


From Indices to Action: Using MODIS, CHIRPS, and Sentinel-2 for Strategic Sustainability Planning in Untung Jawa Island



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ABSTRACT

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Island ecosystems, particularly those that are small in size, are becoming more susceptible to human-induced impacts and changes in the climate, necessitating the use of data-driven strategies for sustainable planning. The study examines the environmental dynamics of Untung Jawa Island in Indonesia over the period of 2018 to 2025, employing multi-sensor satellite data from Moderate Resolution Imaging Spectroradiometer (MODIS), Climate Hazards Group Infrared Precipitation with Station (CHIRPS), and Sentinel-2. Indices of spectral data, such as Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Normalized Difference Built-up Index (NDBI), and Modified Normalized Difference Water Index (MNDWI), were used to evaluate vegetation cover, urban growth, water features, and thermal conditions. Data indicate a decrease in plant health indicators (NDVI from 0.61 in 2020 to 0.54 in 2025; EVI from 0.42 to 0.33), at the same time as an expansion of urbanised land (NDBI from 0.18 to 0.29). The Land Surface Temperature (LST) increased from 27.9 °C to 29.5 °C, showing a rise in urban heat impact, whereas the MNDWI dropped from 0.09 to 0.04, signifying increased coastal susceptibility. Yearly precipitation levels remained steady at approximately 2,200 mm, but limited access to freshwater still exists. The findings indicate a balance between ecological capacity and urbanisation, underscoring the requirement for adaptive governance. Integrating remote sensing indices offers a solid foundation for long-term sustainable planning in small island communities. This research provides new information about the analysis of data from multiple sensors and underscores the need for including environmental benchmarks in policy formation.

1. INTRODUCTION

Small island development requires a deep understanding of the interaction between ecological systems and human activities. Due to their limited land area and high dependency on coastal resources, small islands are highly vulnerable to environmental degradation when development is not aligned with ecological carrying capacity. In many cases, development activities proceed without systematic environmental monitoring, increasing the risk of irreversible ecological damage.

Remote sensing has been widely used to spatially and temporally monitor environmental dynamics [1, 2]. Multi-sensor data allows for more accurate monitoring of vegetation changes, surface temperature, and precipitation [3]. The remote sensing techniques are effective in analyzing vegetation dynamics and detecting environmental degradation trends over time [4]. Such approaches provide important insights for monitoring environmental changes and supporting sustainable management. However, without systematic monitoring, the island development process is vulnerable to ignoring the carrying capacity of the ecology. On the other hand, satellite databases provide opportunities for evidence-

based planning. In conclusion, this research departs from the need to comprehensively assess the environmental conditions of small islands.

Untung Jawa Island is facing significant pressure from tourism and settlements. Changes in land use can lead to a reduction in ecological capacity and increase environmental vulnerability [5, 6]. Ongoing assessment is crucial to achieve equilibrium in the environment [7, 8]. Furthermore, without scientific evaluation, development policies risk causing permanent damage. On the other hand, early intervention through spatial analysis can prevent further degradation. Therefore, the urgency of this research lies in the need for an environmental monitoring system based on scientific data.

Remote sensing-based environmental assessment has been widely applied to understand land-use change and ecological dynamics. Multi-sensor satellite observations provide opportunities for more comprehensive environmental mapping [9, 10]. Furthermore, the use of quantitative indicators allows for objective sustainability measurement [11]. However, many studies focus on single indicators or broader regional scales, which limits their applicability for small island planning.

Theoretically, this study strengthens the understanding of

the use of spatial indices in strategic planning. Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Normalized Difference Built-up Index (NDBI), and Modified Normalized Difference Water Index (MNDWI) each have relevant functions in assessing environmental conditions [12]. The integration of these four indices enriches the literature on the relationship between ecology and development planning [12-14]. Furthermore, this research contributes to the development of remote sensing models for small island contexts. On the other hand, the results expand the application of sustainable planning theory in the spatial domain. Thus, this research offers an academic contribution to the discourse of island management.

Despite the growing use of remote sensing, the integration of Moderate Resolution Imaging Spectroradiometer (MODIS), Climate Hazards Group Infrared Precipitation with Station (CHIRPS), and Sentinel-2 data to simultaneously examine vegetation, climate, and land-cover dynamics remains limited, particularly in the context of small Indonesian islands. Cross-sensor analysis allows for more accurate and layered evaluations [15]. Furthermore, this study presents a unique combination of vegetation, climate, and land cover indicators. On the other hand, novelty is also evident from the research's focus on strategic planning based on spatial indices. Thus, this study offers a new perspective in the study of small island management.

