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Spatio-Temporal Analysis on Land Use/Land Cover Change in Banda Aceh: A Preliminary Study of Disaster Resilience

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Spatio-Temporal Analysis on Land Use/Land Cover Change in Banda Aceh: A Preliminary Study of Disaster Resilience

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Abstract. The devastating tsunami that struck Banda Aceh resulted in profound destruction to both its built environment and natural areas. The city's urban infrastructure suffered extensive damage, with essential zone being severely affected. Despite these challenges, the population of this tsunami-prone city has continued to increase steadily over time. This research examines the land use/ land cover (LULC) in Banda Aceh following the 2004 Indian Ocean Tsunami through spatio-temporal analysis, with a particular focus on investigating urban growth trends through the examination of built-up areas. The study seeks to discern the evolving patterns of land use and land cover transitions over this period, shedding light on the transformative processes associated with urbanization and its consequent impact on the landscape. The insights obtained from this research can inform urban planners, policymakers, and disaster management authorities in devising effective strategies for urban growth in coastal front cities that vulnerable to tsunami.

Keywords: *land use land cover, disaster resilience, spatio-temporal analysis*

1. Introduction

As urbanization accelerates, especially in regions prone to natural disasters, the potential consequences become increasingly evident. Rapid population growth often leads to haphazard development, inadequate infrastructure, and encroachment into hazardous zones, elevating vulnerability to disasters such as tsunami. The higher the urbanization rate in disaster-prone areas, the greater the risk posed to lives, property, and overall community well-being. This surge in urbanization can result in a reduction in resilience. In the realm of natural disasters, the pursuit of higher resilience stands as a prevailing goal [1]. The context of natural disasters is characterized by the unpredictability and magnitude of destructive events, making it imperative for urban systems to fortify themselves against potential impacts [2]. In this scenario, resilience emerges as a vital attribute that bolsters a system's capacity to absorb shocks, recover swiftly, and adapt to changing circumstances [3–5].

As urbanization progresses and environmental systems undergo shifts, understanding the patterns and trends of land use/land cover (LULC) alterations becomes pivotal in shaping sustainable urban development and disaster resilience strategies [6]. Banda Aceh has experienced substantial built environment changes over the years, driven by factors such as population growth and urban expansion.

Studying resilience through the lens of LULC dynamics provide a tangible representation of how urbanization influences the spatial layout of an area and its potential vulnerability to disasters. By analyzing these changes over time, researchers can discern trends and patterns in the conversion of land covers and the proliferation of built-up areas [7]. Moreover, the study of LULC dynamics enables the identification of potential areas of concern where urbanization may be exacerbating vulnerabilities or compromising resilience efforts.

Research on urban tsunami impact has been previously conducted in Banda Aceh, showcasing the post-tsunami urban conditions. Urbanization has seen a higher increase in zones once considered safe from tsunamis, due to factors such as land ownership, pricing dynamics, socio-economic conditions, urban planning strategies, distance from the city center, and population growth within the city of Banda Aceh [8]. Conversely, the distance between communities and the city center, as well as economic hubs, has been found to influence urban growth in Banda Aceh following the tsunami [9]. Furthermore, significant increase between 2005 and 2011 has been observed in the dynamics of building density and vegetation in Banda Aceh. This analysis utilized satellite imagery and relied on the calculation of the Normalized Difference Build-Up Index (NDBI) and Normalized Difference Vegetation Index (NDVI) [10,11]. Additionally, a comprehensive assessment of tsunami risk at the village level in Banda Aceh revealed 26 villages with minimal tsunami risk and 73 villages at risk [12]. The city's planned development direction, as proposed by the government, is situated in the southern part of Banda Aceh, an area unaffected by the 2004 tsunami. Interestingly, urban settlements have tended to concentrate in the northern regions, which are closer to the coastline [13]. In terms of built-up area patterns, rapid growth was observed between 2005 and 2009, followed by a gradual decline from 2009 to 2019 [14]. The culmination of these studies provides a multidimensional understanding of the urban landscape's evolution in the aftermath of the tsunami.

However, these studies also underscore research gaps that deserve further exploration in adaptation and growth of land use land cover in shaping urban form. Addressing these gaps would lead to a more nuanced understanding of the complex interplay between urbanization, disaster resilience, and adaptive strategies. The dynamic urban environment demands a holistic and longitudinal exploration, delving into the changing patterns of urban development, resilience assessment, and the implications for long-term disaster resilience. Analyzing the alignment of development plans with urban growth patterns can collectively enhance our understanding of the urbanization-resilience relationship [7]. Addressing these gaps can pave the way for more informed policies and strategies that strengthen disaster resilience in urban environments vulnerable to natural hazards.

