

Chapter 23

Impacts of Urban Expansion on Landscape Pattern Changes: A Case Study of Da Nang City, Vietnam



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Abstract The paper deals with an integration of remote sensing, GIS, and landscape metric indices to employ the spatiotemporal characteristics of urban expansion and to explore the impacts of urban expansion on landscape pattern changes in Da Nang city, Vietnam, from 1996 to 2015. Key landscape change indices were selected to characterize the urban landscape patterns at the landscape and class levels. Several critical urbanization indicators were being developed: urban resident's ratio, urban resident's density, nonagriculture GDP proportion, and nonagriculture labor ratio. The impacts of urbanization on urban landscape changes were determined through analyzing the correlation between the urbanization indicators and landscape change indicators. The results indicate that the built-up area has been increased by 8187.18 ha in an average expansion area of 430.90 ha per year. The urban landscape has undertaken a complicated transformation in landscape structure and composition of which there was the conversion mainly from agriculture land to built-up land. Spatial distribution of different patches became more separated, complex, and irregular, and the patch types became more fragmented. The significant relationship between urbanization indicators and landscape change indicators indicated that the intensity of human activities were decisive factors for the urban development.

Keywords Urban expansion · Landscape pattern changes · Landscape metrics · Da Nang · Vietnam

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1 Introduction

Urbanization is considered to be one of the most dramatic land transformations and their ecological consequences (Luck & Wu, 2002; Zhang, Wu, Zhen, & Shu, 2004). Globally, 55% of the world population resides in urban areas as of 2018, and it is projected that by 2050, there will be more than two-third urban population (68%) in the world. Especially, Africa and Asia are urbanizing more rapidly than other regions all over the world (United Nations, 2019). In Vietnam, the urban population was 35.9% in 2018, and it is expected that this proportion will have reached 57.3% by 2050 (World Bank, 2011). The urban expansion causes loss of arable land, devastation in vegetation cover, and rapid increase in the impervious surface and artificial structure (Dewan & Yamaguchi, 2009; Zhang, Tu, & Li, 2016). Moreover, the accelerated urbanization leads to environmental changes and affects ecosystem services (Dai, Wu, & Du, 2017). Humans have the ability to greatly modify their environment, which tends to profoundly alter the pattern and structure of urban landscapes by making more and more patches smaller and leads to the exacerbated spatial heterogeneity and fragmentation of the landscape (Dai et al., 2017; Luck & Wu, 2002; Zhang et al., 2004). Therefore, quantifying its change is essential to monitor and assess the ecological and artificial consequences of urban land use/land cover (LULC) change, as well as to have a proper land use planning and sustainable development policies.

Some recent research has proved the effectiveness of integrating remote sensing, GIS, and landscape pattern metrics for detecting urban sprawl processes and quantifying the pattern features of LULC in the context of urbanization (Dai et al., 2017; Giordano & Marini, 2008; Zhou, Shi, Wu, Ma, & Yu, 2014). A large collection of landscape metrics has been developed to describe landscape patterns and its spatial-temporal dynamics for each LULC from the satellite classification proposed by FRAGSATs (McGarigal, Marks, & Barbara, 1995). In addition, the impact of urbanization on landscape pattern change has also been studied by analyzing correlation coefficients between landscape patterns and urbanization indicators (Yang, Huang, & Li, 2017; Yi et al., 2016; Zhou et al., 2014).

Da Nang is a coastal city in the key economic region of the Central of Vietnam. Since becoming a type-I city under the management of Central Government (in 1997), Da Nang has experienced a rapid development and considered to be one of the cities with a relatively fast and strong urbanization speed (World Bank, 2011). The development of its commercial port, international airport, industrial zones, and new urban areas, as well as the expanding tourism activities along the coastal area, has led to the huge developments in the socioeconomic aspects and spatial structure of the city. In addition to the achievements in the urbanization process, Da Nang is facing pressing issues that deteriorate the living environment quality (Tien, Sy, & Hang, 2006). The change of land use types and the expansion of urban land have resulted in the changes in the natural environment, socioeconomy, and culture of the study area. Previous studies in Da Nang city were mainly focused on environmental quality issues (Tien et al., 2006), LULC change and spatial environmental index

(Tu, Hai, Ha, & Ngan, 2015), urbanization and climate change (The, Cu, Nhuan, & Vuong, 2015), and urban expansion and flood risk change (Huong, Ryota, & Tsutsui, 2013), but studies on the urban expansion and landscape pattern changes have been poorly documented (Linh & Erasmi, 2012). Therefore, in this paper, Da Nang city was selected to study the impacts of urban expansion on the landscape pattern changes. The objectives were to (i) obtain LULC data from the remote sensing images and detect LULC changes in 1996, 2003, 2010, and 2015; (ii) quantify and visualize the urban sprawl; (iii) characterize landscape pattern changes by using landscape metrics; and (iv) explore the impact of the urban expansion on landscape pattern changes.

2 Methodology

2.1 Description of the Study Area

Da Nang city is located in the middle of Vietnam, between the range of $15^{\circ}55'15''$ – $16^{\circ}13'15''$ north latitude and $107^{\circ}49'05''$ – $108^{\circ}20'18''$ east longitude. Da Nang is a dynamic city of the key economic zone in the Central of Vietnam with its international airport, deep-water seaport, and National Highway 1. The topography is very diverse, combining mountains and a coastal plain, where the mountainous area dominates with a high range between 700 and 1500 m. The average annual precipitation is 2504 mm, and the mean annual temperature is 25.8 °C (Da Nang Construction Planning Institute, 2014) (Fig. 23.1).