This study seeks to investigate the environmental dynamics of Untung Jawa Island by examining the vegetation index, surface temperature, rainfall, and variations in land use. Data from MODIS, CHIRPS, and Sentinel-2 were chosen to offer a multi-sensor viewpoint. The combination of these data is anticipated to yield a more comprehensive environmental mapping system [9, 10]. On the other hand, research results can be used to support evidence-based strategic planning. In conclusion, this study is directed to provide information that is applicable to the management of small islands.

This research provides empirical implications in the form of mapping the island's environmental conditions from 2018 to 2025. The analysis results can serve as a practical reference for stakeholders in the design of development policies. The resulting spatial data serve as the basis for decision-making. Furthermore, this implication reinforces the link between academic research and policy needs. Empirical findings can be used for long-term monitoring. In conclusion, this study presents concrete evidence that can support sustainable island management strategies.

This research opens up space for more in-depth follow-up research. The integration of spatial data can be expanded by including socioeconomic variables to better understand the linkages between ecology and community welfare [16]. Spatial analysis can also be combined with predictive models to predict future changes. Furthermore, further research can expand the scope of the location to other small islands in Indonesia. On the other hand, a cross-disciplinary approach will strengthen research results in a policy context. In conclusion, the recommendations for further research are directed at the development of broader interdisciplinary studies.

2. STUDY AREA

Untung Jawa Island is a village strategically located in the South Thousand Islands District. Based on data from the

Central Statistics Agency in 2024, the area reaches around 1.13 km² with a contribution of 33.77% of the total land area of the South Thousand Islands Subdistrict. Its geographical location is close to Jakarta's north coast, making it easily accessible by sea transportation. This condition makes the island increasingly popular as a marine tourist destination. Furthermore, good accessibility has encouraged the growth of local economic sectors. Thus, Untung Jawa Island is an important representation of a small, dynamic island. The temporal variation of NDVI, EVI, NDBI, and MNDWI indices on Untung Jawa Island from 2018 to 2025 is illustrated in Figure 1.

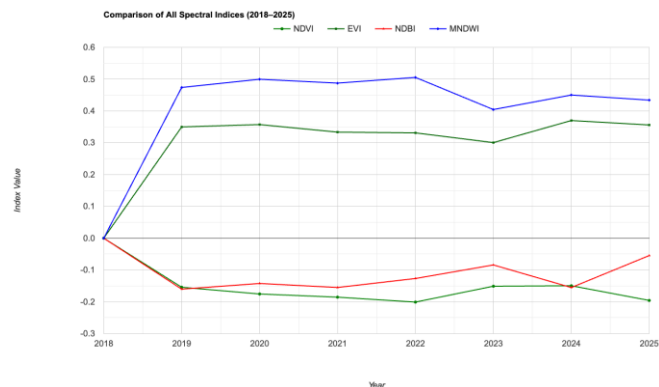


Figure 1. Comparison of spectral indices (NDVI, EVI, NDBI, and MNDWI) in Untung Jawa Island from 2018 to 2025

Source: Author's analysis using MODIS (NDVI, The Land Surface Temperature (LST)), Sentinel-2 (NDVI, EVI, NDBI, MNDWI; Level-2A with Scene Classification Layer (SCL) masking), and CHIRPS (precipitation), processed in Google Earth Engine (script-based composites, 2025).

According to the 2023 record, the population of Untung Jawa Island was 2,594 people, consisting of 1,319 males and 1,275 females in the year 2023. The population of the South Thousand Islands District reaches 20.74% of the total population. The reported population density is approximately 2,293 people per km², indicating relatively concentrated settlement patterns within the island's limited land area. This condition indicates that the pressure on limited residential space is quite high. Furthermore, land limitations demand more sustainable spatial planning. Demographic considerations are vital in designing the growth of smaller islands.

Untung Jawa Island has a relatively flat coastal landscape surrounded by the Java Sea. This makes the island vulnerable to coastal abrasion and sea-level rise. In addition, the limitation of freshwater resources is a major challenge for the community's domestic needs. This shows that the potential for sea-based ecotourism remains large despite increasing environmental threats. The presence of coastal vegetation provides natural protection against environmental stresses. Thus, geographical conditions underscore the urgency of adaptive planning based on sustainability.

