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Remote Sensing-Based Evaluation of Mangrove Cover Change in Taman Hutan Raya Ngurah Rai, Bali

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Abstract

The mangrove ecosystem plays a vital role in supporting coastal resilience and mitigating climate change. However, monitoring changes in mangrove cover is necessary to ensure adaptive and sustainable area management. This study aims to investigate changes in mangrove area in 2016, 2020, and 2024 within the Ngurah Rai Taman Hutan Raya (Tahura), as well as to identify potential land for mangrove expansion based on land cover and ecological conditions. The methods used include primary data collection through interviews with park managers and local communities, and secondary data from Sentinel-2 imagery and previous studies. Data analysis applied remote sensing techniques, including the calculation of NDVI and NDMI indices, vegetation density classification, and spatial analysis of mangrove cover changes. The results show an expansion of mangrove area from 1.027,609 hectares in 2016 to 1.068,911 hectares (an increase of about 3,86%) in 2024, with a significant rise in the dense vegetation category from 643,055 hectares to 766,344 hectares (approximately 16,01%). The analysis also identified 198,974 hectares of water bodies suitable for mangrove expansion, offering considerable potential for additional carbon storage.

Keywords— *Mangrove Cover Change, Sentinel-2, Extensification*

I. INTRODUCTION

Indonesia accounts for approximately 23% of the world's total mangrove area, equivalent to around 3.36 million hectares (KLHL, 2021). The largest mangrove area in Bali is located within the Ngurah Rai Taman Hutan Raya (TAHURA), covering approximately 1,253 hectares (Husnayaen et al., 2023). It is located across the regions of Denpasar and Badung. This area plays a pivotal role in conserving coastal ecosystems, mitigating coastal abrasion, and functioning as the estuary for major rivers. Its designation has undergone several changes in status before being officially established as a Taman Hutan Raya in 1992 (Kumparan, 2022). Management of Tahura is carried out by the Ngurah Rai TAHURA Technical Implementation Unit (UPTD), with the area divided into specific zones: special, collection, utilization, rehabilitation, religious-cultural, and traditional, as depicted in Figure 1.

This area plays an essential role as a natural barrier against coastal abrasion and as a carbon reservoir. However, its existence is threatened by land-use conversion, infrastructure development, waste pollution, and sedimentation. These pressures have the potential to reduce the ecological functions of mangroves, even though this ecosystem is critically important for coastal protection and climate change mitigation. To ensure sustainability, periodic monitoring of changes in mangrove cover and identification of potential land for expansion are required. Remote sensing technology, particularly Sentinel-2 imagery combi ned with NDVI and NDMI analyses, enables multitemporal monitoring of mangrove dynamics with a high level of accuracy (Pujianikiet al.,2022, 2023, 2025). This study focuses on investigating changes in mangrove extent from 2016 to 2024 in Ngurah Rai Taman Hutan Raya, and identifying potential areas for mangrove expansion based on spatial and ecological characteristics. The results of this research are expected to serve as a foundation for sustainable mangrove management, enhance coastal protection, and support climate change mitigation through increased carbon stock conducted.

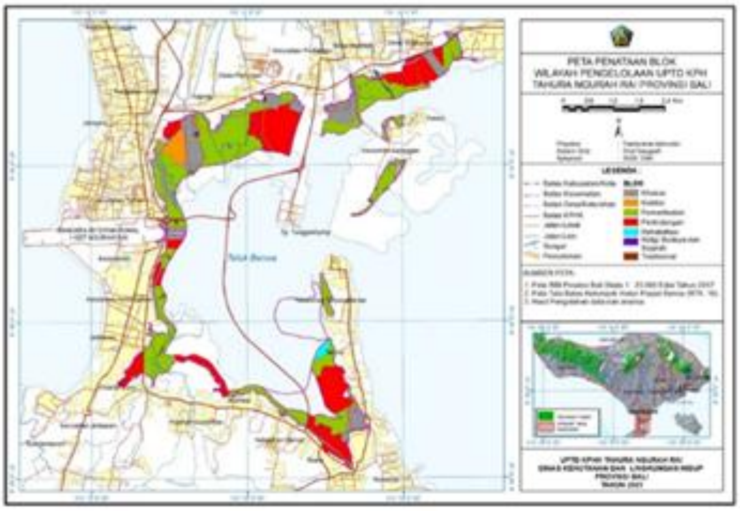

Figure 1. Management Area Block Arrangement Map of UPTD TAHURA Ngurah Rai, Bali Province
Source: UPTD TAHURA Ngurah Rai