The city has an area of 1283.42 km² with a population of 1,064,070 people (2017). It consists of six urban districts, including Hai Chau, Thanh Khe, Lien Chieu, Son Tra, Ngu Hanh Son, and Cam Le, one rural district (Hoa Vang) and one island district (Hoang Sa). Over the past two decades, Da Nang has experienced a rapid urbanization, which is clearly reflected in the increasing population concentration in the inner city. The proportion of the urban population in Da Nang is the highest in the country. In 2017, the average urban population proportion of Da Nang is 87.1%, 2.6 times higher than the national average ratio (33.9%), and higher than that of Ho Chi Minh city (80.1%), the crowdest city of Vietnam.

2.2 Data Sources and Processing

In this study, time series satellite images and demographic statistical data are collected for assessing the temporal and spatial characteristics of the urban expansion from 1996 to 2015 and determining the relationship between urbanization indicators and landscape change indicators. The urban expansion process and LULC changes were investigated by using the image classification of Landsat 5 TM (1996),

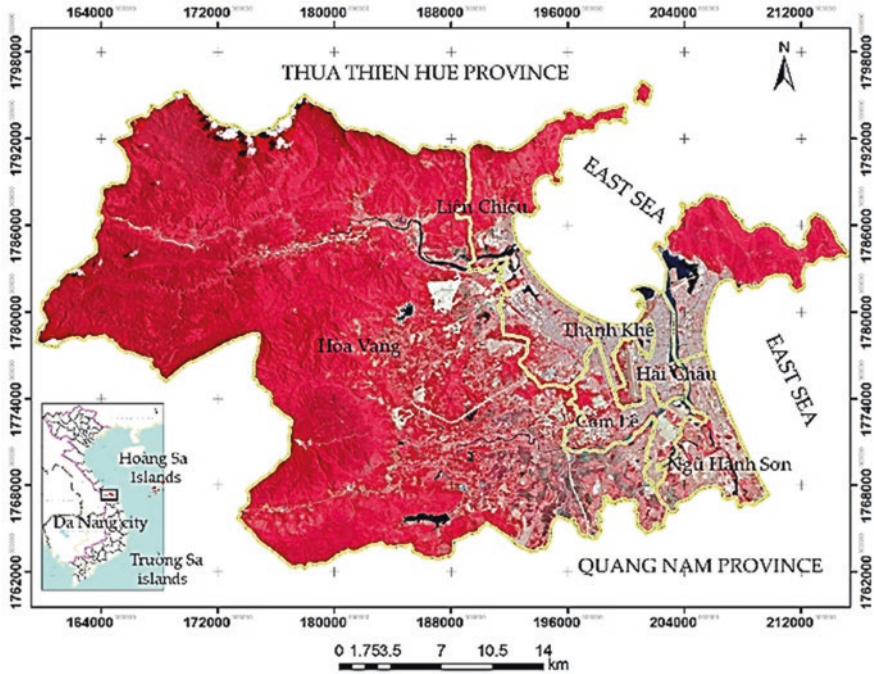


Fig. 23.1 The location of Da Nang city in Vietnam

Table 23.1 Satellite data for image interpretation

Year	Satellite	Acquired date	Cloud cover	Significant period	Sources
1996	Landsat 5 TM	07/07/1996	0%	Before establishing the city	USGS
		14/07/1996	9%		
2003	Landsat 7 ETM+	14/04/2003	2%	Recognized as class I city under central government	USGS
		21/04/2003	4%		
2010	ALOS Avnir-2	16/05/2010	3%	Land inventory time	METI & JAXA
2015	Landsat 8 OLI	10/06/2015	1.73%	Land inventory time	USGS
		01/06/2015	20.5%		

Landsat 7 ETM+ (2003), ALOS Avnir-2 images (2010), and Landsat 8 OLI (2015) (Table 23.1). The four-period remote sensing images of 1996, 2003, 2010, and 2015 were used to study the spatial-temporal evolution characteristics of the urbanization expansion in Da Nang City. All satellite images were geo-rectified with a topographic map and then masked by the boundary of Da Nang City by using ArcGIS 10.4. The error was controlled within 0.5 pixels. These created a temporal dataset that allowed analysis of the changes in the urban expansion and LULC in a nearly 20-year period. In addition, administrative division maps, topographic map (1:

25,000) in 2000, land use (1:25.000) in 2010 and 2015, and adjustment master planning (1:25.000) of Da Nang City were used for secondary data.

2.3 Methodology

2.3.1 Land Use/Land Cover Classification and Change Detection

Six LULC classes were defined for image classification based on the modified Anderson LULC scheme level I (Anderson, Hardy, Roach, & Witmer, 1976), Vietnam's regulation on land use, and the existing condition of study area, including built-up land, water body, agricultural land, forest land, shrubs, and grassland and bare land.

Object-based image analysis has been applied more frequently for remote sensing image classification compared to pixel-based analysis due to its strength, which is the ability to combine spectral information and spatial information for extracting target objects (Kindu, Schneider, Teketay, & Knoke, 2013; Tamta, Bhadauria, & Bhadauria, 2015). Therefore, in this study, all images were classified into the object-oriented classification based on the class hierarchy by defining the threshold of the indices such as calculated indices—Normalized Difference Built-up Index (NDBI), Normalized Difference Water Index (NDWI), Soil Adjusted Vegetation Index (SAVI), and default indices (NIR, Brightness) using eCognition software 9.1. The formulations for calculating those indices are presented as follows:

$$\text{NDBI} = (\text{SWIR1} - \text{NIR}) / (\text{SWIR1} + \text{NIR}) \quad (23.1)$$

$$\text{SAVI} = (\text{NIR} - \text{RED}) / (\text{NIR} + \text{RED} + 0.5) \times (1 + 0.5) \quad (23.2)$$

$$\text{NDWI} = (\text{GREEN} - \text{NIR}) / (\text{GREEN} + \text{NIR}) \quad (23.3)$$

Finally, the LULC classification results were resampled at a spatial resolution of 30 m. The accuracy of the satellite image classification was assessed using “ground truth” data, land use map, and high-resolution images from Google Earth at the same time as reference data. For evaluation, a grid point with 1 km grid spacing was created and converted into a .kml file that included 955 points. Subsequently, each individual point was trained by visual interpretation of the Google Earth image/previous land use maps. The coded grid points were then overlaid by the Landsat and ALOS satellite images classification in order to compare the accuracy of the results. Four LULC maps of the year 1996, 2003, 2010, and 2015 were produced with six categories.

