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Urban Growth Dynamics in the New Capital of North Maluku: A Spatiotemporal Perspective on Land Cover Transformation in Sofifi

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ABSTRACT

The transition of North Maluku Province's capital city from Ternate to Sofifi in Halmahera Island is expected to spawn a new growth center. However, the development and expansion of urban areas in Sofifi reflect significant land cover transformation. This process is shaped by complex interactions influenced by the island's geographical context and limited environmental carrying capacity. To ensure the sustainability of urban growth dynamics in Sofifi, this study aims (1) identify and analyze the spatiotemporal dynamics of land cover transformation from 1995 to 2020 in Sofifi and (2) analyze the growth pattern of urban expansion in Sofifi. This study employed multitemporal Landsat imageries within the 1995 to 2020 period with supervised classification using the CaRT classifier in Google Earth Engine and the NDBI maps to calculate the urban expansion rate and intensity index. The multitemporal analysis shows the rapid transformation of vegetation cover into built-up areas, especially in the 2010–2015 periods, which gradually developed from coastal areas towards inland following the development of road networks and government offices. The spatial expansion index shows the average urban growth in Sofifi from 1995 to 2020 is about 28.61%. This study reveals that the transformation of Sofifi land cover is shifting the vegetation cover to the built-up area by 967 hectares (27.61% of the Sofifi Area) from 1990 to 2020. Parallelly, urban expansion happens in stages. Moreover, this research advances the understanding of how land cover transformation and urban expansion happened in the island cities, particularly in the Indonesian context.

Introduction

Urban expansion is a critical phenomenon with significant implications for the development and sustainability of cities [1]. As cities expand, they often experience a surge in economic activities that can lead to environmental degradation such as natural landscape transformation [2,3], declining ecosystem services [4], water pollution [5], air pollution [6], habitat fragmentation, and biodiversity loss [7,8]. Because urban expansion is a complex and dynamic process, a holistic spatiotemporal understanding of its development patterns based on its geographic characteristics is essential for developing effective strategies to manage this growth and ensure that cities remain productive, inclusive, resilient, and sustainable. Indonesia is the largest archipelago country in the global south, with 17,024 island and about 90% of its urban areas in coastal areas [9] have its own challenges in understanding the complexity of urban expansion in island cities. Compared to mainland territory, islands are more vulnerable to urban expansion and land use change because of their simple ecosystem structure, limited environmental carrying capacity, poor economic foundation, weak technological support, and vulnerability to disasters [10–13]. Simultaneously, Indonesia National Mid-Term Planning (*Rencana Pembangunan Jangka Menengah Nasional* / RPJMN) 2020–2024 directs the development of four new independent and integrated cities to be built outside Java-Bali, one of which is Sofifi City, which currently acts as the definitive capital of North Maluku Provinces [14].

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Historically, the transition of the capital of North Maluku Province from Ternate City to Sofifi was intended to solve the problem of overpopulation, environmental pollution, and the high risk of volcanic disasters on Ternate Island [15,16]. Unfortunately, 26 years after Sofifi's establishment as the capital of North Maluku province based on Law no. 46 of 1999 [17], this transition experienced delays due to multidimensional and cross-sectoral problems. Gracianto [18] found that the slow development of definitive capital was influenced by the problem of infrastructure readiness in the economic sector, such as the provision of transportation facilities, communication networks, clean water sources, electricity facilities, and other supporting facilities. Meanwhile, Muslihin [19] found that socially, these obstacles were caused by the initial policy-making process for determining the capital city that did not involve society, including traditional leaders and communities, even though there were territorial boundaries based on local cultural aspects, thus potentially giving rise to various interpretations and polemics over territorial struggles after the establishment of Sofifi.

However, infrastructure development in Sofifi is ongoing, followed by land-use and land-cover changes. Recent studies in Sofifi and North Maluku reveal that most studies are primarily focused on Sofifi spatial planning [18], mangrove management [20,21], analysis of the economic sector [22,23], and conflicts of interest in Sofifi expansion [19,24], and there are several gaps in the existing literature related to the assessment of land cover change dynamics that can be explored further within this research. Under these circumstances, it is important to monitor urban expansion and land cover transformation in Sofifi to operate synergistically with environmental sustainability and proportionate to its limited carrying capacity. The advancement of geospatial technology has significantly enhanced the ability to monitor and analyze urban expansion through remote sensing, providing valuable insights into urban growth dynamics [10,25]. This study aims to (1) identify and analyze the spatiotemporal dynamics of land cover transformation from 1995 to 2020 in Sofifi, and (2) analyze the growth pattern of urban expansion in Sofifi. Moreover, this research is coupled with harnessing the enormous dataset of remote sensing imagery and cloud computing of the Google Earth Engine (GEE), which can provide cloud cover-free imagery that tackles the main challenge of remote sensing research in tropical areas.

Materials and Methods

Study Area

This study was conducted in the administrative area of the Sofifi Urban Area (Kawasan Perkotaan Sofifi), which is delineated within the North Oba Sub-district. Sofifi is currently part of Tidore City on Halmahera Island, North Maluku Province. The study area covers approximately 3,508.18 hectares (ha), comprising 13 villages which is presented in Figure 1. Sofifi was designated as the capital of North Maluku Province in 1999, yet its urban growth has been relatively slow compared to other provincial capitals in Indonesia. As a newly developing administrative center, its urban expansion is influenced by various factors, including government-driven infrastructure development, geographical constraints, and environmental limitations. Given Sofifi's unique position as a provincial capital on an island with limited environmental carrying capacity, understanding its urban growth dynamics is essential for sustainable planning.