By employing GIS techniques and harnessing the capabilities of satellite imagery, the research seeks to delineate and classify the various LULC categories, including built-up areas, non-built expanses, green spaces, and water bodies. The objective of this preliminary study is to conduct a comprehensive spatio-temporal analysis of LULC changes within Banda Aceh. The emphasis of this study lies in examining urban growth dynamics through the lens of built-up areas. By gaining insights into this phenomenon, the outcomes of this research can be employed as a reference point for investigating the trajectory of resilience of Banda Aceh in subsequent studies. This is due to the fact that the present research serves as a preliminary exploration within a larger framework intended to investigate the resilience of the area in the face of tsunami events, thereby manifesting as adaptive responses. The knowledge derived from this study holds significance in the context of urban planning and development, providing a nuanced comprehension of the evolving urban landscape and its implications. The findings are anticipated to tangibly contribute to the advancement of urban planning strategies and policies, guiding the direction of urban development in Banda Aceh.

2. Data & Methods

The research location is in Banda Aceh, Indonesia (Figure 1). This city was once hit by the 2004 Indian Ocean tsunami, which originated from an earthquake. Banda Aceh is situated on the coastal area, so during that disaster, many built-up areas experienced destruction and damage. This city serves as the capital of Aceh Province, which is the center for economic, governmental, socio-cultural, and educational activities.

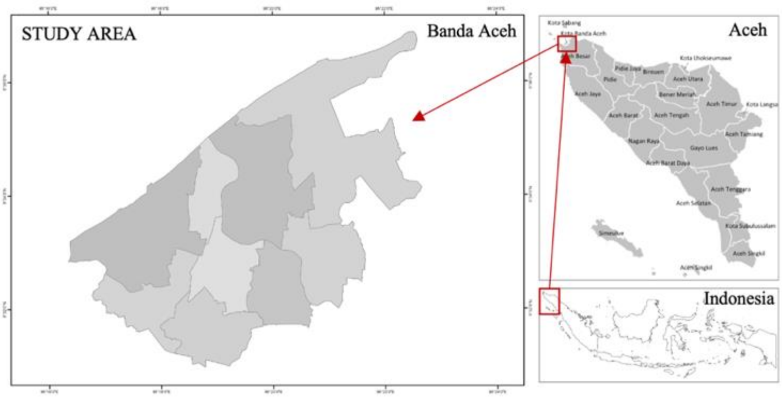


Figure 1. Banda Aceh as Study Area

The study's methods involve a multi-faceted approach comprising data acquisition, pre-processing, classification, and analysis. High-resolution satellite imagery from SPOT 5 and Sentinel sources is acquired and processed. A supervised classification method employing machine learning algorithms is then applied to categorize area study into built-up area, open land, vegetation, and water body [15]. Ground-truth data validation is conducted for accuracy assessment. Subsequently, these findings are utilized to analyze the expansion of built-up areas, indicating urban growth from 2004 to 2023. Figure 2 shows the research method flowchart that illustrates data collection, processing, and obtaining the output of spatiotemporal analysis.

2.1 Data of Satellite Imagery

Satellite imagery has revolutionized our ability to understand and analyze land use and land cover changes over time. In the context of Banda Aceh, a city marred by the tsunami, the utilization of satellite imagery, particularly from SPOT 5 and Sentinel platforms, offers a unique opportunity to examine the spatio-temporal dynamics of the region's landscape. This paper delves into the significance of employing satellite images from 2004, 2005, 2014, and 2023 in a preliminary study of LULC changes, tracking the city's journey from pre-tsunami times to the post-reconstruction era. SPOT 5 and Sentinel satellites provide resolution of 10 meter that enables detailed analysis of LULC patterns. The choice of these platforms for the present study is driven by their capability to capture fine details of the urban landscape, critical for discerning changes over time. The selection of satellite images has been executed (Table 1).

The combination of SPOT 5 and Sentinel-2 images was chosen due to their superior quality and matched resolution capabilities. SPOT 5, a product of the French space agency CNES, operates in multiple spectral bands, allowing researchers and analysts to study Earth's surface in incredible detail. The Sentinel 2 satellites, developed by the European Space Agency as part of the Copernicus program, are equipped with a high-resolution multispectral imager that can capture imagery in 13 spectral bands, ranging from visible to shortwave infrared. This pairing ensures that the highest level of image quality is maintained, enabling accurate and consistent analysis. The decision to integrate these images allows for a comprehensive assessment of the area under study, as their respective qualities harmoniously align, facilitating precise and reliable comparisons.

