Journal of Infrastructure Planning and Engineering Vol. 4, No. 2, Year 2025, pp 104 - 112

JIPE Journal of Infrastructure Planning and Engineering

Journal of Infrastructure Planning and Engineering

Journal homepage: https://ejournal.warmadewa.ac.id/index.php/jipe

From destruction to enhanced greening: Quantifying vegetation cover dynamics in Banda Aceh 20 years after the tsunami

Raja Al-Fath[1*], Shiti Maghfira[2], Ahmad Jihan Muzaki[3], Arief Gunawan[1]

[1]Department of Architecture and Planning, Syiah Kuala University, Banda Aceh, 23111, Indonesia
[2]Department of International Environment and Resources Policy, Tohoku University, Sendai, 980-8577, Japan
[3]Department of Urban and Regional Planning, Diponegoro University, Semarang, 50275, Indonesia
[*]raja.alfath@usk.ac.id

Received on 15 September 2025, accepted on 22 October 2025, published on 31 October 2025

ABSTRACT

The 2004 tsunami disaster caused severe ecological damage in Banda Aceh City, destroying a vast majority of its vegetation cover. This study aims to analyze the spatio-temporal dynamics of post-disaster vegetation recovery over two decades (2004-2024) to identify the stages of ecological succession. Using a remote sensing approach, Landsat satellite imagery from 2004 (pre-tsunami), 2005 (post-tsunami), 2014 (one decade later), and 2024 (two decades later) was analyzed using the Normalized Difference Vegetation Index (NDVI). The NDVI classification results show a drastic change: the non-vegetated area surged from 67.58% in 2004 to 89.01% in 2005, while the dense vegetation class was entirely eliminated. However, a recovery process unfolded over the subsequent two decades. By 2024, the non-vegetated area had drastically shrunk to just 13.11%, while the combined area of moderate and dense vegetation surged to over 45% of the city's total area, surpassing the pre-tsunami condition. This study concludes that Banda Aceh has not only successfully restored its vegetation cover but has also undergone a significant ecosystem maturation phase. These findings provide a robust scientific basis for integrating NDVI analysis as a proactive monitoring instrument into the Banda Aceh City Spatial Plan (RTRW) to support sustainable and disaster-resilient urban development.

Keywords: NDVI, vegetation recovery, tsunami 2004, spatial-temporal dynamics, Banda Aceh

1 Introduction

Transformation of a city is a multidimensional phenomenon, concurrently involving four primary domains: demographic and socioeconomic dynamics, the evolution of the built environment, shifts in land-use patterns, and the subsequent effects on the natural environment [1]. As a key aspect of these effects, a city's development has both positive and negative influences on its vegetation and green spaces [2]. This transformative process, now accelerated by the rapid pace of global urbanization and increasing resource scarcity, has given rise to a host of environmental challenges [3]. As a result, continuous environmental degradation has become an increasingly pressing issue in urban areas worldwide.

As a vital component, urban vegetation helps create a healthy and comfortable city environment. Its diverse benefits include improving human health, regulating natural systems, and providing habitats [4], [5], [6]. Therefore, understanding and documenting the dynamics of these changes is a critical step in planning for sustainable urban development. The use of remote sensing and geographic information system (GIS) technologies enables the tracking of spatial and temporal patterns [7]. In this context, remote sensing technologies offer a powerful and efficient method for monitoring the dynamics of urban vegetation [8]. The Normalized Difference Vegetation Index (NDVI) is frequently utilized to represent vegetation cover, such as agricultural and forest lands, within an urban context [9].

The urban development trajectory of Banda Aceh City was severely interrupted and came to a standstill in late 2004 due to a catastrophic earthquake and tsunami. The event resulted in critical impacts, including the degradation of land use areas, an altered coastline in the northern region, and severe ecological damage [10]. This damage was most evident in the substantial loss of vegetation cover, as coastal ecosystems such as mangrove forests, beach vegetation formations, and agricultural lands were completely swept away. Given the severity of this

DOI: https://doi.org/10.22225/jipe.4.2.2025.104-112 E-ISSN: 2829-5153

destruction, analyzing the dynamics of post-tsunami vegetation is crucial for evaluating the success of long-term recovery efforts and guiding sustainable urban planning.

Previous studies have laid a critical foundation for understanding post-tsunami landscape dynamics in Banda Aceh, utilizing mid-term NDVI analysis (2004-2017) [11], comparing vegetation (NDVI) against built-up areas (NDBI) [12], and employing multi-index approaches up to 2020 [13]. Nevertheless, this study addresses a fundamental gap by being the first to extend the analysis to a full two-decade period (2004-2024). This extended timeframe is vital for capturing the maturation phase of the urban vegetation ecosystem, which has previously gone unobserved. Beyond simply prolonging the timeline, this research provides a novel interpretive framework, explicitly analyzing NDVI data to represent distinct stages of post-tsunami vegetation recovery.

The most profound distinction of this study is its practical aim to integrate NDVI findings directly into spatial planning policy, namely the Banda Aceh City Spatial Plan (RTRW). This work actively bridges the divide between scientific analysis and policy application. The objective is to establish NDVI not as a tool for retrospective assessment, but as a proactive monitoring instrument for the city government, enabling the design of truly adaptive and disaster-resilient urban spaces.

