QUANTIFYING URBAN LAND EXPANSION AND THE DRIVING FORCES OF URBAN SPRAWL IN VIETNAM'S CENTRAL HIGHLANDS FROM 2000 TO 2023

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Abstract

This study developed a dataset on land cover to analyze the continuous urban land extension in Buôn Ma Thuột City, located in the Central Highlands of Vietnam, from 2000 to 2023. The analysis employed object-based image analysis (OBIA) for backward classification and calculated expansion indices. The results reveal that the total urban land area increased by 22.75% over two decades, despite an average annual population growth rate of only 1.91%. The spatial growth exhibited relatively uniform growth in all directions, but it was most concentrated in the urban core and the northern and eastern parts of Hoa Thuan, Tan Loi, Tan An, Tan Hoa, and Tan Lap wards. This expansion included edge development (6.69%), leapfrog expansion (18.39%), and infill increase (5.44%). Driving factors, analyzed through Pearson correlation coefficients, indicate that urban land growth between 2000 and 2023 was positively influenced by GDP, urban population, and total population but was inversely correlated with the poverty rate. This study provides quantitative methodologies for better understanding urban land dynamics and offers practical strategies for sustainable urban development.

Keywords: Buôn Ma Thuột, driving forces, object-based classification, remote sensing, QGIS, urban land expansion, Việt Nam

1. Introduction

Sustainable development has emerged as a global trend and is now a preferred development model for many countries. The 2030 Agenda for Sustainable Development, adopted by the United Nations General Assembly on September 25, 2015, outlines a comprehensive framework for all nations to achieve over the next 15 years (United Nations General Assembly, 2015). Any successful pathway to implementing the 2030 Agenda must prioritize the sustainable development of urban and peri-urban environments (Acuto et al., 2018). Urbanization is characterized by three interconnected aspects: spatial, demographic, and economic dimensions. However, the relationship between these aspects has not been adequately addressed, particularly within the context of rapid spatial expansion, which often fails to align with population and economic growth over the past few decades (Zhang et al., 2019).

Information on urban land cover has become a valuable indicator for assessing ecological environments and climatic impacts across various spatial and temporal scales (Jensen, 2009, Song et al., 2015). Therefore, describing urban expansion patterns is a prerequisite for integrated urban planning and sustainable regional development (Seto, Güneralp, et al., 2012). Remote sensing technology provides earth observation data with high temporal frequency across clear spatial and temporal scales (Lillesand & Kiefer, 1994). When integrated with Geographic Information Systems (GIS), remote sensing has been widely applied in urbanization research, focusing on extracting urban land cover and quantifying expansion patterns (Cheng et al., 2018). Among various remote sensing datasets, Landsat data, with its medium resolution, easy accessibility, and well-developed processing techniques, is a key resource for extracting urban land and quantifying expansion models (Zhang & Wu, 2020; Wu & Zhan, 2007).

In their study on urban morphology theory, Harvey and Clark (1965) identified three primary forms of urban expansion: low-density continuous urban growth, ribbon development, and leapfrog development (Clark, 1965). These forms align with the classifications proposed by Wilson et al. (2003): Infill expansion involves the conversion of undeveloped land into urban use within areas where at least 40% of the surrounding parcels are already developed. Outlying growth refers to the development of undeveloped land beyond existing urbanized areas (Bev Wilson & Arnab Chakraborty, 2013), often categorized into isolated, linear branch, and clustered branch (nucleated) patterns, which are commonly observed in peri-urban or suburban contexts (Heimlich, William Anderson, 2001). Edge expansion describes unidirectional growth forming strips of land parallel to already urbanized regions. The relationship between newly developed and existing urban areas plays a critical role in identifying the type of urban growth that has taken place.

Typically, the analysis of driving forces is conducted using one of two main approaches: qualitative or quantitative, based on two types of factors - spatial data or socio-economic statistical data. Population and economic conditions, as reflected by socio-economic statistical data, may not directly influence urban expansion. Instead, other factors, such as policies, topography, hydrology, the influence of neighboring cities (particularly satellite cities surrounding urban areas), and land availability, are significant but challenging to quantify. Additionally, explicit spatial data are more suitable for localized studies at smaller scales, such as individual cities, while socio-economic statistical data, including population, income, and investment, are better suited for regional or global-scale research.

Over nearly four decades of economic reforms and opening, Vietnam has undergone rapid urbanization, leading to a significant decrease in the average per capita agricultural land area, which is now less than 0.10 hectares per person (Vietnam Ministry of Construction, 2003). While urbanization is an irreversible process, it has occurred unevenly across major cities and smaller urban areas (Nguyen et al., 2022). By 2030, Vietnam's urbanization rate is projected to exceed 50%, with urban construction land covering 1.9-2.3% of the total land area and supporting approximately 1,000-1,200 urban centers (Vietnam Ministry of Construction, 2003). Urban areas are expected to contribute around 85% of the national GDP (Bui, 2021). However, rapid urbanization presents challenges to sustainable development, including inefficient land use and negative socioeconomic and environmental consequences (Le et al., 2020). The city's rapid physical expansion has led to the peri-urbanization of peripheral settlements, accompanied by the growth of infrastructure such as roads, schools, hospitals, and other facilities, resulting in increased consumption of suburban land (Hai et al., 2019). To address these challenges, this study uses Landsat satellite imagery and survey data to create a medium-resolution urban land cover dataset (30m) for Buôn Ma Thuột City, covering the years 2000, 2005, 2010, 2015, and 2023. The study applies expansion indices to examine urban land expansion patterns and assess their quantitative impacts on socioeconomic factors.