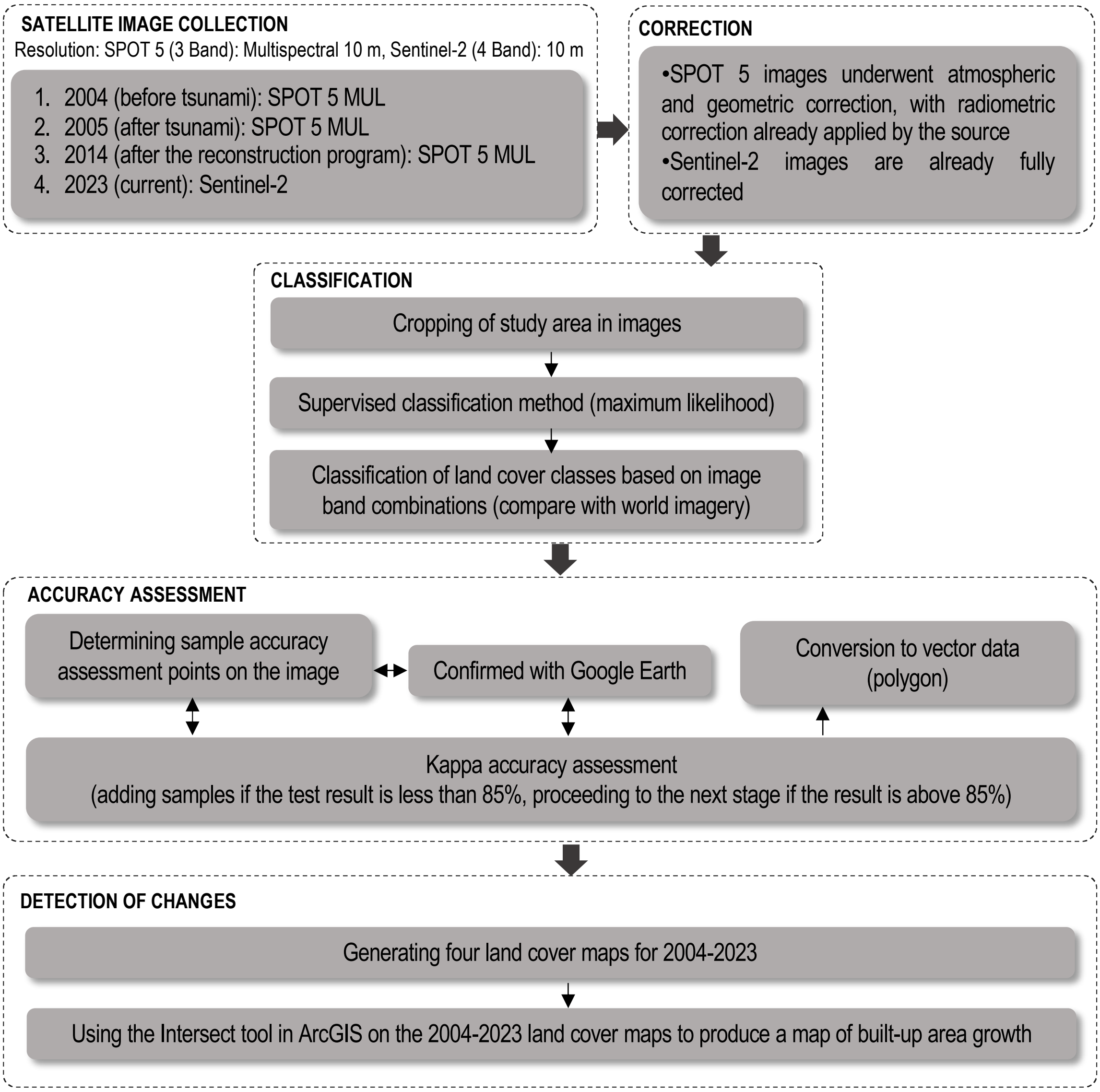


Figure 2. Methods

Table 1. Satellite image collections

Year	Sensor	Acquisition date	Resolution	Description
2004	SPOT 5	05-08-2004	10 m	Pre-Tsunami
2005	SPOT 5	24-05-2005	10 m	Post-Tsunami
2014	SPOT 5	05-11-2014	10 m	Post-Reconstruction
2023	Sentinel-2	21-06-2023	10 m	Current

The utilization of SPOT 5 imagery exclusively incorporates multispectral bands, without the inclusion of panchromatic data. This deliberate approach aims to align the resolution of SPOT 5 images with that of Sentinel-2. By focusing solely on the multispectral bands, the intention is to ensure consistency in resolution between the two image sources. This strategic decision enables more effective and accurate comparative analysis, facilitating seamless integration of information derived from both datasets. While the panchromatic band, known for its high spatial resolution, offers detailed imagery, its omission in this case serves to prioritize uniformity in resolution for optimal compatibility and reliable interpretation across different image sources.

