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Land Use, Built-Up, and Vegetation Index in North Halmahera Regency through Spatio-Temporal Analysis

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Abstract

Monitoring land use, buildings, and vegetation index of ecotourism areas in North Halmahera can support planning space utilization in urban areas for tourist areas as the concept of land use management and urban planning. This study offers ideas for analyzing the distribution of buildings, vegetation index, and land use in the mangrove ecotourism area of North Halmahera Regency using the spatio-temporal analysis method. The spatio-temporal analysis method comprises several stages: data selection, preprocessing, data integration, spatial analysis, temporal analysis, spatio-temporal analysis, data visualization, interpretation and understanding, and data visualization. The results of this study show that changes in the livelihood strategy of local people, from farmers and fishermen to traders, also affect land use patterns, from agricultural activities to economic activities, which triggers an increase in the number of buildings for production activities to product distribution. The implications of these findings on ecotourism development programs and policies and infrastructure development in the North Halmahera Regency are to consider community livelihoods and space or land use behavior in ecotourism areas based on vegetation, soil, and building index values. Thus, the intensification of building distribution and changes in vegetation index values from 2013–2023 reflect changes in people's livelihood strategies from agrarian activities to trade and from fishermen's activities to tourism transportation service providers.

Keywords: *land use, built-up, vegetation index, ecotourism, spatio-temporal*

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Introduction

Land use to create tourist places has been acknowledged as a technique that has the potential to support local economic growth and drive the improvement of social welfare in the surroundings (Wu et al., 2020). Tourism destinations can provide new employment opportunities and bolster local household income through increased investment in infrastructure, lodging, and other ancillary services (Centinaio et al., 2022). In addition, increasing the number of tourists can foster the growth of commercial and service industries, such as restaurants, souvenir shops, and local transportation, which can raise residents' incomes (Munanura & Kline, 2023). In addition to economic factors, the development of tourism destinations typically incorporates environmental and cultural conservation initiatives that can protect natural and cultural treasures and preserve the identity of local populations, thereby enhancing aspects of social welfare in this context (Johann et al., 2022). Although these benefits are substantial, it should be emphasized that the development of tourist areas must also consider potential adverse impacts, such as environmental and social problems, and that their management must be conducted sustainably and with the participation of local communities to maximize economic and social benefits while minimizing adverse effects (Singgalen et al., 2019; Singgalen, 2020, 2022).

Sustainable land use for the growth of the tourism industry and economy substantially impacts the expansion of physical infrastructure, such as installing buildings for tourism-related support facilities and other economic functions (Zhu et al., 2023). This phenomenon increases the possibility of land-use changes that could affect the field's physical and social environment (Feng et al., 2020). Consequently, it is crucial to closely monitor and assess this physical growth. Utilizing constructed indices in analyses using remote sensing technologies is a practical strategy (Wang et al., 2022). The built-up index identifies and maps areas developed to a specific density, simplifying the geographical and temporal monitoring of urbanization and infrastructure development (Pandya et al., 2023). This method facilitates the adoption of suitable land management policies, considering environmental and social factors, and promoting sustainable economic growth and positive community effects (Ma et al., 2022).

Land use for improving the tourism sector has broader consequences than merely increasing the number or expanding the spread of structures (Gelbman, 2022). Land use changes drastically alter environmental characteristics, including vegetation and land cover (Chu et al., 2021). Remote sensing technology for monitoring has become vital in this context, as it enables spotting and assessing changes in vegetation indices (Zhou et al., 2023). An increase in the quantity and intensity of structures around tourism regions can result in the loss of green land or changes in the type of land cover, which can harm local ecosystems and environmental quality (Wang et al., 2023). Therefore, continuous monitoring utilizing remote sensing techniques aids in quantifying the ecological impact of land use on tourism and enables evidence-based decision-making to decrease negative impacts and enhance environmental sustainability in developing the tourism sector (Chu et al., 2021).

Using remote sensing to monitor ecotourism areas over time is critical for environmental preservation and sustainable management. Remote sensing technologies facilitate the collection of high-quality spatial data and a comprehensive understanding of the changes in land cover, vegetation, and general environmental conditions (Maaiah et al., 2023). Using satellite imagery and other data, observers can systematically monitor changes in tourist regions, such as deforestation, soil degradation, habitat alteration, and other disturbances that have the potential to harm ecosystems and are susceptible to climate change (García et al., 2023). Remote sensing helps evidence-based decision-making to maintain natural balance, implement effective conservation policies, and guarantee the long-term sustainability of ecotourism regions.

Observing and comprehending the change in land use, building distribution, and vegetation indices in ecotourism zones over time is significantly aided by remote sensing through spatial-temporal analytic techniques (Niavis, 2020). Using remote sensing technology, consistent and reproducible spatial data can be collected, enabling systematic monitoring of changes in land use, building distribution, and vegetation dynamics in ecotourism regions (Chen et al., 2022). Spatio-temporal analysis permits the identification of long-term trends and patterns of change that may be difficult to distinguish from a single spatial study. This is essential for effective planning, management, and preservation within the context of ecotourism sustainability (Ding et al., 2023). In addition, using vegetation indices derived from satellite imaging data provides an objective assessment of habitat quality and ecological conditions, provides a broader understanding of ecosystem health in ecotourism areas, and enables improved decision-making regarding their preservation and development (Subramaniam et al., 2023).

In the tourist region of the North Halmahera Regency, the significance of spatio-temporal analysis in terms of land use observation, building distribution, and vegetation index values cannot be overstated. This region is home to rare species that require stringent conservation due to their exceptional natural variety. Spatial-temporal analysis provides ongoing monitoring of land use evolution, infrastructure development, and ecological health in this environment. This is essential for effectively preserving and managing this ecotourism region in the face of possible risks, such as climate change and unchecked growth. Thus, spatial-temporal analysis is essential for supporting evidence-based decision-making and sustainable planning to maintain the natural wealth and beauty of ecotourism regions in the North Halmahera Regency, North Maluku Province, Indonesia.

This study significantly contributes to ecotourism, remote sensing, and geographic information systems by employing spatial-temporal analysis to assess changes in land use, building distribution, and vegetation index values in the North Halmahera Regency mangrove areas. This research provides a more comprehensive understanding of the dynamics of mangrove ecosystems over a more extended period through the normalized difference vegetation index (NDVI) (Vargas et al., 2021), soil-adjusted vegetation index (SAVI) (Wen et al., 2020), and normalized difference built-up index (NDBI) (Rendana et al., 2023) models (Guha et al., 2020). This study used Landsat 8 Operational Land Imager (OLI) raster data collected in 2013, 2018, and 2023. The findings of this study have significant implications for the conservation and management of ecotourism in the region because they provide essential insights into environmental change and the influence of human development. This research also contributes to developing spatio-temporal analysis approaches relevant to observing various ecotourism locations.