Data Collection

This study mainly used multitemporal Landsat satellite imagery from 1990 to 2020 within 5 years period. For 1995 and 2000, we used Landsat 5 TM, while Landsat 7 ETM was used for 2005 and 2010, and Landsat 8 OLI for 2015 and 2020. Instead of downloading and processing it manually, we utilized the GEE platform (https://code.earthengine.google.com/ accessed on 7 May 2024) to perform radiometric correction and cloud cover elimination on all of the satellite imagery we used. The GEE is renowned for its peta-byte-sized database of satellite imagery and provides powerful cloud computing performance for satellite pre-processing for land cover change analysis [26–29]. In addition, the administrative boundary of Sofifi is obtained from detailed spatial plan for the Sofifi Urban Area 2022 to 2024, which is determined through the Tidore Islands Mayor's Regulation No.40/2020 [30].

Data Analysis

To fulfill the research objectives, this study conducted three stages of data processing and analysis. First, pre-processing was performed on multitemporal Landsat satellite imagery to ensure data consistency and accuracy. Second, land cover classification and transformation analysis were carried out to identify changes in land use over time. This step was crucial in understanding the extent and pattern of landscape modifications in the study area. Third, urban expansion analysis was conducted using the Normalized

Difference Built-up Index (NDBI) and the Spatial Expansion Index. These methods provided quantitative insights into the growth and spatial distribution of urban areas. Overall, the schematic procedure of this research is presented in the workflow shown in Figure 2.

Pre-processing of Multitemporal Landsat Imagery

The multitemporal Landsat imagery available in the GEE was radiometrically corrected using top of atmosphere (ToA) correction. The presence of cloud cover throughout the observation years was eliminated using the CFmask algorithm to mask the cloud and cloud shadow pixels, and unobstructed pixels in the satellite images were preserved, as recommended by Mateo-García et al. [31]. Then, the pixels were aggregated using a median image composition to avoid extreme values and produce a single composite image of cloud-free Landsat imagery for land cover classification and urban expansion analysis in each observation year.

Land Cover Classification

The classification of land cover dynamics in this study was performed using Supervised Classification based on the Classification and Regression Tree (CaRT) classifier in GEE (classifier.smileCart), which is commonly used for land cover classification owing to its ability to process large data in a short time and produce models that are easy to interpret [32,33]. Owing to the limitation of the spatial resolution of Landsat imagery at 30 m, we classified the land cover in Sofifi into three categories: vegetation, water bodies, and built-up areas. The built-up area covers buildings and open land with impervious surface. This process generated a multitemporal land cover map for 1995, 2000, 2005, 2010, 2015, and 2020.

To validate the results of this modeling, we conducted a model accuracy assessment using a confusion matrix to produce the overall accuracy (OA) and Kappa Coefficient of the study area. The confusion matrix is a table often used to describe the performance of a classification model on a set of test data whose true values are known [34]. The overall accuracy shows the percentage of correctly tested / mapped data obtained from the ratio of the number of correctly classified pixels to the total number of pixels in the testing dataset, and the Kappa Coefficient shows the performance of the classification result with the interpretation of a value close to 1, indicating that the classification is significantly better [32,34].

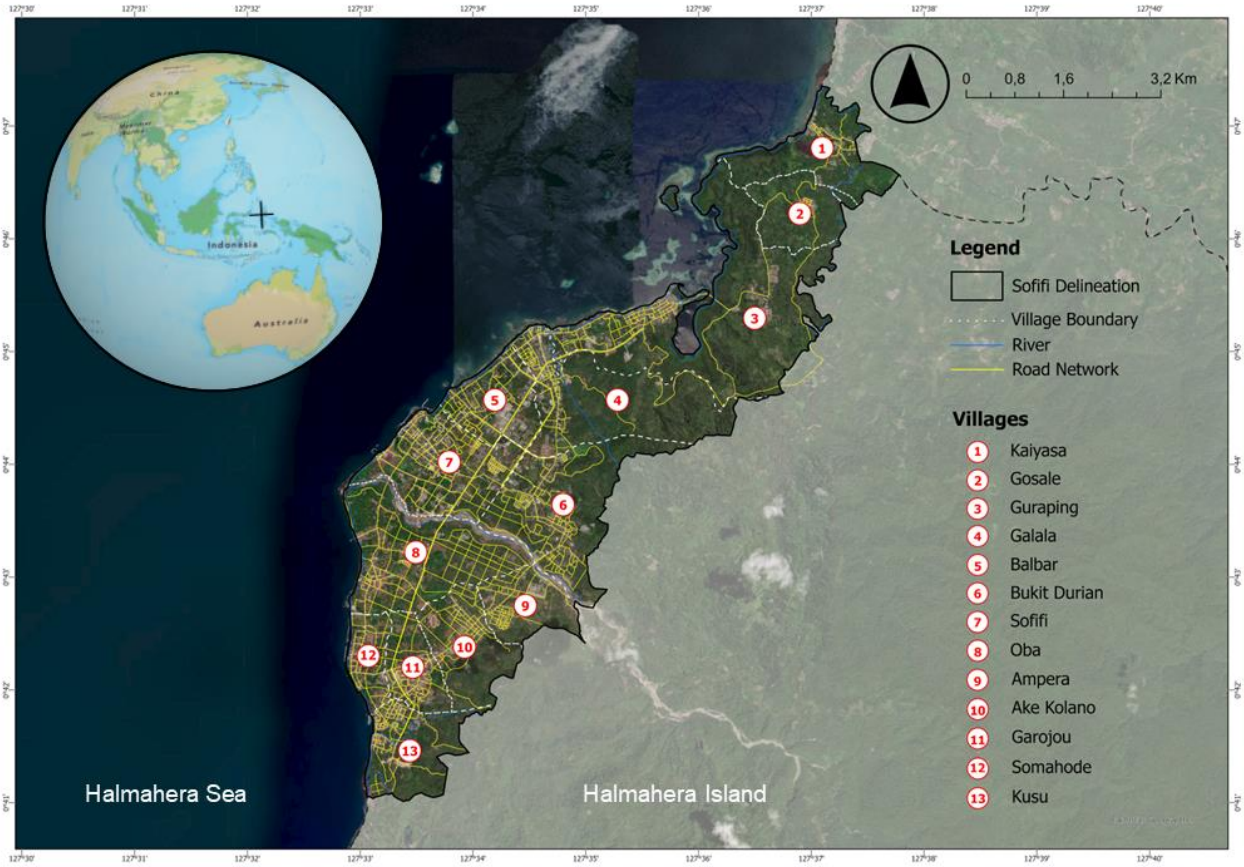

Figure 1. Map of study area.