2.3.2 Urbanization Expansion and Land Use/Land Cover Change Analysis

The urban expansion can be detected by comparing two classified images between the two periods, as 1996–2003, 2003–2010, 2010–2015, and 1996–2015. The urbanization intensity index (UII) was used to analyze the urbanization expansion from 1996 to 2015 (Zhou et al., 2014).

The equation is as follows:

$$UII = \frac{EAB_i \times 100}{TA \times \Delta t_i} \quad (23.4)$$

where UII is the urbanization intensity index; EAB_i is the expansion area of built-up land during a certain period, i ; TA is the total area of the study area; and Δt_i is a time span of a certain duration, i .

Spatial and temporal LULC changes were analyzed with GIS by comparing two classified images, 1996–2003, 2003–2010, and 2010–2015. Besides, the indispensability of urbanization expansion was also clarified via analyzing several critical urbanization indicators, in 1997, 2003, 2010, and 2015, such as urban resident's ratio, urban resident's density, nonagriculture GDP proportion, and nonagriculture labor ratio.

2.3.3 Urban Landscape Pattern Metrics Analysis

The LULC map extraction from satellite images was applied for analyzing the urban LULC landscape pattern characteristics. The changes of urban landscape pattern can be detected/defined and measured using landscape metrics, which are used to quantify and categorize complex landscapes into identifiable patterns and reveal some ecosystem properties such as composition, fragmentation, and configuration (Weng, 2007).

Landscape indices for measuring the urban landscape change are performed at two levels, namely class level and landscape level. Six landscape metrics such as percent of landscape (PLAND), largest patch index (LPI), area-weighted mean patch fractal dimension (AWMPFD), interspersion and juxtaposition index (IJI), Contagion (CONTAG), Shannon diversity index (SHDI), and Shannon evenness index (SHEI) were selected for quantifying the urban landscape pattern analysis.

The raster version of FRAGSTATS 4.2 (McGarigal et al., 1995) developed by the Forest Science of Oregon state university was adopted for calculating some landscape and class-level metrics (Table 23.2).

Table 23.2 Landscape metrics utilized to quantify the spatial pattern of the urban landscape in Da Nang city (based on McGarrial et al. 1995)

Landscape Metric index	Unit	Significance	Level calculation
Percent of landscape (PLAND)	%	Indicate the proportional abundance of each patch type in the landscape	Class
Largest patch index (LPI)	%	Indicate ratio of the largest patch area to the total landscape area	Landscape/class
Area-weighted mean patch fractal dimension (AWMPFD)	#	Reflect the complexity of self-similarity of a patch	Landscape/class
Contagion (CONTAG)	%	Express the agglomeration degree among different landscape types	Landscape
Shannon diversity index (SHDI)	#	Reflect landscape heterogeneity	Landscape
Shannon evenness index (SHEI)	#	Indicate even degree of different landscape types	Landscape

2.3.4 Statistical Analysis

Statistical correlations were calculated between the significant landscape pattern change metrics and critical urbanization indicators. Pearson’s correlation coefficient (r) between the urbanization indicators and landscape metrics was applied to quantify the relationship between urbanization and urban landscape patterns. A p -value (less than 0.05) was considered a significant correlation (Field, 2013).

The correlations were performed in such a way that a higher absolute value of the correlation coefficient represented a stronger correlation; positive values indicated positive correlations, and negative values meant that the correlation was negative. All statistical analyses were performed using the IBM SPSS version 26. The impact of urbanization on landscape pattern changes was analyzed in the period of 1996–2015.

3 Results

3.1 Land Use/Land Cover Changes

The image segmentation was done by applying multiresolution segmentation (MS) in eCognition Developer 9.01 software. The MS algorithm is also an optimization procedure that minimizes the average heterogeneity for a given number of objects and maximizes their homogeneity based on defined parameters such as scale, shape, and compactness. Through trial and error to successfully segment objects in an image, four segmentation levels were defined differently depending on the types of satellite image (Landsat 5 TM, Landsat 7 ETM+, ALOS Avnir-2, Landsat 8 OLI) and the nature of LULC to be detected for the analysis (Table 23.3).

Table 23.3 Segmentation levels of the classified objects

Segmentation level	Parameter (scale, shape, compactness)			
	1996	2003	2010	2015
	Landsat 5 TM	Landsat 7 ETM+	ALOS Avnir-2	Landsat 8 OLI
Level 1: Water body and land	10; 0.2; 0.5	10; 0.2; 0.5	15; 0.2; 0.5	10; 0.2; 0.5
Level 2: Vegetation/no-vegetation (built-up land, bare land)	5; 0.2; 0.5	5; 0.2; 0.5	5; 0.2; 0.5	5; 0.2; 0.5
Level 3: Forest land/other vegetation land	30; 0.1; 0.5	30; 0.1; 0.5	20; 0.1; 0.5	30; 0.2; 0.5
Level 4: Agricultural land and shrub and grass land	5; 0.2; 0.5	5; 0.2; 0.5	3; 0.1; 0.5	5; 0.2; 0.5