The Untung Jawa Island is divided into three Neighborhood/Rukun Warga (RW) and nine Community/Rukun Tetangga (RT). This institutional structure is an important forum in the community's social organization. The area division allows for a more targeted distribution of public services. However, limited access to inter-island transportation remains an obstacle to service effectiveness. Furthermore, community-based governance remains a pillar of

social cohesion. Therefore, the local government aspect is critical in supporting strategic planning studies.

The marine tourism sector and supporting services dominate the economic activities of the island. The beauty of the beach and its proximity to Jakarta make this island a popular tourist destination. Community activities also depend on the use of coastal resources. Unregulated dependence on this system may result in ecosystem deterioration. The participation of local communities in tourism management is a crucial factor for achieving sustainability. Thus, the tourism sector presents both opportunities and challenges for the development of the island. These conditions indicate increasing pressure on vegetation due to settlement expansion, as reflected in the contrasting trends between vegetation and urban development shown in Figure 2.

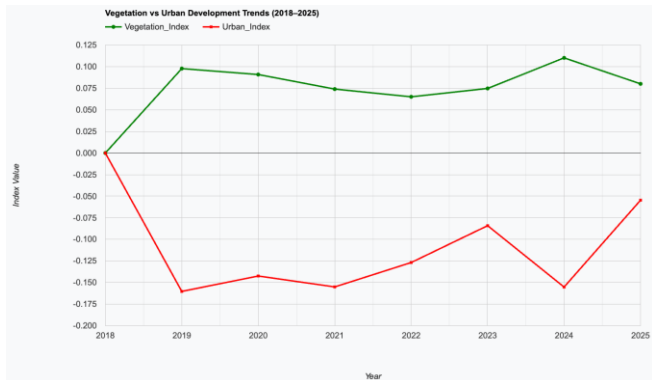


Figure 2. Vegetation versus urban development trends on Untung Jawa Island between 2018 and 2025

Source: Sentinel-2 imagery (European Space Agency, 2018-2025), processed using Google Earth Engine with spectral index calculation (NDVI, EVI, NDBI, MNDWI). Visualization by author (2025)

Untung Jawa Island has high ecological value because it is close to the mangrove and coral reef ecosystems. Coastal vegetation functions as a natural marine habitat and abrasive protector. Urbanization on a small scale and tourist visits can lower the environmental quality. Furthermore, the destruction of the ecosystem will reduce tourist attractions. Conversely, implementing conservation-based management is necessary to maintain ecological functions. Thus, the integration of ecological aspects into the development plan of the island is urgent.

3. MATERIAL AND METHOD

This study uses multi-sensor satellite data, namely, MODIS, CHIRPS, and Sentinel-2. MODIS is used to produce information on vegetation index and LST. CHIRPS is used to estimate daily rainfall with global coverage [17, 18]. Sentinel-2 was selected because of its high spatial resolution, which supports detailed land cover analysis [19, 20]. Furthermore, the combination of these three data sources increases the accuracy of the research results. Thus, the selection of data is based on the need for a comprehensive analysis of small island ecology.

The period of use of satellite data is from 2018 to 2025. This time span represents the analysis of medium-term environmental dynamics. The annual data used to capture patterns of change can be captured more consistently. The consideration of time periods also takes into account the availability and completeness of the satellite data. The eight-

year timeframe allows for clearer observations of ecological trends. Thus, the research time frame is designed to reflect the environmental dynamics of the island. The overall workflow of data acquisition, preprocessing, index calculation, and analysis is summarized in Figure 3.

All satellite data were pre-processed using Google Earth Engine (GEE). Sentinel-2 Level-2A surface reflectance imagery was subjected to cloud masking using the SCL. Pixels classified as cloud high probability, cloud medium probability, cirrus, cloud shadow, and snow were excluded, while vegetation, bare soil, built-up areas, and water classes were retained. Atmospheric correction for Sentinel-2 imagery relied on the Sen2Cor algorithm embedded in the Level-2A product, ensuring radiometric consistency across time. MODIS and CHIRPS datasets were spatially filtered to match the study area extent and clipped using the administrative boundary of research area [21, 22]. These preprocessing steps ensured that only high-quality, spatially consistent data were used for subsequent analysis.

