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Analysis of Land Use Change Based on NDVI and Bamboo Conservation Strategy for Climate Change Mitigation and Water Conservation in the Canggu Watershed

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ABSTRACT : Rapid land use change driven by tourism and urbanization in coastal Bali, particularly within the Yeh Luwi watershed in Canggu, has intensified environmental degradation. The conversion of vegetated areas into built-up land has disrupted hydrological balance, reduced infiltration, increased surface runoff, and elevated flood and sedimentation risks, while vegetation loss has diminished carbon sequestration capacity, exacerbating local climate vulnerability and seawater intrusion in coastal zones. Although numerous studies have employed the Normalized Difference Vegetation Index (NDVI) to assess vegetation dynamics in Bali, few have focused specifically on the Canggu–Yeh Luwi watershed, which faces severe urbanization pressure. Existing research mostly emphasizes spatial land use mapping without connecting the findings to ecological restoration or vegetation-based mitigation strategies, and studies integrating bamboo conservation—a species with high hydrological and carbon-sequestration value—into coastal watershed management remain limited. This study integrates NDVI-based spatial analysis with bamboo conservation strategies to develop a holistic, nature-based approach for watershed restoration and climate mitigation. Landsat imagery from 2015–2025 was processed using QGIS to compute NDVI values through the formula NDVI = (NIR – Red) / (NIR + Red). NDVI results were classified into six land use categories—Water, Built-up, Barren Land, Shrub and Grassland, Sparse Vegetation, and Dense Vegetation—and land use change was quantified by comparing NDVI-derived areas between 2015 and 2025. Overlay analysis identified degradation zones and conservation priorities, with areas shifting from Dense Vegetation to Built-up designated as Priority 1 for restoration using bamboo-based mitigation. The NDVI analysis revealed a drastic reduction in Dense Vegetation (−74.84%) and Sparse Vegetation (−52.96%) alongside a 327.31% increase in Built-up areas, indicating severe ecological degradation. Integrating NDVI monitoring with bamboo conservation thus offers a data-driven, nature-based framework to restore hydrological functions and enhance climate resilience in tropical coastal watersheds like Yeh Luwi.

KEYWORDS - NDVI, land use change, bamboo conservation, Yeh Luwi watershed, nature-based solutions, climate resilience

I. INTRODUCTION

Rapid land use change in the coastal regions of Bali, particularly in the lower Yeh Luwi River area (Canggu, Badung), has become one of the main environmental management challenges. Massive tourism growth and urbanization have driven the conversion of vegetated land into built-up areas, leading to the degradation of ecosystem quality [1], [2], [3]. The loss of vegetation cover has increased surface runoff, flood risk, and riverbank degradation, triggering erosion and sedimentation[4], [5], [6]. Additionally, the reduction of infiltration areas has decreased groundwater recharge, increasing vulnerability to seawater intrusion in coastal zones. From a climate change perspective, the reduction in vegetation also lowers the environment’s capacity for carbon sequestration, worsening local microclimate conditions. These issues highlight the importance of monitoring land use change while implementing nature-based solutions to reduce hydrometeorological disaster risks and strengthen local climate resilience. Previous studies have utilized the Normalized Difference Vegetation Index (NDVI) to monitor land use change in Bali and other coastal regions of Indonesia [7]. However, studies specifically focusing on the Canggu watershed that discharges into the Yeh Luwi estuary remain limited, even though this area experiences the highest urbanization pressure due to tourism development. Most NDVI studies emphasize land use analysis without integrating vegetation conservation strategies for ecosystem restoration. Research linking bamboo . conservation with climate change mitigation and water Conservation in coastal regions is still scarce, Even though bamboo possesses significant ecological and hydrological functions, such as soil stabilization, enhanced infiltration, and carbon absorption. NDVI has proven effective in monitoring vegetation dynamics and ecosystem degradation in tropical regions [8], [9]. Meanwhile, studies have shown that rapid urbanization in Bali has accelerated the conversion of agricultural and vegetated land into tourism and residential zones[10], [11]. Yet, specific analyses of the Canggu watershed are still limited, despite its high environmental degradation risk. Bamboo has been recognized as an effective nature-based solution [12], [13], [14] due to its dense root system that prevents erosion, high biomass enabling carbon sequestration, and capacity to enhance infiltration crucial for groundwater conservation. Globally, recent watershed management trends emphasize the integration of spatial monitoring and conservation vegetation for disaster risk mitigation and climate adaptation[15], [16]. Therefore, combining NDVI-based spatial analysis with bamboo conservation offers strong scientific and practical relevance. This study focuses on the Canggu watershed, which experiences intense development pressure from tourism. The approach emphasizes bamboo's dual function: climate change mitigation through increased carbon sequestration and water conservation through improved hydrological function. Furthermore, the study offers a spatial data-based model for vegetation rehabilitation planning using a nature-based solution approach. This integration is rarely found in previous studies and thus contributes significantly to sustainable watershed management in tropical coastal regions. The objectives of this study are: (1) to analyze land use change in the lower Yeh Luwi River between 2015 and 2025 using NDVI; (2) to evaluate the implications of vegetation loss for climate change mitigation and water conservation; and (3) to formulate a bamboo-based conservation strategy to reduce disaster risks and strengthen local climate resilience. The results are expected to provide a scientific basis for sustainable watershed management planning.