Table 23.4 Rule set classification

Level	Target class	Calculated parameter threshold			
		1996	2003	2010	2015
Level 1	Wa	Mean NIR ≤ 60	LWM ≤ 120 Mean NIR ≤ 60 mean NIR > 0	NDWI ≥ 0.45	NIR ≤ 600
	La	–	Mean blue > 0	–	NIR > 600 , Mean blue > 0
Level 2	NoVe	Mean blue ≥ 20	NDVI ≤ 0.36	Mean blue ≥ 145	Mean blue ≥ 700
	VeLa	Mean blue < 20	NDVI > 0.36	Mean blue < 145	Mean blue < 700
	BaL	Brightness ≥ 95	Brightness > 95	Brightness ≥ 165	Brightness ≥ 2500
	BuL	Brightness < 95	Brightness ≤ 95	Brightness < 165	Brightness < 2500
Level 3	FoL	SAVI ≥ 0.80	SAVI ≥ 0.85	SAVI ≥ -0.15	SAVI ≥ 0.98
	NoFo	SAVI < 0.80	SAVI < 0.85	SAVI < -0.15	SAVI < 0.98
Level 4	AgL	SAVII ≥ 0.78	SAVI < 0.70	SAVI ≤ -0.35	Brightness ≥ 1240
	ShGrL	SAVI < 0.78	SAVI > 0.70	SAVI > -0.35	Brightness < 1240

The hierarchical scheme object-based classification of four levels in each image was implemented by approaching fuzzy membership functions. The classification firstly started from the whole landscape into water body (Wa) and land (La) (level 1). Secondly, the land class was further subdivided into more specific class: vegetation (Ve)/no-vegetation (NoVe), in which the no-vegetation was classified into built-up land (BuL) and bare land (BaL) (level 2). The vegetation class was used to extract the forest land (FoL) and no-forest land (NoFoL) (Level 3). And finally, level 4 was used to extract the remaining target class LULC type: agricultural land (AgL), shrub and grassland (ShGrL). The classification of target class was extracted following the defined rule set classification (Table 23.4), in which mainly threshold of default

indices (blue, NIR, brightness), Normalized Difference Built-up Index (NDBI), Normalized Difference Water Index (NDWI), and Soil Adjusted Vegetation Index (SAVI) were utilized for achieving LULC classes (Table 23.4).

The series of LULC classification maps over the past 20 years by time are shown in Fig. 23.2, and the trend change of some major LULC area is shown in Fig. 23.2 and Table 23.5.

Table 23.5 and Fig. 23.3 show that the area of built-up areas increased steadily from 1996 to 2003, 2010, and 2015 from 4183.73 ha to 5211.38, 10,140.07, and 12,370.91 ha, respectively. In contrast, the area of agricultural land from 1996 to 2003, 2010, and 2015 has continuously decreased from 8089.31 ha to 8089.31, 5069.31, and 4332.12 ha, respectively.

The decline in agricultural land during this period is suitable for the development strategy of Da Nang City as follows: “service, industry, and agriculture,” of which the proportion of service and industry has been increasing and the proportion of agriculture has been decreasing. The city authorities have invested actively in building Da Nang into a modern city with strong industrialization, modernization, and high services. Therefore, most bare lands were reclaimed and covered with industrial zone, infrastructure, and newly built-up areas, which showed a rate of decline from 4805.52 ha to 2563.62 ha in 1996 and 2015, respectively. The area of shrub and grassland increased from 4881.92 ha to 6814.53 ha due to deforestation; forest fires in the West of the City and many urban areas were “hanging planning” to be abandoned along coastal roads.

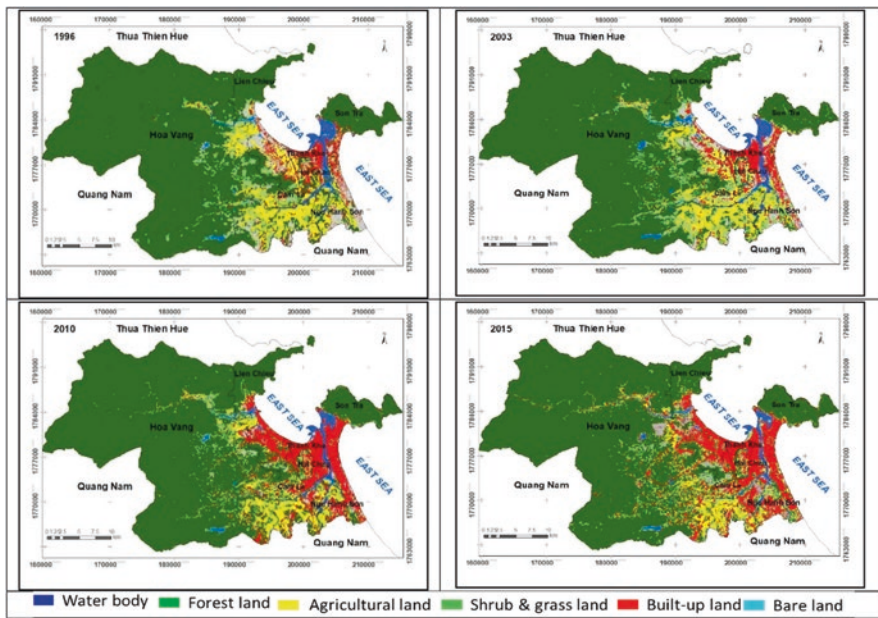


Fig. 23.2 LULC map in 1996, 2003, 2010, and 2015 of Da Nang City

Table 23.5 Area and percentage of LULC types in Da Nang City from 1996 to 2015

LULC type	1996		2003		2010		2015	
	Area (ha)	(%)	Area (ha)	%	Area (ha)	%	Area (ha)	%
AgL	8089.31	8.25	7532.84	7.68	5069.31	5.17	4332.12	4.42
BaL	4805.52	4.90	3254.29	3.32	1540.71	1.57	2563.62	2.61
BuL	4183.73	4.27	5211.38	5.32	10,140.07	10.34	12,370.91	12.62
FoL	74,043.69	74.81	71,024.37	72.44	73,784.11	75.26	69,785.02	71.18
ShGrL	4881.92	4.98	7947.33	8.11	5074.75	5.18	6814.53	6.95
Wa	2731.02	2.79	3069.79	3.13	2431.05	2.48	2173.80	2.22
Total	98,040.00	100.00	98,040.00	100.00	98,040.00	100.00	98,040.00	100.00

