022, which may have been influenced by various natural factors or human activities (Table 5).

Table 5. Water Surface Area of Lake Ranau During the Period 2016--2022

Year	Water Surface Area (ha)
2016	12.644,3
2018	12.640,9
2020	12.708,2
2022	12.672,6

Source: Primary data (2023)

Based on the data, the water surface area of Lake Ranau has experienced fluctuations during the study period. In 2016, the lake area was recorded at 12,644.3 hectares, then slightly decreased to 12,640.9 hectares in 2018. However, by 2020, the lake's area increased again to 12,708.2 hectares before slightly decreasing to 12,672.6 hectares in 2022. Although relatively small, these recorded changes suggest that Lake Ranau may be undergoing recovery or alterations potentially influenced by management practices or environmental factors affecting its ecosystem (Hogg et al., 2020). The minor decline in 2018 could be attributed to natural variability, such as fluctuations in rainfall or evaporation, as well as human activities around the lake, such as water extraction or land use changes that impact the water body area (Pavlov et al., 2017). Conversely, the increase in the lake's area in 2020 and 2022 may be linked to the reduction of human activities threatening the sustainability of the lake's ecosystem, such as deforestation or sedimentation, or to increased water flow due to changes in the hydrological dynamics of the catchment area (Rahman et al., 2021). Studies on changes in the surface area of water bodies like this are essential for monitoring ecosystem conditions, detecting potential threats, and evaluating the success of conservation efforts and freshwater resource management, contributing to ecosystem balance (Turner et al., 2021).

7. The Relationship Between Land Cover Changes and Lake Area

The regression results between land cover changes and lake surface area from 2016 to 2022 reveal an interesting relationship between the changes in each land cover category and the changes in the lake's surface area. Generally, it is observed that fluctuations in bare land are inversely related to the changes in the lake's surface area (Table 5). This suggests that as the area of bare land decreases, the area of the lake’s surface area tends to increase, and vice versa. This could indicate that changes in land cover, particularly in categories such as bare land, might influence the hydrological processes or the balance of the lake's ecosystem, potentially affecting water retention, sedimentation, and other environmental factors. Therefore, further investigation into the interaction between land use changes and lake dynamics is crucial to understanding how land cover alterations contribute to the overall health and sustainability of the lake's ecosystem.

Table 6. Regression between Land Cover and Lake Surface Area

Bare Land (ha)	Vegetation (ha)	Water Body (ha)	Built-up Area (ha)	Lake Surface Area (ha)
556,21	40.683,94	12.668,32	80,05	12644,30
527,88	40.712,10	12.665,10	83,05	12640,90
408,82	40.735,00	12.756,50	87,64	12708,20
476,18	40.717,90	12.705,10	89,15	12672,60

Source: Primary data (2023)

Table 6. indicates that, generally, there is a fluctuation in bare land that is inversely related to changes in the lake area. In 2016, the area of bare land was recorded at 556.21 hectares, but it decreased to 476.18 hectares by 2022, while the lake area only showed minor changes, from 12,644.3 hectares in 2016 to 12,672.6 hectares in 2022. This suggests that although the area of bare land decreased, the lake area did not experience a significant decline (Schneider et al., 2019). Furthermore, the vegetation and water bodies categories displayed more stability, with very minimal changes between the years under review. The vegetation area 2016 was recorded at 40,683.94 hectares and only slightly increased to 40,717.9 hectares by 2022. Similarly, the water body area remained relatively constant throughout the period, with slight fluctuations ranging from 12,665.1 hectares to 12,756.5 hectares. This suggests a balance in the ecosystem, which may have been influenced by other environmental factors, such as land management and conservation regulations in place (Jin et al., 2020). These changes indicate that the impact on the lake area remains relatively limited despite land use conversion, particularly in bare land and built-up areas. Other factors, such as climate change, natural resource management, and human activities directly affecting the water body, are likely to have contributed to these fluctuations. Therefore, the relationship between land cover and lake area in this study presents opportunities for further research on the factors influencing the dynamics of freshwater ecosystems and their surrounding landscapes (Pereira et al., 2021).