Thus, the aim of this research is to analyze the spatio-temporal dynamics of post-disaster vegetation recovery over two decades through an NDVI-based approach in order to identify the stages of ecological succession in Banda Aceh. To this end, the study specifically maps and quantifies vegetation density conditions within the city for 2004, 2005, 2014, and 2024. Subsequently, the results of this multi-temporal mapping are analyzed to formulate a framework for effectively integrating scientific findings on vegetation density/NDVI into current spatial planning policies, especially in support of disaster mitigation and sustainable urban development strategies.

2 Data and Methods

This study was conducted in Banda Aceh City, the capital of Aceh Province (shown in **Figure 1**), which has an area of 58.99 km^2 and borders the Malacca Strait. The city was struck by the 2004 tsunami disaster, which caused approximately 130,000 fatalities and extensive damage to infrastructure and the environment [14], [15]. In addition, the mangrove forest area, which covered 167.71 hectares in 2004, was completely lost by 2005 [16].

The data used in this study consist of spatial data comprising raster and vector formats. The raster data, which refer to satellite imagery, were obtained from United States Geological Survey (USGS) website (https://earthexplorer.usgs.gov/). Details of the satellite imagery utilized are given in **Table 1**, which includes image analyses based on the acquisition years 2004, 2005, 2014, and 2024. Meanwhile, the vector data were obtained from the Banda Aceh City Development Planning Agency.

The selection of 2004, 2005, 2014, and 2024 is based on historical considerations and the dynamics of urban development in Banda Aceh. The year 2004 represents the pre-tsunami condition, providing a benchmark for vegetation cover before the disaster. 2005 reflects the immediate post-tsunami situation, marked by severe environmental and land cover changes. 2014 captures the recovery phase a decade after reconstruction, and 2024 illustrates the current condition after two decades of urban development and spatial planning implementation. The flowchart of this research is illustrated in the **Figure 2.**

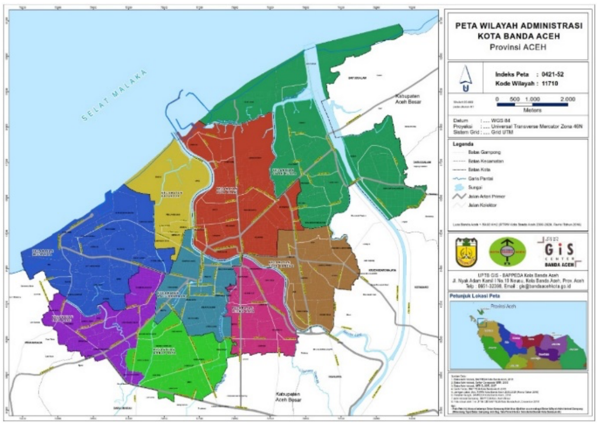


Figure 1. Research Area Map

Table 1. Information on Satellite Images

Sensor	Path/Row	Acquisition Date
Landsat 7 ETM plus	131/56	27-11-2004
Landsat 7 ETM plus	131/56	22-05-2005
Landsat 8 OLI/TIRS	131/56	04-03-2014
Landsat 9 OLI-2/TIRS-2	131/56	30-08-2024

For this research, the satellite image data presented in **Table 1** were processed to derive NDVI values. All calculations were performed using the open-source application QGIS 3.34 Prizren. However, satellite-based remote sensing techniques can achieve this easily and cost-effectively [17]. The Normalized Difference Vegetation Index (NDVI) is widely applied in remote sensing studies to quantify vegetation density, evaluate canopy energy absorption, and assess photosynthetic capacity [12], [18]. The NDVI is computed as a normalized ratio of surface reflectance between the Near-Infrared (NIR) and Red spectral bands. Vegetation density was subsequently derived using the following equation [19], [20].

$$\text{NDVI} = \frac{(\text{NIR} - \text{Red})}{(\text{NIR} + \text{Red})} \quad (1)$$

For Landsat 7 ETM plus, the NDVI is derived using Band 4 (NIR) and Band 3 (Red). In contrast, for Landsat 8 OLI and Landsat 9 OLI-2/TIRS-2, the NDVI is calculated from Band 5 (NIR) and Band 4 (Red). These differences reflect variations in spectral band designations between the two sensors, although the underlying NDVI formula remains unchanged.

The NDVI calculation produces values ranging from –1 to 1 [21]. Objects such as sparse or unhealthy vegetation, clouds, and water bodies generally yield negative NDVI values. Values closer to 1 indicate higher vegetation density or healthier vegetation cover [22]. Subsequently, vegetation cover density was classified into four categories (shown in **Table 2**), namely no vegetation, low vegetation, moderate vegetation, and dense vegetation [13], [23].

Table 2. Vegetation Density Levels

NDVI Value	Level
-1.00 – 0.00	No Vegetation
0.01 – 0.20	Low Vegetation
0.21 – 0.40	Moderate Vegetation
0.41 – 1.00	Dense Vegetation