The justification for the selection of spatial data in 2013 is related to the development plan and massive infrastructure development program in the North Halmahera Regency so that it relates to space utilization and land use change. Furthermore, 2018 was the right time to evaluate and review spatial planning and land use after infrastructure development and regional planning through the five-year development plan. After 2018, space utilization permits for industrialization purposes and the acceleration of economic development in the North Halmahera Regency will last until 2023, ahead of the simultaneous General Elections. Landscape changes due to the use of space for economic purposes have changed ecological aspects and need to be studied scientifically so that development risks that impact the environment can be mitigated or anticipated, as well as the principles of sustainable development.

Methods

Spatio-temporal analysis is a technique for analyzing changes in geographic data through time. In the first stage, Landsat 8 OLI satellite pictures from 2013, 2018, and 2023 were selected for the North Halmahera Regency, North Maluku Province, Indonesia. In addition, the data preprocessing phase was performed to improve data quality by noise removal and atmospheric correction utilizing the QGIS application's Semi-Automatic Classification Plugin. Data integration merges spatial and temporal data into a unified dataset, namely, vector data derived from geospatial data for the nation. Mapping and comprehending spatial patterns based on NDVI, SAVI, and NDBI models comprise spatial analysis. The implementation stages of the spatial-temporal analysis approach are depicted in Figure 1.

Figure 1 illustrates the application of Spatio-Temporal Analysis to observe land use, built-up, and ecotourism areas in the North Halmahera Regency, North Maluku Province, Indonesia. Temporal analysis identifies changes and trends across time through each model's calculated histogram. The spatio-temporal analysis demonstrates the link between space and time by analyzing the lowest, average, and maximum values of the applied model. Based on the land use, built-up, and vegetation index of ecotourism regions in

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North Halmahera Regency, North Maluku Province, Indonesia, NDVI, SAVI, and NDBI model histograms for 2013, 2018, and 2023 were examined at this stage. The observation area is depicted in Figure 2

Figure 2 shows the area to be observed and analyzed using NDVI, SAVI, and NDBI. These areas include urban and coastal areas surrounding the City, such as Mahia-Pelabuhan TPI (Area 1), Pelabuhan Angin Mamiri (Area 2), Gamsungi (Area 3), Rawajaya (Area 4), Wosia (Area 5), and Tanjung Pilawang-Gura (Area 6). This investigation aimed to assess the changes in the region's vegetation, urban land use patterns, building distribution, and soil conditions. This technique has substantial implications for urban planning, coastal environment monitoring, and natural resource

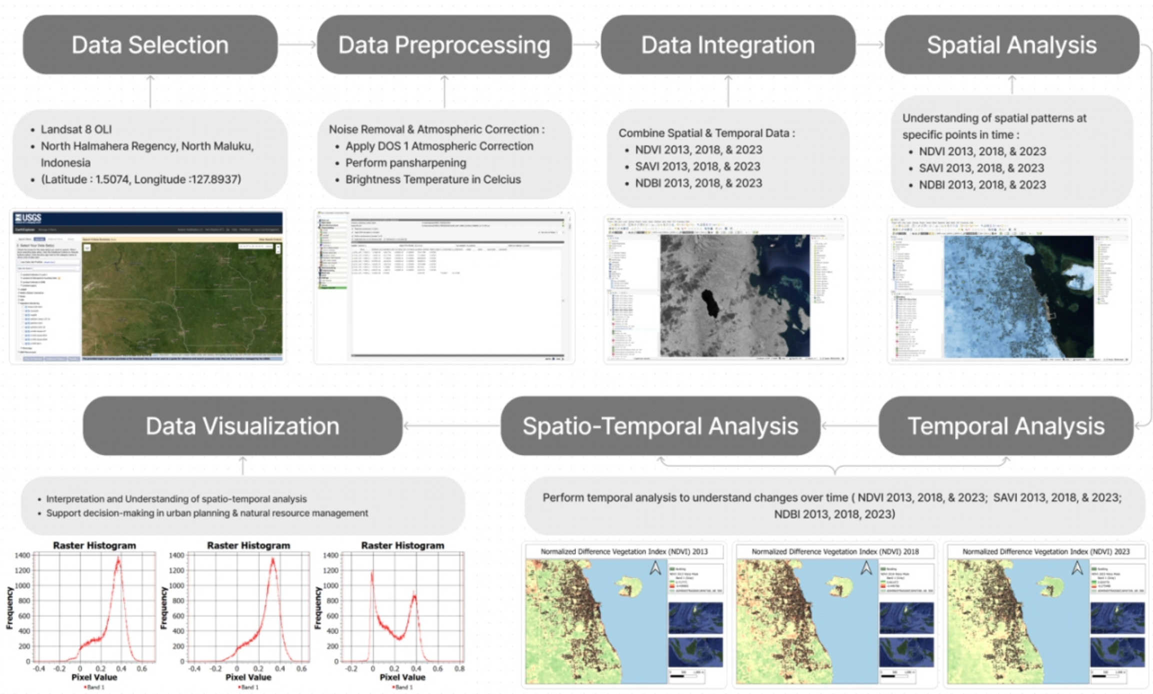

Figure 1 Implementation of spatio-temporal analysis to observe land use, built-up, and ecotourism area in North Halmahera Regency, North Maluku Province, Indonesia.

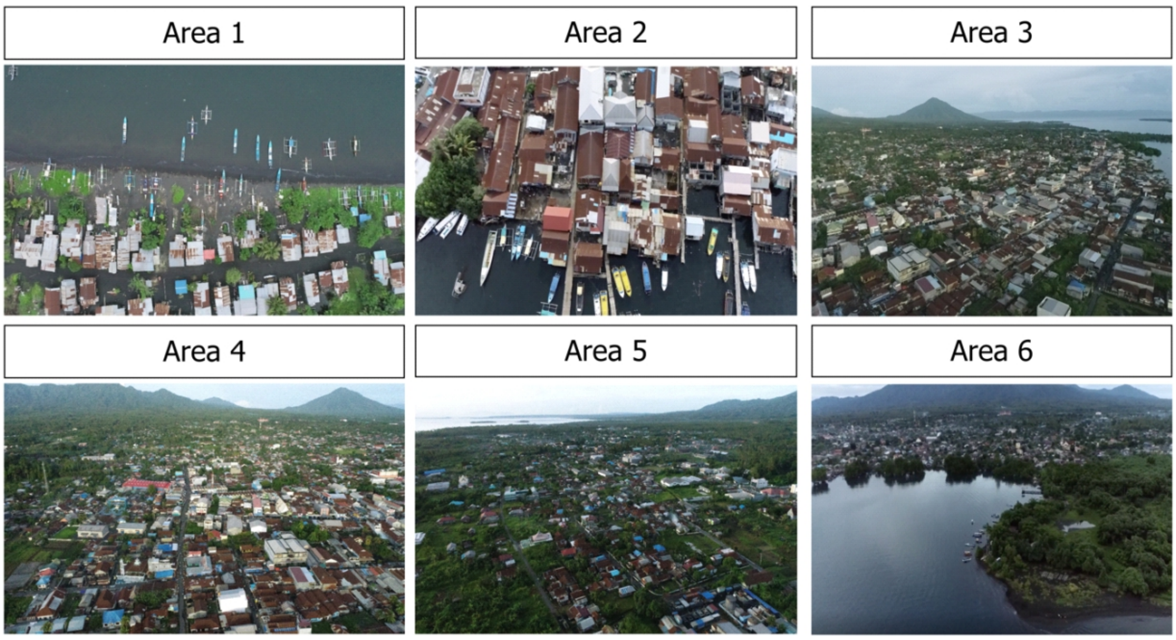

Figure 2 Implementation of spatio-temporal analysis to observevation area in an urban and coastal area of Tobelo City.