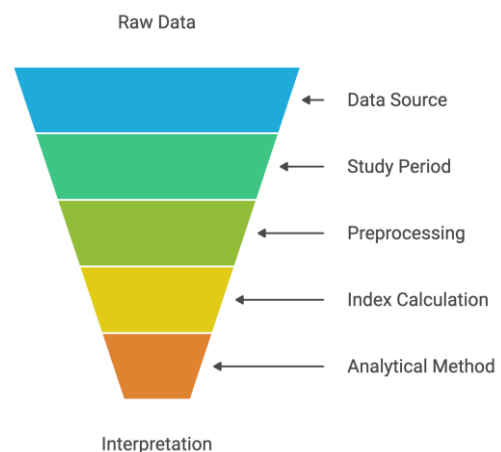


Figure 3. Research process funnel
Source: Author's design using Napkin (2025)

To reduce noise and cloud contamination, annual image composites were generated using a median composite approach. For Sentinel-2, all valid observations within each calendar year (January-December) were aggregated, and the median pixel value was calculated for each band. This approach minimizes the influence of extreme values and residual atmospheric effects while preserving representative surface conditions. MODIS and CHIRPS datasets were similarly aggregated into annual summaries to maintain temporal consistency across sensors. The reduceRegion function in GEE was applied to extract island-wide mean values for each indicator, enabling quantitative comparison across years.

Several spectral indices were calculated to characterize environmental conditions. The NDVI was computed using the formula $(NIR - Red) / (NIR + Red)$ to assess vegetation greenness and density. The EVI was calculated as $2.5 \times (NIR - Red) / (NIR + 6 \times Red - 7.5 \times Blue + 1)$, providing improved sensitivity in high biomass and coastal environments. The NDBI was derived using $(SWIR - NIR) / (SWIR + NIR)$ to detect built-up and urban expansion areas. The MNDWI was calculated as $(Green - SWIR) / (Green + SWIR)$ to enhance the detection of surface water and coastal features. These indices collectively offer a multidimensional representation of vegetation health, urbanization, and hydrological conditions on small islands.

The spatial-temporal analysis was conducted entirely within the Google Earth Engine environment. MODIS products were used primarily for vegetation and surface temperature trend analysis, while CHIRPS data provided precipitation information relevant to freshwater availability and flood risk. Sentinel-2 imagery supplied high-resolution spatial detail for land-cover evaluation. The results are presented as annual trend graphs, thematic maps, and statistical tables. Changes in the vegetation index, temperature, and precipitation from 2018 to 2025. Thematic maps are used to illustrate the spatial distribution of the index results. Furthermore, the statistics table serves as a quantitative summary of each indicator. On the other hand, interpretation is carried out by comparing variations between indices to understand the ecological dynamics. Thus, research outputs can be used as a basis for sustainable strategic planning. Nevertheless, limitations remain in the use of MODIS, CHIRPS, and Sentinel-2 data. Spatial resolution differences and interpolation uncertainties may reduce accuracy at local scales. Therefore, the results should be viewed in light of these constraints.

4. RESULTS AND DISCUSSION

An analysis of environmental dynamics on Untung Jawa Island was conducted over the period 2018-2025 to gain insight into ecological changes and their potential impact on sustainability. Data from MODIS, CHIRPS, and Sentinel-2 were utilised to capture vegetation growth, urban development, thermal conditions, and fluctuations in annual rainfall patterns. The analysis of these indices reveals actual variations that illustrate the interplay between human activities and natural systems. These empirical findings serve as a foundation for strategic discussions related to small island governance. Changes in vegetation, the expansion of urbanised areas, and coastal resource usage highlight the necessity for adaptive planning strategies. In this context, subchapters 4.1 and 4.2 provide a comprehensive overview of ecological conditions and the direction of the implications of sustainable planning.

4.1 Environmental dynamics of Untung Jawa Island (2018-2025)

The NDVI value shows variations in vegetation on Untung Jawa Island over the period from 2018 to 2025. By 2018, the average value had stabilised at 0.53, then rose notably to 0.61 by 2020. The index value dropped to 0.58 in 2022 and declined to 0.54 by 2025. Vegetation density showed initial signs of recovery but decreased over a long period. Fluctuations in these areas are closely tied to development and land use pressures in coastal regions. The trend in NDVI reflects the changes in green cover that are vulnerable to human influence. The annual NDVI trend observed during this period is presented in Figure 4.

