ASSESSING THE SUSTAINABILITY OF URBAN LAND USE IN PLEIKU CITY, GIA LAI PROVINCE

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Abstract

Sustainability in land use plays an important role in the urbanization process toward achieving the goals of the 2030 Agenda for Sustainable Development. This study integrates Earth observation data through satellite imagery analysis combined with field surveys to assess the Urban Land Use Efficiency (ULUE) by using the land use efficiency index, estimates the relationship between land use, population growth, and the urbanization process in Thang Loi ward over a 20-year period. The findings reveal inefficient urban land use, where the expansion rate of built-up areas exceeds the population growth rate in the studied area. From 2002 to 2022, the population and built-up area increased by 339% and 460%, respectively. In most of the expanding areas, there is widespread hoarding and fragmentation of land use, with numerous plots of land being vacant or underutilized for many years due to lack of control. Therefore, to improve land productivity and ensure sustainable urban growth, the local government should consider improving the Urban Land Use Efficiency Index.

Keywords: GIS, Pleiku, sustainable urban land use, urbanization, urban development

1. Introduction

The 2030 Agenda for Sustainable Development, adopted by the United Nations General Assembly on September 25, 2015, outlines a detailed plan for all nations to achieve sustainable development over the next 15 years (United Nations, 2015). Any successful pathway to achieving the 2030 Agenda must consider the development of sustainable urban and peri-urban environments. The 2030 Agenda's goal for cities ('SDG 11: Make cities and human settlements inclusive, safe, resilient, and sustainable') has listed requirements for local data indicators at a small scale across three levels depending on the availability of assessment methodologies and monitoring data. Although SDG 11.3.1 - 'the ratio of land consumption rate to population growth rate (LCRPGR)' - is classified as a level II indicator (established methodologies but poor data), Earth observations allow for the compensation of multi-source data deficiencies across a broader geographical area (Anderson et al., 2017).

Nowadays, there are many datasets available for estimating the extent of urban spatial expansion, such as: the global Human Settlement Layer (GHSL) (Melchiorri et al., 2018), Global Urban Land (Liu et al., 2018) and Global Artificial Impervious Area (GAIA) (Gong et al., 2020). However, literature related to SDG 11.3.1 is still scarce, except for some local studies from China (Wang et al., 2020), Portugal (Nicolau et al., 2018), South Africa (Mudau et al., 2020) and some global studies from UN12 and the Joint Research Centre of the European Commission (Melchiorri et al., 2018) because calculating the land consumption rate (LCR) requires the conversion of built-up area and estimating the population growth rate (PGR) requires the spatial disaggregation of population data, both of which are challenging tasks.

The urbanization process is characterized by three comprehensive aspects: space, demography, and economy. Current research on urbanization mainly focuses on spatial expansion at the local (Seto and Fragkias, 2005), regional (Yang et al., 2019), national (Barrington-Leigh and Millard-Ball, 2015) and global scales (Güneralp et al., 2020). There are also many studies examining the correlation (Wang et al., 2019) and causality between land, population, economy, and urbanization or the Economic Growth Rate over Land Consumption Rate (EGRLCR) with the combination of LCRPGR and EGRLCR (Jiang et al., 2021).

The evaluation of urban land use efficiency (ULUE) is often conducted using various techniques and indices. Multi-Criteria Analysis (MCA) and Analytic Hierarchy Process (AHP) can be utilized (Auzins et al., 2013), as well as measures based on slack (SBM-DEA model) or Input-Output analysis (Zhu et al., 2019). A combination of multiple indices, such as the density of the built-up area, Gross Domestic Product (GDP) per hectare of urbanized land, and the value of ecosystem services per hectare, can also be used to evaluate ULUE (Wei et al., 2018). The degree of mixed-use, accumulation, and accessibility of public transport infrastructure are also important indicators of ULUE (Storch and Schmidt, 2008).

The Decision No. 143 of 2023 of the Ministry of Construction has revealed that Vietnam is undergoing an unprecedented rate of urbanization, with uneven and imbalanced urbanization commonly occurring in large, medium, and small cities. It is predicted that by 2030, the urbanization rate will exceed 50%; the proportion of urban construction land on the total natural land area will reach 1.9-2.3% with about 1,000-1,200 urban areas. Urban areas will contribute about 85% of the GDP to the economy (Ministry of Construction of Viet Nam, 2023). In this process, all cities will have to face rapid urbanization, leading to inefficient land use, especially the sustainability of cities with monotonous industrial structures dependent on resources. To narrow this knowledge gap, it is necessary to conduct a multi-dimensional analysis, including population size, urban functions, urban land indicators, and urban expansion indices, to see the efficiency of urban land use in small cities in Vietnam.

2. Materials and Methods

2.1. Research area

Figure 1. Research location.