2. Research methods

2.1 Study area

Buôn Ma Thuột (Figure 1) is the political, economic, cultural, educational, and scientific-technical center of Dak Lak Province and serves as the central urban hub of the Central Highlands region of Vietnam. The city spans a natural area of 377.09km², divided into 19 administrative subdivisions, accounting for 0.69% of the total area of the Central Highlands (54,548km²). By 2023, the city had a population of 434,256 people, located within the geographical coordinates of 12°35'17" to 12°44'30" N latitude and 107°05'00" to 108°09'50" E longitude (Dak Lak Provincial Statistical Office, 2023).

Buôn Ma Thuột has a tropical monsoon climate with two distinct seasons: the rainy season (from May to October), which contributes 90% of the annual rainfall, resulting in humid and mild conditions; and the dry season (from November to April), characterized by minimal precipitation and low humidity. The average annual temperature is 23.5°C, and the average monthly rainfall ranges from 4mm to 610mm. This area is free from tropical storms.

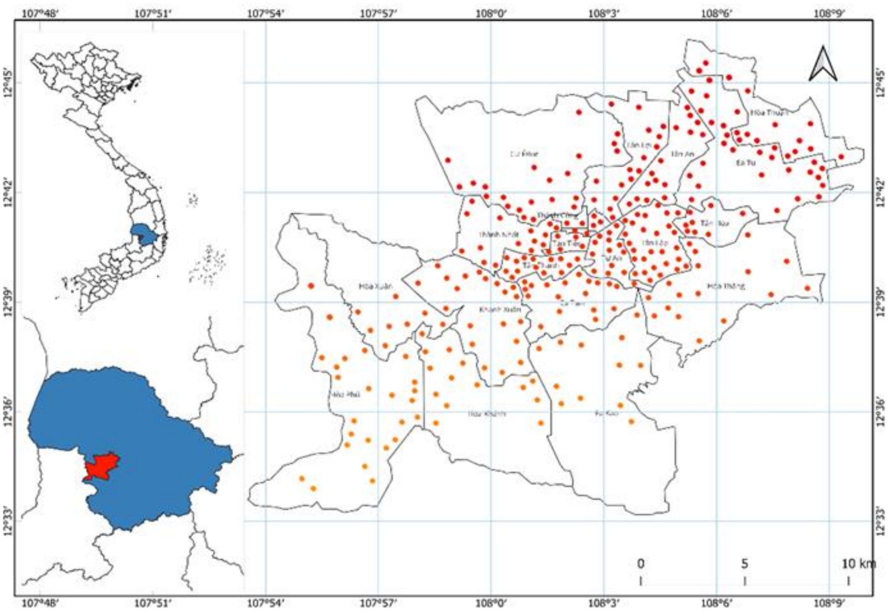

Figure 1. Location of the study area and ground survey points of 2023

The city is endowed with fertile soil, recognized as one of Vietnam's five notable basaltic regions, making it a critical area for coffee production. However, numerous studies have indicated that urban land has significantly encroached on agricultural land, threatening agricultural productivity and the livelihoods of local residents.

2.2 Data sources and processing

This study utilized imagery data from the Landsat Thematic Mapper (TM) and Landsat Operational Land Imager (OLI), with a medium spatial resolution of 30 meters, for the years 2000, 2005, 2010, 2015, and 2023. The images were classified using object-based classification techniques combined with change vector analysis, yielding land cover classification maps with overall accuracies ranging from 86% to 88% for the specified years.

The Landsat data were georeferenced to the WGS 84/UTM Zone 48N coordinate system within the Universal Transverse Mercator (UTM) projection. This projection system is well-suited for the study area, which is located in the Central and Central Highlands regions of Vietnam within longitudes 102° to 108°E (Zone 48N) and adopts the World Geodetic System 1984 (WGS 84) as the reference framework.

Additional geospatial layers, such as city center points, administrative subdivisions, and polygons of administrative boundaries at various levels, were obtained from the Department of Natural Resources and Environment of Dak Lak Province (https://tnmt.daklak.gov.vn).

Field survey points were collected between August and September 2023 using Global Positioning System (GPS) devices with a positional error margin of less than 10 meters (Figure 1). A total of 300 points, covering all land cover types within the study area, were obtained. To validate the accuracy and consistency of classification results with on-ground reality, land use maps, Google Earth imagery, and historical survey data from local experts were used as supplementary references, ensuring a high degree of land cover classification reliability.

For quantitative analysis of the factors influencing urban land expansion, statistical data were extracted from the statistical yearbooks of Buôn Ma Thuột City and Dak Lak Province for the years 2000, 2005, 2010, 2015, and 2023. Based on the correlation and availability of relevant data for this study, ten socioeconomic indicators were selected for the study area: Average annual income per capita (million VND/person), Urban population (people), Total population (people), Built-up area per capita (m^2/person), Percentage of households with access to national grid electricity (%), Percentage of households with access to clean water (% of population served), Agricultural land shrinkage rate (%), Unemployment rate (%), Poverty rate (% of population below the poverty line), Internet usage rate (% of population with access).

2.3 Object-Based image analysis (OBIA) and Urban land use change

2.3.1 Object-based image analysis

OBIA is a classification method that uses the spatial and spectral information of objects (such as agricultural lands, forests, residential areas) rather than individual pixels. This approach was first researched and developed by Blaschke and colleagues in the late 1990s (Blaschke, 2010). Integrated reverse classification methods are applied to detect changes during preprocessing and conduct classifications during postprocessing. This ensures spatial, temporal, and categorical consistency of features, guaranteeing accurate and synchronized results throughout the analytical process (Lin Chen et al., 2018).