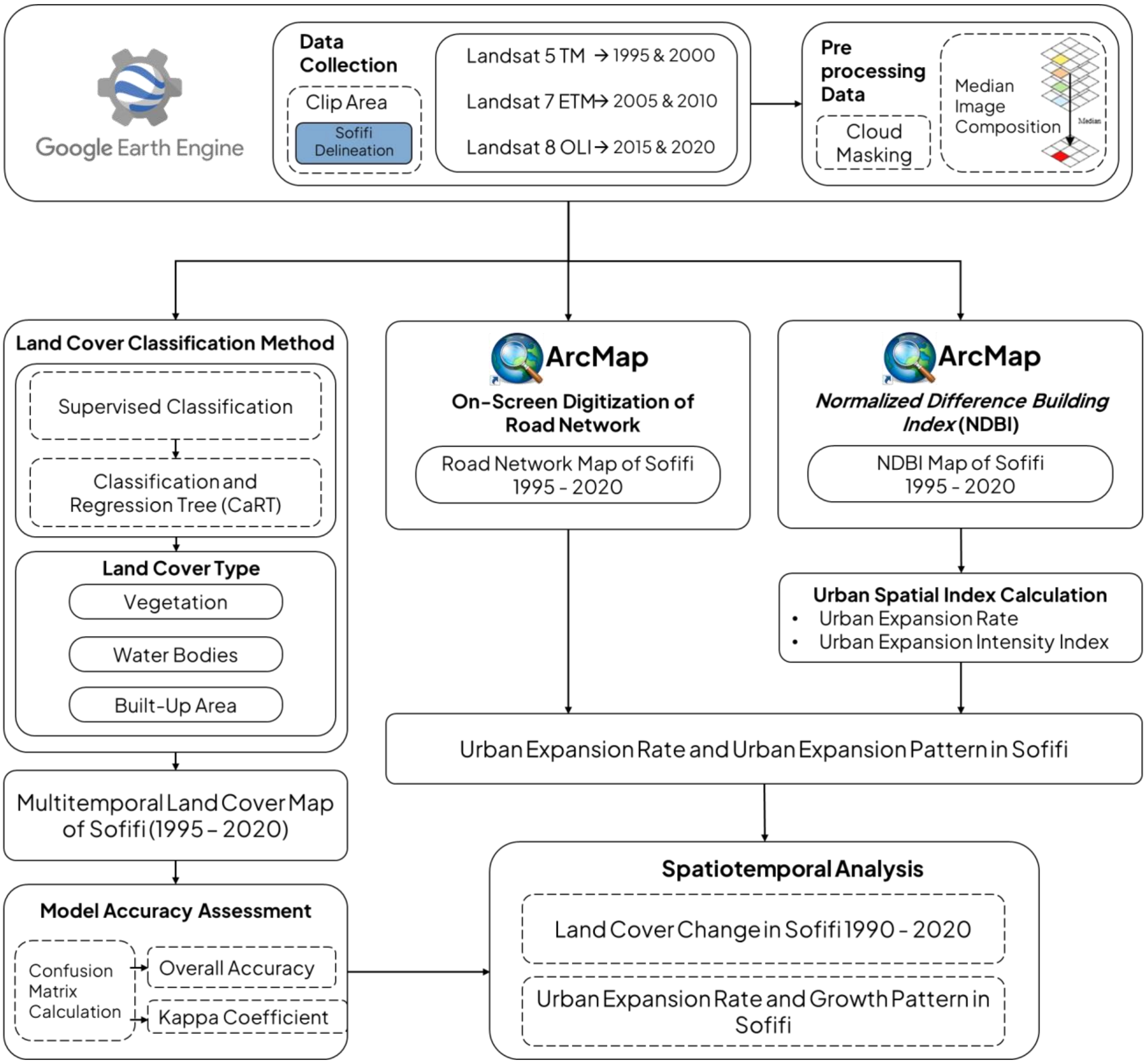

Figure 2. Research workflow of the land cover transformation and urban expansion in Sofifi.

Urban Expansion Analysis

Urban Expansion in Sofifi was identified based on the development of the road network and built-up area dynamics. The road network was obtained through on-screen digitization based on Landsat imagery during the observation years. Built-up area dynamics were generated using the NDBI algorithm based on Zha et al. [35]. Which is shown in Equation 1 as follows.

$$NDBI = \frac{SWIR - NIR}{SWIR + NIR} \tag{1}$$

Description:
NDBI : Normalized difference building index
SWIR : Short wave infra-red spectral band (L7: Band 5, L8: Band 6)
NIR : Near infra-red spectral band (L7: Band 4, L8: Band 5)

After NDBI maps were generated, the area classified as the built-up area was the indicator of urban area expansion, following the definition of urban expansion by He et al. [36], which states that urban expansion is the process of converting land to urban / built-up areas. The urban area per sub-district and the whole Sofifi are then calculated using a spatial expansion index that consists of the urban expansion rate and urban expansion intensity index, as shown in equations 2 and 3, as follows. The urban expansion rate is a substantial indicator of spatial changes in urban expansion [37]. It is calculated using the following equation 2 as recommended by Wang et al. [37] and Xu et al. [38].

$$E_i = \frac{u_b - u_a}{u_a} \times \frac{1}{t} \times 100\% \quad (2)$$

Description:

E_i : Degree of urban expansion

ua : Area of urban built-up land in the study area initially (ha)

ub : Area of urban built-up land in the study area in the following period (ha)

t : Study period (years)

The urban expansion intensity index refers to the percentage of the expanded area of urban land cover in the total land area of a certain spatial unit in a certain period [37]. A larger number represents a faster expansion. This index was calculated using Equation 3 based on Wang et al. [37] and Peng et al. [39].

$$U_{ii} = \frac{u_b - u_a}{TLA \times t} \times 100\% \quad (3)$$

Description:

U_{ii} : Urban expansion intensity index

ua : Area of urban built-up land in the study area initially (ha)

ub : Area of urban built-up land in the study area in the following period (ha)

TLA : Total land area of the study unit (ha)

t : Study period (years)

Results and Discussion

Results

Land Cover Transformation in Sofifi

Globally, the main causes of environmental change are changes in land cover and land use [40]. In contrast to other growing urban areas in Indonesia that experience changes in land cover due to developments in economic activities, such as the expansion of oil palm plantations, mineral mining, or tourism, significant changes in land cover in Sofifi were encouraged after the establishment of Sofifi as the center of government for North Maluku Province. The classification results show the vegetation is still dominant in the research area with 2,338.09 ha (64.95%) of the total area, followed by a built-up area of about 1,133.56 ha (31.49%) and water bodies of 128.09 ha (3.56%) in 2020. During the observation period, the built-up area shows drastic growth in covering the Sofifi Land Cover, with an increase of 2,492.38%. In addition, the accuracy test of land cover modelling using the confusion matrix resulted in an overall accuracy in the range of 75% to 85% and a kappa index of 0.70 to 0.81, which indicates that the results of land cover mapping in Sofifi City are acceptable and can represent conditions in the field with a level of good accuracy. Overall, the land cover area with the accuracy test periodically is shown in Table 1.

Table 1. Sofifi land cover area and growth 1990–2020.

Land cover type	Area (ha)						1995–2020 Growth (%)
	1995	2000	2005	2010	2015	2020	
Vegetation	3,409.98	3,247.98	3,185.90	3,091.96	2,453.52	2,338.09	–31.43
Built-up area	43.73	241.26	259.03	375.30	1,034.60	1,133.56	2,492.38
Water bodies	146.03	110.49	154.81	132.47	111.61	128.09	–12.28

Partially, the vegetation cover experienced a significant decrease in parallel with the built-up land cover that experienced a significant increase during the observation period, with the most significant changes occurring in 2010–2015, which was related to President Susilo Bambang Yudhoyono's visit to Ternate to inaugurate the relocation of the capital of North Maluku Province from Ternate to Sofifi on August 4, 2010. The water bodies fluctuated every year of observation. During 1995–2020, about 967.48 ha of vegetation were shifted to built-up areas, equal to 27.6% of the total area of Sofifi. Based on land cover transformation analysis, as shown in the Sankey Diagram in Figure 3, most of the vegetation cover is transformed into built-up areas, especially for government and administrative offices.

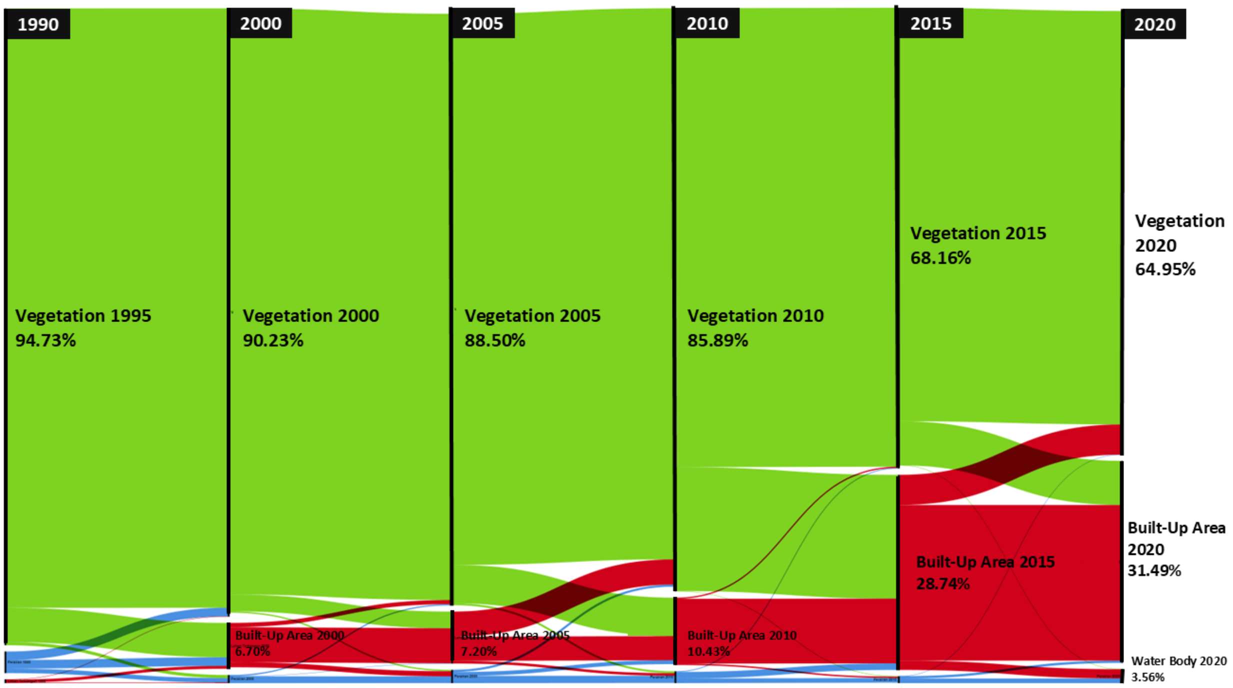

Figure 3. Land cover transformation in Sofifi.