The chosen years of 2004, 2005, 2014, and 2023 form a temporal framework that unveils the profound changes that Banda Aceh has undergone (Figure 2). The 2004 SPOT 5 image serves as the baseline, showcasing the landscape prior to the catastrophic Indian Ocean tsunami on December 26, 2004. This image offers a glimpse into the land use distribution, and natural features before the calamity struck. The 2005 image captures Banda Aceh's immediate post-tsunami landscape. This satellite data encapsulates the aftermath of the devastating event, revealing the extensive destruction and alteration of land cover. The stark contrast between the pre-tsunami and post-tsunami images highlights the unprecedented impact of the disaster on the city's built environment and natural areas. The reconstruction phase that followed the disaster aimed to restore the city's infrastructure and communities. However, the availability of SPOT 5 imagery is in 2014, after the reconstruction period ended in 2009. This image offers insights into the city's progress towards recovery, reflecting the changes in built-up areas, green spaces, and water bodies after the reconstruction efforts. The 2023 Sentinel image brings us to the present, showcasing the most recent state of Banda Aceh's urban landscape. It provides a lens to assess the long-term impact of reconstruction, the trajectory of urban growth, and the conservation efforts undertaken over the years. This image encapsulates the city's current adaptive strategies in the face of environmental and urban changes. SPOT 5 and Sentinel satellite images play a pivotal role in facilitating a nuanced spatio-temporal analysis of Banda Aceh's evolving landscape. The chosen years of 2004, 2005, 2014, and 2023 offer snapshots of the city's journey from pre-tsunami times through the immediate aftermath, post-reconstruction, and into the contemporary era.

2.2 Pre-processing

The pre-processing stage is a critical phase in remote sensing analysis, as it lays the foundation for accurate and meaningful results [16]. In this context, the utilization of ENVI 5.3 for preprocessing SPOT 5 and Sentinel-2 satellite images has facilitated the refinement of data for subsequent analyses. This paper delves into the preprocessing steps applied to each image type. For the SPOT 5 images, the preprocessing commences with atmospheric and geometric correction. Atmospheric effects can introduce distortions and variations in satellite imagery, impacting the reliability of subsequent analyses. Through ENVI 5.3, atmospheric correction algorithms are employed to mitigate these effects, enhancing the accuracy of the data. It's noteworthy that the SPOT 5 images have undergone prior radiometric corrections by the source. In the case of Sentinel-2 images, a distinctive characteristic emerges. These images arrive already pre-processed and corrected, encompassing geometric, radiometric, and atmospheric corrections. Additionally, they exhibit a significant advantage – a lack of clouds. Cloud cover can obscure essential features and hamper analysis accuracy, but the Sentinel-2 in 2023 image is devoid of this hindrance. Consequently, the need for cloud masking, a common practice to remove cloud-affected portions from imagery, is eliminated.

2.3 Supervised Classification

Supervised classification is a fundamental technique in remote sensing and geospatial analysis aimed at enhancing accuracy in determining land cover classes based on the color information present in available satellite imagery [17]. The process uses ArcGIS. The first step in the process involves geo-referencing the satellite images. Geo-referencing aligns the images with real-world coordinates, ensuring spatial accuracy for subsequent analyses. The next phase entails image cropping, where the imagery is trimmed to match the study area. This step is crucial for focusing the analysis on the specific region of interest and discarding irrelevant data. To achieve precise cropping, administrative boundary shapefiles provided by the Badan Informasi Geospasial (BIG) Indonesia are employed, ensuring that the analysis remains within the designated study area.

Land Use and Land Cover (LULC) classification focuses on four distinct classes, each representing a specific aspect of the landscape (Table 2). The first class, "Built-up area," encompasses all human-made structures such as buildings, roads, and infrastructure. This class provides insights into urbanization trends and the extent of human habitation. The "Open land" class represents undeveloped or sparsely populated areas. It includes lands that are not heavily built upon or urbanized. The "Vegetation" class is instrumental in assessing the distribution of green cover, including forests, parks, and other vegetated spaces. Monitoring changes in vegetation helps to understand the impact of urbanization on the environment, as well as potential ecological changes. Lastly, the "Water body" class encompasses rivers, lakes, ponds, and other water features. This class plays a critical role in understanding the hydrological aspects of the landscape, identifying water bodies' changes due to urban development, and assessing potential risks related to tsunami.

The primary method of this research lies in the supervised classification, and the chosen algorithm is maximum likelihood. This method involves training the classification algorithm using known samples of different land cover classes. These samples are representative of the various land cover types present in the study area. A minimum of 50 training samples are selected, enhancing the likelihood of accurate classification results. These samples are chosen based on their spatial distribution and their representation of the class they belong to. The process of supervised classification leverages the combination of different bands within the satellite imagery. These bands capture varying electromagnetic wavelengths and correspond to other land cover characteristics. By analyzing the spectral patterns of these bands, the classification algorithm discerns the unique signature of each land cover class, allowing for accurate identification and delineation. To further refine the classification process, the classified results are compared with high-resolution world imagery available in ArcGIS. This comparison aids in validation and error detection, enhancing the reliability of the results. Areas of discrepancy between the classified map and the world imagery can be further investigated and corrected if needed.