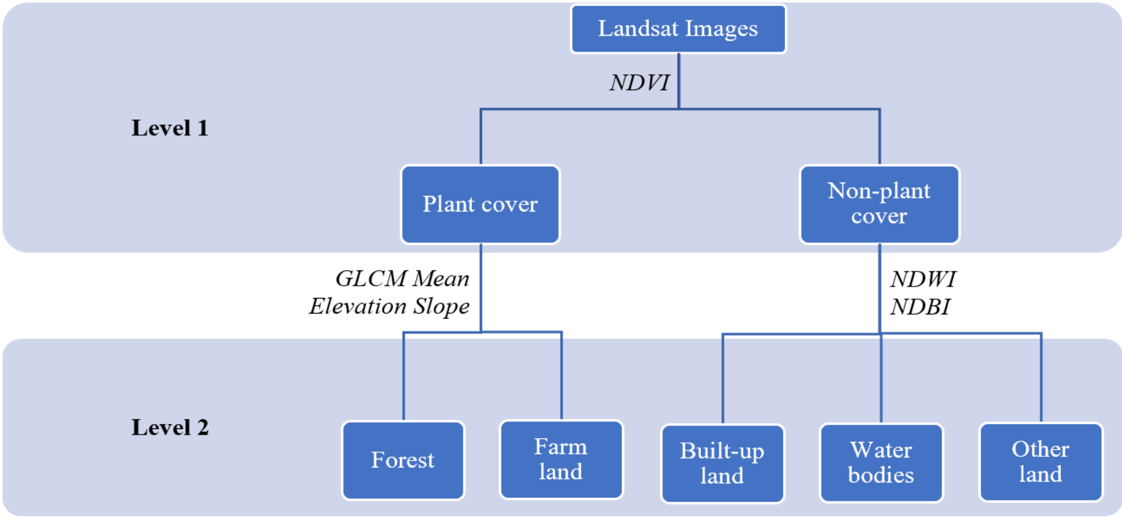

Figure 1. The outline of the decision tree

The workflow begins with a reference map from 2003, using satellite image classification and automated image processing via the Semi-Automatic Classification Plugin (SCP) within QGIS software (Congedo, 2014). To minimize spatial noise effects, often manifested as pixels differing significantly from their surroundings in remote sensing image processing, the OBIA method was employed for Land Use/Land Cover (LULC) data (Blaschke, 2010). Five main land cover classes were identified: *farmland, woodland, water bodies, built-up land*, and *unused land*. Using this method, LULC maps from 2000 to 2023 were generated through the following steps.

Step 1: Producing the Reference Map

The LULC map for 2023 was created from the 2023 Landsat OLI imagery using the SCP tool in QGIS software. Visual image analysis and manual corrections were conducted to validate and adjust classifications, enhancing the accuracy of the reference LULC map. Accuracy assessment was performed using 300 verification points from field survey data, with at least 60 samples for each land use type. The overall accuracy of the 2023 LULC map was 93%, with residential areas achieving 95%.

Step 2: Creating LULC Maps for Other Years

Using the 2023 LULC map as the reference, LULC classification maps for 2000, 2005, 2010, and 2015 were separately developed by applying Object-Based Classification combined with Vector Change Detection. Accuracy assessments were also conducted for the LULC maps of 2000, 2005, 2010, and 2015 using historical field survey points, Google Earth imagery, and Landsat TM image analyses as reference data. The overall accuracy of these classification maps reached 80% for 2000, 85% for 2005, 90% for 2010, and 93% for 2015. For residential areas, accuracy levels were 90%, 91%, and 93%, respectively.

2.3.2 Selection of Urban Land Areas

The selection of urban land areas is conducted through spatial analysis, defining urban land as contiguous built-up areas within the administrative boundaries of a city (Xia et al., 2013). The process involves two key steps: (1) Identifying features categorized under the “settlement and built-up” class from the Land Use/Land Cover (LULC) map. (2) Utilizing vector data layers to delineate and exclude non-urban areas, ensuring a clear distinction between urban land and other land uses such as agricultural land, forested areas, or unused land.

2.3.3 Calculating of Urban Growth Rates

The annual growth rate (AGR) and percentage growth rate (GR) of urban land are calculated to quantify urban expansion over the past two decades. The temporal patterns of urban land expansion within the study area are represented using the formulas:

$$AGR = \frac{(S_{end} - S_{start})}{n} \tag{1}$$

$$GR = \frac{(S_{end} - S_{start})}{S_{start}} \tag{2}$$

Where: S_{end} (km²) is urban land area at the end of the period. S_{start} (km²) is urban land area at the beginning of the period, and *n* is time interval in years.

2.3.4 Calculating the Urban Expansion Index

The Urban Expansion Index (E) is employed to identify three main types of urban land expansion: *infilling, edge expansion*, and *outlying* (Seto & Fragkias, 2005). The index is calculated using the Vector Analysis tool in QGIS to process spatial data and compare urban layers over time (Li & Lu, 2020). The workflow includes extracting new urban areas through the Difference tool, creating buffers around features using the Buffer tool, and computing distances between new and existing urban areas with the Distance Matrix tool. The Expansion Index E is derived through these combined spatial analysis steps.

$$\mathrm{E} = \frac{D}{D_{max}} \tag{3}$$

Where *D* is euclidean distance between new urban areas and the nearest existing urban area, calculated as:

$$d = \sqrt{(x_2 - x_1)^2} + (y_2 - y_1)^2 \tag{4}$$

Where D_{max} is maximum possible distance (a standard value or derived from data).

