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Utilization of Sentinel-1 Imagery for Land Cover Identification and Implications for Sustainability in the Maninjau Lake Area, West Sumatera

Sri Kandi Putri[1]*, Mentari Dian Pertiwi[1], Dinda Mayasari[1], Triya Maya Wirda[1], Agustiyara[2]

[1]*Department of Geography, Faculty of Social Science, Universitas Negeri Padang*
[2]*Environmental Science, Eötvös Loránd University*

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ABSTRACT

The objective for this study is to address existing knowledge gaps by developing a reliable land cover identification approach using Sentinel-1 imagery to support sustainable environmental management in the Lake Maninjau area. This area is significant due to its ecological, economic, and social functions for the community. The research method employed entails the interpretation of objects on the earth's surface in satellite images. This process necessitates the identification of these objects through visual recognition, based on the characteristics or attributes inherent to each object. The visual interpretation of Sentinel 1 SAR (synthetic aperture radar) data utilized Google Earth as a geographical reference platform. The results of this study demonstrate the capability of Sentinel-1 data in distinguishing major land-cover classes, including water bodies, settlements, rice fields, aquaculture ponds, and vegetation. Sentinel-1 is an effective and efficient data source for land cover monitoring, especially in areas frequently covered by clouds.

*Corresponding author: srikandi_25@fis.unp.ac.id

Introduction

Situated within Agam Regency, West Sumatra Province, Lake Maninjau is prominent body of water in the region. This lake plays a pivotal role in the surrounding community's wellbeing and economic activities. The area has ecological, economic, and social functions to the community. The ecological functions of wetlands include providing a habitat for various organisms, maintaining groundwater balance, and creating microclimate. The economic function of the region is aquaculture, particularly the implementation of floating cages (KJA) and the provision of irrigation sources. The social function of the part is facilitated by the scenic beauty of surroundings. The preservation of Lake Maninjau is imperative due to the ecological functions it provides. The lake's surface area, estimated at approximately 99.5 square kilometers, situated at an altitude of about 460 meters above sea level. However, in recent years, this area has experienced significant land cover changes, driven by the dynamics of aquaculture, vegetation changes, infrastructure development, and natural disasters.

Land cover is defined as the physical materials present on the earth's surface. It serves as a crucial indicator in comprehending the interplay between natural processes and human activities. Information regarding land cover is imperative in numerous disciplines, including hydrological modeling, climate change analysis, spatial planning, and natural resource management (Lillesand, Kiefer, & Chipman, 2015). Changes in land cover influenced by human activities and natural phenomena can have a significant impact on the environmental sustainability and ecosystem functioning. Therefore, accurate identification of land cover is essential for comprehending the spatial dynamics of a region and facilitating data-driven decision making (Campbell & Wynne, 2011).

A multitude of prior studies have demonstrated the potential of Sentinel-1 SAR (synthetic aperture radar) data for land cover identification, particularly in regions frequently affected by cloud cover. Pham-Duc et al. (2017) demonstrated the efficacy of Sentinel-1 for mapping surface water and wetland environments, attributing this capability to its capacity to capture backscatter responses irrespective of prevailing weather conditions. In similar, Sarker et al. (2025) revealed that the combination of VV and VH polarizations can successfully discriminate between forest, agricultural areas, and built-up land regions, underscoring the sensor's capacity for detailed land cover classification. In regions susceptible to disaster, Holtgrave (2020) utilized Sentinel-1 imagery to detect vegetation and land-use changes, demonstrating more stable temporal observations in comparison to optical sensors. In West Sumatra, Yuh YG et al. (2024) applied Sentinel-1 for land cover classification using Random Forest and achieved competitive accuracy, thereby reinforcing the sensor's suitability for cloud-dominated tropical landscapes. Additionally, Mashala MJ et al. (2022) examined land use changes and environmental impacts around Lake Maninjau using optical imagery, and their findings emphasized the need for radar-based approaches to overcome persistent cloud constraints. Collectively, these studies underscore the strong potential of Sentinel-1 SAR for land cover mapping; however, its application specifically for the Lake Maninjau region particularly in relation to sustainability implications remains limited and requires further investigation.

These studies substantiate the considerable potential of Sentinel-1 to function as a primary data source for land cover mapping, particularly in regions characterized by persistent cloud cover. However, the application of Sentinel-1 specifically for land cover identification in the Lake Maninjau region remains limited, particularly with regard to its contribution to sustainability assessment and ecosystem management. Therefore, the objective of this study is to address this knowledge gap by developing a reliable land cover identification approach using Sentinel-1 imagery to support sustainable environmental management in the Lake Maninjau area.