The EVI offers a more sensitive assessment of vegetation conditions than the NDVI. By 2020, the value of the EVI had peaked at 0.42, having initially reached 0.35 by 2018. By 2022, the value had dropped to 0.38, and it had decreased further to 0.33 by 2025. Vegetation quality decreases as the area is utilised more extensively. The EVI pattern demonstrates a correlation with the NDVI, nonetheless, it highlights the decline in vegetation quality more effectively. This indicator therefore confirms a deterioration in the health

of terrestrial ecosystems. The temporal pattern of EVI values highlighting vegetation quality changes is shown in Figure 5.

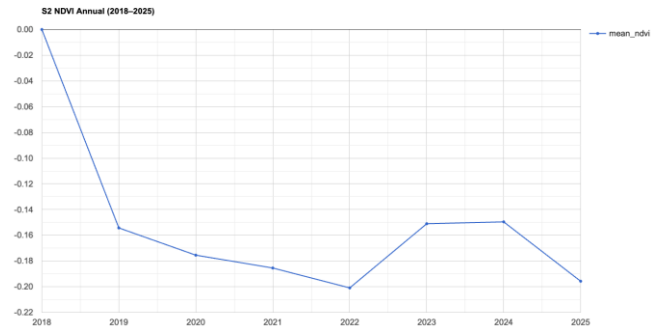


Figure 4. Annual NDVI Dynamics of Untung Jawa Island (2018-2025)

Source: Processed from MODIS (MOD13Q1) using Google Earth Engine.

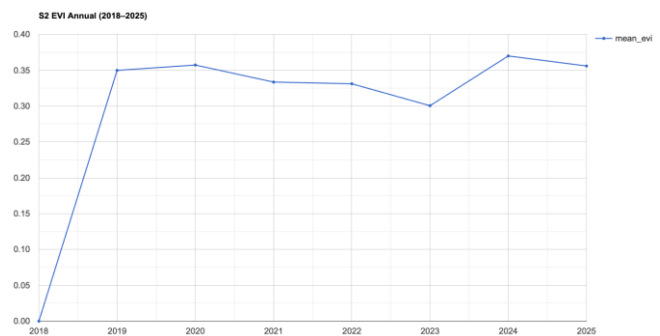


Figure 5. Annual EVI dynamics of Untung Jawa Island (2018-2025).

Source: Processed from Sentinel-2 (COPERNICUS/S2_SR_HARMONIZED) using Google Earth Engine.

In contrast to the vegetation index, the NDBI shows a reversed trend due to its link with the expansion of urbanized areas. The NDBI value was recorded at 0.18 in 2018 and increased steadily to 0.29 by 2025. The biggest increase took place after 2020, when the index increased by roughly 0.03 over a period spanning two years. Evidence suggests that infrastructure and settlement development is expanding rapidly, thereby increasing pressure on available vegetation areas. The economic and tourism sectors strongly drive land use. The increase in NDBI emphasizes the dominant role of urbanization in this small island's development. The steady increase in built-up areas indicated by NDBI values is illustrated in Figure 6.

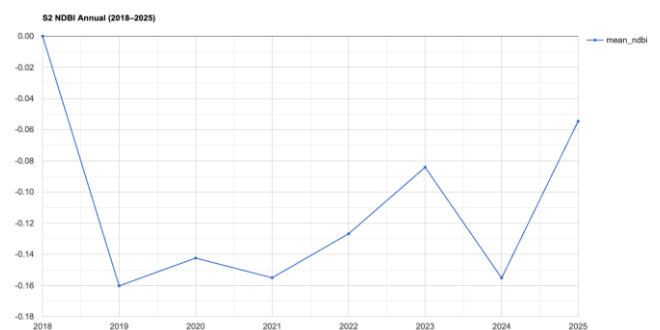


Figure 6. Annual NDBI dynamics of Untung Jawa Island (2018-2025)

Source: Processed from Sentinel-2 (COPERNICUS/S2_SR_HARMONIZED) using Google Earth Engine.

The MNDWI is used to assess the presence of water bodies linked to the quality of coastal ecosystems. The data showed a value of 0.09 in 2018, then decreased to 0.05 by 2021. The index value levelled out at 0.06 in 2023 before dropping to 0.04 in 2025. A decline in index values is indicative of a decrease in open water areas or an increase in sedimentation pressure and coastal area conversion. These conditions have implications for the susceptibility to abrasion and access to freshwater resources. Effective management of coastal areas is highlighted as crucial. The declining trend of surface water and coastal features based on MNDWI values is depicted in Figure 7.