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management in the region, and it can provide more profound knowledge of spatial and temporal dynamics in the context of the region's evolution. In addition, Tobelo City is surrounded by islands, as shown in Figure 3.

Figure 3 depicts an excellent vantage point for the islands surrounding Tobelo City. Kumo Island (Area 7), Kakara Besar Island (Area 8), Kakara Kecil Island (Area 9), and Tagalaya Island (Area 10) were the observed islands. This archipelago contains a mangrove environment that is a valuable natural asset in the coastal zone and a popular tourist destination and source of income for local fishermen. Consequently, analysis utilizing NDVI, SAVI, and NDBI models is essential to comprehend the condition and dynamics of mangrove ecosystems and the effect of human activities on ecological equilibrium in this region.

There are several reasons why these variables are represented in the analysis as follows: first, there are limited human resources (HR) within the North Halmahera Regency Government who have spatial analysis capabilities based on remote sensing approaches, especially in understanding NDVI, NDBI, and SAVI models; second, spatial analysis based on the NDVI model makes it easier for policymakers to carry out control functions on space utilization in North Halmahera Regency by considering ecological conditions, namely vegetation; third, the NDBI model is helpful for policymakers to consider infrastructure development with soil and land contours so that it becomes an anticipatory step against the problem of land degradation scarcity due to development; fourth, the SAVI model is helpful for policymakers to identify areas classified as minimal vegetation so that they can be considered in the process of determining infrastructure development programs and environmental preservation. Without the analysis of NDVI, NDBI, and SAVI, development planning is based on political negotiations and economic interests that potentially pose risks of long-term environmental damage due to infrastructure development and land use for production purposes, without risk control and mitigation.

There are limitations and challenges in the process of retrieving, processing, and analyzing data related to the spatial database owned by the North Halmahera Regency Government. First, the processed spatial data were limited to polygon data with geoprocessed coordinate points processed using geoprocessing to ensure the accuracy of the coordinate points of the observed area when mapping the area according to the regional development plan. Second, observations using drones show that land use for economic activities is not integrated with the development plan map that has been utilized. Third, the observations show that there is limited coverage related to space utilization socialization programs for various economic sectors. This is the main reason for people to use private space or land for various economic interests without adjustment to regional development directions and policies as digitally mapped. Fourth, remote sensing analysis is only a guide as well as a consideration for policy makers, but the final decision is dominated by politics, economics, and socio-culture. Although the output in the form of spatial utilization analysis results based on a spatio-temporal analysis approach recommends academic views related to existing conditions and long-term risks, stakeholders need to develop human resources and optimize a goal-oriented bureaucratic system as well as make data-based decision-making culture a strategic and objective step in determining the direction of regional development.

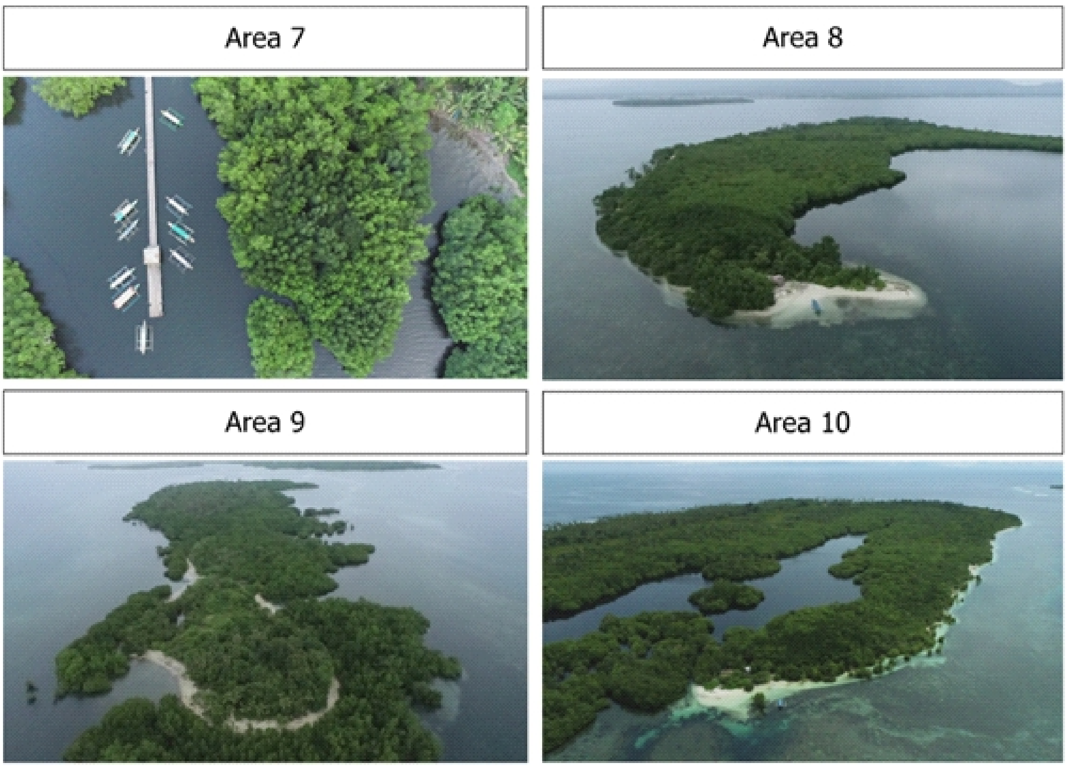

Figure 3 Implementation of spatio-temporal analysis of Kumo, Kakara, and Tagalaya Island.

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Based on the challenges and limitations of this research process, the research question that needs to be answered is how the NDBI, NDVI, and SAVI models can be used as guidance and decision-making considerations to determine the direction, policies, and regional development programs. Furthermore, how can the spatio-temporal analysis method be applied using NDBI, NDVI, and SAVI models to identify land use changes in the districts of North Halmahera, as well as their relationship with socio-cultural activities and the economy of the community in Tobelo City? Through this question, the processing of spatial data using NDBI, NDVI, and SAVI models is limited to areas identified as areas with rapid changes in space or land use from to 2013-2018 and 2018-2019. Specifically, the specified area is divided into two parts, namely the area around the city of Tobelo, namely Pelabuhan Mahia-TPI Port (Area 1), Angin Mamiri Port (Area 2), Gamsungi (Area 3), Rawajaya (Area 4), Wosia (Area 5), and Tanjung Pilawang-Gura (Area 6). The areas used for ecotourism activities with high mobility are Kumo Island (Area 7), Kakara Besar Island (Area 8), Kakara Kecil Island (Area 9), and Tagalaya Island (Area 10). Through this study, it can be known how the dynamics of land use are based on the year and predetermined area.