Methodology

The research is situated at Lake Maninjau in Tanjung Raya, Agam Regency, West Sumatra. Lake Maninjau is a caldera lake with an elevation of 459 meters above sea level. Lake Maninjau's volcanic origin is attributed to a major eruption of a volcano that expelled approximately 220–250 km^3 of pyroclastic material. The caldera was formed by the eruption of a composite stratovolcano that developed in the tectonic zone of the Sumatran Fault System, known as Mount Sitinjau (according to local legend), as evidenced by the surrounding hills that resemble walls. The Maninjau Calder, measuring 34.5 km x 12 km, is occupied by a lake with dimensions of 8 km x 16.5 km (132 km^2). The Maninjau Caldera, a geological formation of significant interest, has a maximum depth of 157 meters and walls that rise 459 meters above the lake surface.

Table 1. Characteristics of Sentinel 1 Imagery

Type	*Characteristic*
Polarization	*VV/VH*
Tipe Produk	*GRD*
Beam Mode	*IW*
Resolusi Spactral	*VH + VV*
polarisasi komposit	*Red: VV; Green:VH; Blue:VV/VH.*

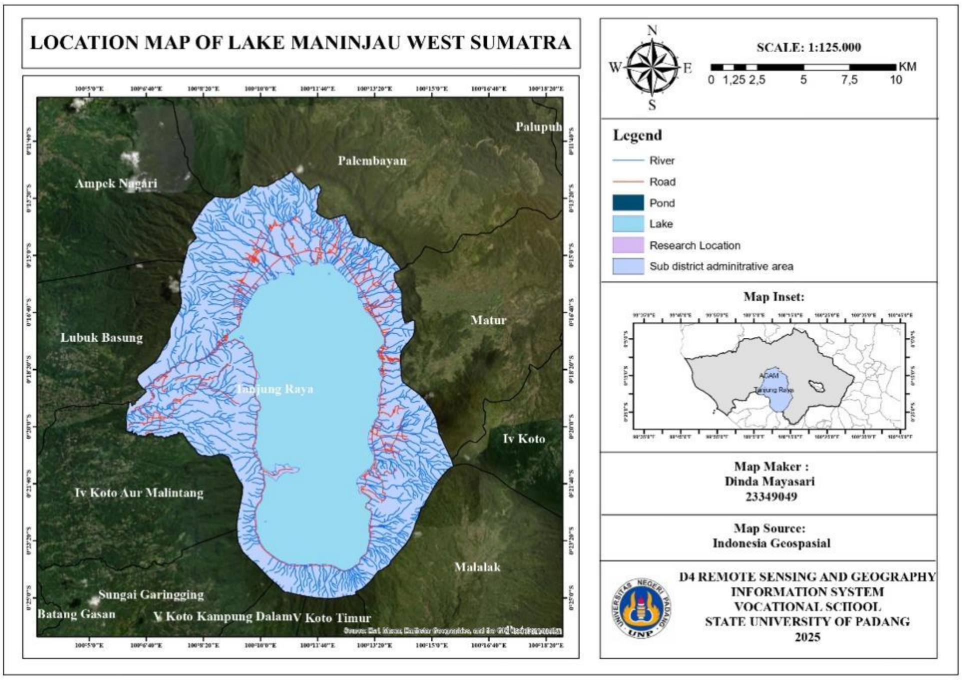


Figure 1. Research Site Map

The Sentinel-1 image subset to be processed only covers the research area. Cutting the image into a narrower coverage will facilitate the data processing process. Calibration This is done by looking at the polarization of the image, namely VH (vertical horizontal) and W (vertical vertical) to produce sigma_0 band output. Speckle Filter Filtering is performed to remove speckle from the image using the LEE operator as a filter (Arief et al., 2017).

Terrain Correction Involves Digital Elevation Model (DEM) and orbit files to correct SAR errors such as layover, foreshortening, and shadow, or is intended to reduce these errors so that the geometric representation in the image matches the field coordinates (Septiana et al., 2017). Converting backscatter to decibels (linear to dB) is the final step for the operator to convert the band to dB. In this case, the parameter used is the available band source. And RGB displays the visualization of the Sentinel-1 image with composite polarization Red:VV; Green: VH; Blue: VV/VH.