The regression analysis aims to understand how land cover changes affect the lake area, focusing on four land cover classes: bare land, vegetation, water bodies, and built-up land. The results indicate a strong relationship between water bodies and lake areas, while the relationship with other land cover types shows varying strength levels. The results of the regression analysis of land cover changes against lake area changes are presented in Table 7 below.

Table 7. Results of Regression of Land Cover Changes in Lake Area

Land cover	Correlation with Lake Surface Area	R	Correlation Level	R^2
Bare Land	y = -0,4698x + 12.898	-0,9743	Very Strong	0,9492
Vegetation	y = 1,1958x – 3.6017	0,8128	Very Strong	0,6606
Water Body	y = 0,7332x + 3.356	0,9994	Very Strong	0,9988
Built-up Land	y = 5,6258x + 1.2188	0,7540	Strong	0,5686

Source: Primary data (2023)

Table 6 shows variations in the strength of the relationship between land cover changes and lake areas. For the land cover category of bare land, a correlation coefficient of -0.9743 with an R^2 value of 0.9492 was obtained, indicating a very strong and negative relationship. This suggests that the decrease in lake area is closely correlated with the increase in bare land area, which aligns with previous studies indicating that land conversion to bare land is often associated with the degradation of aquatic ecosystems (Smith et al., 2020). Meanwhile, a strong positive relationship for vegetation cover is reflected in a correlation coefficient of 0.8128 and an R^2 value of 0.6606, indicating that an increase in lake area tends to be accompanied by an expansion in vegetation area. However, this relationship is weaker than that with bare land, as described in research by Wang et al. (2018) regarding the role of vegetation in maintaining lake quality.

For water bodies, a strong and positive relationship with lake area is reflected in the correlation coefficient of 0.9994 and an exceptionally high R^2 value of 0.9988. This underscores that changes in water bodies, such as the expansion or reduction of the lake area, have a direct and highly significant impact on the lake's size itself, a phenomenon discussed by Zhang et al. (2019) in their study on dynamic lake ecosystems. Finally, a weaker relationship is observed for built-up land, with a correlation coefficient of 0.7540 and an R^2 of 0.5686. This indicates that, although a strong correlation exists, the impact of built-up land changes on lake size is lower compared to water bodies or bare land, consistent with the findings reported by Liu et al. (2021), which showed that the influence of built-up land changes on lake quality is less significant than that of natural land changes.

CONCLUSION

This study reveals that between 2016 and 2022, significant changes occurred in land cover in the catchment area of Lake Ranau. The categories of water bodies, vegetation, and built-up areas showed an increase in area by 36.78 hectares, 33.96 hectares, and 9.1 hectares, respectively, while bare land experienced a decrease of 80.03 hectares. The increase in the surface area of Lake Ranau by 28.3 hectares indicates a direct influence from changes in land cover, as evidenced by significant regression relationships, especially in the water body category (99.88%) and bare land (94.92%). These results provide scientific evidence that land cover changes significantly affect the dynamics of the lake ecosystem. These implications contribute significantly to understanding the relationship between land cover change and water body area, which could serve as a scientific basis for water resource management and regional planning. This underscores the importance of sustainable land cover management for practitioners to prevent ecosystem degradation and preserve Lake Ranau's ecological functions.

It is crucial for the government and stakeholders to continuously use remote sensing technologies, such as Sentinel-1A, to monitor land cover changes and water surface area. This will support data-driven decision-making in conservation efforts. Intensive greening or revegetation programs should also be implemented in the bare land category, as this category is most vulnerable to erosion and sedimentation, which can threaten the Lake Ranau ecosystem. This study recommends further research to assess the impact of land cover changes on water quality and biodiversity, enabling the integration of comprehensive lake ecosystem conservation efforts.

ACKNOWLEDGEMENT

The authors are grateful to the Geospatial Information Agency, ESRI, the U.S. Geological Survey, and ESA-Copernicus for providing the research data.

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