II. RESEARCH METHODS

Research Location : The study was conducted in the Canggu Watershed, covering the upstream to downstream areas, with a particular focus on the lower part at the Yeh Luwi estuary, North Kuta District, Badung Regency, Bali. The watershed plays an important role in regulating water flow from highlands to the coast and serves as a critical area for mitigating disasters such as floods and high wave[17]. The upstream area of the Canggu watershed is dominated by agricultural and semi-natural vegetation, contributing to rainfall absorption and erosion control. In contrast, the middle to lower areas have experienced significant land conversion into residential, villa, and tourism facilities, especially near the Yeh Luwi estuary. The estuary itself is a low-lying coastal plain directly connected to the Bali Sea, making it vulnerable to tidal flooding, seasonal inundation, and seawater intrusion, especially during heavy rainfall or high tides.

Data Requirements : The study utilized Landsat satellite imagery with a spatial resolution of 30 meters, obtained from the United States Geological Survey (USGS) Earth Explorer platform. Landsat imagery is particularly suitable for land use and land cover (LULC) analysis because it provides a balance between spatial, temporal, and spectral resolutions. The imagery typically includes seven multispectral bands (Bands 1–7 for Landsat 5 TM or Landsat 7 ETM+, and Bands 2–7 for Landsat 8 OLI), covering wavelengths from the visible to shortwave infrared spectrum. These bands enable detailed identification of vegetation, water bodies, built-up areas, and bare land based on their distinct spectral reflectance characteristics. he watershed boundary data were sourced from the Bali-Penida River Basin Authority (Balai Wilayah Sungai Bali-Penida). This dataset defines the hydrological boundary of the study area and ensures that all analyses (e.g., land cover change, NDVI extraction, and morphometric analysis) are confined within the official watershed extent. The boundary was provided in vector (shapefile) format, projected in the UTM Zone 50S coordinate system (WGS 84 datum), which aligns with the projection used in the Landsat imagery, ensuring spatial consistency and accurate overlay.

All image processing and spatial analyses were conducted using Geographic Information Systems (GIS) and remote sensing software, specifically QGIS, an open-source platform widely used for environmental and hydrological applications. The Raster Calculator tool in QGIS was employed to compute NDVI and other derived indices from the Landsat bands, while vector analysis tools were used to clip the imagery according to the watershed boundary and to quantify land cover changes in area (km^2).

Pre-processing : The pre-processing stage was a crucial step to ensure that all subsequent analyses were spatially and radiometrically accurate within the Yeh Luwi watershed. The first step involved cropping or masking the satellite imagery according to the official watershed boundary obtained from the Bali-Penida River Basin Authority. This ensured that all calculations—such as NDVI, land cover classification, and change detection—were performed strictly within the study area. The cropping was conducted in QGIS using the *Clip Raster by Mask Layer* function, and the coordinate reference system (CRS) was standardized to UTM Zone 50S (WGS 84) to maintain spatial consistency between datasets. After pre-processing, vegetation analysis was performed through Normalized Difference Vegetation Index (NDVI) computation. NDVI quantifies the greenness and vigor of vegetation by measuring the difference in reflectance between the near-infrared (NIR) and red bands.

NDVI Calculation : NDVI values were calculated using the formula:

$$NDVI = (NIR - Red) / (NIR + Red) \qquad (1)$$

For Landsat 8, band 5 (NIR) and band 4 (Red) were used. The resulting NDVI raster represented vegetation conditions in the Yeh Luwi estuary area.