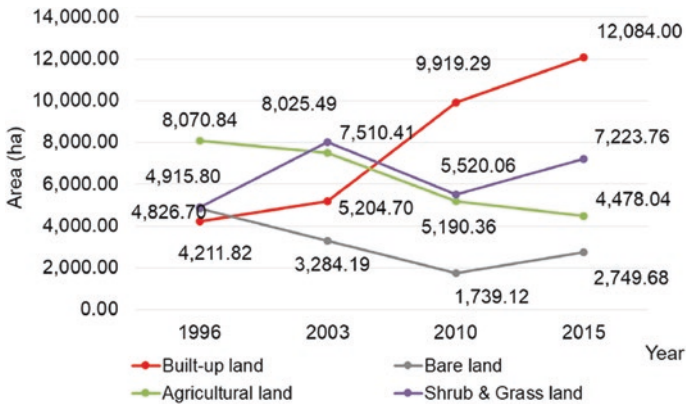


Fig. 23.3 Area of some main Da Nang LULC in the period of 1996–2015

The overall classification accuracy of the LULC map for 1996, 2003, 2010, and 2015 was determined to be 93.51%, 91.31%, 91.20%, and 92.88%, respectively. The overall Kappa coefficient for the four times was over 0.8, which was considered to indicate acceptable or good agreement with the optical data. For the built-up areas, the Kappa coefficient was extracted with good agreement, over 0.85. Therefore, these data were available for continuous study (Table 23.6).

3.2 Evolution characteristic of Urbanization Expansion

From the analysis of the LULC changes, Da Nang City has clearly undergone a rapid urban expansion over the past two decades, amounting to 12,370.91 in 2015 as compared to only 4183.73 ha in 1996. The built-up area grew by 8187.18 ha between 1996 and 2015 (2.9 times) and nearly 430.9 ha per year on average. The evolution of urbanization expansion in Da Nang City in the period of 1996–2015 is clearly shown in Table 23.5 and Fig. 23.4.

Table 23.6 LULC classification accuracy assessment

Land use/land cover type	Kappa coefficient			
	1996	2003	2010	2015
Built-up land	0.86	0.85	0.93	0.85
Bare land	0.80	0.70	0.83	0.87
Water body	0.92	0.95	0.83	0.96
Agricultural land	0.69	0.73	0.69	0.88
Forest land	0.89	0.92	0.85	0.85
Shrub and grass	0.67	0.52	0.53	0.68
Overall kappa coefficient	0.86	0.82	0.81	0.85
Overall classification accuracy	93.51%	91.31%	91.20%	92.88%

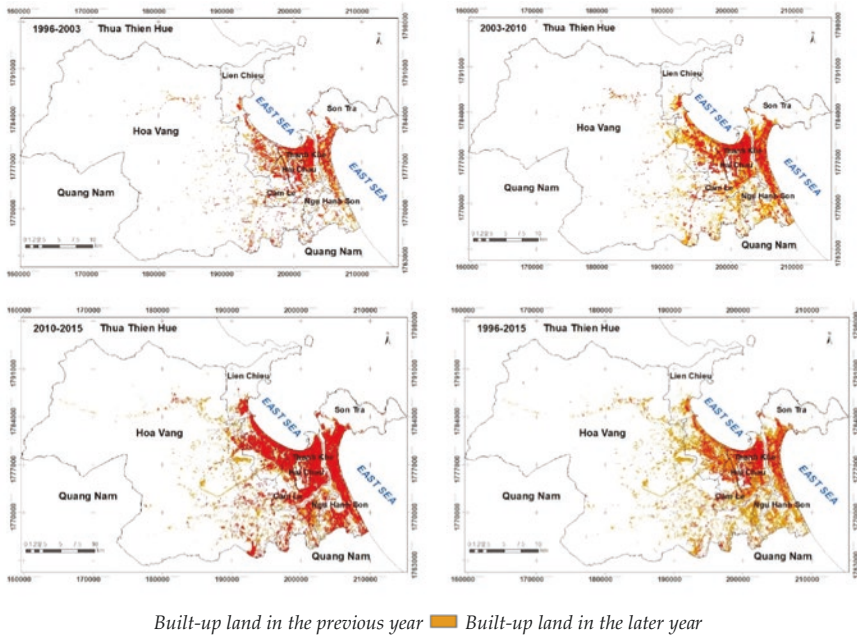


Fig. 23.4 Evolution of urbanization expansion in Da Nang City in the period of 1996–2015