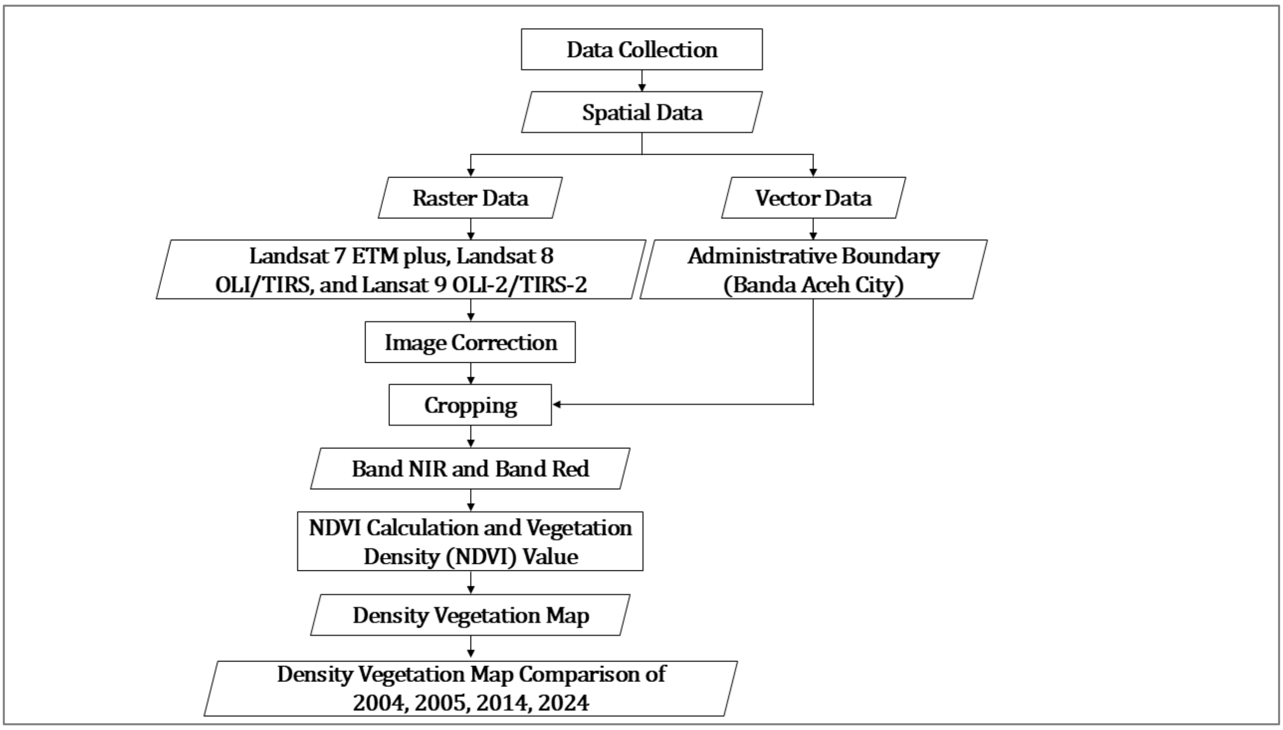


Figure 2. Research Flowchart

3 Results and Discussion

The distribution of different vegetation cover density classes in Banda Aceh from 2004 to 2024 shows significant fluctuations in the area occupied by each category. The rate of change in vegetation density is calculated based on the area for each category—no vegetation, low, moderate, and dense across four key periods: the pre-disaster condition (2004), the immediate post-disaster condition (2005), a decade post-tsunami (2014), and two decades post-tsunami (2024). **Table 3** shows that the vegetation density distribution changed drastically, with a sharp decline in all vegetation classes particularly moderate vegetation and the complete disappearance of dense vegetation following the tsunami, from 2004 to 2005. However, in 2014 and culminating in 2024, vegetation density increased remarkably. The combined area of moderate and dense vegetation, which constituted only about 8% of the total area in 2004, surged to over 45% by 2024. Conversely, the non-vegetated area, which dominated nearly 90% of the territory post-tsunami, drastically shrank to just about 13% by 2024.

This phenomenon can be definitively attributed to the impact of the December 26, 2004 tsunami, which inflicted its most severe damage on the northern coastal areas of Banda Aceh. As the area directly facing the sea, this region bore the brunt of the waves impact, causing a total loss of vegetation cover in many places. The causes of this destruction were multifaceted; stemming not only from the physical force of the waves, which uprooted and swept away vegetation, but also from soil salinization due to seawater inundation, which rendered the land infertile, as well as the deposition of thick debris and sediment that covered productive land [24].

In 2004, satellite image analysis yielded an NDVI value range between -0.59375 and 0.4328358. The classification results indicate that the largest portion of the area was the no vegetation class, covering an area of 3,986.35 ha (67.58%). This area represents built-up zones such as settlements, infrastructure, and water bodies distributed throughout the city. This class was followed by low vegetation cover, which occupied a significant area of 1,433.02 ha (24.29%), commonly found in open lands, yards, and roadsides. Furthermore, moderate vegetation was identified over 479.20 ha (8.12%), representing areas with denser tree cover such as the mangrove forests in the Kuta Raja District and shrublands in the southern part of the city. The smallest area was classified as dense vegetation cover, accounting for only 0.45 ha (0.01%) of the total study area. Overall, the 2004 data depicts the baseline landscape condition of Banda Aceh before the tsunami event, where built-up areas were more dominant than green spaces, and the presence of dense vegetation ecosystems was extremely limited (**Figure 4**).

The 2005 image data, obtained with an NDVI value range between -0.5348837 and 0.283237, reveals a landscape dominated by the no vegetation class, with a total coverage reaching 5,250.86 ha (89.01%). This area was distributed across all districts, with a particular concentration in the coastal regions directly impacted by the tsunami. This was followed by low vegetation cover, spanning 634.85 ha (10.76%), which was identified as either remnant vegetation or pioneer species beginning to regrow post-disaster. Meanwhile, higher-density vegetation cover was minimal; moderate vegetation occupied only a small area of 13.31 ha (0.23%), and the dense vegetation class was not detected at all (0.00 ha). Thus, it can be concluded that in 2005, the vast majority of Banda Aceh was in a state of open land devoid of vegetation cover. This condition clearly reflects the catastrophic impact of the preceding tsunami (the satellite image shown in **Figure 5**), which caused massive vegetation destruction in the city, particularly in the northern coastal areas.