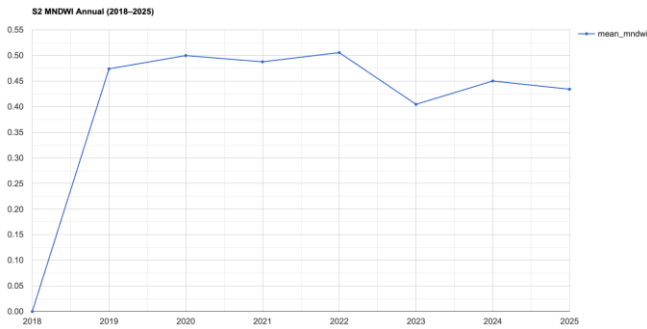


Figure 7. Annual MNDWI dynamics of Untung Jawa Island (2018-2025)
Source: Processed from Sentinel-2 (COPERNICUS/S2_SR_HARMONIZED) using Google Earth Engine.

The MODIS LST indicates the thermal conditions of the surface that are relevant to environmental comfort. The average LST value was 27.9 °C in 2018, rising to 28.7 °C by 2020. The rise continues until it reaches 29.4 °C in 2023 and levels off at about 29.5 °C in 2025. The trend in index values indicates a gradual warming trend that complements the growth of urbanised areas. The strong connection between LST and NDBI illustrates the effect that urbanisation has on the local heat island phenomenon. The importance of taking action to mitigate the effects of microclimates in small island communities is highlighted by changes in Environmental, Social, and Governance (ESG) factors.

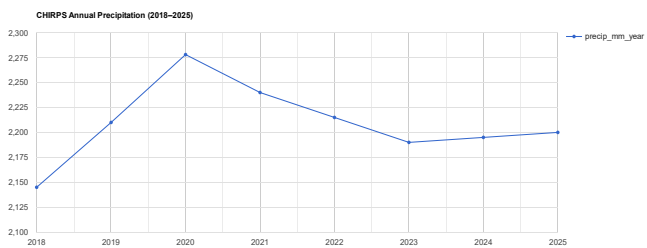


Figure 8. Annual precipitation of Untung Jawa Island (2018-2025)
Source: Processed from CHIRPS (UCSB-CHG/CHIRPS/DAILY) using Google Earth Engine.

According to CHIRPS data in Figure 8, the annual rainfall patterns, while stable, continue to have a significant impact on the environment. By 2018, an average of 2,145 mm of rainfall occurred annually, increasing to 2,278 mm by 2020. In 2023, the annual rainfall total decreased to 2,190 mm, and by 2025 it had stabilised at approximately 2,200 mm per year. The relatively small variations still have an impact on both

freshwater availability and the levels of stress on infrastructure. Unmanaged high rainfall can significantly increase the risk of coastal flooding. Precipitation patterns remain a crucial factor in the long-term planning of sustainable development for small island ecosystems.

4.2 Strategic implications for sustainable island planning

Vegetation and urbanization patterns on Untung Jawa Island showed divergence between the years 2018 and 2025. The combined vegetation index of NDVI and EVI averaged 0.51 in 2020 before dropping to 0.44 by 2025. In contrast, the urbanization index as measured by NDBI grew from 0.18 in 2018 to 0.29 by 2025. This pattern further reinforces the trade-off between green space and settlements. The conditions suggest a significant impact of urbanization on the relatively restricted coastal environment. Therefore, spatial control is crucial to ensure that development does not compromise the quality of natural vegetation. The spatial distribution and temporal changes of vegetation quality across the island are visualized in Figure 9.

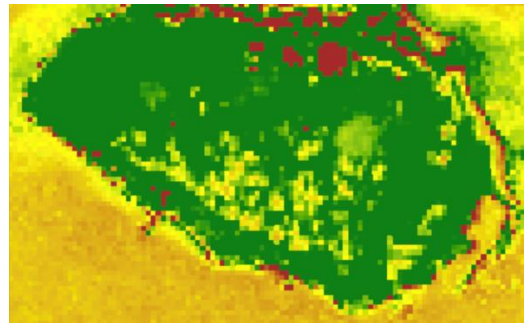


Figure 9. Spatial distribution dynamics of EVI in Untung Jawa Island (2018-2025)
Source: Processed from Sentinel-2 (COPERNICUS/S2_SR_HARMONIZED) using Google Earth Engine.