The urban area increased 1027.65 ha from 4183.73 ha in 1996 to 5204.70 ha in 2003 with the average expansion urban area of 146.81 ha per year. The area of built-up area was 4183.73 ha, mainly distributed in the center of Hai Chau and Thanh Khe district in 1996 (which previously belonged to the core center of Quang Nam-Da Nang Province: District 1, 2, and 3). The urbanization process in Da Nang speeded up sharply since the separation of Da Nang city from the Quang Nam-Da Nang Province (in 1997) and the recognition of Da Nang as a type-I city under Central Government (in 2003). In the next seven years (2003–2010), the area of urban land expanded up to 9919.29 ha in 2010 with the average expansion urban

area of 704.1 ha per year (nearly 5 times higher in comparison with that of the seven-year period of 1996–2010). Corresponding to that stage, there was the development of emerging pork industry and major infrastructure as well as the road and bridge networks (such as Han Bridge River in 2000, Thuan Phuoc Bridge in 2009) creating connection with other districts (Lien Chieu, Son Tra). After 2010, the city authority accelerated the development of sea park and tourism zones/resorts on the coastal road from Son Tra district to Hoi An city (Quang Nam Province) in the southeast. Therefore, the urban area has not only expanded to the west and northwest but also largely expanded beyond the central city to the south and southeast and along the coastal line, connecting Ngu Hanh Son to Cam Le, demonstrating a complete interconnection of urban areas (Fig. 23.4). During the five-year period of 2010–2015, the expansion area of built-up land was 2230.84 ha. The annual increase in the area of construction land was 446.17 ha in this period, which was lower than that in the 2003–2010 year period, because the urban land fund has gradually stabilized.

The urbanization progress of Da Nang could be divided into three clear stages, which were in the initial construction stage (1996–2003), the rapid development stage (2003–2010), and stable development (2010–2015). The built-up area grew 8187.18 ha within 19 years (1996–2015), and the values of urbanization intensity index were 0.15, 0.72, 0.46, and 0.44 in 4 stages of 1996–2003, 2003–2010, 2010–2015, and 1996–2015, respectively. The high value of urbanization intensity index in the period of 2003–2010 indicated that the urban expansion was great (Table 23.7).

Over the past two decades, Da Nang has experienced a strong urbanization process, which is reflected in the indicators of urbanization such as urban resident's ratio, urban resident's density, nonagriculture GDP proportion, and nonagriculture labor ratio (Table 23.8). The proportion of urban population in Da Nang is the highest in the country. Compared to the national urban population of 33.9%, the urban population of Da Nang is 2.6 times higher than that of Ho Chi Minh City (81.6%). According to the result of a population census, just within 20 years from 1996 to 2015, the population of the city has increased by nearly 1.5 times, from 672,468 to 1,028,838 persons, respectively, in which, the urban population occupied the high

Table 23.7 Built-up land expansion from 1996–2015 in Da Nang City

Duration	The time span of a certain duration	The expansion area of built-up land (ha)	Annual expansion area (ha per year)	Urbanization intensity index
1996–2003	7	1027.65	146.81	0.15
2003–2010	7	4928.69	704.10	0.72
2010–2015	5	2230.84	446.17	0.46
1996–2015	19	8187.18	430.90	0.44

Table 23.8 Some indicators of urbanization in Da Nang City from 1996 to 2015

Urbanization indicators	Abbreviation	Unit	Year			
			1996	2003	2010	2015
Urban population rate	PoUrban	%	79.04	79.59	86.97	87.28
Urban population density	PoDensity	Per/km ²	2581.87	2841.76	3268.08	3657.17
Nonagriculture GDP proportion	GDPNAgri	%	93.34	96.57	97.03	97.04
Average income per person	Income	USD/ per	27.13	35.92	102.31	166.66
Nonagriculture employment rate	EmpNAgri	%	67.00	74.18	90.62	92.49

Da Nang Statistical Office [DNGSO] (1998, 2004, 2011, 2016).

rate and increased steadily from 1996 to 2015 Da Nang Statistical Office [DNGSO] (1998, 2004, 2011, 2016).

As shown in Table 23.8, the urban population density has increased by 1.4 times from 1996 to 2015, reflecting the increasing concentration of the population in the inner city. The average monthly income of people has improved dramatically, increasing more than 6 times, from only 27.13 USD in 1996 to 166.66 USD/a person in 2015. Corresponding to the increase in the average income per capita, Da Nang has had no poor households according to the national poverty line (2015). It can be said that the expansion of construction land area in Da Nang is inevitable due to a number of main reasons as follows: (1) coastal location advantage for forming a key economic city, (2) changes in boundary and upgrading urban administrative classification unit, and (3) economic transition.

3.3 Urban Landscape Pattern Fragmentation Changes from 1996 to 2015

The urban landscape pattern became more heterogeneous mainly due to the fragmentation. The temporal changes in the landscape pattern metrics at the landscape level of built-up land are depicted in Fig. 23.5.

3.3.1 Largest Patch Index (LPI)

LPI is defined as the percentage of the largest patch in the total landscape (%). It refers to the dominance of one type of patch (McGarigal et al., 1995). In Fig. 23.5a, in landscape level, the value of LPI decreased from 50.77 to 47.43 within nearly 20 years, in which, its value sharply decreased to 35.53 in 2003, corresponding the period of speed urbanization. This decrease of LPI indicated that the dominant landscape of agricultural land had declined according to the orientation development of “service, industry, and agriculture.” In contrast, the LPI of built-up land showed a