One of the unique geographical aspects of the North Halmahera Regency is the high mobility of tourist activities on weekends, so access to tourist sites in the surrounding islands using traditional sea transportation modes is high. This shows that areas such as ports have become transit points for tourist trips to the islands around Tobelo as tourist destinations. The intensity of tourist demand makes the area highly economically active on weekends (depending on the season). This crowded point triggers local people to take advantage of economic opportunities by building supporting facilities for space utilization and land conversion from green to economic space. On the other hand, the island area, as a tourist location, also triggers community participation to build tourism-supporting facilities and infrastructure to bring economic benefits. This triggered the local government's policy of investing in building supporting facilities to increase the original local government revenue (PAD). Thus, the intensity of tourism that supports infrastructure development at tourist sites can affect the ecology of the surrounding environment. Therefore, it is necessary to conduct a comprehensive analysis usingremote sensing to recommend areas worth building and areas that need to be preserved. Concerns about determining regional tourism infrastructure development planning programs without the basis of scientific studies and development risk analysis are the urgency of this research, so it is essential to discuss them through a spatio-temporal analysis approach.

Results and Discussion

Previous studies using NDVI, NDBI, and SAVI models have succeeded in showing areas with vegetation, buildings, and soil characteristics that need to be used as infrastructure development and conservation areas. The results of the NDVI-based spatial data interpretation were used to identify the causes of land degradation in an area and produce policy recommendations to overcome this (Žížala et al., 2019). Furthermore, the remote sensing approach maps areas based on vulnerability levels and controls development programs in the mapped areas (Sun et al., 2022). Remote sensing is used to anticipate the impact of climate change on agricultural activities and infrastructure development plans in various regions (Brock Porth et al., 2020). This demonstrates the importance of remote sensing for sustainable development (Kantakumar et al., 2019; Gandharum et al., 2021; Wu et al., 2022a; Zhang et al., 2022; Du et al., 2023). This study discusses the use of remote sensing through a spatio-temporal analysis approach based on NDVI, NDBI, and SAVI, as well as the regional context of the North Halmahera Regency, North Maluku Province, Indonesia.

There are advantages and consequences in regions that do not use a remote sensing approach in determining regional development policies and planning, as follows: first, conflicts due to economic interests occur because trade areas are not optimally mapped, so that the density of buildings for the production and distribution process produces various forms of disturbances that affect the work activities of other entrepreneurs; second, without territorial arrangement based on remote sensing or spatio-temporal analysis approach, policymakers do not get an idea of changes in land and space utilization for various interests related to vegetation and soil contour periodically, so that various risks of environmental damage affecting plants and soil degradation cannot be optimally anticipated; third, technological developments have enabled the use of Landsat 8/9 satellite imagery data OLI is based on NDVI, NDBI, and SAVI models, to be managed into spatial information related to the condition of vegetation and soil contour in an area, so that it can be used as a basis for decision making in regional development planning. Although various approaches have the same results as the application of NDVI, NDBI, and Savi models, regions with limitations on human resource readiness in remote sensing-based spatial data processing can use the model in this study as a basis for decision-making. Furthermore, districts with human resource readiness and expertise in remote sensing can utilize more complex models based on the interests of each region.

The distribution pattern of buildings as an indicator of settlements and economic centers can be used to determine the extent to which economic growth in Tobelo City has affected the community's social welfare level. Improvements in physical development, such as an increase in residential buildings and commercial infrastructure, have resulted from sustained economic expansion. In this aspect, the increasingly egalitarian and diverse distribution of buildings has paralleled the expansion of people's access to suitable housing and diverse employment options. In addition, the expanding economic centers surrounding Tobelo City have boosted citizens' access to jobs and economic services, which may positively impact residents' salaries and overall living levels. However, it should be recognized that economic growth can lead to social inequality if not balanced by policies that promote social inclusion and the equitable distribution of gains. To preserve the equilibrium and sustainability of Tobelo City's development, continual monitoring and evaluation of the influence of economic expansion on social welfare are required.

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The significance of the constructed index analysis, particularly the NDBI model based on the spatial-temporal analysis method, becomes particularly relevant in detecting patterns of land use that include settlements, socioeconomic activities, and significant factors such as education, politics, and technology. This strategy allows for the monitoring of complicated land-use changes over time, which is essential for urban planning, land-use management, and evidence-based decision making in various industries. By spatially temporally evaluating the distribution and changes in the NDBI index, we can understand the dynamics of urban growth, the distribution of buildings, and their impact on the community's social, economic, and political life. Consequently, this research has substantial implications for sustainable regional planning initiatives and for enhancing people's quality of life in an era of rapid urbanization.

The results of the calculations for the NDBI, NDVI, and SAVI models in Wosia and Mahia for 2013, 2018, and 2023 are presented in Table 1. Processing raster data in Wosia and Mahia using the NDBI index revealed a significant increase in the quantity and distribution of residential and commercial structures. In addition, calculating the NDVI and SAVI indices revealed a remarkable shift in land use for structures. It can be seen that the average values of the NDVI and SAVI indices have reduced significantly, indicating a significant transition from vegetation to construction development. These findings represent considerable changes in land use in both regions, which can substantially impact the physical, social, and economic environments and necessitate careful planning and management for sustainable spatial development, as shown in Figure 4.

The observed land use changes in Mahia and Wosia indicate a transition from subsistence agriculture to residential areas and sites of more intensive economic activity. Examining Landsat 8 OLI raster data using the NDBI, NDVI, and SAVI models for the 20132018 and 20182023 periods demonstrates this transition. The drop in the average values of the NDVI and SAVI and the increase in

Table 1 Comparison of NDBI, NDVI, and SAVI in the observation area of Mahia and Wosia from 2013, 2018, and 2013

Observed area	NDBI			NDVI			SAVI		
	Min	Std.Dev	Max	Min	Std.Dev	Max	Min	Std.Dev	Max
Mahia 2013	-0.80	-0.64	-0.11	-0.18	0.35	0.1	-0.09	0.27	0.66
Mahia 2018	-0.80	-0.61	-0.12	-0.10	0.28	0.48	-0.08	0.22	0.42
Mahia 2023	-0.73	-0.55	-0.11	0.01	0.22	0.44	0.01	0.13	0.37
Wosia 2013	-0.78	-0.56	-0.01	-0.11	0.27	0.56	-0.07	0.20	0.48
Wosia 2018	-0.79	-0.52	-0.09	-0.11	0.20	0.51	-0.08	0.15	0.46
Wosia 2023	-0.70	-0.51	-0.32	0.02	0.17	0.44	-0.02	0.13	0.37