Table 2. LULC Scheme

LULC classes	Description
Built-up area	Building (residential, industrial, commercial, etc.), transport network
Open land	Beach/ sand, paddy field, hills, wasteland, open ground
Vegetation	Forest, natural vegetation, shrub, grass
Waterbody	River, pond, wetland, sea, other water feature

2.4 Accuracy Assessment

Following the classification process, the subsequent stage involves conducting an accuracy assessment on the resultant classified images. This assessment is crucial in quantifying the reliability and precision of the classification outputs [18]. The accuracy assessment is carried out through the utilization of the Kappa accuracy tool within ArcGIS. The accuracy assessment commences with the selection of reference points, also known as ground truth points. These points serve as benchmarks against which the classified images are compared. To ensure robust results, a minimum of 100 reference points are chosen from each classified image. To validate the accuracy of the classified images, comparison with high-resolution satellite imagery is necessary. Google Earth provides an invaluable resource for this purpose, offering detailed views of the land cover classes on the ground. The reference points chosen earlier are then cross-referenced with the Google Earth imagery to verify the correctness of the classification. This validation process helps identify areas of agreement and discrepancies between the classified images and real-world conditions. After calculating the Kappa statistic, a threshold for acceptable accuracy is established. If the Kappa result falls below 85%, additional ground truth points are added, and the classification is refined. This iterative process aims to improve the accuracy until the Kappa value surpasses the predetermined threshold. Once the Kappa accuracy exceeds 85%, the accuracy assessment is considered successful, and the classification results are deemed reliable for further analysis.

2.5 Change Detection

The initial step in the process involves converting the raster-based LULC maps into polygon format. This conversion enhances the precision and versatility of the data. The subsequent phase entails the isolated detection of changes within the built-up class across the three selected time intervals: 2004 to 2005, 2005 to 2014, and 2014 to 2023. This involves identifying areas that have transformed from non-built-up to built-up status within each timeframe. The culmination of the analysis consists in amalgamating the three separate change detection results—spanning the chosen time intervals—into a comprehensive representation of urban growth trends. This is achieved through the application of the "intersect" tool available within the ArcGIS software. The tool spatially overlays the three change detection outcomes, generating an output that depicts areas where urban growth has occurred during each interval.

3. Result and Analysis

3.1 Land Use Land Cover Map

Following the comprehensive analysis process detailed earlier, the time has come to present the outcomes of the study. These results have undergone rigorous accuracy assessment, achieving scores exceeding 85%. The accuracy rates exceeding 85% indicate a high level of agreement between the classified images and the reference data. One of the challenges encountered in this process is the interpretation of colors captured during analysis to translate them into real-world conditions. Instances like paddy fields that can shift from green to brown or open fields that mimic flooded or damaged areas pose significant challenges. The results of the accuracy assessment are as follows: 2004 yields an accuracy rate of 88.03%, 2005 achieves 87.26%, 2014 demonstrates a rate of 92%, and 2023 delivers an impressively high accuracy rate of 97.99%.

The analysis unveils significant spatio-temporal trends in LULC alterations. Urban expansion is observed through increased built-up areas, often at the expense of green spaces and water bodies. Built-up areas, including buildings, roads, and various physical infrastructures, have experienced substantial expansion. The accompanying image maps a compelling trend over time, depicting the gradual increase in non-natural, built-up area and the subsequent decrease in naturally occurring spaces. This transition signifies the encroachment of human development, underpinning the urbanization phenomenon that has become a hallmark of this era. Figure 3 presents the LULC maps for each respective year, offering a visual journey through the shifts in land cover classes.

In the LULC map for 2004, the dominant feature is the built-up area, concentrated in the city center along the Krueng Aceh River. The coastal zone mainly comprises water bodies, reflecting the prevalence of fish ponds and coastal wetlands. Moving southward, the landscape transforms into agricultural fields. The interplay of urban, agricultural, and coastal elements is evident, signifying the city's diverse characteristics. The LULC map for 2005 vividly portrays the devastating impact of the Indian Ocean tsunami. The coastal and central urban areas suffered extensive destruction, as indicated by the transformation of the built-up and coastal zones. By 2014, the LULC map illustrates the post-reconstruction phase, with evident changes in the distribution of land cover classes. Notably, the urban development appears to have shifted away from the coastal areas, reflecting a conscious reconfiguration of the city's layout post-tsunami. The LULC map for 2023 introduces an intriguing dynamic—the expansion of built-up areas encroaching upon the coastal zones. Despite the earlier trend of distancing development from the coast, this latest portrayal hints at renewed urban growth along the shoreline.