Based on the value of E, the type of urban expansion is classified as infilling when E>0.5, edge expansion when 0<E≤0.50, and outlying expansion when E=0.

2.3.5 Urban Expansion Analysis

To assess Urban Land Use Efficiency (ULUE), two indicators developed by UN-Habitat have been employed (UN-Habitat, 2018).

(1) ULUE is based on the annual land consumption rate and the population growth rate (LCRPGR) to measure the relationship between urban land consumption and population growth. The methodology for SDG 11.3.1 has been established and referenced in the SDG Indicator Metadata Repository (https://unstats.un.org/sdgs/metadata). The LCRPGR is calculated using the following formula:

$$LCRPGR = \frac{\mathrm{LCR}}{\mathrm{PGR}} \tag{5}$$

Where:

Population Growth Rate (PGR): $$PGR = \frac{\text{LN}(Pop_{t+n}/Pop_t}{(\text{y})} \qquad (5.1)$$

Where: *LN* represents the natural logarithm value

Pop_t is the total population in the urban area in the past.

Pop_{t+n} is the total urban population in the current year.

y is representing the number of years between the two periods.

Land Consumption Rate (LCR): $$LCR = \frac{\text{Vpresent}-\text{Vpast}}{\text{Vpast}} * \frac{1}{(\text{t})} \qquad (5.2)$$

Where: $V_{present}$ is the total built-up area in the current year.

V_{past} is the total area in the past.

t is the year number in the past and current year

If LCRPGR ≤ 0: Population decline with reduced urban sprawl.

If 0 < LCRPGR ≤ 1: Increased population density.

If 1 < LCRPGR ≤ 2: Urban sprawl outpaces population growth.

If LCRPGR > 2: Urban sprawl grows at least twice as fast as population growth.

(2) The Urban Land Index (UI) and the Urban Expansion Index (UX) are analytical metrics employed to evaluate the extent of urban expansion and the growth dynamics of urbanized areas (Seto, Golden et al., 2012). The UI quantifies the proportion of urban land relative to the total land area at a given time, with calculations performed for the years 2000 and 2023. Conversely, the UX assesses changes in urban land area between two specific time points, thereby providing a relative measure of urban spatial expansion. The UX is derived for the 23-year interval from 2000 to 2023, enabling the measurement of spatial urban growth. These indices are computed using the following formulations (Hu et al., 2009):

$$\text{UI} = \frac{UL}{TL}\ x\ 100\% \qquad (6)$$

$$\text{UX} = \frac{UL_{t2} - UL_{t1}}{UL_{t1}}\ x\ 100\% \qquad (7)$$

Where UL is urban land area and TL is total land area.

2.4 Statistical Analysis

The correlation between urban expansion and socio-economic development was analyzed using Pearson’s correlation coefficient (Karl Pearson, 1896). This approach examines the linear relationship between urban built-up area and 10 socio-economic variables. The formula is:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2 \sum_{i=1}^{n}(y_i - \overline{y})^2}} \qquad (8)$$

Where x_i, y_i are urban expansion and socio-economic development values, $\overline{x}$ and $\overline{y}$ are values of variables x and y. Correlation r_{xy} is considered significant if p<0.05p < 0.05.

3. Results

3.1 Spatiotemporal Characteristics of Urban Expansion

Between 2000 and 2023, Buôn Ma Thuột city experienced significant land use changes across a total area of 377.10km² (Figure 3 and 4). The overall trend reflects rapid urbanization coupled with the reduction of agricultural and forested lands, indicating a transition from agricultural production to urban development and infrastructure expansion. Notably, the urban land area increased at a faster rate during 2010-2023 compared to 2000-2010. Built-up areas were predominantly concentrated in the urban core and the northern and eastern parts of the wards of Hoa Thuan, Tan Loi, Tan An, Tan Hoa, and Tan Lap, with an average annual growth rate of 0.99%.