Interviews with relevant stakeholders indicated that mangroves within TAHURA Ngurah Rai comprise 28 species, predominantly Rhizophora, Sonneratia alba, dan Burguiera gynorecia. Mangroves are intertidal plant species with specialized adaptations. Their functions include:

1. Mitigating abrasion and erosion through root systems that stabilize sediments
2. Attenuating waves and tsunamis by effectively reducing wave energy
3. Preventing seawater intrusion into inland areas
4. Providing habitat for coastal biota and maintaining water quality
5. Acting as significant carbon sinks, thereby supporting climate change mitigation initiatives.

Mangrove extensification refers to the expansion of mangrove coverage into potential areas such as estuaries and intertidal zones. Unlike restoration, which targets the recovery of degraded or damaged mangrove areas, extensification is more proactive and preventive, focusing on utilizing natural or semi-natural areas such as shallow water bodies, river estuaries, and undisturbed intertidal lands (Alongi, 2008). Key biophysical parameters include temperatures of 28 – 32 °C, salinity ranging from 10 – 30‰, pH between 7 and 8.5, muddy or sandy substrates, and low to medium tidal ranges.

Remote sensing is a method for acquiring information about an object without direct contact, using satellite sensors such as Sentinel-2. This satellite offers several advantages, including high spatial resolution (10–20 m), rapid acquisition frequency (every 5 days), and higher mangrove classification accuracy compared to Landsat 8. Commonly used indices include:

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1. NDVI (Normalized Difference Vegetation Index), indicating vegetation health and density, with the following classifications: sparse (≤ 0.33), moderate (0.34 – 0.42), dense (≥ 0.43).
2. NDMI (Normalized Difference Moisture Index), indicating vegetation moisture content.

II. RESEARCH METHOD

The study location map is presented in Figure 2 while the management boundary map of TAHURA Ngurah Rai under the supervision of the local technical management unit (UPTD) is shown in Figure 3 this boundary map served as the basis for the spatial analysis in this study.

Figure 2. Location of Ngurah Rai Taman Hutan Raya
Source: Google Earth

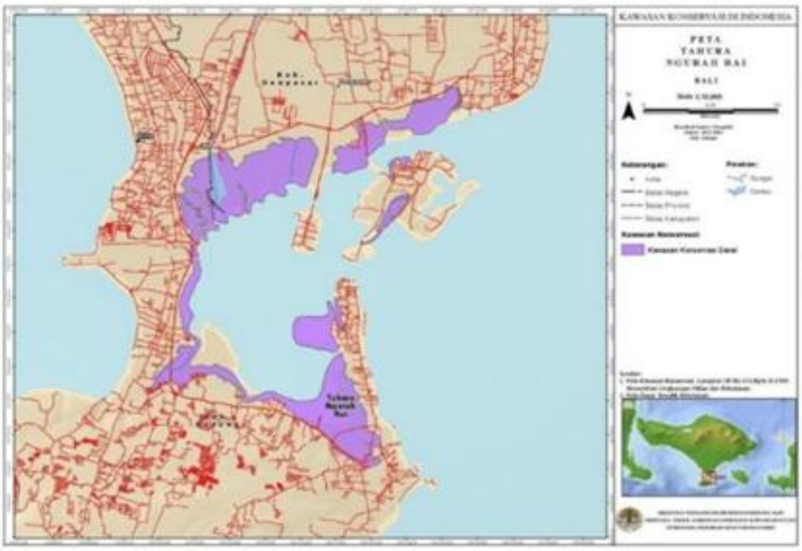

Figure 3. Map of TAHURA Ngurah Rai
Source: Ministry of Environment and Forestry (Indonesia)

The research methodology followed a systematic framework consisting of five primary stages: planning, data collection, data processing, analysis, and conclusion formulation.

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A. Data Collection

Two types of data were used: (1) Primary data were obtained through interviews with the Ngurah Rai TAHURA Management Unit (UPTD) and local fishing/coastal community groups to gather information on mangrove management practices and environmental conditions and (2) Secondary data included Sentinel-2 L2A satellite imagery from 2016, 2020, and 2024, downloaded from the Copernicus Data Space with a cloud cover threshold of ≤ 25%. Supporting literature and previous studies were also consulted to strengthen the analysis.