Table 3 provides a more quantitative perspective, detailing the extent of each LULC class for the selected years. In 2004 and 2005, open land dominated the landscape. However, a notable shift occurred after the reconstruction phase, as built-up areas became the predominant feature from 2005 to

2023. Remarkably, the area of open land decreased significantly from 2881,2 hectares in 2004 to 529,1 hectares in the present. Vegetation, on the other hand, exhibited a fluctuating trend, experiencing an initial increase in 2014 but subsequently declining by approximately 500 hectares by 2023. The coastal transformation is particularly remarkable. After the 2005 tsunami, the coastal zone prominently featured water bodies, indicative of the inundation caused by the disaster. However, over the years, this water body area has diminished, reflecting a gradual recovery and rehabilitation process that has reshaped the coastline.

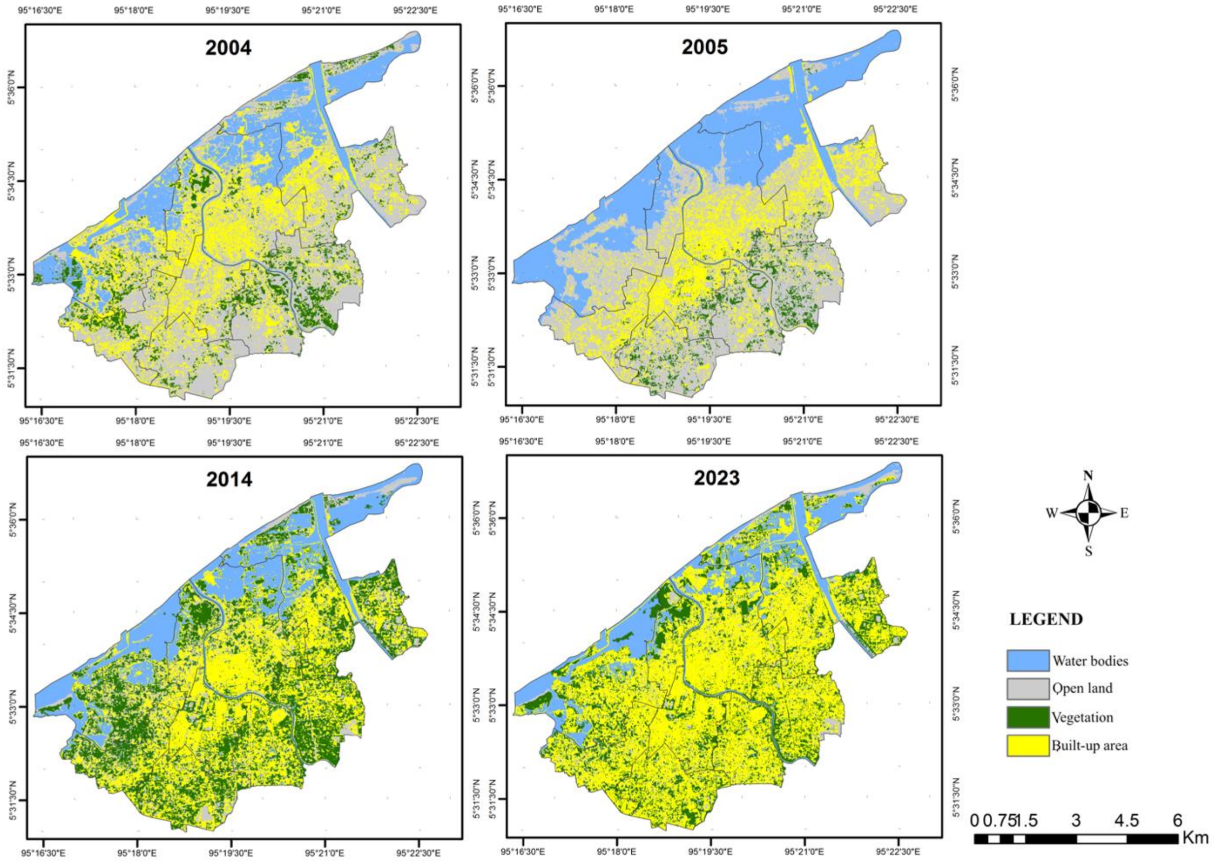


Figure 3. LULC Change from 2004 to 2023

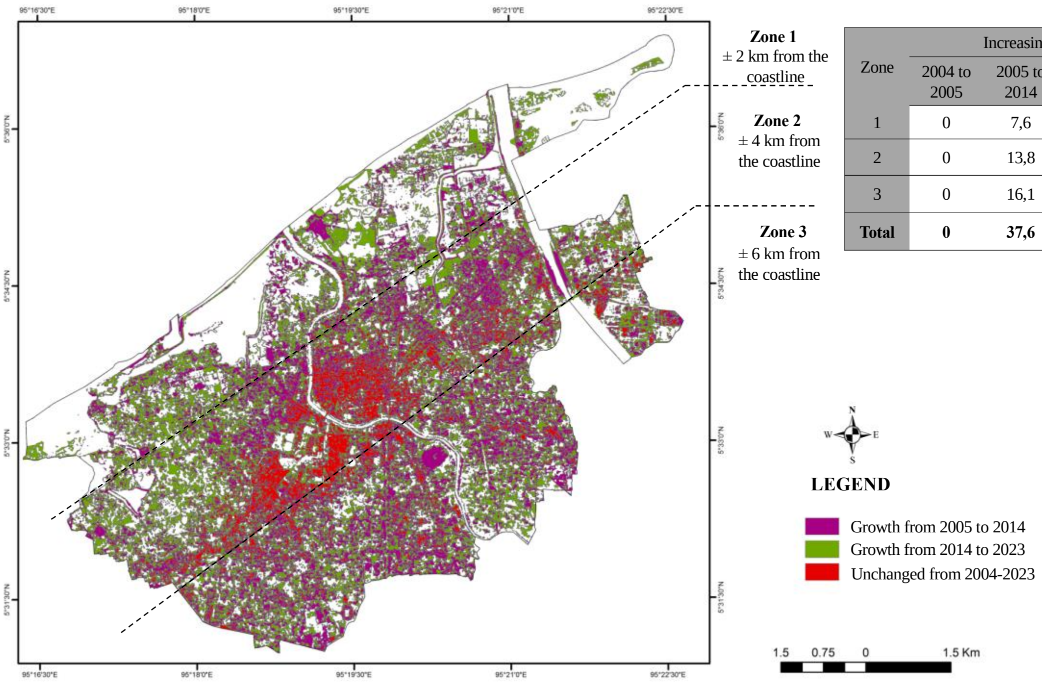
Table 3. Area of LULC

Classes	Area in hectares			
	2004	2005	2014	2023
Built-up area	1515,6	1226,9	2157,6	3345,8
Open land	2881,2	2872,3	851,7	529,1
Vegetation	513,1	243,2	1735,8	1173,8
Water bodies	1134,2	1702,3	1298,7	995,7

3.2 Spatial Trend of Change in Built-up

The LULC maps for 2004 and 2005 delineate three distinct zones that define Banda Aceh's landscape. The typology of built-up area change zones forms three patterns delineated approximately 2 kilometers from the coastline based on these patterns and considerations of area allocation by the Government of Banda Aceh. The southern part of the city is designated for the development of the new central business district after the tsunami. The northern part of the city was the most severely damaged area, while the central part of the city, which is the most dominant, remained unchanged.

Zone 1, the coastal area, is marked by the prevalence of water bodies, reflecting the coastal nature of the zone and its significance in terms of fisheries and aquatic resources (Figure 4). Zone 2, the city center, occupies the central space between the coastal area and the open land zone. This zone is characterized by a concentration of built-up structures, indicating urban development and economic activities. Zone 3, in contrast, is typified by the dominance of open land, suggesting a