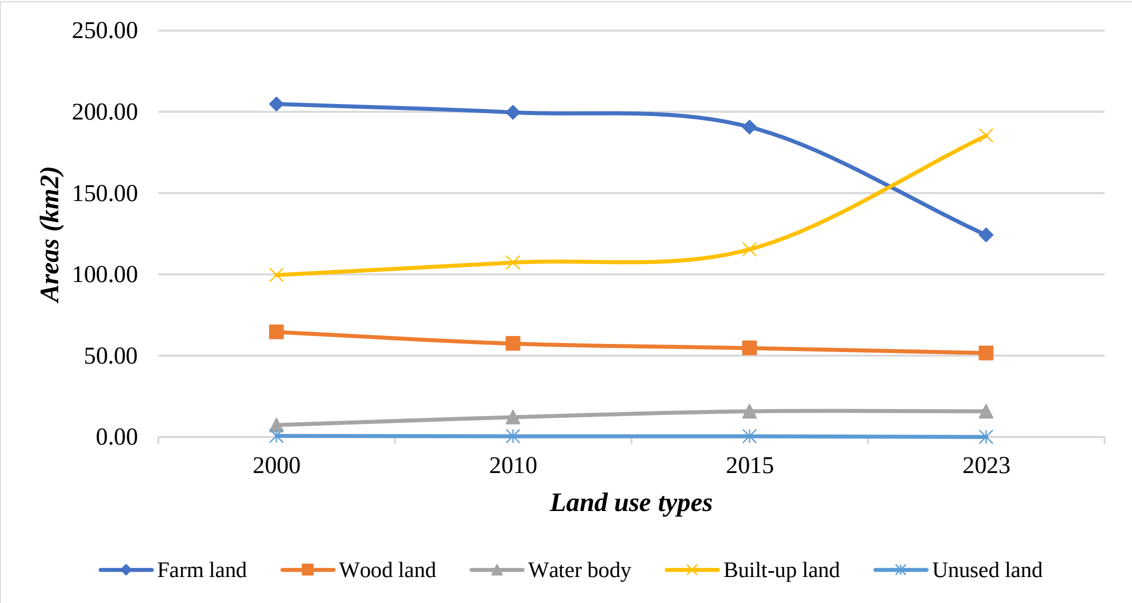

Figure 3. Land use change in Buôn Ma Thuột city

Agricultural land experienced a marked decline, decreasing from 204.86km² (54.32%) in 2000 to 124.20km² (32.94%) in 2023-a net loss of 80.66km² (21.39%). This corresponds to an average annual reduction of 4.03km², driven primarily by urbanization pressures and land-use conversion. Similarly, forested land decreased from 64.57km² (17.12%) to 51.64km² (13.69%), amounting to a loss of 12.93km² (3.43%).

Conversely, built-up land expanded significantly, increasing by 85.78km² over the study period, from 99.63km² (26.41%) in 2000 to 185.41km² (49.17%) in 2023. This reflects an average annual increase of 4.29km², indicative of intense urbanization and infrastructure development. Water bodies also showed a steady increase at an average annual growth rate of 0.42km², expanding from 7.37km² (1.95%) in 2000 to 15.82km² (4.20%) in 2023. This trend highlights significant investments in hydrological infrastructure, including reservoirs and irrigation systems, aimed at enhancing water resource management for agricultural production, flood control, and domestic and industrial water supply.

Unused land exhibited a slight reduction during the study period, decreasing by 0.64km² (0.17%) from 0.67km² (0.18%) in 2000 to 0.03km² (0.01%) in 2023, indicating improved land utilization efficiency.

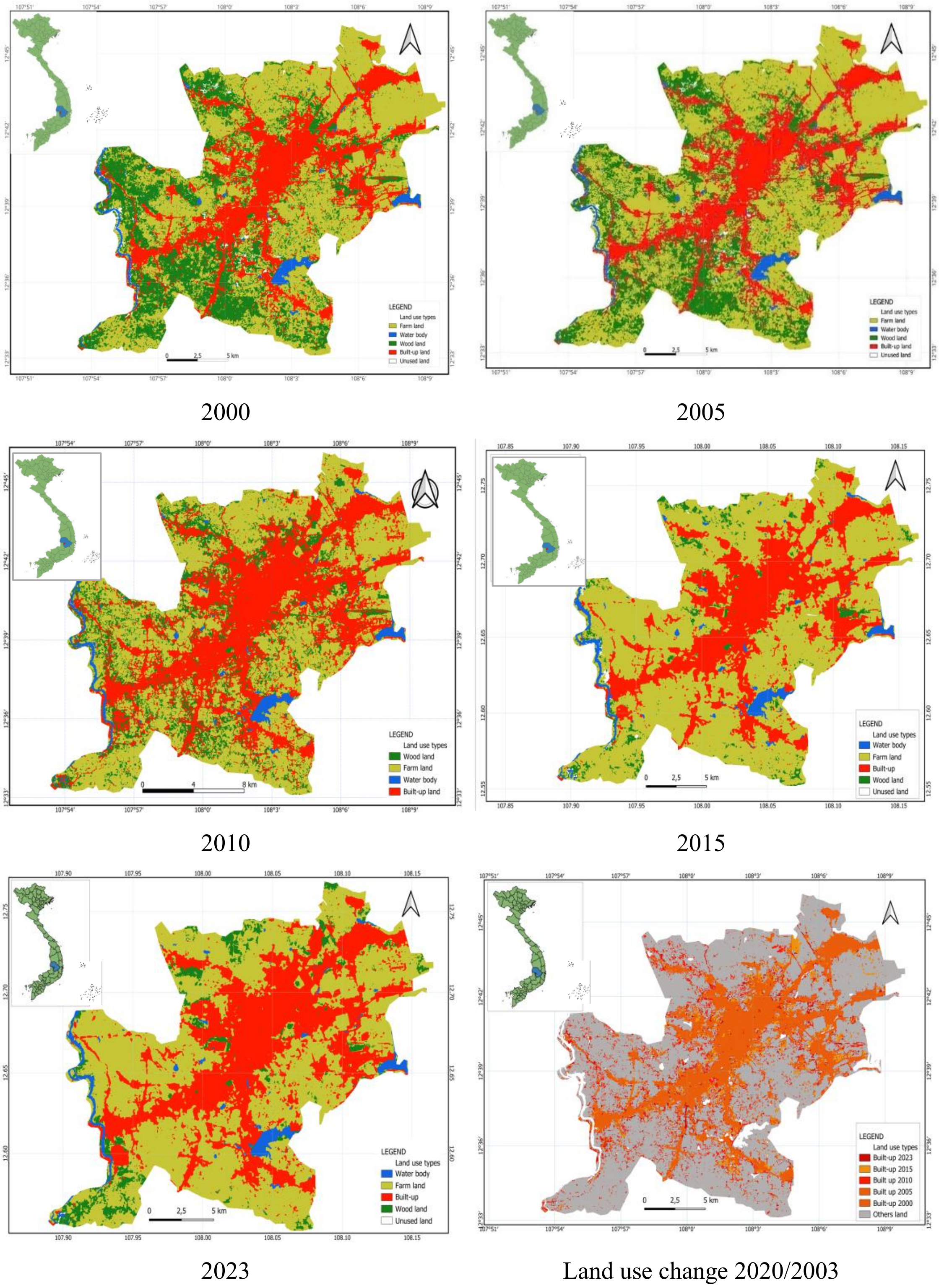

Figure 4. Typical growth in Buôn Ma Thuột city

Figure 5 illustrates three critical metrics of urban development between 2000 and 2023: the Land Consumption Rate (LCR), the Population Growth Rate (PGR), and the Land Consumption to Population Growth Ratio (LCRPGR).