NDVI Classification : The Normalized Difference Vegetation Index (NDVI) was classified to distinguish various land use and vegetation types surrounding the Yeh Luwi Estuary. The NDVI values were categorized into six classes representing different surface and vegetation conditions. Pixels with NDVI values less than 0.015 were identified as Water, indicating areas such as rivers, ponds, or coastal waters where vegetation is absent. NDVI values ranging from 0.015 to 0.14 correspond to Built-up Areas, which include settlements, roads, and other impervious surfaces that typically reflect low or negative NDVI values due to minimal vegetation cover. The range of 0.14 to 0.18 represents Barren Land, characterized by exposed soil or sand with little to no vegetation. NDVI values between 0.18 and 0.27 were classified as Shrubs and Grassland, indicating transitional zones dominated by low to medium vegetation density. The interval of 0.27 to 0.36 corresponds to Sparse Vegetation, which signifies areas with scattered plants or partially vegetated surfaces. Finally, NDVI values greater than 0.36 were classified as Dense Vegetation, representing well-developed green cover such as forests or dense mangrove stands. This classification enabled detailed spatial identification and analysis of land cover patterns and vegetation health in the Yeh Luwi Estuary region, providing essential information for assessing ecosystem conditions and monitoring environmental changes over time.

Spatial Analysis for Disaster Mitigation : NDVI classification results were used to identify disaster-prone zones. Low NDVI values in upstream areas indicated reduced infiltration capacity, increasing flood potential downstream. Low NDVI values on steep slopes indicated landslide susceptibility, while seasonal NDVI declines indicated drought vulnerability. In the coastal Yeh Luwi estuary, NDVI also served to monitor mangrove vegetation, a key indicator of coastal resilience against seawater intrusion.

Bamboo Conservation Strategy in the Lower Reaches : Areas with low NDVI in the lower estuary were prioritized for conservation. Bamboo planting was proposed along riverbanks and buffer zones, given bamboo’s ability to prevent erosion, enhance infiltration, and act as a natural buffer against flooding. Integrating bamboo with other vegetation types would strengthen ecosystem resilience while supporting disaster mitigation.

Interpretation for Mitigation : The resulting NDVI maps served as indicators of conservation priority zones. Areas with NDVI values below 0.3 were identified as requiring immediate conservation action, such as reforestation or land-use restructuring. Time-series NDVI monitoring was emphasized to detect vegetation degradation trends associated with increasing disaster risk (floods, landslides, droughts, and seawater intrusion) in coastal Canggu.

III. RESULT AND DISSCUSSION

NDVI Classification Based on Land Use : NDVI analysis was used to classify land cover conditions within the Yeh Luwi watershed. The NDVI values corresponded to land use classes as follows: Water (1), Built-up (2), Barren Land (3), Shrub and Grassland (4), Sparse Vegetation (5), and Dense Vegetation (6). This classification indicates varying vegetation density, from non-vegetated areas (Built-up, Barren Land) to high-density vegetation (Dense Vegetation). Hence, NDVI serves as an initial indicator for assessing vegetation conditions in relation to land use.

Tabel 1. NDVI Classification Based on Land Use

NDVI	LANDUSE	Area (km²)	
		2015	2025
<0.015	Water	0.0036	0.0018
0.015 - 0.14	Built-up	0.4779	2.0421
0.14 - 0.18	Barren Land	0.8055	1.6605
0.18 - 0.27	Shrub and Grassland	1.6461	2.2509
0.27 - 0.36	Sparse Vegetation	2.3400	1.1007
>0.36	Dense Vegetation	2.3823	0.5994