Table 3. Distribution of Vegetation Cover (NDVI Value) of Banda Aceh (Ha) from 2004 to 2024

Range NDVI Value	Year			
	2004	2005	2014	2024
No Vegetation	3986.35	5250.86	1014.08	773.26
Low Vegetation	1433.02	634.85	2818.04	2404.83
Moderate Vegetation	479.20	13.31	2061.50	2377.95
Dense Vegetation	0.45	0.00	5.40	342.98
Total	**5899.02**	**5899.02**	**5899.02**	**5899.02**

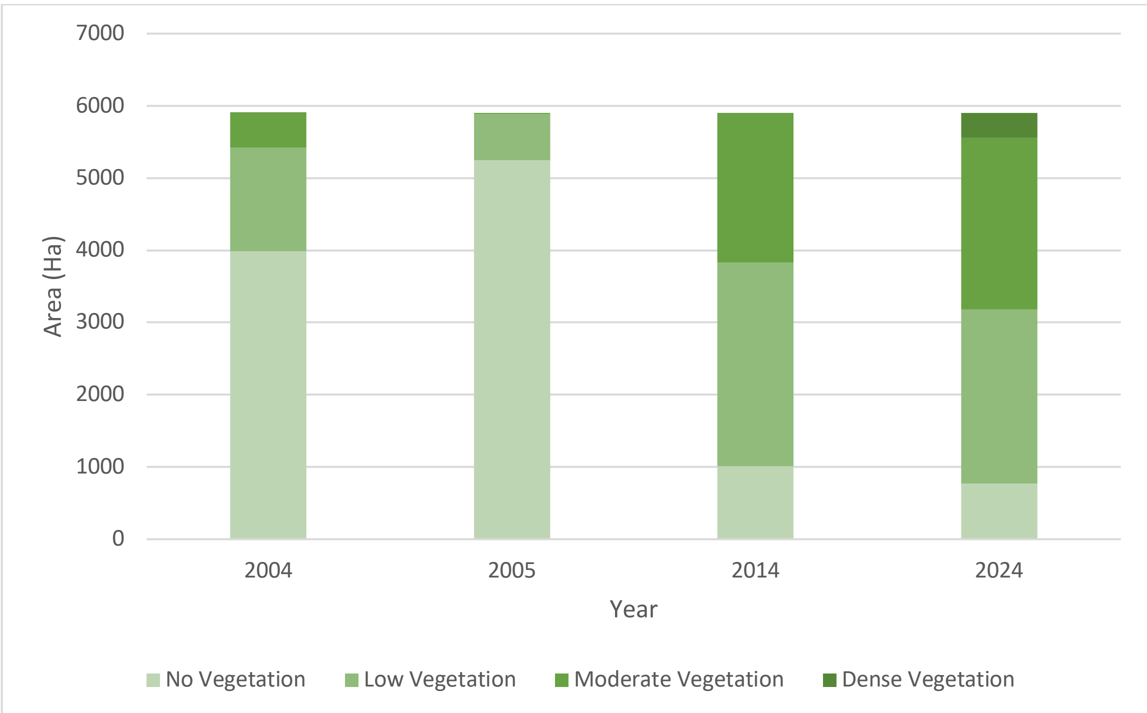


Figure 3. Area Distribution of Vegetation Cover (NDVI Value) of Banda Aceh from 2004-2024

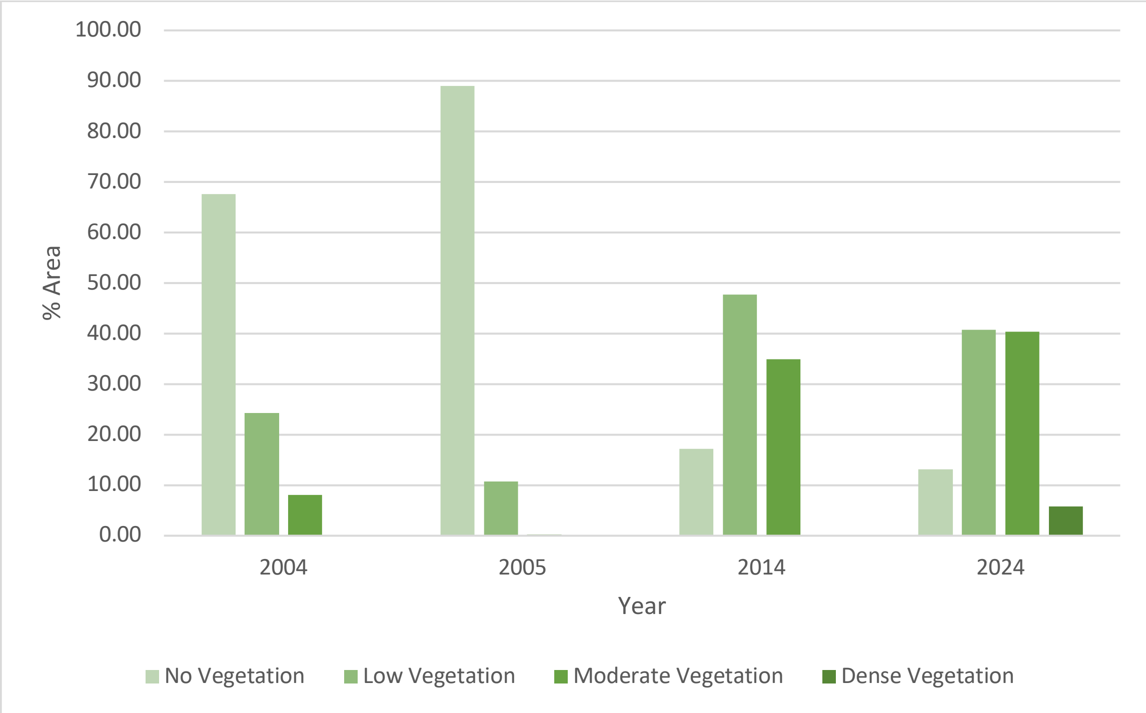


Figure 4. Percentage of Vegetation Cover (NDVI Value) of Banda Aceh from 2004-2024