Spatially, massive patterns of land cover change occur along the coast and propagate inland, following road patterns. The multi-temporal pattern and changes in Sofifi City land cover are shown in the map in Figure 4. The vegetation cover in the study area consisted mainly of natural vegetation and local community plantations. Based on its habitat, the natural vegetation in Sofifi City is divided into mangrove forests on the northern coast (Guraping Mangrove Forest and Lake Gosale) and tropical rainforests in the eastern Silo hills, which are included in the Halmahera ecoregion and are dominated by dipterocarpaceae plants [41].

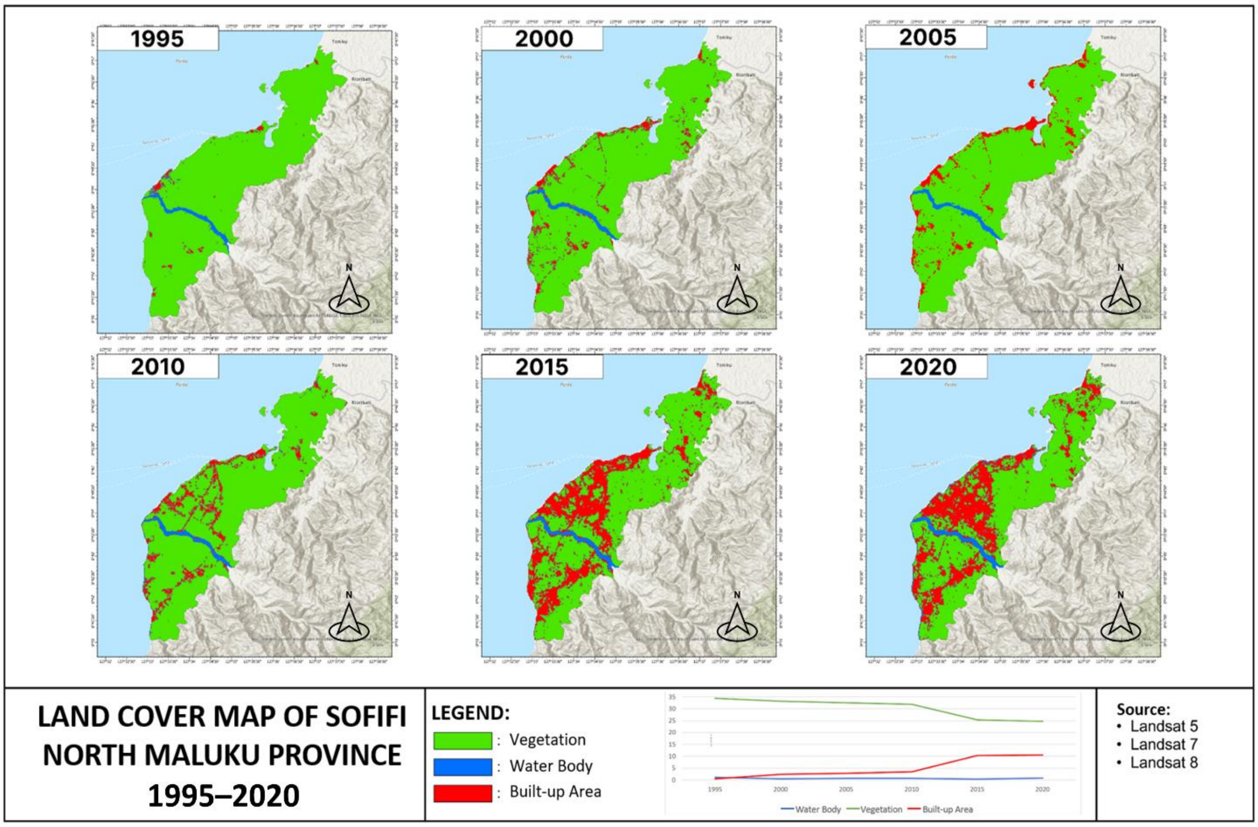

Figure 4. Land cover map of Sofifi.

As shown in Figure 4, the built-up area experienced rapid expansion between 2010 and 2015, with an increase of up to 19.09% in the Sofifi area, which gradually developed inland from coastal areas following the development of road networks and government offices. This significant increase is related to the transfer of government activities since the formation of North Maluku Province from Ternate as the transitional capital to the Sofifi area as the centre of government for North Maluku Province, which was only implemented in stages and inaugurated by President Susilo Bambang Yudhoyono in August 2010, despite the Law establishing North Maluku Province and its capital in Sofifi have been promulgated in Law No. 46 of 1999 concerning the establishment of North Maluku Province, Buru Regency, and Maluku Barat Daya Regency. Developments that began with the construction of government buildings, such as governors' offices, DPRD (*Dewan Perwakilan Rakyat Daerah*) offices, and other local institutions, have created gravitational forces for the development of residential areas. Because of government activities, other infrastructure developments will follow, such as roads, airports, housing, and markets [42].

Indirectly, the emergence of these facilities will create a need for housing, food, drinking accommodation, and recreation areas. Therefore, it is possible to argue that the construction of government buildings in Sofifi served as a catalyst for the city's development because it established a new center of growth. The development of the government office in Sofifi is shown in Figure 5. The main water body on the mainland of Sofifi is dominated by the Oba River in the southern part of Sofifi. Throughout the observation period, the water bodies fluctuated following the discharge and sediment flux that were affected by climate change and human disturbance in the form of sand and gravel extraction from the Oba riverbed. Overall, land cover changes in Sofifi were more intense in the coastal areas in the west and tended to stagnate in the east. This is because of the eastern area physiography, which has a steeper slope, limiting the development of built-up land in Sofifi.