The NDVI-derived land use analysis between 2015 and 2025 demonstrates a significant transformation of vegetation cover and surface characteristics within the study area. In 2015, Dense Vegetation (NDVI > 0.36) occupied approximately 2.3823 km², representing the dominant land cover type, followed by Sparse Vegetation (0.27–0.36) covering 2.3400 km², and Shrub and Grassland (0.18–0.27) occupying 1.6461 km². Meanwhile, non-vegetated surfaces such as Barren Land (0.14–0.18) and Built-up areas (0.015–0.14) accounted for 0.8055 km² and 0.4779 km², respectively, whereas Water bodies (<0.015) were the smallest class, covering only 0.0036 km². By 2025, substantial changes occurred across all land use categories, primarily reflecting vegetation loss and urban expansion. Dense Vegetation experienced a drastic reduction to 0.5994 km², indicating a decline of nearly 75% over the decade. Similarly, Sparse Vegetation decreased sharply from 2.3400 km² to 1.1007 km², showing the conversion of moderately vegetated areas into more disturbed surfaces. Conversely, Built-up areas exhibited a fourfold increase from 0.4779 km² in 2015 to 2.0421 km² in 2025, highlighting rapid urban growth and infrastructure development. Barren Land also expanded from 0.8055 km² to 1.6605 km², suggesting land degradation and clearing activities preceding construction or agricultural intensification. Interestingly, Shrub and Grassland increased slightly to 2.2509 km², potentially due to transitional vegetation growth in semi-disturbed or previously cultivated lands. Water areas showed a minor reduction to 0.0018 km², possibly linked to sedimentation or land reclamation in low-lying zones.

NDVI Changes 2015–2025 : Comparison of NDVI maps between 2015 and 2025 showed vegetation decline in several segments. Areas classified as Dense Vegetation (NDVI high) in 2015 were largely converted into Built-up areas (NDVI low) by 2025. Similarly, Sparse Vegetation (class 5) and Shrub/Grassland (class 4) areas were converted to built-up land. This trend indicates increasing development and urbanization pressure, particularly in the downstream area near the coast.

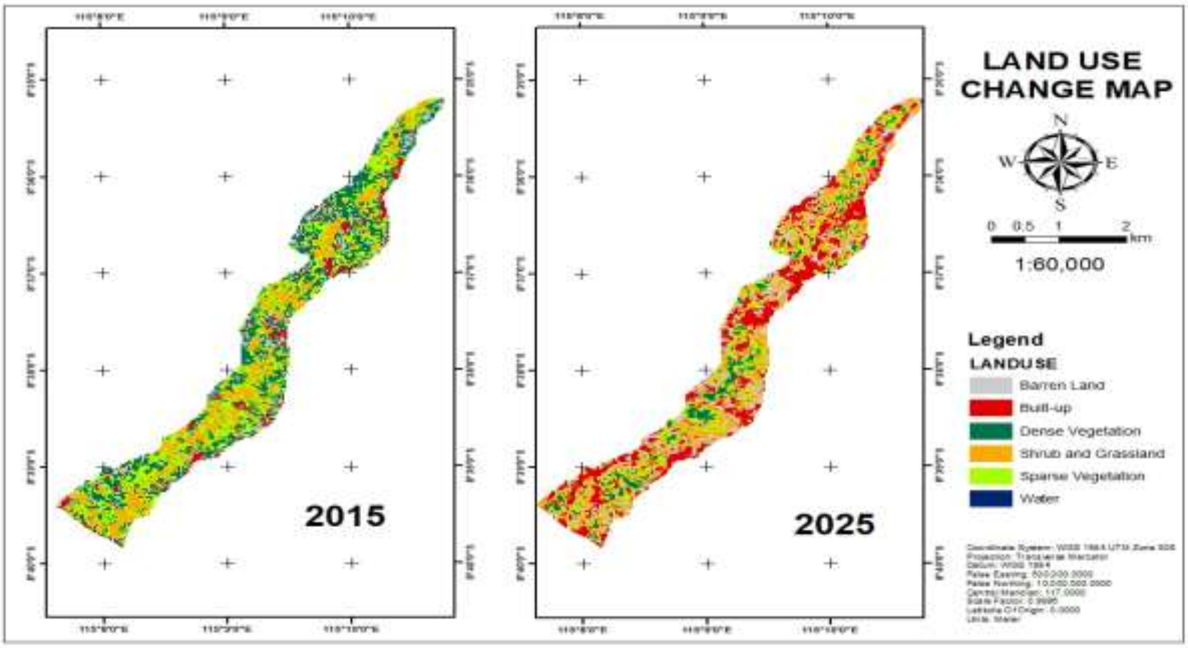

Figure 1. Land Use Change Map

The NDVI-based land use change analysis between 2015 and 2025 reveals a significant decline in vegetation cover across the study area. In 2015, large portions of the region were dominated by *Dense Vegetation* (high NDVI values) and *Shrub/Grassland* classes, particularly in the central and upstream zones. By 2025, these vegetated areas had substantially decreased, with extensive conversion into *Built-up* and *Barren Land* categories (low NDVI values). The *Built-up* areas, indicated in red, expanded notably along the downstream and coastal zones, signifying rapid urban development and land conversion for residential and infrastructural purposes. Concurrently, the reduction in *Dense Vegetation* (green) and *Sparse Vegetation* (light green) demonstrates the growing anthropogenic pressure on natural land covers.