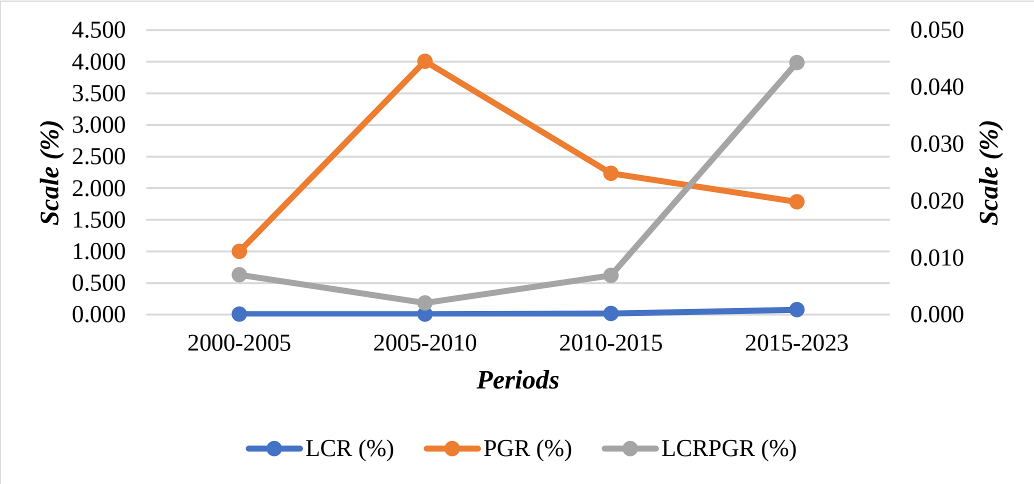

Figure 5. UI and UX Index of Buôn Ma Thuột City, 2000-2023

Between 2000 and 2010, the LCR was recorded at 0.037%, indicating that urban land expansion was effectively managed and aligned with actual urban demands. This demonstrates a sustainable approach to urban growth, limiting excessive and uncontrolled urban sprawl. Concurrently, the annual PGR reached 2.33%, reflecting a substantial increase in the urban population. This demographic growth was likely driven by favorable economic and social factors, such as job creation, expanded business opportunities, and improved urban living conditions.

In contrast, the period from 2010 to 2023 exhibited a significant decline in both LCR and PGR. The LCR dropped to a mere 0.008%, while the PGR decreased to 1.53% annually, suggesting a deceleration in urban land expansion and population growth. This reduction may be attributed to population control policies, economic structural adjustments, or other socio-economic influences.

However, the LCRPGR demonstrated a marked increase, rising from 0.003 during 2000-2010 to 0.037 in 2010-2023. This trend indicates that while population growth slowed, urban land consumption intensified disproportionately. Such dynamics underscore inefficiencies in land use and urban planning, where land consumption exceeded the actual needs implied by population growth.

Overall, during the 2000-2023 period, despite an average annual population growth rate of only 1.91%, land consumption rose sharply. These findings underscore the critical need for comprehensive and sustainable land-use planning to harmonize urban development with resource conservation and environmental sustainability.

3.2 Types of Urban land expansion

Between 2000 and 2023, Buôn Ma Thuột City experienced rapid urbanization, with the total built-up area increasing by 85.78km², accounting for 22.75% of the total study area. This urban growth primarily occurred in the northern and eastern parts of the wards of Hoa Thuan, Tan Loi, Tan An, Tan Hoa, and Tan Lap. The expansion manifested in three main forms: infill development, edge expansion, and Outlying expansion in peripheral areas (Figure 6). Each form played a critical role in shaping the city's urban development structure while presenting significant challenges.