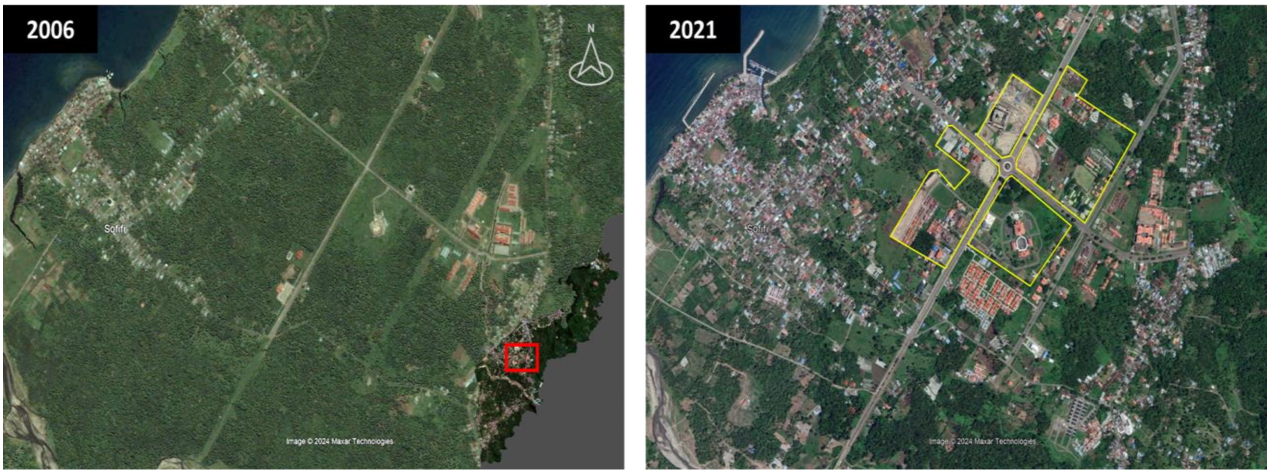

Figure 5. Built-up area cover dynamics in Sofifi.

Urban Expansion in Sofifi

Based on NDBI analysis, as shown in Table 2, the urban area encompassed 216.62 ha in 2020, signifying a remarkable 8.15 times increase in an urban area. The average annual urban expansion rate for all sub-districts in Sofifi stood at 28.61%, with the higher trends of urban expansion rate experienced by the lowland- and coastal-sided sub-districts. The same spatial pattern is shown in the urban expansion intensity index, with the Sofifi Sub-District being the highest due to its role as the administrative center, followed by the Guraping Sub-District as its function as a healthcare service center, and the governor's office.

The urban expansion dynamics based on the NDBI value in Sofifi, as illustrated in Figure 6, show that the urban expansion growth and direction follow the road network development and are limited by natural barriers, such as rugged terrain in the east. The establishment of a road network increases accessibility in an area that encourages the emergence and increasing intensity of human activities, and has implications for changes in surrounding land cover into more urbanized areas. Based on its physiography, the spatial pattern of development of urban areas in Sofifi tends to be limited to point B, which is the transition point between flat and hilly areas.

Table 2. Urban area expansion dynamics in study area in 1995–2020.

Sub-district	Urban area (ha)						Urban expansion rate (%)	Urban expansion intensity index (%)
	1995	2000	2005	2010	2015	2020		
Ake Kolano	0.54	1.43	0.63	2.15	9.30	9.47	66.65	0.0102
Ampera	1.70	2.15	2.06	2.98	8.41	8.66	16.39	0.0079
Balbar	-	0.27	0.80	2.95	19.47	26.81	395.95*	0.0303*
Bukit Durian	0.63	1.37	2.92	4.47	19.63	20.74	128.59	0.0229
Galala	1.16	1.57	4.51	8.06	27.87	29.71	98.30	0.0326
Garojou	0.54	1.52	0.80	1.34	13.72	13.94	100.00	0.0153
Gosale	-	-	0.80	1.97	2.14	3.13	11.56**	0.0026**
Kaiyasa	1.14	2.84	2.84	2.92	6.77	7.44	22.11	0.0072
Kusu	2.58	4.27	2.68	3.22	11.71	12.78	15.82	0.0116
Oba	0.83	1.08	1.73	2.26	9.70	13.78	62.04	0.0148
Somahode	1.16	1.43	0.80	0.80	5.99	6.93	19.87	0.0066
Guraping	5.00	8.77	11.42	18.56	31.09	34.62	23.71	0.0338
Sofifi	11.30	11.98	13.15	18.06	39.44	42.08	10.90	0.0351
Grand total	26.57	41.67	45.15	69.73	214.71	216.62	28.61	0.2167

*Calculation started from 2000 to 2020; ** Calculation started from 2005 to 2020.