Tabel 2. Land Use change

NDVI	LANDUSE	Change
<0.015	Water	-50.00%
0.015 - 0.14	Built-up	327.31%
0.14 - 0.18	Barren Land	106.15%
0.18 - 0.27	Shrub and Grassland	36.74%
0.27 - 0.36	Sparse Vegetation	-52.96%
>0.36	Dense Vegetation	-74.84%

The analysis of NDVI-derived land use changes from 2015 to 2025 reveals a pronounced transformation in the landscape, marked by extensive vegetation loss and a sharp increase in built-up and barren surfaces. The most significant positive change occurred in the *Built-up* category (NDVI 0.015–0.14), which expanded by 327.31%, indicating rapid urbanization and infrastructure development over the ten years. Similarly, *Barren Land* (NDVI 0.14–0.18) increased by 106.15%, reflecting processes such as land clearing, construction site expansion, and soil exposure due to decreased vegetation cover. *Shrub and Grassland* (NDVI 0.18–0.27) also showed a moderate increase of 36.74%, likely representing transitional or secondary vegetation in previously disturbed or semi-developed areas. Conversely, substantial declines were observed in vegetated land covers. *Dense Vegetation* (NDVI > 0.36) experienced the most drastic reduction, decreasing by 74.84%, followed by *Sparse Vegetation* (NDVI 0.27–0.36), which declined by 52.96%. These reductions indicate widespread deforestation, vegetation degradation, and the conversion of natural green spaces into non-vegetated surfaces, especially in the downstream and coastal regions. The *Water* class (NDVI < 0.015) also decreased by 50%, which may be attributed to sedimentation, land reclamation, or reduced water surface extent caused by anthropogenic and climatic factors.

The Conservation Priority Zoning : The conservation priority zoning of the Yeh Luwi Estuary area was developed based on the integrated analysis of NDVI values, land use change, and environmental degradation levels. This spatial assessment identified three distinct conservation priority zones, as illustrated in the accompanying map. Priority 1 zones (shown in dark red) represent areas that experienced conversion from Dense Vegetation (NDVI class 6) to Built-up areas (class 2). This transition indicates a severe ecological disturbance, as the removal of dense vegetation reduces carbon sequestration capacity, infiltration potential, and biodiversity, while simultaneously increasing the risks of surface runoff, flooding, and microclimatic imbalance. These areas require immediate conservation and restoration efforts, including reforestation, the establishment of vegetative buffers, and strict land-use regulation. Priority 2 zones (shown in orange) correspond to regions converted from Sparse Vegetation (class 5) to Built-up areas (class 2). Although the initial vegetation density in these zones was lower than in Priority 1 areas, their conversion still contributes to significant land degradation, habitat fragmentation, and hydrological disruption. Restoration measures in these areas should focus on urban green infrastructure, rainwater infiltration systems, and low-impact development practices to mitigate further damage. Priority 3 zones (depicted in yellow) include areas that transitioned from Shrub and Grassland (class 4) to Built-up areas (class 2). The ecological impacts are relatively lower compared to the first two categories; however, continuous urban expansion into these zones can gradually reduce the region’s ecological resilience. These areas should be monitored and managed through preventive conservation policies, controlled urban planning, and community-based green space initiatives.