B. Data Processing

Data processing was performed using QGIS software and involved the following steps: (1) extraction of spectral bands (B4, B8, B8A, B11), (2) creation of the Area of Interest (AOI), and (3) image masking to separate mangrove areas from non-mangrove regions.

C. Data Analysis Techniques

1. NDMI (Normalized Difference Moisture Index): used to distinguish wet vegetation (mangroves) from non-vegetated areas.
2. NDVI (Normalized Difference Vegetation Index): applied to evaluate vegetation density and health, categorized as sparse, moderate, or dense.
3. Area calculation: mangrove area was quantified according to density categories for the years 2016, 2020, and 2024.
4. Change analysis: comparative analysis of mangrove extent across the three years to determine trends of degradation or expansion.
5. Potential land identification: conducted on water bodies and ecologically suitable sites, supported by literature review and stakeholder interviews.

III. RESULTS AND DISCUSSION

Sentinel-2 satellite imagery was processed using polygon masking to delineate mangrove areas. NDMI analysis depicted the distribution of wet vegetation, while NDVI mapped the vegetation density levels. Classification results divided the study area into four categories: sparse mangrove, moderate mangrove, dense mangrove, and water bodies. Based on Sentinel-2 image classification results presented in Table 1, mangrove cover in the Ngurah Rai Grand Forest Park area experienced changes during the 2016 – 2024 period. In general, there has been a trend of increasing mangrove area, indicating natural expansion as well as human interventions. The land cover change maps are shown in Figure 4 until Figure 6.

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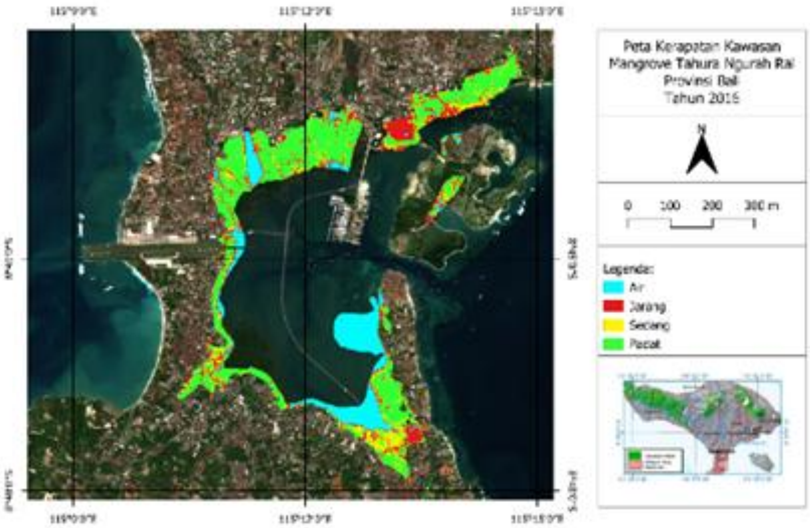

Figure 4. Density Map 2016

Source: Analysis Results (2025)

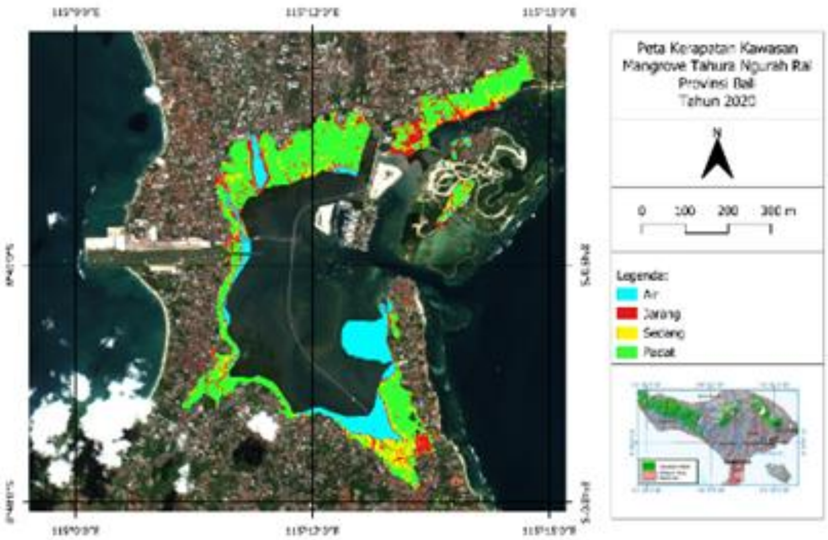

Figure 5. Density Map 2020

Source: Analysis Results (2025)