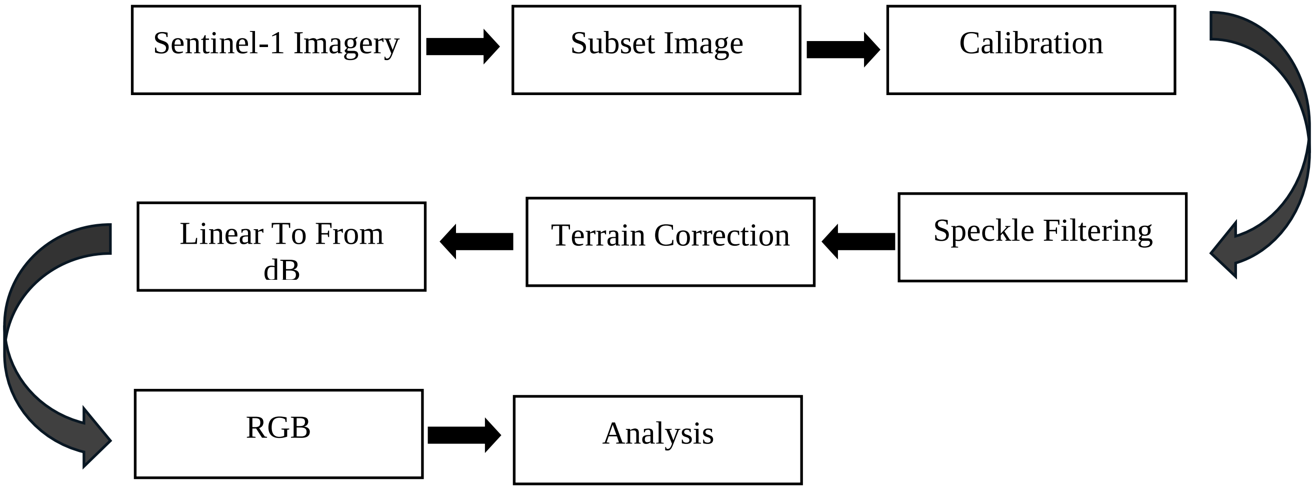


Figure 2. Research Flowchart

Result and Discussion

Result

The processing results of the Sentinel-1 imagery demonstrate a discernible variation in backscatter values among the various land-cover types within the study area. In the composite visualization, the dark blue region that occupies a significant portion of image's central areas signifies minimal backscatter values. These regions are characterized by the presence of water bodies with smooth surfaces, which have the capacity to deflect radar signals away from the sensor. Meanwhile, the bluish-green areas with moderate backscatter values represent dense vegetation such as forests and medium-rough land surfaces. The bright yellow regions appear mainly on slopes and ridge areas characterized by rough textures, which produce high backscatter values. This spatial variation demonstrates that Sentinel-1 imagery is effective in distinguishing between water, vegetation, and rough surfaces based on their backscatter responses, making it suitable for land-cover analysis in regions with high cloud cover. These findings align with previous studies stating that SAR imagery, especially Sentinel-1, can successfully identify land-cover types through differences in VV/VH backscatter values and image texture (Gargiulo, M., et al.2020).

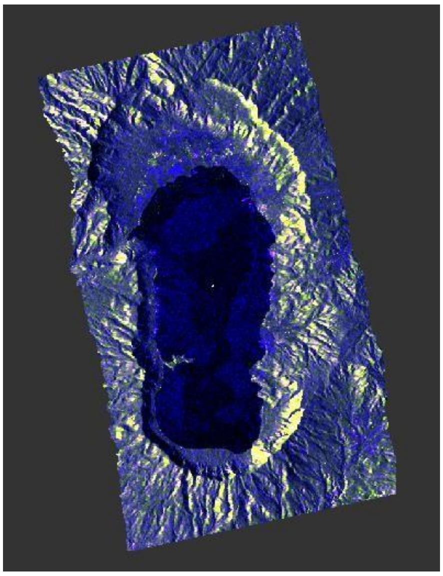


Figure 3. Sentinel-1 image of Lake Maninjau in 2025

The vectorization results demonstrate that each land-cover object was successfully mapped into polygons based on its spectral and textural characteristics. The dark blue polygons in the figure represent the water body of Lake Maninjau, which is characterized by low backscatter values and the typical smooth-surface response of open water. The purple polygons represent settlement areas, which exhibit high backscatter values due to the rough and reflective structure of buildings. The light blue polygons indicate paddy fields, which show medium-to-low radar backscatter levels depending on moisture content and water presence. Meanwhile, the dark bluish polygons correspond to aquaculture ponds, which generally display a combination of smooth texture and water-dominated surface patterns. The yellow polygons represent vegetated areas, including forest and mixed vegetation, which produce medium-to-high backscatter due to canopy structure. The grey polygons denote objects that were not identified or not included in the analyzed land-cover classes. Overall, these results demonstrate that the combination of Sentinel-1 SAR imagery with segmentation and vectorization techniques is capable of producing reliable land-cover maps in regions with persistent cloud cover (Petrushevsky, N., et al 2021). These findings are consistent with previous studies that highlight the effectiveness of Sentinel-1 SAR for land-cover classification based on differences in backscatter values, polarimetric responses, and texture (Jacob, A. W, 2020).