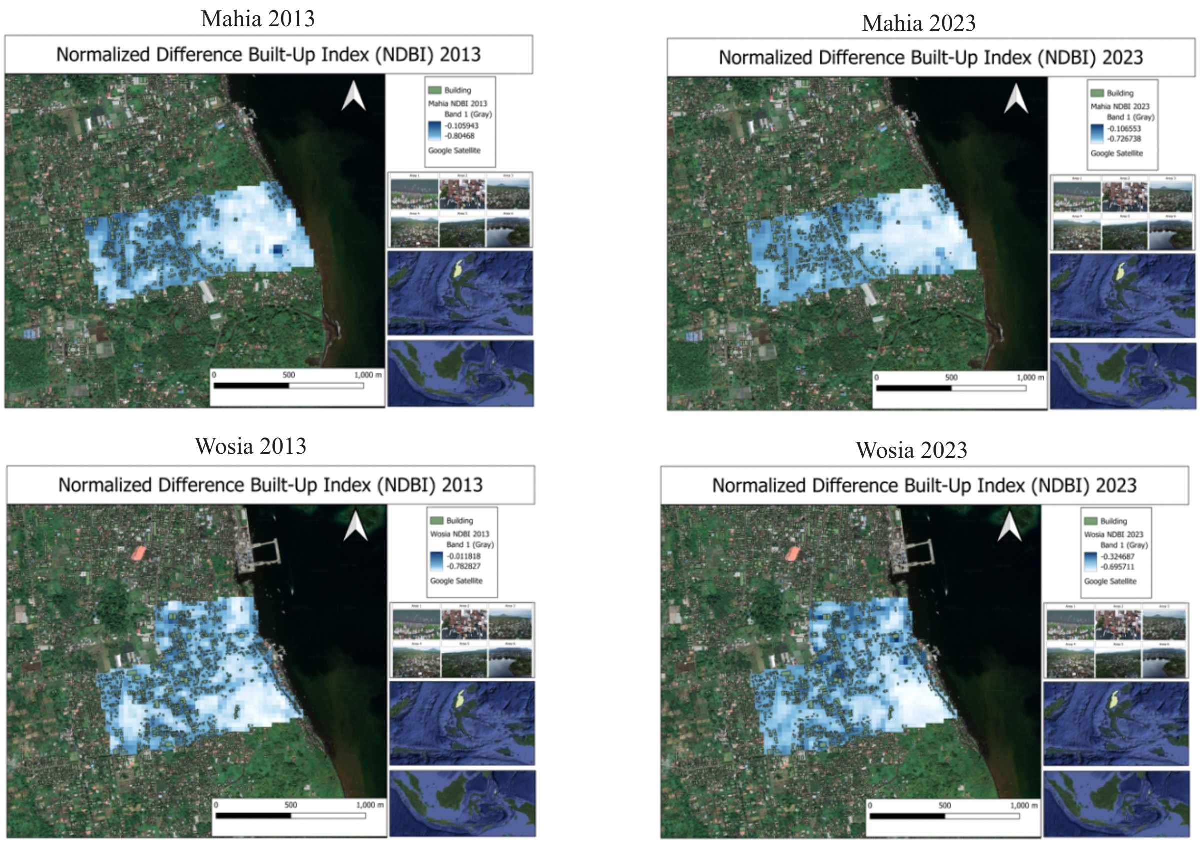

Figure 4 Implementation of spatio-temporal analysis of Kumo, Kakara, and Tagalaya Island.

the value of the NDBI indicate significant changes in land use, an increase in development activity, and a shift in the region's economic structure throughout the studied period. This adjustment will expand road infrastructure to increase mobility and accessibility and promote sustainable development in Tobelo City by improving interregional connectivity and access to commercial and social services. In addition, another observed region exhibited results comparable to those reported in Table 2.

Table 2 is the outcome of calculating raster data for 2013, 2018, and 2023 using NDBI, NDVI, and SAVI models in Areas 2, 3, 4, 5, and 6 (Gura, Rawajaya, and Gamsungi) using NDBI, NDVI, and SAVI models. Based on the NDBI data, the average value in each observation region decreased between 2013 and 2018 and between 2018 and 2023. This demonstrates the rapid rate of land use for buildings. In contrast, the average NDVI value decreased between 2013 and 2018 and between 2018 and 2023, indicating a change in land use from habitation to economic activity in the observation region. Moreover, the SAVI value was related to NDVI, whose average value decreased from 2013 to 2018 and 2018 to 2023. Thus, the average NDBI, NDVI, and SAVI fluctuated significantly every five years.

Due to dynamic sociocultural and economic activities, the Gura, Gamsungi, and Rawajaya region index values changed dramatically. Local governments were obligated to develop progressive laws because of the significant structural growth surrounding the ancient market area. Providing land and developing several facilities in a new market in different regions are some of the strategies adopted. Observations and research suggest substantial changes in the characteristics of the Gura, Gamsungi, and Rawajaya settlements over the past decade, indicating rapid urbanization and complex dynamics. The results for land use, built-up area, and ecotourism area in an archipelago are presented in Table 3.

Table 3 compares the Kumo, Kakara Besar, and Tagalaya Islands NDBI, NDVI, and SAVI values. In the context of variations in the values of NDBI, NDVI, and SAVI in archipelagic regions, it is essential to note that these alterations are not of notable significance. This can be examined by noting that the significant economic center is still centered on the Tobelo City region, which stimulates land conversion for permanent population settlements that can be effectively managed on Kumo Island, Kakara Besar Island, and Tagalaya Island. Despite specific changes in land use, such as higher building densities around economic areas, NDBI, NDVI, and SAVI did not experience significant shifts. This demonstrates that prudent land management and efforts to balance economic development and environmental preservation in the archipelago have produced reasonably constant results. To ensure environmental sustainability on Kumo Island, Kakara Besar Island, and Tagalaya Island, it is crucial to maintain control over sustainable land use change in this setting. In the case of Kakara Kecil Island, there is no settlement on the island; therefore, the models used to calculate NDVI and SAVI to observe the vegetation index and soil around the island are

Table 2 Comparison of NDBI, NDVI, and SAVI in the observation area of Gura, Rawajaya, and Gamsungi from 2013, 2018, and 2013

Observed area	NDBI			NDVI			SAVI		
	Min	Std.Dev	Max	Min	Std.Dev	Max	Min	Std.Dev	Max
Gura 2013	-0.81	-0.54	-0.20	-0.12	0.21	0.48	-0.07	0.15	0.40
Gura 2018	-0.82	-0.51	-0.20	-0.15	0.14	0.42	-0.10	0.11	0.36
Gura 2023	-0.67	-0.50	-0.32	-0.01	0.14	0.34	-0.01	0.11	0.28
Gamsungi 2013	-0.82	-0.67	-0.14	-0.14	0.36	0.59	-0.09	0.28	0.45
Gamsungi 2018	-0.81	-0.65	-0.10	-0.13	0.26	0.48	-0.09	0.20	0.42
Gamsungi 2023	-0.81	-0.60	-0.15	-0.02	0.28	0.46	-0.02	0.23	0.40
Rawajaya 2013	-0.75	-0.42	-0.02	-0.19	0.10	0.47	-0.11	0.07	0.39
Rawajaya 2018	-0.76	-0.38	0.08	-0.19	0.04	0.44	-0.11	0.03	0.37
Rawajaya 2023	-0.63	-0.42	-0.15	-0.03	0.08	0.33	-0.02	0.06	0.27