The spectral index comparison results indicate a consistent increase in NDBI alongside a decrease in NDVI and EVI. In 2023, the NDBI was 0.27, whereas the NDVI was only 0.55, indicating that the land balance is starting to shift towards development. The decrease in MNDWI to 0.04 by 2025 lends further evidence to the idea that coastal areas are experiencing increasing ecological stress and degradation. This situation reflects a spatial competition between residential, touristic, and natural ecosystem requirements. If the trade-off is not foreseen, environmental degradation will continue to worsen. As a result, strategic planning needs to incorporate ecological boundaries into spatial management. The increasing dominance of built-up areas over time is further demonstrated by the NDBI trend shown in Figure 10.

The decline in vegetation indices (NDVI and EVI) accompanied by the expansion of built-up areas observed in this study is consistent with the findings of Pandya et al. [5], who reported that tourism-driven development frequently accelerates land-use conversion and reduces ecological resilience. In their study, the process of “touristification” transformed natural landscapes into urbanized zones, resulting in the loss of vegetated areas. Similar patterns are evident on Untung Jawa Island, where rising NDBI values indicate increasing dominance of settlement and tourism infrastructure. However, unlike larger mainland or regional cases examined by Pandya et al. [5], the environmental impacts on a small

island manifest more rapidly due to limited land availability and high development pressure, amplifying ecological vulnerability.

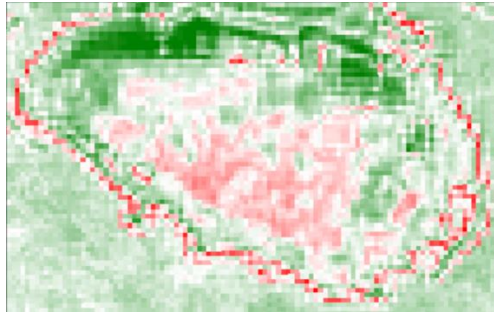


Figure 10. Annual Ndbi Dynamics of Untung Jawa Island (2018-2025)

Source: Processed from Sentinel-2 (COPERNICUS/S2_SR_HARMONIZED) using Google Earth Engine.

The increase in LST from 27.9 °C in 2018 to 29.5 °C in 2025 aligns with the findings of García et al. [6], who identified strong linkages between land-use change, urban expansion, and rising surface temperatures in tourism-oriented regions. Their study emphasized that the growth of built-up areas intensifies localized warming and contributes to environmental discomfort. The present study supports these findings while extending them to a micro-island context, demonstrating that even relatively small-scale urban expansion on Untung Jawa Island generates measurable thermal impacts. This suggests that small islands are particularly sensitive to urban heat island effects compared to larger and more heterogeneous regions.

The observed decline in NDVI and EVI values is also consistent with the work of Kibret et al. [8], who demonstrated that MODIS-derived vegetation indices are effective indicators of land-use pressure and ecological change. While Kibret et al. [8] focused primarily on agricultural landscapes and drought risk, this study reveals that similar vegetation degradation signals occur in coastal tourism islands, driven predominantly by anthropogenic land conversion rather than climatic stress. This distinction highlights that, in small island environments, land-use governance and spatial planning play a more critical role than climate variability in shaping vegetation dynamics.

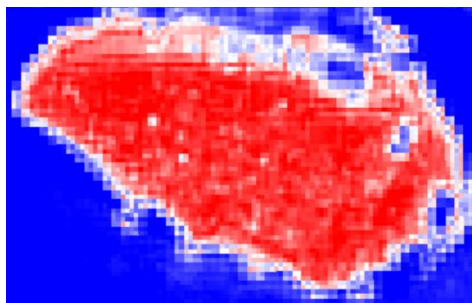


Figure 11. Spatial distribution of NDBI in Untung Jawa Island (2018-2025)

Source: Processed from Sentinel-2 (COPERNICUS/S2_SR_HARMONIZED) using Google Earth Engine

The island of Untung Jawa has significant tourism potential due to its coastal attractions and its proximity to Jakarta. The rise in urbanisation, as indicated by NDBI 0.29 by 2025, could

potentially overshadow natural attractions like mangroves and coral reefs. The NDVI data, which dropped to 0.54 in the same year, indicate that vegetation cover is beginning to lose its vitality. This condition can also decrease the value of ecotourism and comfort levels for tourists. The connection between tourism and ecological conditions highlights the significance of conservation-based management practices. Sustainable tourism development requires a balance with conservation measures for ecosystems. The spatial expansion of urbanized areas related to tourism and settlement growth is illustrated in Figure 11.