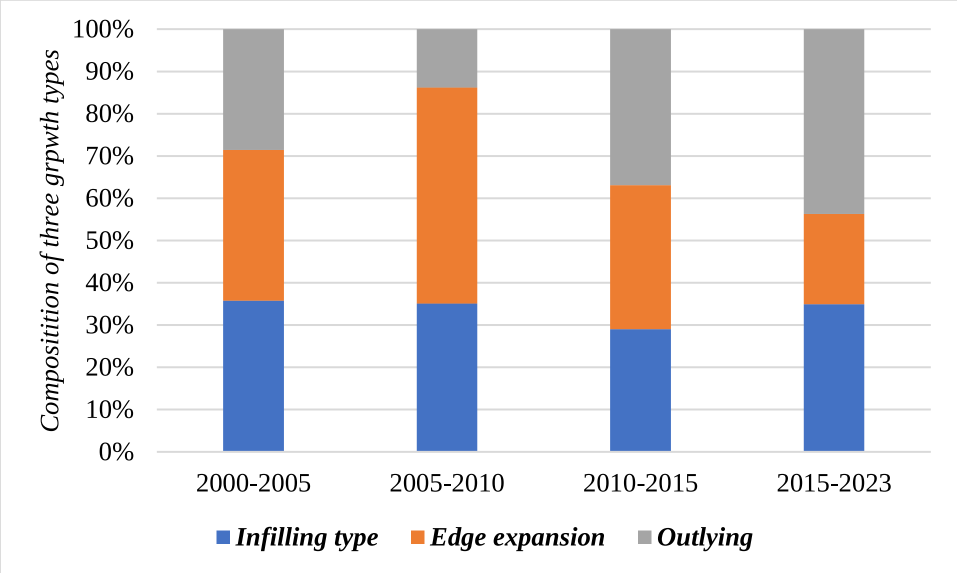

Figure 6. The proportion of three urban sprawl types in research area

Infill development accounted for 4.67km² (5.44% of the total urban area), predominantly occurring in areas such as Tu An, Tan Tien, and Tan Loi. This form reflects efforts to maximize the use of vacant land and increase building density within the urban core, minimizing land resource wastage and leveraging existing infrastructure efficiently. However, if not adequately planned, these areas risk higher population densities, leading to pressures on public services, transportation systems, and overall quality of life.

Edge expansion represented 5.74km² (6.69%), primarily concentrated in Ea Tam, Hoa Thang, and Hoa Xuan. This natural outward growth trend radiates from the city center toward the urban periphery. It is suitable for establishing new functional zones such as residential or industrial areas with the advantage of accessible transportation links. However, it requires substantial investment in new infrastructure and may result in imbalances between urbanization and the preservation of green spaces or agricultural land. Poorly managed fringe expansion could exacerbate environmental pressures and disrupt peri-urban ecosystems.

Outlying expansion represented the most prominent form of urban expansion in Buôn Ma Thuột between 2000 and 2023, encompassing 15.78km² (18.39%) of the study area and materializing through three distinct subtypes: *Isolated growth* accounted for 7.01km², primarily observed in standalone developments such as Hoa Phu (3.30km²) and Ea Kao (0.59km²). These areas, primarily designed as new residential zones, effectively alleviated urban pressure from the city center. However, they encountered significant challenges related to infrastructure connectivity and the provision of essential services. *Linear growth* covered 7.0km², concentrated along major transportation corridors, including Hoa Phu (1.08km²) and Hoa Khanh (0.80km²). This growth pattern capitalized on strategic interregional traffic networks, presenting notable economic opportunities. However, its unregulated progression risked fostering imbalanced development and increasing congestion along critical transit routes. *Nucleated growth* spanned 1.17km², characterized by the development of cohesive clusters in strategic locations such as Hoa Khanh (0.78km²). While this subtype prioritized the formation of well-organized urban hubs, it faced constraints in expansion potential and lacked seamless integration into the broader urban framework.

Collectively, the subtypes of Outlying expansion in Buôn Ma Thuột reflect a complex and dynamic process of urban transformation, characterized by both significant opportunities for economic development and considerable challenges in achieving sustainable and integrated urban planning. The diversity of growth patterns presents substantial economic potential; however, it necessitates rigorous management to optimize land use efficiency and ensure long-term sustainability. These developments highlight the critical need for proactive and forward-looking urban planning strategies that balance the pressures of expansion with the conservation of resources and the resilience of urban ecosystems.