minimally structured area, potentially designated for future development. Analyzing the growth trends from 2005 to 2014 reveals a shift in urban growth dynamics. The expansion of built-up areas seems to gravitate towards Zone 3, suggesting a planned urban development strategy by the city authorities to establish a new urban center. Subsequently, the analysis of growth from 2014 to 2023 portrays a more dispersed urbanization pattern. Built-up areas appear to fill the city, indicating more balanced and widespread development throughout Banda Aceh. In Zone 2, the city center, the analysis demonstrates consistent built-up patterns from 2004 to 2023. On a macro scale, the entire city of Banda Aceh experiences a notable increase in built-up areas. The built-up area, which primarily comprises urban structures and infrastructure, has expanded across all zones by 2023. The most substantial growth occurs from 2014 to 2023, registering a remarkable increase of 45.1%. Conversely, a significant portion, 17.4%, remains unchanged in built-up area from 2004 to 2023.



Zone	Increasing Built-up Area in %			
	2004 to 2005	2005 to 2014	2014 to 2023	Unchanged (2004-2023)
1	0	7,6	12,5	0,5
2	0	13,8	16,7	11,9
3	0	16,1	15,9	5
Total	**0**	**37,6**	**45,1**	**17,4**

Figure 4. Urban Growth of Banda Aceh from 2004 to 2023

The intricate relationship between the LULC data and the study of disaster resilience in Banda Aceh is pivotal. The urban growth trends unveiled in this analysis provide critical insights into the city's resilience strategies and priorities. The notable concentration of urban development in Zone 2, the city center, underscores the prominence of this zone in Banda Aceh. The shift of growth towards Zone 3 suggests intentional planning to redistribute urban functions and create new urban centers, contributing to a more balanced urban form. The dynamic urbanization patterns across the zones illustrate Banda Aceh's evolving response to tsunami, urbanization pressures, and the pursuit of sustainable development. Further investigation into the meso-scale urban planning intricacies and the spatial arrangements of the built environment is imperative. Such detailed studies can offer deeper insights into how Banda Aceh's urban landscape adapts to the challenges of tsunamis, while simultaneously striving for equitable growth, infrastructure resilience, and community well-being.