Table 3 Comparison of NDBI, NDVI, and SAVI in the observation area of Kumo Island, Kakara Besar Island, and Tagalaya Island from 2013, 2018, and 2013

Observed area	NDBI			NDVI			SAVI		
	Min	Std.Dev	Max	Min	Std.Dev	Max	Min	Std.Dev	Max
Kumo 2013	-0.87	-0.75	-0.26	-0.05	0.38	0.47	-0.04	0.28	0.38
Kumo 2018	-0.87	-0.76	-0.22	-0.09	0.34	0.42	-0.07	0.27	0.36
Kumo 2023	-0.79	-0.73	-0.34	0.00	0.34	0.43	0.00	0.27	0.35
Kakara Besar 2013	-0.88	-0.77	-0.29	-0.23	0.38	0.27	-0.12	0.29	0.39
Kakara Besar 2018	-0.89	-0.78	-0.28	-0.27	0.33	0.45	-0.16	0.26	0.39
Kakara Besar 2023	-0.86	-0.77	-0.35	-0.14	0.35	0.45	-0.09	0.27	0.37
Tagalaya 2013	-0.88	-0.78	-0.32	-0.34	0.36	0.48	-0.17	0.26	0.40
Tagalaya 2018	-0.89	-0.79	-0.29	-0.37	0.30	0.36	-0.19	0.23	0.40
Tagalaya 2023	-0.89	-0.77	-0.36	-0.28	0.31	0.47	-0.14	0.23	0.38

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shown in Figure 5.

Figure 5 depicts the NDVI and SAVI Histograms for Kakara Kecil Island for 2013, 2018, and 2023. Analysis of the NDVI and SAVI histogram values for 2013, 2018, and 2023 on Kakara Kecil Island revealed considerable changes in land and vegetation. The reduction in the average NDVI value from 0.35 in 2013 to 0.31 in 2023 results from considerable changes in the island's vegetation and land use. These changes have significant ecological consequences in fragile mangrove ecosystems. Possible consequences include biodiversity loss, habitat loss, and susceptibility to damage from human activities and environmental changes. Therefore, it is crucial to conduct more in-depth research to understand the mechanisms driving these changes and design appropriate conservation strategies to mitigate their negative impacts and protect the sustainability of the mangrove ecosystem on the Kakara Kecil Island.

Based on the index values of NDBI, NDVI, and SAVI in regions such as Gura, Gamsungi, Rawajaya, Mahia, Wosia, Kumo Island, Kakara Besar Island, Tagalaya Island, and Kakara Kecil Island in the North Halmahera Regency, interpretations can be made regarding land use change or land use from socio-cultural to economic interests. By comprehending the interpretation of these values, the analysis reveals profound insights into urban growth, changes in the natural environment, and the influence of human activities on the land and vegetation in those places. Understanding NDBI can aid in identifying building expansion and urban development, while understanding NDVI and SAVI provides information about vegetation health and ecological changes. Consequently, using these indices in the analysis can facilitate improved spatial planning, natural resource management, and monitoring of environmental and social consequences in the North Halmahera Regency Region.

Sustainability through spatial planning and management of land use, built-up areas, and investment in the tourism sector of the North Halmahera Regency Satellite image analysis produces a range of numbers that can be used to determine the significance of the NDBI, NDVI, and SAVI index values. Positive values of NDBI denote land cover by buildings, and negative values reflect open land or vegetation fields (Fadlin et al., 2020). In addition, positive values of NDVI indicate the presence of greener and healthier vegetation, and negative values indicate less vegetated land or water levels (Gultom et al., 2023). Otherwise, positive values of SAVI indicate healthier flora, and negative values indicate land that may be infertile or damaged by diverse land uses (Hardianto et al., 2021). By understanding this range of values, the interpretation of land-use conditions, vegetation, and other environmental aspects in satellite image analysis is more nuanced. This applies to various applications, such as environmental monitoring, spatial planning, and natural resource management.