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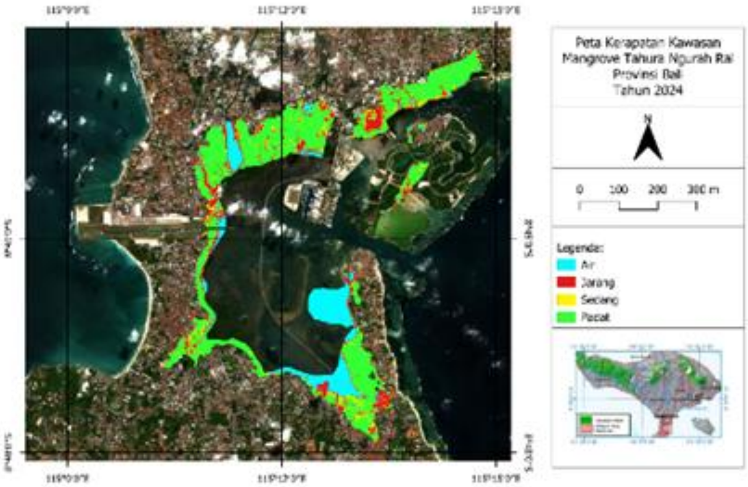

Figure 6. Density Map 2024

Source: Analysis Results (2025)

Table 1. Mangrove Area by Density in 2016–2024

Sparse	Moderate	Dense	Total Area	Water Bodies	Year
(Ha)					
221,944	162,610	643,055	1027,609	265,717	2016
203,961	167,353	662,851	1034,166	253,889	2020
203,994	98,573	766,344	1068,911	237,511	2024

Table 1 presents the results of the mangrove area change analysis for Ngurah Rai Taman Hutan Raya in 2016, 2020, and 2024, based on vegetation density (sparse, moderate, and dense). Data were obtained from land cover classification using Sentinel-2 satellite imagery from each year, analysed with QGIS software. The table shows changes in mangrove area according to density category. Percentage changes in Ngurah Rai TAHURA's mangrove area are as follows: sparse density at 8.8%, moderate density at 64.96%, dense density at 16%, and water body area has decreased in line with mangrove expansion.

This demonstrates the success of rehabilitation by UPTD TAHURA Ngurah Rai and the local community, including large-scale planting during the G20 Summit (2022). Currently, mangrove cover has reached 81.8% of the total area. Rehabilitation efforts were supported by adaptive planting methods such as spaced cluster planting, the use of gabions, mound methods, and the api-api method (effective for sandy substrates). The main factors driving success include increased community awareness, control of illegal activities, and innovation in planting techniques. Nevertheless, challenges remain, such as suboptimal substrates, household waste, and abandoned boats.

Extensification is focused on water bodies and open land with suitable biophysical characteristics. Analysis indicates that there are ±198.97 hectares of potential land, currently classified as water bodies, as shown in Figure 7. Optimal biophysical criteria include temperatures of 28 – 32°C, salinity of 10 – 30‰, pH of 7 – 8.5,

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and clay/sandy clay loam substrates. Much of South Denpasar and Kuta meets these criteria, while South Kuta faces challenges with higher temperatures and lower salinity.

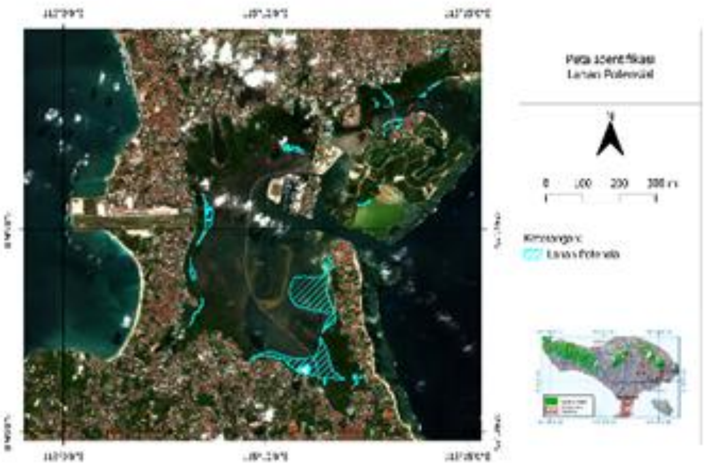

Figure 7. Potential Land Identification
Source: Analysis Results (2025)