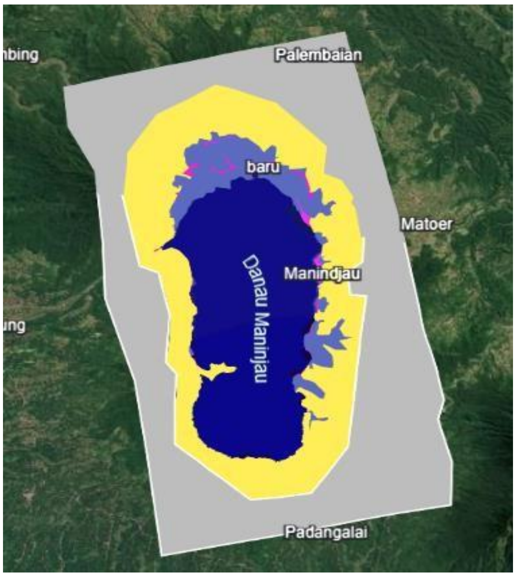
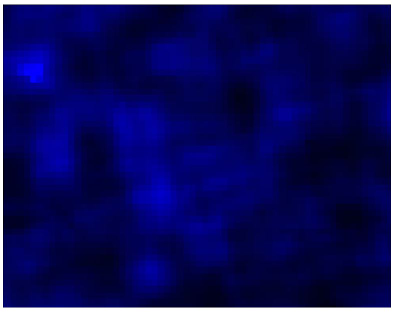
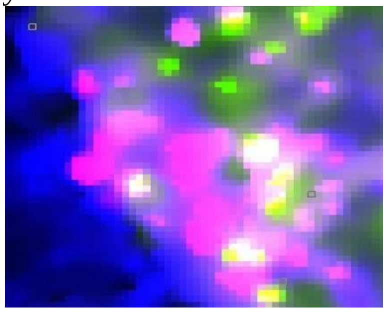
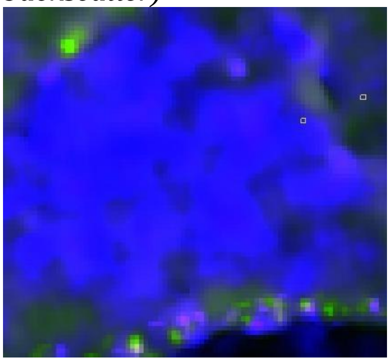
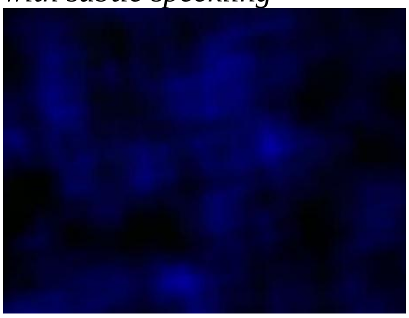
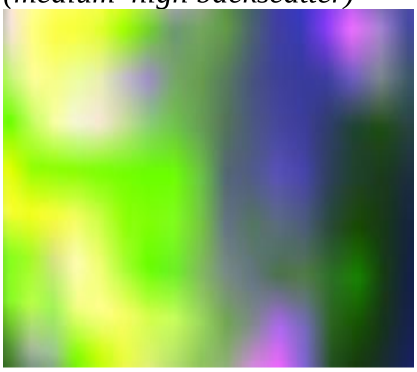


Figure 4. Polygon map of each object

Table 2. The land-cover comparison between Sentinel-1 backscatter data and high-resolution Google Earth imagery

No.	*Object Description*	*Sentinel-1 Appearance*	*Google Earth Appearance*
1	*Water Body (Lake)*	*Very dark (low backscatter), dark blue color* 	*Natural blue water surface with smooth texture* 

No.	*Object Description*	*Sentinel-1 Appearance*	*Google Earth Appearance*
2	*Settlement*	*Bright (high backscatter), purple or yellow color* 	*Dense buildings, rooftops clearly visible* 
3	*Paddy Field*	*Light/bright blue color (medium–low backscatter)* 	*Patchwork pattern, green or brown depending on the season* 
4	*Aquaculture Pond*	*Dark bluish color, smooth texture with subtle speckling* 	*Rectangular water-filled pond structures* 
5	*Vegetation*	*Yellow or bright green color (medium–high backscatter)* 	*Dense green color, visible as forest or shrubland* 

The visual comparison, supported by accuracy assessment, indicates that Sentinel-1 provides reliable land-cover separation, particularly between water, built-up areas, and vegetation. This result is consistent with previous studies that emphasize the capability of Sentinel-1 SAR for land-cover classification using backscatter intensity, texture, and structural characteristics (Mastrorosa, S.,et al 2023).