The rapid economic growth and intensity of social

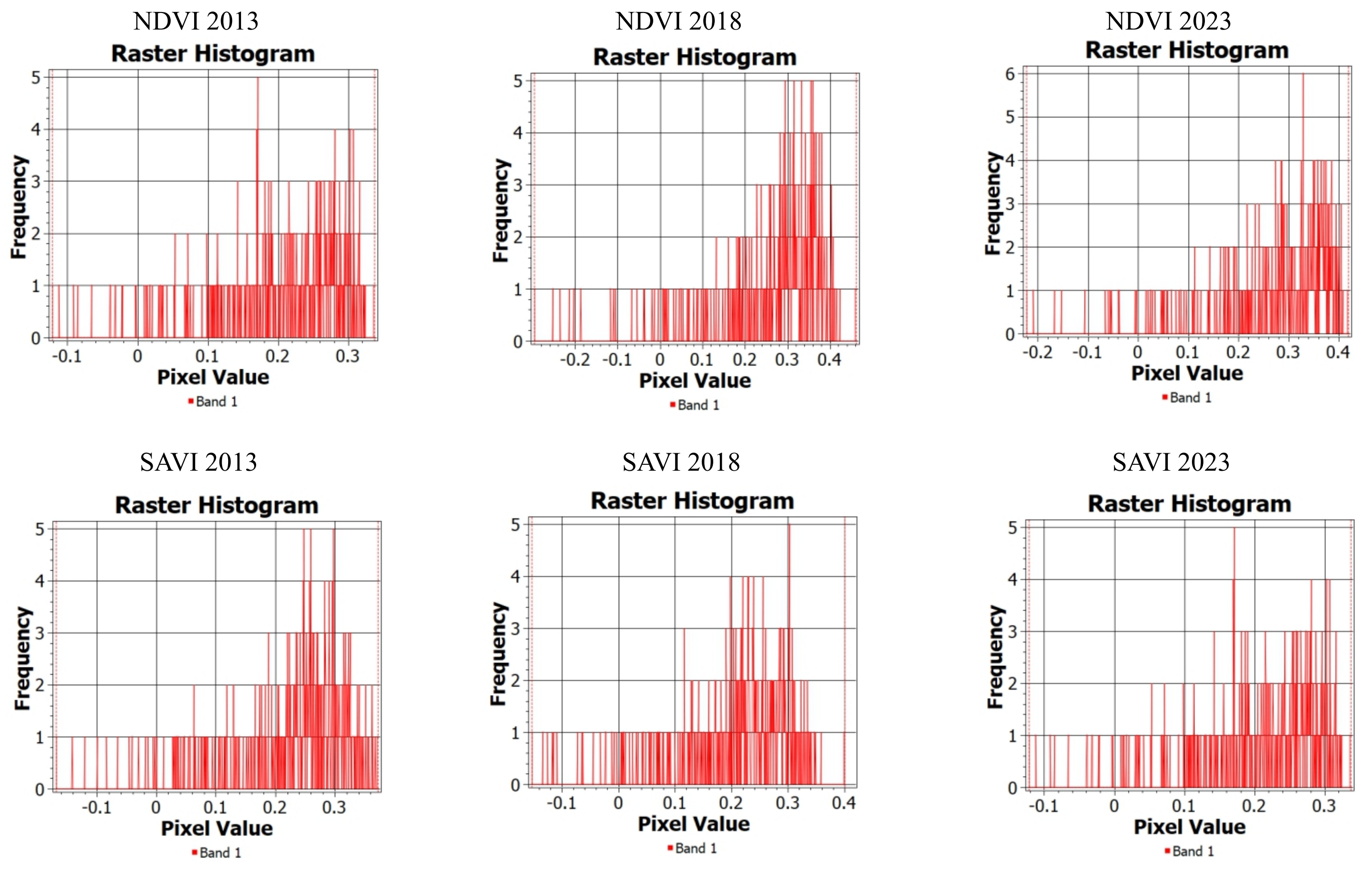

Figure 5 The NDVI and SAVI histogram of Kakara Kecil Island in 2013, 2018, and 2023.

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activities in Tobelo City profoundly affect the cityscape, as seen by the increased structures and decreased land or open space. This process transforms green spaces into residential and commercial districts (Andriansyah et al., 2023). The structural increase, particularly in the economic center, is a direct outcome of the region's substantial economic expansion, attracting investment and residents, including the tourism sector (Wong et al., 2023). While these advancements demonstrate positive economic and urban growth dynamics, it should be recognized that their effects may include increased environmental pressure, deteriorating air quality, and the loss of ecologically significant open spaces (Wu et al., 2022b). To balance sustainable economic growth and environmental preservation in Tobelo City, it is crucial to incorporate sustainable spatial planning and prudent land management.

The significance of spatial management planning relevant to the social and cultural environment of the Tobelo City community is essential to avoid potential disputes caused by legislation or policies that disregard the cultural values of Hibualamo, Higaro, and Hirono (Apituley & Eddyono, 2022). In this context, it is essential to emphasize that the people of Tobelo City have strong links to traditional cultural values, including land use, settlement spatial planning, and profound social customs. Neglecting these cultural values in spatial design can result in community discontent, possible conflicts, and even resistance to legislation (Miradj & Tohe, 2021). In addition, to produce laws and regulations that are more congruent with the social and cultural demands of the Tobelo City people, judicious spatial planning should involve in-depth engagement with local communities and significant consideration of their cultural values (Marsaoly et al., 2018). This will promote sustainable development and coexist with preserving society's priceless cultural legacies.

Considering the current state of Tobelo City, the significance of coastal and island-specific spatial management planning is increasing. Tobelo City is a seaside city surrounded by various islands. Combining urban, economic, and maritime ecosystems rich in biodiversity complicates spatial planning. Additionally, Tobelo City's spatial planning must incorporate the demands of local populations, environmental preservation, natural catastrophe risk management, and sustainable economic development. This necessitates an in-depth comprehension of the local culture and values that coexist with enhanced socioeconomic well-being. Tobelo City will achieve sustainable development while preserving its valuable natural and cultural resources through space management planning.

Specialists and academics have constantly stressed the significance of spatial management planning pertinent to coastal and archipelagic regions. According to experts, such as Flynn et al. (2021), coastal areas have different landscapes and challenges due to climate change. The increased risk of natural catastrophes in coastal and archipelagic regions illustrates the need for spatial management centered on adaptation and mitigation. In addition, Morf et al. (2022) emphasized the significance of planning incorporating ecological, social, and economic factors concerning coastal areas. Handiani et al. (2022) underlines the importance of ecosystem-based management and local community participation for successful spatial planning in coastal and archipelagic regions. Otherwise, to balance natural environment preservation, economic development, and social welfare in coastal areas and islands, pertinent and holistic spatial management planning is necessary, as stated by this perspective.

Local communities, as farmers, use land for plantation activities, among which coconut plantations are still maintained (Dumade et al., 2022). This reflects agrarian practices that have been fundamental to the lives and livelihoods of local people for generations. Coconut plantations are essential for coastal and archipelagic ecosystems and provide a source of revenue. Coconuts produce many economically valuable byproducts, including coconut oil and fiber (Samili & Hasim, 2021). Consequently, coconut plantations provide significant economic and ecological benefits to local populations in the region, highlighting the close relationship between people, land, and the environment (Muhammad & Buturu, 2019).

The transition from coconut farmers to merchants is one of the primary causes of changes in land use patterns from agricultural to non-agricultural uses, such as stores and production sites for new enterprises (Dapilah et al., 2019). These alterations are intimately tied to civilization's economic and social growth, in which expanding commerce and non-agricultural economic activities drive individuals to abandon traditional agricultural lifestyles (Pramudiana, 2018). Along with this change, there has been an increase in demand for commercial and industrial buildings in the region. Therefore, land formerly used for agricultural operations, such as coconut plantations, has been transformed into structures that support commerce and production activities, reflecting changes in economic dynamics and the employment structure of the community (Ahmadi et al., 2023). It also creates problems related to land management and monitoring of environmental change that must be considered in sustainable urban development.

Changes in land use patterns by coconut plantation landowners are influenced by various factors related to financial demand and economic opportunities, which can enhance the community's social welfare (Yin et al., 2023). One of the primary motivations for landowners to seek more lucrative livelihood choices is monetary necessity. These demands, including education and family health, are frequently related to rising costs of living (Wahyono et al., 2023). In addition, landowners are frequently enticed to change their land use through economic opportunities beyond the agriculture sector, such as in industry, commerce, or services. This may involve the construction of commercial or industrial infrastructure and investment in enterprises with the potential to generate more stable and substantial income (Huang et al., 2023). As depicted in the Figure 6, the transition in land use patterns from coconut farms to other economic activities illustrates the response to economic and financial processes that influence people's social lives.

Figure 6 demonstrates that the cultural values of the Hibualamo community and collaborative actions such as *hirono* (mutual assistance) and *higaro* (mutual assistance) in socio-economic activities are successful solutions for preserving social, economic, and environmental sustainability. In the context of the livelihood of coconut plantation proprietors, the cultural values of *higaro* and *hirono* minimize the cost of manufacturing copras to be sold to collectors. All contributors to the copra-producing process will receive compensation from the landowner proportional to the copra sales revenue. Meanwhile, the copra production process occurs on plantation land utilizing smoking techniques, which are classified as traditional methods employing "*para-para*" containers for smoking copra, as shown in Figure 6.

The issue with the way of life of coconut plantation proprietors is the financial requirement that motivates the decision to sell land to buyers, who then use it to build residences or stores. By contrast, landowners with sufficient financial capital diversify by constructing dwellings and switching from traditional to modern production methods so that all coconut resources can be exploited or managed for sale at a profit. These two scenarios illustrate how the intensification of social and economic activity in the North Halmahera Regency led to changes in land usage.