These challenges may be addressed with environmental engineering approaches. Remedial efforts include:

1. Hydrological engineering via expanded mangrove river channels can restore natural tidal patterns and maintain salinity balance, contributing to mangrove ecosystem recovery (D. E. Marois dan W. J. Mitsch, 1994).
2. Considering the influence of nitrogen input and sediment texture on early growth and root formation; both factors are critical for successful mangrove colonization and regeneration (He et al., 2022).
3. Nurse plants/shading vegetation that provide microhabitats more favorable for seed germination and seedling growth, improving establishment success rates (Ren et al., 2008).

Thus, most water bodies in Ngurah Rai Taman Hutan Raya may be categorized as suitable land for mangrove planting/ extensification, except for special blocks designated for settlements, community activities, telecommunications, electricity, transport infrastructure, and other strategic utilities.

Stakeholder interviews yielded recommended methods for mangrove planting at the study site:

1. Manual reforestation: effective on stable substrates
2. Spaced cluster planting: for poorer substrates
3. Gabions: protection against pests/waves
4. Api-api: for mud-trapping, ideal for sandy substrates
5. Mound methods: suitable for Rhizophora species in central zones

Results indicate that the Ngurah Rai TAHURA area is experiencing positive mangrove expansion rather than degradation. This provides opportunities for management strategies focusing not only on restoration but also on extensification. However, expansion is uneven; some coastal areas still show low vegetation health. Some challenges identified include:

1. Ecological: pests, contaminated sedimentation, suboptimal substrates, shipwreck debris.
2. Social: uneven community involvement.

3. Technical: limited success with conventional planting methods.
4. Governance: development pressures from infrastructure projects.

In view of these results, it is recommended that mangrove planting and extensification programs in Ngurah Rai TAHURA be implemented in a planned, continuous manner based on local biophysical conditions. Such efforts will not only maintain coastal ecosystem stability and increase resilience against climate change impacts but also have the potential to strengthen local economies through fisheries, ecotourism, and community-based development. Furthermore, officially verified mangrove areas can be utilized as alternative funding sources through carbon trading schemes in national and international markets. Success of these initiatives requires cross-sectoral collaboration among government, communities, and supporting institutions. Prior to extensification activities, it is critical to conduct thorough field assessments of biophysical conditions, including substrate characteristics, salinity levels, tidal access, and suitability of mangrove species with ecological site conditions. This ensures accurate targeting and high success rates for planting activities.

These findings indicate significant recovery and expansion of the Ngurah Rai TAHURA mangrove ecosystem, offering high potential for climate change mitigation and green economic development. In terms of coastal rehabilitation technology, the use of artificial mangrove roots offers an innovative solution for accelerating ecosystem recovery and protecting shorelines from erosion prior to optimal growth of natural mangroves. This technology replicates the complex natural root structure, slowing currents, trapping sediment, and creating microhabitats conducive to marine life and substrate stability. Application of artificial mangrove roots can be an initial step in areas subject to high wave pressure or where substrate conditions have not yet fully supported natural mangrove growth, as part of an adaptive ecohydrological approach (Pujianiki Ni Nyoman; 2025),(Charoenlerkthawin 2025) ,(Charoenlerkthawin et al. 2026).

IV CONCLUSION

Based on research into mangrove land cover change in Ngurah Rai Grand Forest Park from 2016 to 2024, it can be concluded that the mangrove ecosystem has expanded both in area and vegetation density. Mangrove cover increased from 1,027.609 hectares in 2016 to 1,068.911 hectares in 2024, a rise of 3.86%. This growth was accompanied by an increase in dense mangrove from 643.055 hectares in 2016 to 766.344 hectares in 2024, representing a 16.01% increase. These results demonstrate significant improvements in both the quantity and quality of mangrove ecosystems in the study area. In addition, analysis identified 198.974 hectares of water bodies as potential land for mangrove extensification, which also store substantial carbon reserves.

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REFERENCE

- Kementerian Lingkungan Hidup dan Kehutanan, Peta Mangrove Nasional. Jakarta: Kementerian Lingkungan Hidup dan Kehutanan, 2021.