(a) Mangrove forests in 2004 (pre-disaster)

(b) Mangrove forests in 2005 (post-tsunami)

(c) Mangrove forests in 2014 (a decade)

(d) Mangrove forests in 2024 (two decades)

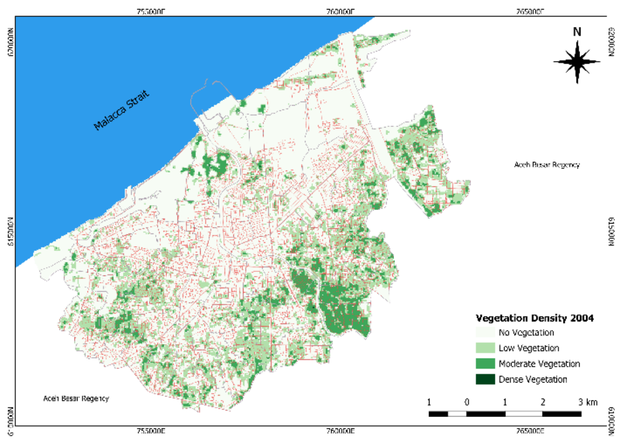
Figure 5. Condition of Mangrove in Banda Aceh Pre- and Post-Tsunami

A decade after the tsunami, the 2014 image data, with an NDVI value range between -0.1526247 and 0.4734576, indicates a significant vegetation recovery process. In this year, the land cover was dominated by the low vegetation class, reaching an area of 2,818.04 ha (47.77%), which was evenly distributed throughout the city. This signifies the success of primary ecological succession in the previously devastated areas. This class was followed by moderate vegetation, which also showed a remarkable recovery, covering an area of 2,061.50 ha (34.97%). Meanwhile, the no vegetation area had drastically shrunk to 1,014.08 ha (17.19%). The dense vegetation cover class, although still the smallest, began to reemerge, covering an area of 5.4 ha (0.09%). Overall, the 2014 data reflects a crucial transitional phase, where the landscape of Banda Aceh had shifted from being dominated by open land to a green landscape dominated by growing and recovering vegetation.

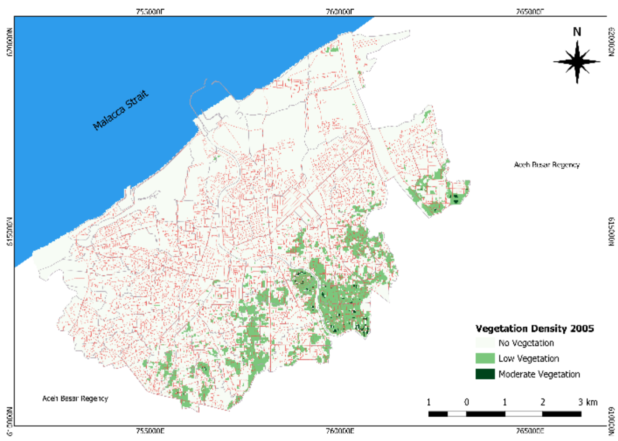
In 2024, two decades after the tsunami, image data with an NDVI value range between -0.2230473 and 0.6145164 indicates a landscape condition that has ecologically recovered and matured. The classification results show a landscape dominated by low vegetation covering 2,404.83 ha (40.77%) and moderate vegetation covering 2,377.95 ha (40.31%). The nearly balanced distribution of these two classes indicates an advanced successional process, where pioneer vegetation has developed into more complex and dense communities. This maturation is quantitatively evidenced by a substantial shift in the city's vegetation profile, the weighted average NDVI increased from 0.0714 in 2014 to 0.1412 in 2024, representing a 97.65% increase over the decade. Furthermore, the combined area of moderate and dense vegetation (representing higher-quality vegetation cover) expanded from 2,066.90 ha (35.04%) in 2014 to 2,720.93 ha (46.13%) in 2024, an increase of 654.03 ha at a rate of 65.40 ha per year. Most notably, the dense vegetation class exhibited an exceptional growth rate of 33.76 ha per year during this maturation phase, increasing from 5.40 ha to 342.98 ha, a remarkable 6,251% increase that confirms the transition to a mature, ecologically complex urban forest ecosystem.

The most prominent feature of this period is the significant surge in the dense vegetation class, which now covers 342.98 ha (5.81%) of the city, a drastic increase that signifies the success of reforestation and greening programs. Spatially, the strongest regrowth occurred predominantly along the northern coastal zone, particularly in the rehabilitated mangrove forest areas of Kuta Raja Sub-District and Syiah Kuala Sub-District (as illustrated in **Figure 5d** and **Figure 6d**), where dense vegetation coverage has been extensively re-established. This coastal mangrove belt, which was completely destroyed in 2005 (167.71 ha reduced to 0 ha), now represents the largest concentration of dense vegetation in the city and serves as a critical green infrastructure for tsunami wave attenuation and coastal ecosystem restoration.