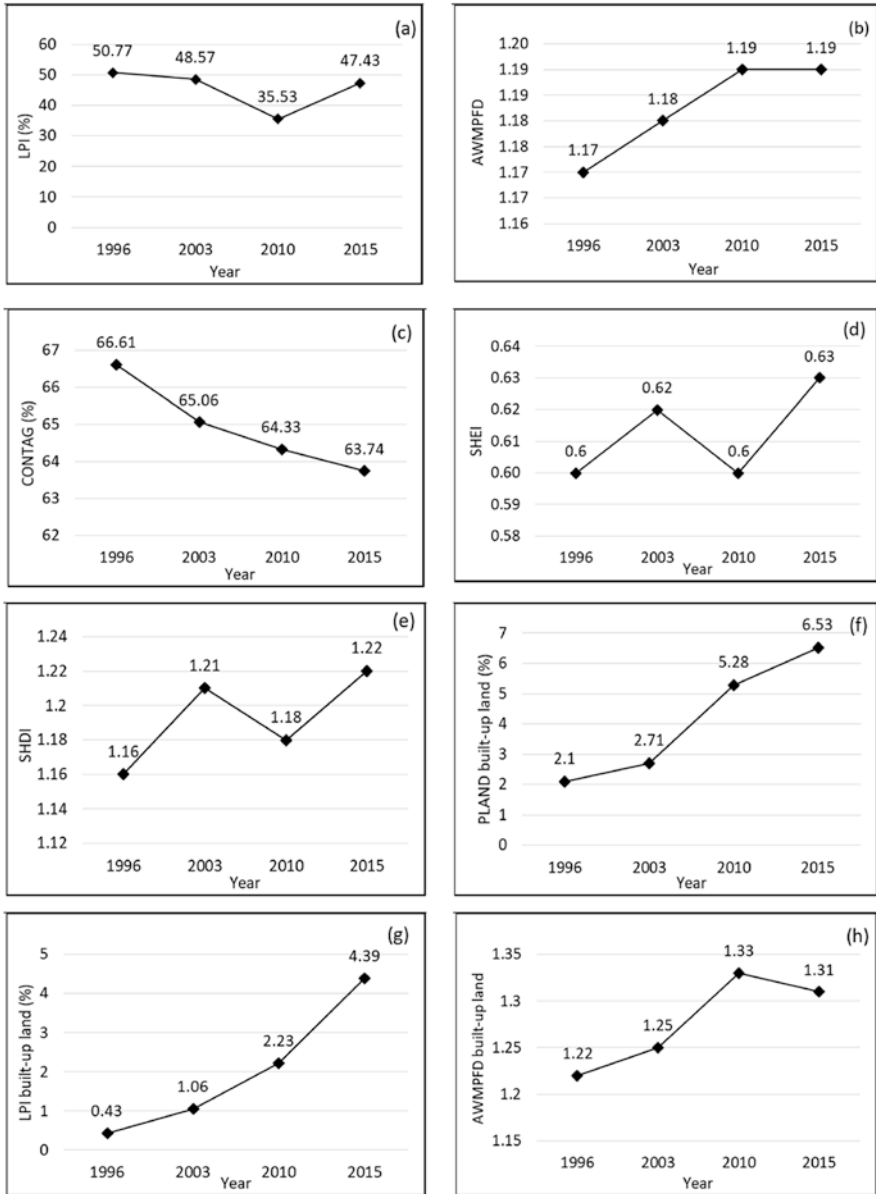


Fig. 23.5 Temporal changes in the landscape pattern metrics at the landscape level (a) LPI, (b) AWMPFD, (c) CONTAG, (d) SHEI, (e) SHDI, and in the class level (f) PLAN built-up land, (g) LPI built-up land, and (h) AWMPFD built-up land

trend of a gradual increase from 0.43% to 4.29% within the period of 1996–2015 (equivalent to nearly 10 times) (Fig. 23.5g). This indicated the built-up land expanded and became larger in the urbanization process.

3.3.2 Area-Weighted Mean Patch Fractal Dimension (AWMPFD)

In the landscape shape dimension, AWMPFD metric reflects the complexity of a patch. The value of the AWMPFD index is within the threshold as follows: $1 \leq \text{AWMPFD} \leq 2$. If this index goes to 2, the patch will have a more complex and fragmented shape (McGarigal et al., 1995). From calculation in the landscape level, the value of AWMPFD metric indicated a slight gradual increase from 1.17, 1.18, 1.19, and 1.19 in 1996, 2003, 2010, and 2015, respectively (Fig. 23.5b). This increase represented that the shape of the landscape became more irregular and complex within 19 years of urbanization. This trend was also depicted clearly in the class level for the built-up land and indicated an increase from 1.22 to 1.31 from 1996 to 2015. Especially, this index showed the period of 2003–2010 with the high-value increase from 1.25 to 1.33, which indicated that the built-up land became more irregular and complex in the rapid development stage (Fig. 23.5h).

3.3.3 Contagion (CONTAG)

CONTAG is a metric used to characterize scattered and concentrated landscape types (He, Gap, Niu, & Zhao, 2011). It is affected by the dispersion and interspersions of patch types and regarded as one of the significant indicators for reflection of connectivity and fragmentation over the whole landscape [6, 9]. In this study, the CONTAG was four times smaller, and decreased from 66.61 to 63.74 in the period of 1996–2015 (Fig. 23.5c). This decrease of the CONTAG metric indicated that the spatial distribution of different patches became more separated and the patch types became more disaggregated due to the strength of human interferences.

3.3.4 Shannon Diversity Index (SHDI) and Shannon Evenness Index (SHEI)

The SHDI indicates landscape heterogeneity and is sensitive to less-occupied patch types, while the SHEI expresses such an even distribution of areas among patch types' results in maximum evenness (Dai et al., 2017). As a measure of landscape heterogeneity, SHDI is especially sensitive to the nonbalanced distribution of all patch types in the landscape. SHEI is applied to indicate the diversity of different landscapes or a certain landscape in different periods, which results in maximum evenness (Zhou et al., 2014). Both SHDI and SHEI with a noticeable increase during the period of 1996–2015 indicated that the landscape of study was more fragmented and heterogeneous (Fig. 23.5 d, e).

3.3.5 Percent of Landscape (PLAND)

PLAND is defined as the percentage of the landscape comprising a particular patch type (McGarigal et al., 1995). The spatial analysis of the urban area showed a significant increase in the percentage of landscape index (PLAND) from 2.10% to 6.53% in 1996 and 2015, respectively (approximately 3 times higher). Especially, this trend showed a sharp increase from 2003 to 2010 with a value of 2.71% to 5.28%, respectively (Fig. 23.5f). This corresponded to the decline in other types of land use/land cover (agricultural land and bare land) for expanding the urban area.