Discussion

The results of this study demonstrate that Sentinel-1 data is capable of distinguishing major land-cover classes such as water bodies, settlements, rice fields, aquaculture ponds, and vegetation. However, the accuracy obtained is strongly influenced by the inherent characteristics of radar imagery, particularly speckle noise, similarity of backscatter values between classes, and dynamic surface conditions. Speckle noise, a common phenomenon in radar remote sensing, produces granular patterns that reduce image clarity and object boundary definition. This finding is consistent with previous studies by Garcia, A. D et al. (2024) and Saputro, A. H et al. (2021), which reported that speckle noise is one of the primary factors reducing classification performance in SAR data, especially in areas with smooth textures such as calm water or flooded rice fields.

In addition, several land-cover classes exhibit similar backscatter patterns, leading to classification errors. For example, flooded rice fields and aquaculture ponds often share comparable backscatter characteristics, causing misclassification between these two classes. Similar issues were noted by Hoshikawa, K., et al. (2018), who pointed out that distinguishing inundated surfaces in SAR imagery can be challenging due to the overlap in radar backscatter responses. Furthermore, the similarity in texture between densely built-up areas and dry vegetation also contributes to misclassification, particularly when incidence angle conditions increase backscattering from building structures.

Another factor affecting accuracy is the spatial resolution of Sentinel-1 (10 meters), which limits the detection of small objects such as irrigation channels, small aquaculture plots, and small residential buildings in rural areas. This limitation has been widely discussed in previous literature, such as Ozdogan, M., et al. (2010), who noted that small-sized features tend to form mixed pixels, thereby reducing classification precision.

The accuracy assessment in this study indicates that classes with homogeneous textures and strong contrast such as water bodies—show higher accuracy, while classes with highly variable conditions such as rice fields and aquaculture ponds produce lower accuracies. This trend aligns with existing literature, which emphasizes that SAR imagery performs best in distinguishing between strong absorbers (e.g., water) and strong reflectors (e.g., buildings), but is less effective for mixed or dynamic land surfaces such as moist vegetation, temporarily flooded areas, or wet soil.

Overall, the findings highlight that although Sentinel-1 is effective for land-cover mapping, several key limitations need to be considered, including speckle noise, overlapping backscatter values, and spatial resolution constraints. Therefore, applying additional techniques such as adaptive speckle filtering, integrating optical imagery (e.g., Sentinel-2 or PlanetScope), and incorporating texture-based machine learning algorithms can significantly improve classification accuracy. These findings have important implications for coastal management, agricultural monitoring, and settlement mapping, particularly in regions frequently affected by cloud cover where radar data are essential for continuous spatial observation.

Conclusion

This investigation elucidates that Sentinel-1 imagery demonstrates a notable capability in differentiating various principal land cover categories, encompassing aquatic environments, urbanized territories, vegetation, paddy fields, and aquaculture ponds. The distinctive backscatter coefficients pertinent to each object facilitate the classification process, particularly for entities exhibiting substantial contrast, such as aquatic environments and urbanized territories. However, the efficacy of this classification system is susceptible to several inherent limitations of radar imagery, including speckle noise, the uniformity of backscatter coefficients across different classes, and the 10-meter spatial resolution that contributes to the occurrence of mixed pixels in small objects. Classes characterized by dynamic surface conditions, such as paddy fields and aquaculture ponds, demonstrate elevated rates of misclassification in to more homogeneous classes.

These findings emphasize the necessity of implementing complementary techniques, including adaptive speckle filters, the integration of high-resolution optical imagery, and the utilization of texture-based machine learning algorithms, to augment mapping accuracy. In conclusion, Sentinel-1 persists as an effective and reliable data source for land cover monitoring, particularly in areas frequently obscured by cloud cover; however, the refinement of image processing methodologies is essential for attaining classification results that are more accurate and representative.

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Competing Interests

The author(s) declare no competing interests.

Data Availability

The datasets analysed in the present study were obtained entirely from publicly accessible open-source websites. All data are secondary, non-identifiable, and can be accessed directly from the original open-source platforms cited in the Methods section, in accordance with the terms of use of each website. Additional information regarding data retrieval and processing is available from the corresponding author upon reasonable request.

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