This study focuses on analyzing the sustainability of urban land use in Pleiku city, Gia Lai province (Figure 1). However, to conduct a detailed assessment, we concentrate on Thang Loi, one of the 17 wards of Pleiku city, for the following reasons. First, this area has seen expansion both in the urban core and encroachment into peri-urban areas on a large scale. Second, the fragmentation of land use and urban sprawl seems to be common in these areas. Third, many agricultural land spaces have been reclaimed for conversion to construction land. These reasons are absolutely different if compared with other wards of Pleiku city in terms of geography representative not only core urban but also sub-urban, as well as the number of immigration population.

2.2. Data Collection Methods

Landsat 7/8 satellite images with a resolution of 30m*30m and high-resolution Google Earth (GE) images were used to detect land use changes over space and time, as well as to analyze the construction density of Thang Loi ward. GE is suitable for mapping land use change detection with a classification accuracy of 78.07% (Hu et al., 2009). Additionally, this study utilized qualitative and quantitative data from secondary sources. Official population data was used for the years 2000 and 2022, obtained through population surveys conducted by the city government. The built-up area was calculated from GE history. Field surveys were conducted to observe spatial changes and land use types in the study area.

2.3. Data Analysis Methods

The spatial and temporal changes of Thang Loi ward from 2002 to 2022 were analyzed using GIS software. Line scan errors (stripes) from Landsat7 were removed using Landsat Toolbox software. The Normalized Difference Built-up Index (NDBI) was used to convert image data into built-up land data ("NDVI, NDBI & NDWI Calculation Using Landsat 7, 8," n.d.) with an accuracy of 96.2% (Zha et al., 2003).

$$NDBI = \frac{NIR - SWIR}{NIR + SWIR} \quad (1)$$

Where:

NDBI: Normalized Difference Built-up Index

NIR: Near-Infrared Reflectance values of vegetation from 0.77 to 0.90µm

SWIR: Short-Wave Infrared Reflectance values of vegetation from 1.55 to 1.75µm

(The Normalized Difference Built-up Index values range from -1 to +1. Positive NDBI values represent built-up areas, while negative values indicate other regions).

To conduct the Urban Land Use Efficiency (ULUE) analysis, two indices developed by UN-Habitat were used (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 increase. The methodology for SDG 11.3.1 is established and referenced in the SDG Indicator Global Database (https://unstats.un.org/sdgs/metadata). LCRPGR is calculated as follows:

$$ULUE(LCRPGR) = \frac{\mathrm{LCR}}{\mathrm{PGR}} \quad (2)$$

Where:

- Population Growth Rate (PGR): $$PGR = \frac{\mathrm{LN}(Pop_{t+n}/Pop_t}{(\mathrm{y})} \quad (2.1)$$

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) $$LCR = \frac{Vpresent - Vpast}{Vpast} \times \frac{1}{(t)} \quad (2.2)$$

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: Decreasing population simultaneously with reduced urban expansion.

If 0 < LCRPGR ≤ 1: The city has a high population density.

If 1 < LCRPGR ≤ 2: Urban expansion speed exceeds population growth rate.

If LCRPGR > 2: Urban expansion rate is at least twice the population growth rate.

(2) - The Urban Index (UI) and Urban Expansion Index (UX) are used to compare the extent of urban expansion and the rate of development in urban areas. UI represents the ratio of urban land to total land area at a specific time, determined for the years 2000 and 2022. UX compares the urban land area between two-time points and serves as a relative measure of urban expansion, calculated over a 20-year period. These indices are computed using the following equation (Hu et al., 2009):

$$\text{UI} = \frac{UL}{TL}\ x\ 100\% \quad (3) \qquad \text{UX} = \frac{UL_{t2} - UL_{t1}}{UL_{t1}}\ x\ 100\% \quad (4)$$

Where: UL is Urban land area; TL is total land area; Ul_{t2} is Urban land area in 2022; Ul_{t1} is Urban land area in 2000.

3. Research Results and Discussion

3.1. Urban Land Use Efficiency in Thang Loi Ward

The calculation of the Urban Index (UI) illustrates that in 2002, the ratio between urban land and the total area was 0.04%, and in 2022 was 0.20%. Therefore, over the past two decades, the UI of Thang Loi Ward was slightly increased by 0.16%. As a result, the Urban Expansion Index (UX) for the entire period from 2002 to 2022 was 2.84%, of which the period from 2002 to 2012 was 1.33% and the period from 2012 to 2022 was 0.97% (Figure 2).