Changes in land use patterns for economic reasons affect not only the livelihoods of coconut plantation growers but also those of fishermen and the tourism sector. Changes in land use that result in commercial and industrial growth in coastal areas and islands frequently have adverse effects on coastal environments and marine ecosystems that provide fishermen with a source of income. Moreover, tourism infrastructure development and land-use changes for the tourism service business can modify landscapes and natural characteristics, affecting visitor attraction and livelihoods. Therefore, changes in land use patterns for economic gain must be studied holistically, since their impact is not restricted to a single sector. It also has broad ecological, social, and economic repercussions on coastal and archipelagic communities and habitats.

Diversifying fishermen's livelihoods to provide sea transportation services for visitors visiting Kumo Island, Kakara Island, and Tagalaya Island is a response to the economic opportunities created by the tourism sector in coastal and island communities. Formerly dependent on fishing as their sole source of income, fishermen now see an opportunity to provide transportation services for tourists seeking to explore islands. This diversification provides additional income opportunities for fishermen and contributes to the region's thriving tourism business. In addition, allowing tourists to appreciate the islands' natural beauty and indigenous culture can improve the social welfare of coastal communities. This variety of lifestyles demonstrates how individuals respond to economic shifts and environmental opportunities, as shown in Figure 7.

Figure 7 depicts the diversification of fishermen's incomes as providers of sea transportation services for visitors visiting Kumo Island, Kakara Island, and Tagalaya Island. The diversification of means of subsistence is driven by economic opportunities to meet financial needs outside of fishing. The intensification of marine activities affects the utilization of coastal areas as parking spaces for traditional marine transportation (*ketinting*). In addition, berthing affects space availability, cleanliness, and spatial arrangement at the port. The development of tourism-related activities has piqued the interest of fishermen in providing sea transportation services for domestic and international tourists. Thus, tourism influences the livelihoods of fishermen and the utilization of space in the port of Angin Mamiri in Tobelo City.

Changes in the pattern of space and plantation land usage can be evaluated from various perspectives, including social, cultural, economic, and environmental perspectives. Based on a case study conducted in the North Halmahera Regency, the increase in building distribution between 2013 and 2023 reflects a shift in people's livelihood strategies from agriculture, trade, and fishing to tourism transportation service providers. These developments represent society's response to the region's expanding economic potential as commerce and tourist industries continue to flourish.

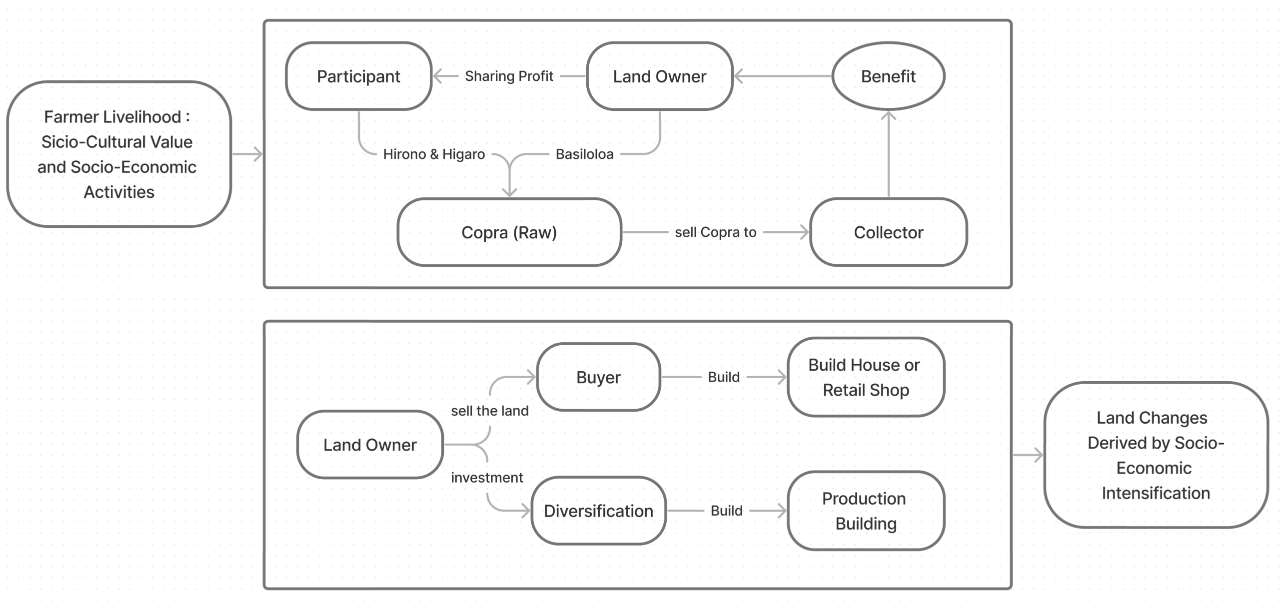

Figure 6 The farmer's livelihood and land changes derived by socio-economic intensification.

Figure 7 The fishermen's livelihood and coastal land use derived by socio-economic opportunities.

Additionally, these changes necessitate a transformation in society's cultural and social values, as agriculture and fishing are no longer the only feasible subsistence possibilities. In addition, the environmental impact of these changes must be considered, especially in light of the high land consumption for human activity and development. To aid in the sustainable planning and management of the region, a comprehensive understanding of changing space and land use patterns must consider these factors.

Conclusion

Land use, building distribution, and vegetation index in mangrove ecotourism regions must be studied using spatio-temporal analysis to comprehend landscape changes in the livelihood choices of fishermen and coconut plantation farmers in the North Halmahera Regency. This analysis shows how land-use patterns and alterations affect people's economies and ways of life. Thus, spatial-temporal analysis can be an indispensable tool for planning and maintaining mangrove ecotourism regions, considering the sustainability of natural resources and the social welfare of residents. The findings of this study indicate that changes in the livelihood strategies of local farmers, fishers, and merchants impact land use patterns from agricultural to economic activities, increasing the number of structures for production and distribution. Thus, the intensification of building distribution and variations in vegetation index values between 2013 and 2023 indicate shifts in subsistence strategies from agriculture to commerce and fishing to tourism transportation service providers. The implications of these findings on ecotourism development programs and policies and infrastructure development in North Halmahera Regency are to consider community livelihoods and space or land use behavior in ecotourism areas based on vegetation, soil, and building index values.

Recommendation

Recommendations derived from the results of vegetation value identification and landscape change analysis of community livelihood patterns in the North Halmahera Regency can be a crucial basis for establishing sustainable land use management and urban planning. Changes in the vegetation index and placement of buildings can be analyzed spatially and temporally to assist stakeholders in balancing economic development and environmental protection. In addition, these recommendations can serve as guidelines for developing the regional tourism industry, where a better understanding of landscape changes can aid in making informed decisions regarding infrastructure, environmental preservation, and sustainable tourist experiences for visitors. Consequently, integrating spatial-temporal analysis results into regional planning and regional development can enhance North Halmahera District's efforts toward sustainable development.

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