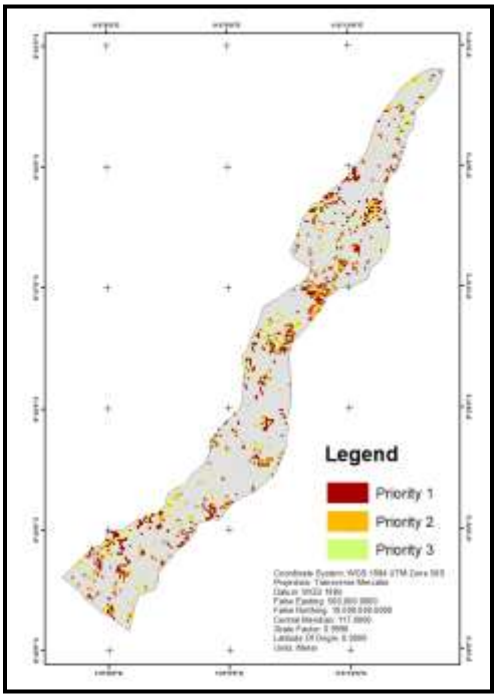

Figure 2. Priority Zoning

The implementation of bamboo as Mitigation Strategy : High-priority zones—particularly Priority 1 areas—have been identified as the most suitable locations for implementing bamboo-based conservation programs. Bamboo is selected as a key vegetation type due to its dense and deeply interconnected root system, which effectively enhances soil infiltration, stabilizes slopes and riverbanks, and significantly reduces erosion. These biophysical characteristics make bamboo an ideal species for restoring degraded areas, especially along the downstream sections of the Yeh Luwi River, where land conversion and hydrological disturbances are most severe.

Figure 3. Implementation of Planting Bamboo Along the River Bank

The implementation of bamboo as a mitigation strategy in the Yeh Luwi River focuses on high-priority zones, particularly along the riverbanks that are most vulnerable to erosion, slope instability, and hydrological disturbances caused by rapid land conversion. Bamboo is chosen as the primary vegetation due to its dense and fibrous root system, which strengthens soil structure, enhances water infiltration, and effectively stabilizes riverbanks. The initiative is carried out collaboratively, involving community members, students, and local stakeholders who actively participate in planting bamboo along critical riparian zones. This participatory approach ensures that the restoration program is both environmentally and socially sustainable. The bamboo planting activity provides multiple benefits, including reducing erosion, increasing groundwater recharge, maintaining soil moisture, and contributing to climate change mitigation through high carbon sequestration. By integrating ecological restoration with community involvement, the bamboo-based conservation effort in the Yeh Luwi River serves as a practical model of nature-based solutions for climate adaptation and sustainable water management.

IV. DISCUSSION

The NDVI analysis from 2015 to 2025 clearly reveals significant transformation in the Yeh Luwi watershed, where vegetated surfaces declined while built-up and barren land expanded rapidly. NDVI values lower than 0.015 were identified as water bodies, while those between 0.27–0.36 represented sparse vegetation. This classification aligns with the NDVI thresholds proposed by who defined NDVI ranges below 0.1 as non-vegetated and above 0.3 as healthy vegetation. The observed reduction in vegetated classes (Dense Vegetation −74.84%; Sparse Vegetation −52.96%) thus quantitatively indicates a degradation of vegetative vigor and ecosystem stability. The conversion of natural land cover into built-up areas (+327.31%) has substantial hydrological implications. According to Guan et al [18], urbanization increases surface runoff due to impervious surfaces that reduce infiltration and delay time. Similar with Ballaran [19] in Candaba, Pampanga, Philippines, revealed significant land conversion from agricultural and vegetated areas to built-up zones, primarily driven by expanding settlements and infrastructure. This transformation was reflected in decreasing NDVI values, indicating loss of vegetation cover. The decline in NDVI correlates with increased flood susceptibility, as reduced vegetation lowers soil infiltration capacity and disrupts the natural drainage network efficiency, leading to more frequent and prolonged flooding in the low-lying areas. In the Yeh Luwi watershed, the same pattern is evident — reduced vegetative cover implies lower infiltration capacity and increased runoff potential, leading to heightened flood risk and sediment delivery into the estuarine zone.

V. CONCLUSION

The analysis of NDVI-based land use change from 2015 to 2025 in the Yeh Luwi watershed demonstrates a clear pattern of environmental degradation driven by rapid urbanization and land conversion. The substantial decline in dense and sparse vegetation, accompanied by a marked increase in built-up and barren land, signifies reduced ecological integrity and hydrological function across the watershed. These transformations have increased surface runoff, reduced infiltration capacity, and heightened the risk of flooding and sedimentation in the downstream estuary. Spatial conservation zoning further revealed that the most critical areas requiring intervention are those converted from dense vegetation to built-up land, representing severe ecological disturbance zones. Integrating bamboo conservation within these priority zones offers a strategic, nature-based solution for both climate mitigation and water resource management. Bamboo's ecological advantages—including its deep root system, high carbon sequestration potential, and capacity to enhance infiltration—make it an effective species for stabilizing degraded riparian zones and restoring watershed function. Therefore, combining NDVI-based spatial monitoring with bamboo bioengineering provides a scientifically grounded and operationally feasible framework for sustainable watershed rehabilitation and climate adaptation in coastal regions such as Yeh Luwi.

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