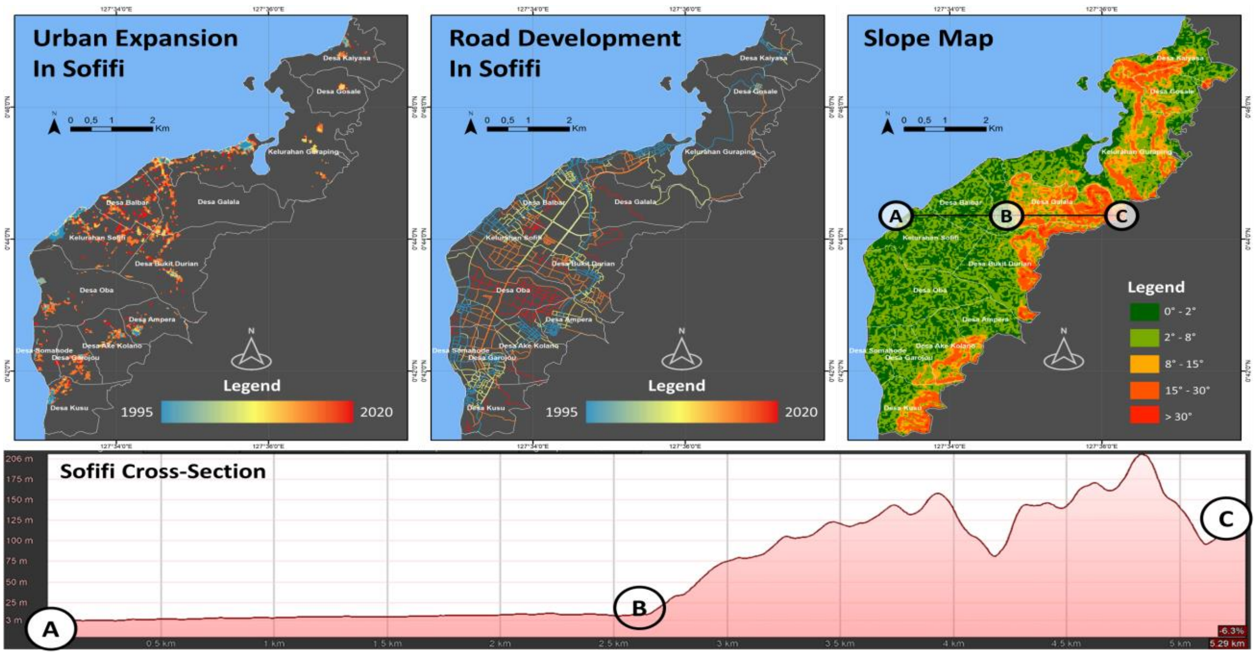

Figure 6. The driving and limiting factor of Sofifi urban area.

Discussion

This study finds that massive land cover transformation and rapid urban expansion occurred in the 2010–2015 period and then slowed down in the period 2015–2020, which is consistent with the research conducted by Gracianto [18] in 2021. Those study compared the Sofifi condition in 2015 and 2019 to evaluate the effectiveness of Sofifi new city project on the physical and population development of the Sofifi and exposes that those projects are not significantly contributing to the development of the Sofifi. Beyond that, the historical study that depicts Sofifi land cover transformation is still very limited for comparison. Furthermore, this study reveals the spatiotemporal changes in land cover and its interaction with road network development and the physical condition of Sofifi, which cause urban expansion dynamics in Sofifi, this study synthesizes 3 primary patterns of urban expansion in Sofifi as follows.

Urban Expansion in Sofifi Happened in Stages

After 24 years of being designated as the capital of North Maluku, the development of Sofifi as an administrative capital has progressed relatively slowly. However, national and local policies have influenced the expansion of Sofifi's urban area at different stages. First, the issuance of Law No.46/1999 regarding establishing North Maluku Province, Buru Regency, and Maluku Barat Daya Regency marked the initial stage of Sofifi development. However, due to several socio-economic problems, urban development in Sofifi was delayed and the expansion of urban areas in Sofifi slowed during 2000–2005 [18,19]. However, a massive road network was constructed during that period to improve accessibility and connectivity between sub-districts. This stimulated the development of urban areas, especially in the coastal areas of Sofifi, during the 2005–2010 period. Following presidential visits to Sofifi in 2010, urban expansion experienced an exponential increase related to the president's instructions to transfer government activities from Ternate to Sofifi. During this period, large-scale construction of government offices such as the North Maluku governor's office, North Maluku DPRD office, and local institutional offices was executed, followed by the emergence of supporting facilities for civil servant housing areas and public housing, markets, and basic service facilities.

Meanwhile, during the 2015–2020 period, urban expansion slowed due to the emergence of several policies related to spatial planning both on a national and local scale that regulate urban expansion development in Sofifi, such as RPJMN 2015–2019, the Regional Development Plans of Sofifi by the Ministry of Public Works and Housing in 2016, the delineation of Sofifi by Mayor of Tidore Islands in 2017, and the Technical Materials for for Sofifi's *Rencana Detail Tata Ruang* (RDTR) in 2018. In addition, regulations and policies related to spatial planning and accelerating the development of Sofifi after 2020 are still being issued, such as the grand design of Sofifi infrastructure development in 2021, the technical assistance for Sofifi's RDTR in 2022, and the recent update of the Sofifi delineation area by Mayor of Tidore Islands in 2022. This series of spatial plan regulations indicated that Sofifi is designed to be the spatially efficient center of administrative capital of North Maluku Province and a regional economic center with a high-end service function and the environmentally sustainable archipelago city. This study is in line with the findings of Liu et al. [43] in China, which shows that the Min Delta Region experienced a rapid transformation during 2010–2015 after there was political will from their government along with the implementation of the Xiamen-Zhangzhou-Quanzhou Metropolitan Area Master Plan. In Summary, national and local government policies played a vital role in urban expansion in Sofifi, and the publication of the spatial plan after the city of Sofifi began to be built and developed, showing a delay in urban planning progress. The stages of urban expansion area increase are shown in Figure 7.

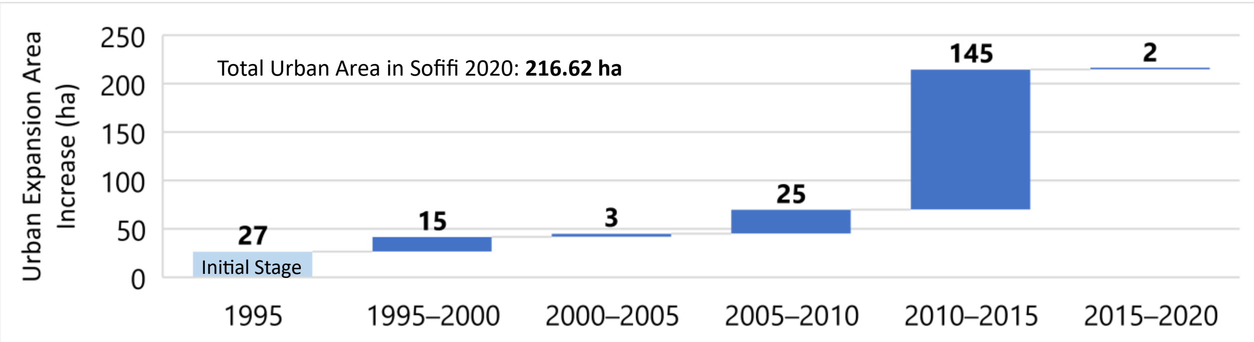

Figure 7. Urban expansion stages in Sofifi during observation period in 1995–2020.