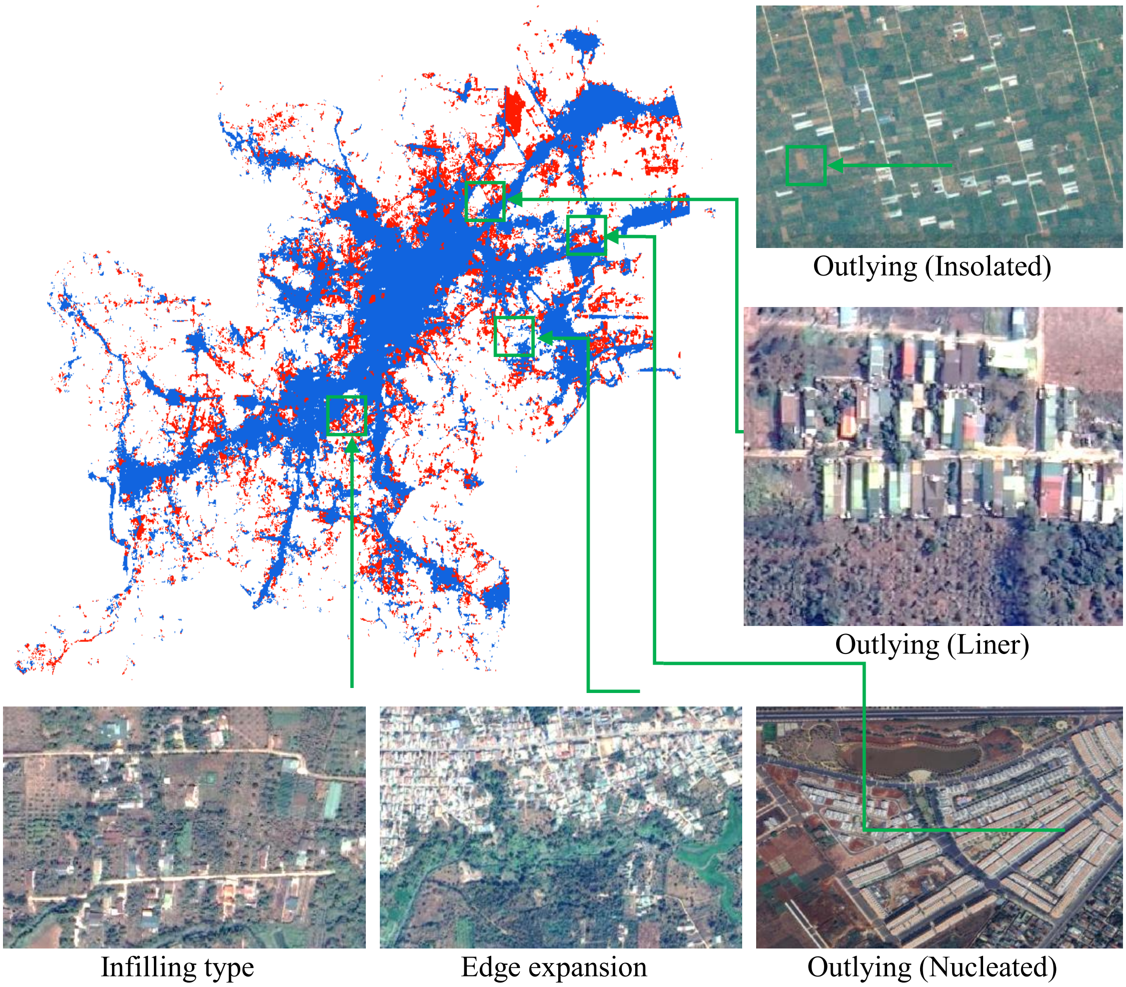

Figure 7. Typical forms of urban expansion

3.3 The relationship between Urban Land Expansion and Socio-Economic Development

Table 1 presents the relationship between built-up land area and socio-economic indicators through Pearson correlation coefficient (r) and p-value.

The results show that built-up land area has a strong correlation with Gross Domestic Product (GDP) ($r = 0.923$, $p < 0.001$), urban population ($r = 0.829$, $p = 0.003$), and total population ($r = 0.796$, $p = 0.006$). This indicates that the expansion of built-up land area is often accompanied by population growth and economic development in the region. Additionally, the ratio of built-up area per capita ($r = 0.788$, $p = 0.007$) also shows a certain impact on the quality of life and population distribution.

Other factors such as the rate of clean water usage ($r = 0.894$, $p < 0.001$), electricity usage rate ($r = 0.645$, $p = 0.044$), and internet usage rate ($r = 0.840$, $p = 0.002$) have significant correlations with built-up land area, indicating that the expansion of built-up land not only promotes infrastructure conditions but also creates opportunities for access to modern amenities. Notably, the built-up land area and the rate of agricultural land reduction have a very strong correlation ($r = 0.999$, $p < 0.001$), reflecting the relationship between urban construction growth and land use conversion processes, posing challenges in transitioning from agricultural land to urban land, which may negatively impact agricultural production and long-term food security.

It is noteworthy that the built-up land area has an inverse relationship with the poverty rate ($r = -0.754$, $p = 0.012$), suggesting that the expansion of built-up land may contribute to reducing poverty rates in the study area. The unemployment rate also has a significant and strong correlation with built-up land area ($r = 0.927$, $p < 0.001$), indicating that the increase in built-up land area can create new job opportunities and promote labor stability. These results highlight the important role of land planning and development in promoting economic, social, and infrastructure aspects in urbanized areas.

TABLE 1: The Pearson correlation coefficient (r) of the correlation analysis between the urban area and statistical data

Relationship with Pearson Correlation Coefficient	**r**	**p-value**
Total population (person)	0,796	0,006
Urban population (person)	0,829	0,003
Income (million VND)	0,923	0,001
Electricity usage rate (percentage/total household)	0,645	0,044
Clean water usage rate (percentage/total household)	0,894	0,001
Rate of agricultural land reduction	0,999	0,001
Unemployment rate (percentage/working-age population total)	0,927	0,001
Poverty rate (percentage/total household)	-0,754	0,012
Internet usage rate (percentage/total household)	0,840	0,002
Built-up area per capita (m^2/person)	0,788	0,007

4. Conclusion

This study created a medium-resolution urban land cover dataset to describe the continuous urban development process in Buôn Ma Thuột, Central Highlands, Vietnam, from 2000 to 2023. The dataset has proven valuable in quantifying spatial and temporal expansion patterns of urban land using the urban expansion index. Through statistical analysis, the study sheds light on the spatial and temporal impacts of socio-economic factors on urban land expansion.

The study identifies three main findings: First, the rate of urban land growth has consistently increased from 2000 to 2023, primarily focusing on the central and northern-eastern areas of the city. Second, urban expansion occurs in various directions, with a relatively uniform spread in all directions, across all growth patterns, including edge expansion, infill expansion, and outlying expansion. Third, socio-economic factors such as total population, urban population, and income strongly influence urban land expansion.

The acceleration of urban expansion in Buôn Ma Thuột has led to various economic and social benefits, improving the quality of life. However, this also presents a significant challenge for local authorities in balancing urban development with environmental protection. To ensure sustainable urban development, it is necessary to implement effective land use and labor management policies to minimize potential negative impacts, such as the loss of agricultural land and employment issues. The findings from this study provide valuable scientific and practical support for local authorities in urban land planning and sustainable development.

One limitation of this study is the use of medium-resolution satellite imagery instead of higher-resolution images, such as those from IKONOS and QuickBird, which could provide more detailed and accurate information in classifying different settlement types. Future research should extend the scope to include multiple cities and apply multivariable linear regression methods to evaluate the simultaneous effects of various independent variables, identifying the factors most influencing urban expansion. Furthermore, the study should explore in more detail the relationship between urban expansion and agricultural land degradation, as well as consider the dynamics of non-urban land types to provide a more comprehensive perspective.

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