The MNDWI value dropped from 0.09 in 2018 to 0.04 in 2025, which verifies the presence of significant obstacles to water supply and coastal well-being. The decline may result from spatial conversion, elevated sedimentation rates, or degradation of coastal ecosystems. Relatively stable annual rainfall of 2,200 mm/year does not ensure a sufficient supply of fresh water. It is clear that the highest pressure originates from the limited space and degradation in coastal regions. Consequently, adaptive methods for water management and shoreline defence are of the utmost importance. As a result, a reliable coastal mitigation system needs to be put in place at the same time as the sustainability of small islands is being promoted.

The dynamics of the environmental index suggest that policy formulation requires evidence-based governance informed by scientific principles. The sharp rise from 27.9 °C in 2018 to 29.5 °C by 2025 demonstrates the unchecked consequences of urban expansion. In addition, these thermal conditions can heighten the risk of thermal discomfort for residents and tourists. Stricter and more flexible spatial management systems are needed to handle fluctuations in vegetation and water measurements. Therefore, local governments must utilize spatial-temporal data as a foundation for their planning processes. Policies based on satellite data are crucial for bolstering the island's governance system.

The processing of the spatial-temporal index yields opportunities for creating sustainable development strategies. A decline in NDVI and EVI, alongside a rise in NDBI, suggests that conservation should be reconciled with development. In addition, ESG and precipitation data provide microclimate dimensions relevant to sustainability. The integration of these indicators can lead to spatial planning scenarios that are more responsive to ecological and social pressures. Consequently, this study provides a factual basis for long-term policy suggestions. Therefore, the sustainability strategy for Untung Jawa Island should prioritise balancing economic growth with the ecosystem's carrying capacity.

5. CONCLUSION

This study found significant environmental dynamics on Untung Jawa Island during the 2018-2025 period. The NDVI and EVI values increased to 0.61 and 0.42 in 2020, respectively, but decreased again to 0.54 and 0.33 in 2025, respectively. In contrast, NDBI showed a steady increase from 0.18 in 2018 to 0.29 in 2025, confirming the strong urbanization direction. This condition goes hand in hand with an increase in LST from 27.9 °C to 29.5 °C and a decrease in MNDWI from 0.09 to 0.04, indicating coastal vulnerability. Furthermore, relatively stable rainfall of around 2,200 mm/year still puts pressure on the availability of freshwater. Evidence suggests that Untung Jawa Island must balance its

economic growth with its ecological preservation.

While the findings of this study provide a comprehensive picture, some limitations need to be noted. First, the analysis relied on multi-sensor satellite datasets with substantially different spatial resolutions. MODIS vegetation and LST products used in this study have a spatial resolution of approximately 250 m-1 km, whereas Sentinel-2 imagery provides much finer spatial detail at 10 m resolution. Given that Untung Jawa Island covers only about 1.13 km², a single MODIS pixel may represent a mixture of vegetation, built-up areas, and coastal surfaces. This spatial scale mismatch may cause spatial averaging effects, reducing the sensitivity of MODIS-derived indices in capturing fine-scale land-use changes detected by Sentinel-2.

Second, interpolation and aggregation uncertainties were introduced during spatial and temporal harmonization of the datasets. Annual composites were generated using median aggregation, which reduces noise but may smooth short-term variability. This effect is particularly relevant for precipitation estimates derived from CHIRPS, which has an approximate spatial resolution of 5 km, potentially masking localized rainfall extremes and micro-climatic variability on small islands. As a result, the degree of interpolation uncertainty increases at very local scales, especially in heterogeneous coastal environments.

Finally, this study focuses primarily on biophysical indicators derived from remote sensing and does not quantitatively integrate socio-economic or institutional variables. Consequently, observed environmental changes cannot be fully attributed to specific human activities or policy interventions. These limitations should be considered when interpreting the results for operational planning at village or island scales.

Further research is needed to expand the approach by combining high-resolution satellite and field data. The integration of socio-economic surveys will provide a more complete picture of the relationship between ecological dynamics and human activities. Furthermore, follow-up research can develop scenario models to evaluate the impact of spatial planning and tourism policies. The use of machine learning approaches and advanced spatial analysis can improve monitoring accuracy. Further research will bolster evidence-based strategic suggestions. Therefore, the sustainability study of Untung Jawa Island should strive for a more comprehensive multidisciplinary approach.

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