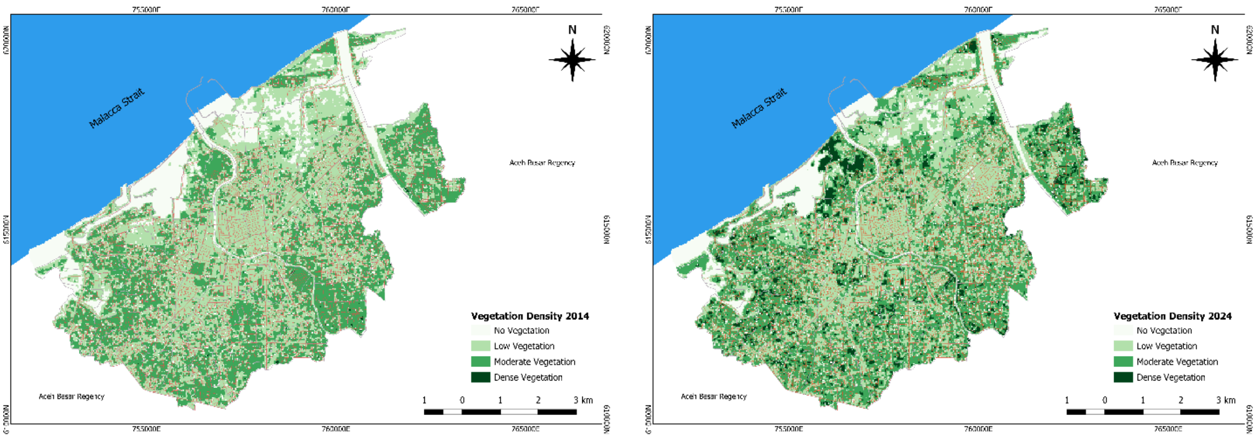
On the other hand, the no vegetation area continued to shrink, reaching its lowest point in two decades at 773.26 ha (13.11%). Overall, the 2024 data depicts the peak of Banda Aceh's ecological recovery, which now possesses a far greener and more diverse urban landscape, even surpassing its pre-tsunami condition. **Figure 7** illustrates the significant changes in vegetation cover within the Banda Aceh city center, comparing the immediate post-tsunami conditions of January 2005 with the landscape two decades later in 2024. The results of the NDVI analysis, showing the distribution of vegetation density in Banda Aceh, can be seen in **Figure 6**.



(a) 2004 (pre-disaster)

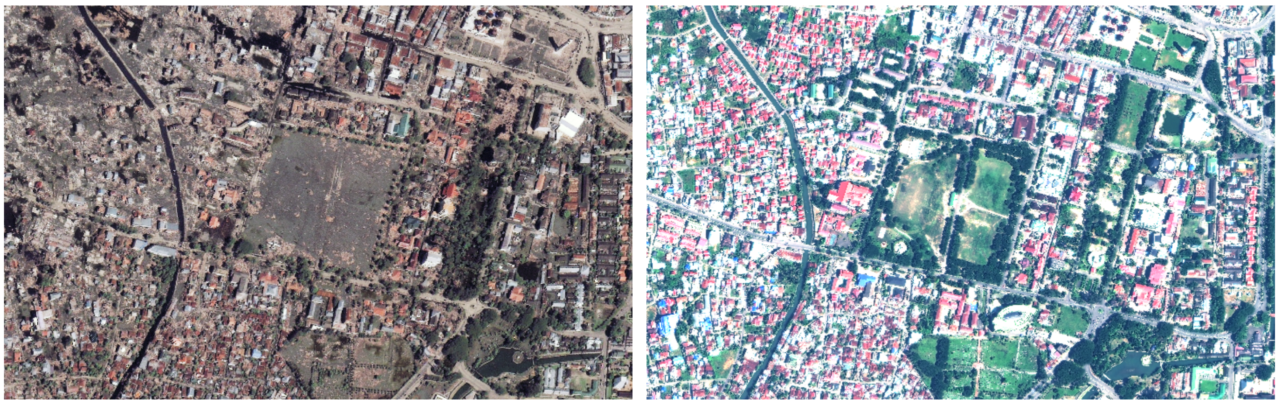


(b) 2005 (5 months after disaster)



(c) 2014 (a decade post-tsunami) (d) 2024 (two decades post-tsunami)

Figure 6. Spatial Distribution of NDVI Value in Banda Aceh City



(a) Post-tsunami (January 2005) (b) Two decades later (2024)

Figure 7. Post-Tsunami Vegetation Recovery in Central Banda Aceh (2005 and 2024)

The findings of this multi-temporal NDVI analysis (2004-2025) have direct implications for the Banda Aceh City Spatial Plan (RTRW). Accordingly, this study posits that NDVI is not simply a scientific index but a critical instrument for evaluating urban planning. The resulting vegetation density data offers measurable, empirical evidence to objectively assess existing spatial policies and guide their revision, effectively bridging the gap between science and urban policy implementation.

As an evaluative instrument, NDVI effectively verifies the practical implementation of the RTRW. It measures the actual condition of Green Open Spaces (RTH), contrasting legal policy allocations with real vegetation cover. Furthermore, the vegetation map can identify "green deserts" in densely populated areas with minimal green space. This finding urges the RTRW to prioritize the creation of new neighborhood parks in these locations to improve air quality and provide equitable recreational spaces for residents. This is consistent with [25], [26], who proved that green spaces play a vital role in enhancing environmental quality and serving as recreational and social activity spaces for urban communities.