The Road Network is the Gravity Forces that attract Urban Expansion Sofifi

The construction of a road network increases accessibility, stimulates the appearance and increasing intensity of human activity, and increases the probability of urban expansion. Road network development in Sofifi City always increased temporally and experienced the highest increase in 2000–2005, reaching 95.79%, followed by the 2010–2015 period of 49.98%. The increase in this period was related to government policies, mainly the issuance of Law No. 46 of 1999 [17], which established Sofifi as the center of government for North Maluku Province, and the inauguration of the capital city of Sofifi as the center of government for North Maluku Province in 2010. Chronologically, road network development in Sofifi City is linear, with increased urban expansion. The growth of the road network occurs first compared to the increase in the urban expansion area, which shows that the road network stimulates the development of urban areas in Sofifi City. This relationship is schematically shown in Figure 8.

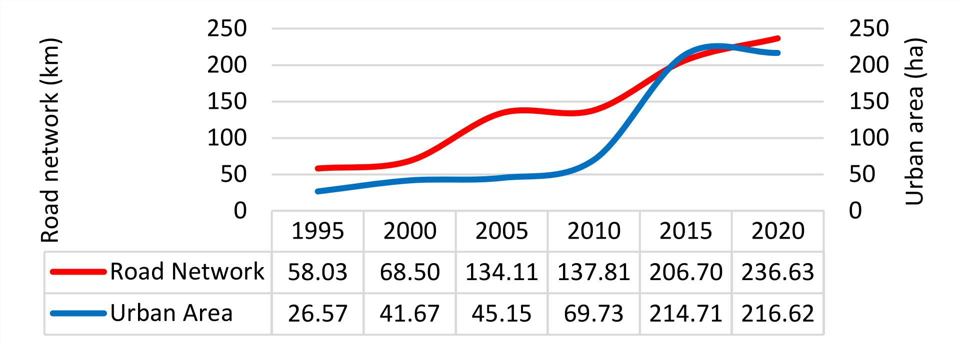

Figure 8. Road network and urban area growth in Sofifi.

This finding is consistent with the research of Shi et al. [44] in Nanjing, China, which shows that urban road network growth correlates strongly with socio-economic factors, indicating that road development drives urban expansion through enhanced accessibility and connectivity. This is also supported by Wang et al. [45], who demonstrated that the center of gravity model applied in the Beijing–Tianjin–Hebei Region highlights that urban land expansion is influenced by spatial interactions among cities driven by road development. Furthermore, Zhang [46] revealed that 264 cities in China have increased their investment in road infrastructure, significantly accelerating urban development. Meanwhile, an Indonesian study by Indrayati et al. [47] showed a similar pattern in the Kedungsepur Metropolitan Area in Central Java. Further development of Sofifi urban areas should consider the availability of basic services facilities after the road was built to avoid the emergence of urban slums in the future and [48–50].

Natural Boundaries are the resistance of Urban Expansion in Sofifi

Figure 6 shows the physiography and slope cross-section of Sofifi. The spatial pattern of the development of urban areas in Sofifi tends to be limited to point B, the transition point between flat and hilly areas. This is because people prefer areas where access to resources is easier, especially stable water resources, which are easy to obtain in flat areas. Apart from the preference for water, flat areas tend to have easier access because they are more conducive to building road infrastructure that connects activity centers so that they develop quickly, as in the studies by Duan et al. [51] and Xu et al. [52] in China. In contrast, areas with high slopes, which require a lot of intervention to be able to build roads and develop settlements, especially land with a slope of 15%, do not meet the basic physical requirements for a residential environment based on SNI 03-1733 of 2004 concerning procedures for planning residential environments in urban areas. Moreover, from the disaster perspective, the threat of disasters such as land erosion and landslides are also an inhibiting factor in expanding urban areas to the eastern side of Sofifi.

Conclusion

This study investigates the land cover transformation in Sofifi, which shows a significant shift in land cover, with 967.48 ha of vegetation shifting to built-up areas. The built-up area experienced an exponential increase of 2,492.38%, while vegetation cover decreased by as much as 31.43% during 1990–2020, which represents rapid urban expansion growth in Sofifi. The pattern of urban expansion growth in Sofifi shows that expansion occurred in stages with rapid urban construction after 2010, which was motivated by political will and supported multi-scale policies that developed gradually. Meanwhile, the urban expansion pattern and direction demonstrate that natural barriers such as topographic boundaries shape the overall spatial pattern and have a long-lasting impact on urban expansion. Transportation factors such as road networks provide a gravitational effect that pulls urban growth in Sofifi. However, this research can be duplicated and continued by integrating socio-economic factors, governance, and other factors in refining findings about urban development's driving and inhibiting factors in the archipelago landscape. Overall, this research reveals the land cover transformation and urban expansion dynamics in island cities, which is applicable for understanding the growth pattern of Indonesian cities to ensure sustainable development in an archipelago landscape. Furthermore, the utilization of high-resolution satellite imagery or unmanned aerial vehicles with a better spatial resolution can enhance the results of land cover classification, including variations in land cover classes, for a better understanding of spatiotemporal land cover transformation.

Author Contributions

MFA: Conceptualization, Project Administration, Writing - original draft; **HSH**: Supervision; Writing - Review & Editing; **RPT**: Supervision, Writing - Review & Editing; **MAF**: Formal Analysis, Methodology, Visualization, Writing - original draft**; SRW**: Investigation, Methodology; Visualization, Writing - original draft.

Conflicts of Interest

There are no conflicts to declare.

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