This spatiotemporal analysis research is closely related to previous research in Banda Aceh as it can expand and deepen the understanding of urban environmental changes in the region. Previous research has provided a general overview of post-tsunami urban environmental changes and vulnerability in Banda Aceh [6–10,12–14]. The results of this spatiotemporal analysis can aid understand in more detail how land use change patterns and building dynamics have evolved from 2004 to 2023. Through the identification of patterns and trends, this can reveal if there are specific patterns in urban development that may pose a higher risk in facing future disasters. According to the analysis results up to 2023, the development of built-up areas in Banda Aceh has not only expanded in the southern part of the city designated for a new city center but also in areas near the coast (north) that previously experienced destruction in 2004. After the reconstruction program, the built-up areas in the coastal zone actually continued to increase until 2023 compared to the period from 2005 to 2014 (Figure 4). The development of built-up areas in the zones closest to the coastline is most likely to experience destruction if the same disaster occurs. Based on these findings, it is potential to conduct further research on the resilience of areas predominantly characterized by unchanged built-up areas and areas that have developed since the 2004 tsunami. By studying these two types of areas in more detail, we can analyze their resilience to potential future tsunami events and identify strategies to enhance their resilience.

Analyzing the alignment of development plans with urban growth patterns is a critical endeavor that can significantly contribute to our comprehension of the intricate relationship between urbanization and resilience. The dynamic interplay between urban growth and disaster resilience has gained increasing attention in recent years due to the mounting challenges posed by urbanization and the escalating frequency of natural disasters [19]. Development plans, often devised by municipal authorities and urban planners, play a pivotal role in shaping the spatial and socio-economic dimensions of a city. These plans encompass a wide range of factors, including land use regulations, infrastructure development, housing policies, transportation networks, and environmental preservation initiatives [20]. One primary aspect of this alignment involves the consideration of disaster-prone areas within a city's urbanization plan. When development plans disregard or inadequately address such areas, the result can be increased vulnerability to disasters [21]. For instance, if development occurs in tsunami-prone city without adequate urban form, the likelihood of tsunami-induced damages rises significantly.

Furthermore, analyzing the alignment between development plans and urban growth patterns provides insights into the resilience strategies adopted by cities. By integrating disaster risk reduction measures, such as land-use zoning to minimize exposure to hazards or building regulations that enhance structural integrity, these cities can effectively reduce the impacts of disasters on both physical assets and human lives [22].

This alignment also allows us to assess the adaptability of urban growth patterns to changing circumstances. Urban areas that exhibit flexibility and adaptability in the face of evolving challenges can adjust their development plans to accommodate new information, changing hazard profiles, and emerging risks [23,24]. Thus, by analyzing how development plans respond to evolving urban growth patterns, we can better understand the city's capacity to adapt to uncertainties and unforeseen events.

4. Conclusion

In the face of rapid urbanization, environmental shifts, and recurring natural disasters, the spatio-temporal analysis of Land Use/Land Cover (LULC) alterations within Banda Aceh's urban fabric takes on paramount significance. This preliminary study has endeavoured to shed light on the dynamics of resilience within the context of LULC change, using advanced Geographic Information Systems (GIS) techniques and satellite imagery from the SPOT 5 and Sentinel platforms. The study's findings reflect an intricate tapestry of urban growth. The resultant patterns, deciphered through supervised classification, reveal the nuanced interplay between human activities and environmental systems. Urban expansion is accompanied by the encroachment of natural environment and built-up growth.

Despite the adversity posed by recurrent natural disasters, Banda Aceh's population persists in its expansion dynamic. However, the coexistence of built-up area growth with vulnerability to natural hazards underscores the pressing need for adaptive strategies. As a preliminary study, this research sets the stage for more extensive inquiries into Banda Aceh's evolving urban landscape. Future investigations could delve deeper into the socio-economic implications of LULC changes, the long-term viability of green spaces, and the potential for natural resource management. Moreover, longitudinal studies could facilitate a more nuanced understanding of disaster resilience strategies employed by the population in the face of environmental and urban transformation.

This preliminary study has unveiled the dynamic interplay between built-up area expansion and environmental shifts in Banda Aceh. Through the lens of spatio-temporal analysis, the research has elucidated critical trends, underscoring the significance of informed urban planning, ecological conservation, and disaster resilience. As Banda Aceh continues its trajectory of growth and change, this study's insights serve as a beacon for fostering sustainable, adaptive, and resilient urban futures.

5. Acknowledgments

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