NDVI data must serve as a proactive foundation for all future revisions of the RTRW. For instance, data showing the regrowth of dense vegetation reaching 342.98 ha by 2024 on the northern coast provides compelling evidence to designate this zone as a coastal green belt specifically a mangrove forest, which must be protected for tsunami mitigation and control, as well as to attenuate future wave energy [27], [28]. Beyond disaster mitigation, the vegetation density map can also be used to design green corridors connecting city parks, an effective strategy for reducing the urban heat island (UHI) effect [29]. Consequently, urban planning can shift towards a data-driven approach to build a city that is truly resilient and livable.

4 Conclusion

This study quantitatively demonstrates the successful vegetation recovery in Banda Aceh City over the two decades following the 2004 tsunami. NDVI analysis reveals a remarkable landscape transformation, where the massive destruction of 2005 gave way to a mature ecological condition by 2024, with a state of greenness that now surpasses pre-disaster levels. This process signifies a successful ecological succession, evolving from an initial phase dominated by low-density vegetation to a more complex landscape marked by a significant surge in dense vegetation cover.

While this study successfully quantifies vegetation recovery through NDVI analysis, several limitations should be acknowledged. First, NDVI primarily measures vegetation quantity and density but does not capture ecological quality dimensions such as species diversity or ecosystem functional integrity. Second, the spatial resolution of Landsat imagery may not detect fine-scale vegetation heterogeneity. Third, this analysis does not quantify the ecosystem services provided by recovered vegetation. These limitations highlight the need for complementary methodologies in future research.

Fundamentally, these findings bridge scientific analysis with policy application, validating NDVI as a proactive and measurable monitoring instrument for the city government. Therefore, it is recommended that periodic NDVI analysis be integrated into the Banda Aceh City Spatial Plan (RTRW). The utilization of this data will provide a strategic foundation for evaluating the effectiveness of green open spaces, guiding sustainable urban development, and strengthening ecosystem-based disaster mitigation strategies to realize an adaptive and resilient city. These findings have broader implications beyond Banda Aceh, offering valuable insights for post-disaster urban recovery globally and contributing to the achievement of Sustainable Development Goals 11, 13, and 15.

5 Acknowledgement

Acknowledgements are extended to the Banda Aceh City Planning and Development Agency (Bappeda) for supplying crucial spatial data and to all parties who offered valuable insights for this research.

References

[1] M. H. Watkins and C. A. Griffith, "Synthesis Report from the 2nd International Conference on Urbanization and Global Environmental Change Urban Transitions & Transformations: Science, Synthesis, and Policy," Tempe, USA, 2015. doi: 10.1017/CBO9781107415324.004.

[2] S. Wu, Z. Liang, and S. Li, "Relationships between urban development level and urban vegetation states: A global perspective," *Urban For Urban Green*, vol. 38, pp. 215–222, Feb. 2019, doi: 10.1016/j.ufug.2018.12.010.

[3] V. Naumov *et al.*, "How to reconcile wood production and biodiversity conservation? The Pan-European boreal forest history gradient as an 'experiment,'" *J Environ Manage*, vol. 218, pp. 1–13, Jul. 2018, doi: 10.1016/j.jenvman.2018.03.095.

[4] Z. Davis, L. Nesbitt, M. Guhn, and M. van den Bosch, "Assessing changes in urban vegetation using Normalised Difference Vegetation Index (NDVI) for epidemiological studies," *Urban For Urban Green*, vol. 88, Oct. 2023, doi: 10.1016/j.ufug.2023.128080.

[5] W. Yang *et al.*, "Remote sensing assessment of urban vegetation's dust retention for mitigating atmospheric particulate pollution," *Urban Clim*, vol. 62, Aug. 2025, doi: 10.1016/j.uclim.2025.102535.

[6] Z. Yan *et al.*, "Spatial and temporal variation of NDVI and its driving factors based on geographical detector: A case study of Guanzhong plain urban agglomeration," *Remote Sens Appl*, vol. 32, Nov. 2023, doi: 10.1016/j.rsase.2023.101030.

[7] I. P. E. Sarassantika, G. B. A. Wicaksana, and K. T. U. Putri, "Assessing the Impact of Environmental Hazards on Educational Facility Structures in Karangasem Regency Implications for Risk Mitigation," *Journal of Infrastructure Planning and Engineering*, vol. 3, no. 2, pp. 41–49, Dec. 2024, doi: 10.22225/jipe.3.2.2024.41-49.

[8] A. R. Shahtahmassebi *et al.*, "Remote sensing of urban green spaces: A review," *Urban For Urban Green*, 2021, [Online]. Available: https://api.semanticscholar.org/CorpusID:234342661

[9] P. Singh, P. Verma, A. S. Chaudhuri, V. K. Singh, and P. K. Rai, "Evaluating the relationship between Urban Heat Island and temporal change in land use, NDVI and NDBI: a case study of Bhopal city, India," *International Journal of Environmental Science and Technology*, vol. 21, no. 3, pp. 3061–3072, Feb. 2024, doi: 10.1007/s13762-023-05141-y.

[10] R. Al-Fath, "Fenomena Pembangunan Kota Banda Aceh Pasca Tsunami 2004," Universitas Gadjah Mada, Yogyakarta, 2022.

[11] Z. Hayati, S. Syahreza, and M. S. Surbakti, "NDVI Based Analysis on the Impact of 2004 Tsunami Disaster Recovery Toward Vegetation Condition in Banda Aceh," *Journal of Aceh Physics Society*, vol. 8, no. 3, pp. 66–71, Sep. 2019, doi: 10.24815/jacps.v8i3.12688.