History of article:
Received: 25 May 2026, Revised: 25 May 2026, Published: 4 June 2026

- H. Husnayaen, P. Amela, D. P. Arini, dan I. K. A. Putra, “Pemetaan Sebaran Dan Kerapatan Hutan Mangrove Menggunakan Machine Learning Pada Google Earth Engine Dan Sistem Informasi Geografi Di Pulau Bali,” J. Perikan. Unram, vol. 13, no. 1, hal. 266–277, 2023, doi: 10.29303/jp.v13i1.474.
- Kumparan, “Mengenal Tahura Ngurah Rai, Tempat Tanam Bakau KTT G20,” Nov 16, 2022.
- D. M. Alongi, Mangrove forests: Resilience, protection from tsunamis, and responses to global climate change, vol. 76, no. 1. 2008.
- M. Dimyati, A. P. Nurhaliza, dan A. Damayanti, “Spatial Analysis of Health and Physical Parameters of the Mangrove Forest at Taman Hutan Raya Ngurah Rai, Bali Using Sentinel-2A,” Indones. J. Geogr., vol. 54, no. 2, hal. 135–142, 2022, doi: 10.22146/ijg.69840.
- D. E. Marois dan W. J. Mitsch, “A Mangrove Creek Restoration Plan Utilizing Hydraulic Modeling,” Atmos. Environ., vol. 23, no. 1994, hal. 248–258, 2017, doi: 10.1016/j.hal.2017.06.001.Submit.
- Z. He et al., “Linkage Between Mangrove Seedling Colonization, Sediment Traits, and Nitrogen Input,” Front. Mar. Sci., vol. 9, no. March, hal. 1–10, 2022, doi: 10.3389/fmars.2022.793818.
- H. Ren, L. Yang, dan N. Liu, “Nurse plant theory and its application in ecological restoration in lower subtropics of China,” Prog. Nat. Sci., vol. 18, no. 2, hal. 137–142, 2008, doi: 10.1016/j.pnsc.2007.07.008.
- G. D. P. Wedayana, I. W. G. A. Karang, dan A. R. As-syakur, “Estimasi Simpanan Karbon Hutan Mangrove Menggunakan Citra (SAR) Synthetic Aperture Radar Sentinel -1 di Taman Hutan Raya Ngurah Rai,Bali,” J. Mar. Res. Technol., vol. 6, no. 1, hal. 13, 2023, doi: 10.24843/jmrt.2023.v06.i01.p03.
- Pujianiki Ni Nyoman; 2025. “Implementation of Artificial Mangrove Roots FADS in Preventing Abrasion.” 2025(01).
- Charoenlerkthawin, Warit. 2025. “Field Evidence of a Nature-Inspired Solution to Mitigate the Impacts of Hard Coastal Structures.” *Ocean Land Atmosphere Reseach*.
- Warit Charoenlerkthawin, Thanawatth Sattabongkot, Narakorn Srinil, Yan Naung Aye, Ni Nyoma Pujianiki, Butsawan Bidorn., 2025. Field Evidence of Nature-inspired Solution to Mitigate Impacts of Hard Coastal Structures, Ocean-Land-Atmosphere Research 107 (https://doi.org/10.34133/olar.0107), 44.
- Pujianiki, N.N., Sattabongkot, T., Charoenlerkthawin, W., Bidorn, B., Armono, H.D.,Sugianto, D.N., 2025. Implementation of artificial mangrove roots FADS in Preventing Abrasion. Journal of Innovation and Technology 2025 (1), 1–8.
- N. N. Pujianiki, “Coastline changes monitoring induced by man-made structures using synthetic aperture radar: A new simple approach,” in IOP Conference Series: Earth and Environmental Science, Institute of Physics, 2022. doi: 10.1088/1755-1315/1117/1/012041.
- N. N. Pujianiki, K. Gede, P. Airlangga, G. Bagus, and S. Dharma, “Analysis of The Utilization of Sentinel-2 Imagery for Satellite-Derived Bathymetry Using Lyzenga Algorithm (Case Study: Bali Province),” 2023. [Online]. Available: https://scihub.copernicus.eu/dhus.
- N. N. Pujianiki, G. R. P. A. Simpangan, S. G. Tonyes, K. G. P. Airlangga, I. N. Simpen, and M. S. I. Bin Ibrahim, “The Impact of Sanur Harbor Development on Shoreline Changes at Sanur Beach Using Sentinel-2 Satellite Imagery,” Construction Technologies and Architecture, vol. 16, pp. 31–42, 2025, doi: 10.4028/p-uH8VRl.