3.4 Impact of Urbanization on Urban Landscape Pattern Changes

The impact of the process of urbanization on the landscape pattern change of Da Nang city was defined by analyzing the correlation between the significant landscape pattern change metrics and urbanization indicators. From the calculation of the urban landscape pattern fragmentation changes from 1996 to 2015, five landscape pattern metrics, which were found to be relatively changed much over 19 years, were chosen for the analysis including the percent of landscape for built-up land (PLAND^{bu}), the largest patch index for built-up land (LPI^{bu}), the area-weighted mean patch fractal dimension for built-up land (AWMPFD^{bu}), CONTAG, and SHEI. The indicators were utilized for quantifying the relationship between urbanization and urban landscape patterns, which reflect the critical urbanization in the study area highlighting the Urban population rate (PoUrban), Urban population density (PoDensity), Non-agriculture GDP proportion (GDPNAgr), and Non-agriculture employment rate (EmpNAgr). The bivariate correlation between the urbanization variables and urban landscape pattern metric is shown in Table 23.9 with the Pearson’ correlation coefficient (r), significant p-value (p), and the determination coefficient (R²).

The result of Pearson’s correlation analysis showed that the sign of the correlation had changed with different urbanization indicators.

Table 23.9 The correlation coefficient between the landscape patterns metrics and the urbanization indicators

	PoUrban			PoDensity			GDPNAgr			EmpNAgr		
	r	p	R ²	r	P	R ²	r	p	R ²	r	p	R ²
PLAND^{bu}	0.97	0.03	0.95	0.99	0.01	0.98	0.74	0.26	0.54	0.98	0.02	0.93
LPI^{bu}	0.87	0.13	0.76	0.98	0.02	0.96	0.68	0.32	0.47	0.89	0.11	0.79
AWMPFD^{bu}	0.96	0.04	0.93	0.98	0.12	0.77	0.82	0.18	0.68	0.98	0.02	0.95
CONTAG	-0.91	0.09	0.83	-0.98	0.02	0.96	-0.89	0.11	0.79	-0.97	0.03	0.93
SHEI	0.24	0.76	0.06	0.57	0.43	0.33	0.53	0.47	0.29	0.37	0.64	0.13

Although SHEI had a significant change during the 19 years of urbanization, there was no significant correlation between the urbanization indicators and Shannon evenness index (SHEI).

The urbanization indicators were significantly positively correlated with PLAND^{bu}, LPI^{bu}, AWMPFD^{bu}, and significantly negatively correlated with CONTAG.

For the PLAND^{bu}, the urban population (PoUrban), population density (PoDensity), and nonagriculture employment rate (EmpNAgr) had a high correlation coefficient with PLAND^{bu}. The highest correlation was with PoDensity (0.99), and the lowest was with the urban population (PoUrban) (0.97). The p-value of these three urbanization indicators and PLAND^{bu} was less than 0.05. The determination coefficient (R^2) of these indicators had a high value, ranging from 0.93 to 0.98. The GDPNAgr has not affected the landscape pattern changes during 19 years of the urbanization. This indicated that the urbanization had been significantly affected the urban landscape pattern changes during the 19 years of Da Nang City's urbanization.

For the LPI^{bu}, only the population density (PoDensity) had a high correlation coefficient with LPI^{bu} with the value of 0.98. The p-value of this urbanization indicator was less than 0.05, and the coefficient of determination (R^2) was 0.96.

For the AWMPFD^{bu}, only the population density (PoDensity) and nonagriculture employment rate (EmpNAgr) had a high correlation coefficient with AWMPFD^{bu} with the values of 0.96 and 0.98, respectively. The p-value of the two urbanization indicators was less than 0.05, and the coefficient of determination (R^2) was 0.93 and 0.95, respectively.

For the CONTAG, PoDensity and EmpNAgr have had a high correlation coefficient with CONTAG, with the values of -0.98 and -0.97 , respectively. The p-value of these three urbanization indicators and PLAND^{bu} was less than 0.05. The determination coefficient (R^2) of these indicators had a high value, ranging from 0.93 to 0.96.

Thus, the analysis result showed that the landscape pattern in Da Nang had changed significantly for nearly two decades. These changes were due to the effects of policy change of the transition of administrative shift, economic shift, and demographic shift. The expansion of the built-up land in the research area was mainly due to the conversion of agricultural land in accordance with the development strategy policy of Da Nang City in the orientation of "service, industry, and agriculture." The city authorities invested actively in building Da Nang into a modern city with strong industrialization, modernization, and high services. The administrative shift and growth of urban population in urban area were a strong driving force on the landscape pattern change in the study period.

4 Conclusion

The process of urbanization and socioeconomic development has changed Da Nang urban space rapidly. From the research results, the LULC maps of 1996, 2003, 2010, and 2015 have been established by approaching the object-based (oriented) classification with the high accuracy. It is shown that the LULC has been changed over time. The area of built-up land increased about 8187.18 ha during the period of 1996–2015. Da Nang City experienced the rapid urbanization from 1996 to 2015, in which the expansion of urban land occurred quickly in the period of 2003–2010. The area of built-up land expanded, mainly through the conversion of agricultural land. The area of built-up land has increased about 8187.18 ha and about 3757.19 ha agricultural land which was lost during the period of 1996–2015. Through the spatial analysis of the LULC, the expansion of the construction land in Da Nang from the center radiated in the different directions of west–north, south, west–south, and southeast.

Da Nang urban spatial landscape distribution became more separated, complex, and irregular. It has resulted from the significant relationship between the urbanization indicators and landscape change indicators in combination with human activities—decisive factors for urban development. This is the significant reality basis for urban planning, proposing policy, and long-term development strategy to ensure sustainable urban development in future.

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