[12] R. N. Trinufi and S. Rahayu, "Analisis Perubahan Kerapatan Vegetasi dan Bangunan di Kota Banda Aceh Pasca Bencana Tsunami," *Ruang*, vol. 6, no. 1, pp. 28–37, 2020, doi: https://doi.org/10.14710/ruang.6.1.29-39.

[13] S. Sugianto, T. Arabia, M. Rusdi, S. Syakur, and M. Trishiani, "Spatial distribution vegetation density, land surface temperature, and land surface moisture of Banda Aceh, Indonesia after 17 years of tsunami: a multitemporal analysis approaches," *Environ Monit Assess*, vol. 195, no. 1, Jan. 2023, doi: 10.1007/s10661-022-10827-w.

[14] E. Frankenberg, T. Gillespie, S. Preston, B. Sikoki, and D. Thomas, "Mortality, The Family and The Indian Ocean Tsunami," vol. 121, pp. 162–182, 2011, doi: 10.1111/j.1468-0297.2011.02446.x.

[15] BRR, *Aceh and Nias Two Years After the Tsunami*. CV Andika Pratama, 2006.

[16] R. Al-Fath and A. Marsoyo, "The Development Of Banda Aceh City Post Tsunami Disaster 2004," *Journal Teknosains*, vol. 12, no. 2, pp. 164–175, 2023, doi: https://doi.org/10.22146/teknosains.77549.

[17] F. Aghazadeh *et al.*, "Spatial-temporal analysis of day-night time SUHI and its relationship between urban land use, NDVI, and air pollutants in Tehran metropolis," *Applied Geomatics*, vol. 15, no. 3, pp. 697–718, Sep. 2023, doi: 10.1007/s12518-023-00515-w.

[18] Putu Aryastana, Maria Imaculata Goran Mosa, Wayan Widiana, I Made Eryana Eka Putra, and Gede Rustiawan, "Application of normalized difference vegetation index in classifying land cover change over Bangli regency by using Landsat 8 imagery," *Journal of Infrastructure Planning and Engineering (JIPE)*, vol. 1, no. 1, pp. 8–14, Apr. 2022, doi: 10.22225/jipe.1.1.2022.8-14.

[19] S. Huang, L. Tang, J. P. Hupy, Y. Wang, and G. Shao, "A commentary review on the use of normalized difference vegetation index (NDVI) in the era of popular remote sensing," Feb. 01, 2021, *Northeast Forestry University*. doi: 10.1007/s11676-020-01155-1.

[20] J. W. Rouse, R. H. Haas, J. A. Schell, and D. W. Deering, "Monitoring Vegetation Systems in the Great Plains with ERTS (Earth Resources Technology Satellite)," in *Proceedings of 3rd Earth Resources Technology Satellite Symposium*, 1973.

[21] A. Hardianto, P. U. Dewi, T. Feriansyah, N. F. S. Sari, and N. S. Rifiana, "Pemanfaatan Citra Landsat 8 Dalam Mengidentifikasi Nilai Indeks Kerapatan Vegetasi (NDVI) Tahun 2013 dan 2019 (Area Studi: Kota Bandar Lampung)," *Jurnal Geosains dan Remote Sensing*, vol. 2, no. 1, pp. 8–15, May 2021, doi: 10.23960/jgrs.2021.v2i1.38.

[22] M. Gascon *et al.*, "Normalized difference vegetation index (NDVI) as a marker of surrounding greenness in epidemiological studies: The case of Barcelona city," *Urban For Urban Green*, vol. 19, pp. 88–94, Sep. 2016, doi: 10.1016/j.ufug.2016.07.001.

[23] A. Putri and H. Maghfirah, "The Mapping of Vegetation Density Changes Based on the Normalized Difference Vegetation Index Using Landsat OLI in The Coastal Region of Aceh Barat," *Indonesian Journal of Computer Science Attribution*, vol. 12, no. 6, pp. 3250–3260, 2023, doi: https://doi.org/10.33022/ijcs.v12i6.3489.

[24] BRR, *Laying Down the Foundation for a Better Tomorrow*. CV Andika Pratama, 2005.

[25] M. J. Koohsari *et al.*, "Public open space, physical activity, urban design and public health: Concepts, methods and research agenda," *Health Place*, vol. 33, pp. 75–82, May 2015, doi: 10.1016/j.healthplace.2015.02.009.

[26] Z. Shafara Aiyub, M. Irwansyah, A. Gunawan, and R. Al-Fath, "How Effective Are Urban Parks? Insights from Lapangan Merdeka and Taman Bambu Runcing in Langsa City," *Built Environment Innovations (BEI)*, vol. 1, no. 1, pp. 41–50, 2025.

[27] A. Mascarenhas, "Response of coastal vegetation and the need for green belts along the Tamil Nadu coast, India: The December 2004 tsunami experience," in *Tsunamis: Causes, Characteristics, Warnings and Protectionon*, 2010, pp. 131–147.

[28] N. Veitch and G. Jaffray, *Tsunamis: Causes, Characteristics, Warnings and Protection*. New York: Nova Science Publisher, Inc., 2010.

[29] J. Ge, Y. Wang, D. Zhou, Y. Guo, J. Wang, and Z. Gu, "Urban parks as effective airborne cooling sources: planning suggestions based on an empirical study in Xi'an, China," *Urban Clim*, vol. 62, Aug. 2025, doi: 10.1016/j.uclim.2025.102571.