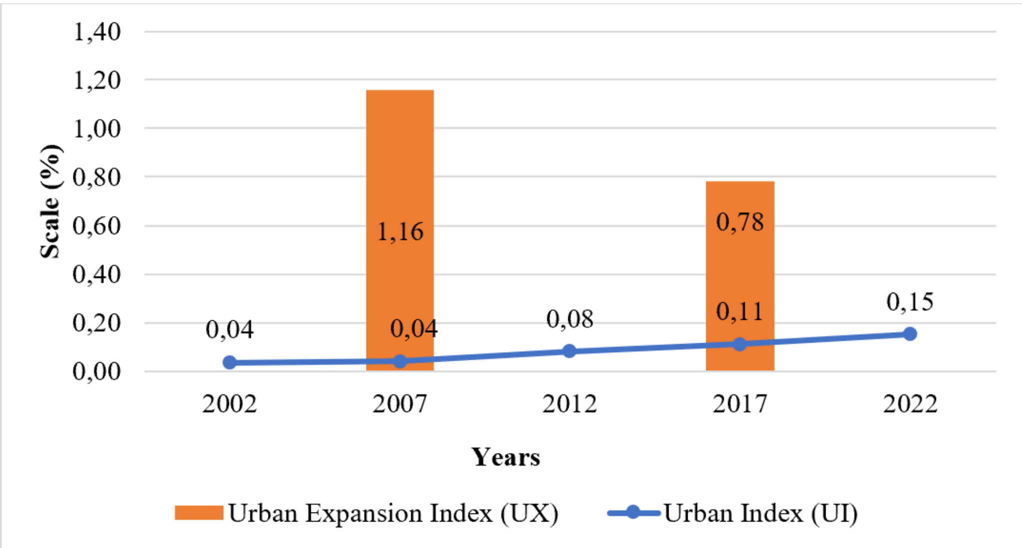
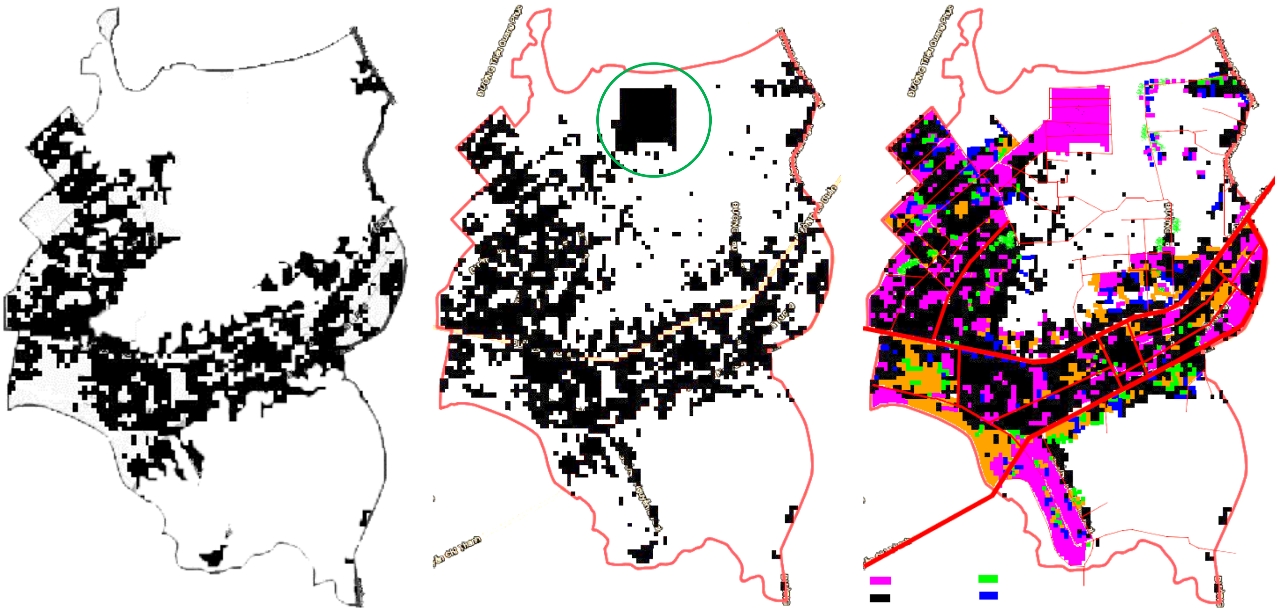


Figure 2. UI and UX index of Thang Loi ward.

This result confirms that Thang Loi Ward has undergone significant expansion of built-up areas over the past 20 years. The peri-urban areas have expanded more than the urban core. The total area of land converted during this period is 101.17 hectares, and the average annual growth rate is quite fast, with K value = 14.22% over 20 years. This means that each year, approximately 5.06 hectares of agricultural land in Thang Loi Ward have been converted for construction purposes (including residential land), resulting in an increase in the urbanization rate from 9.91% in 2002 to 28.64% in 2022. For instance, the low-income residential area (depicted by the green circle) predominantly consisted of vegetation cover before 2012. However, subsequent changes occurred as the built-up area encroached upon agricultural land (Figure 3a and b) and continued to expand in the following years. By 2022, most peri-urban areas have been transformed into built-up zones (Figure 3c).



(a) (b) (c)

Figure 3. Changes in the land cover of Thang Loi ward in 2002 (a), 2012 (b), 2022 (c)

The land use analysis in Figure 4 indicates that the development of Thang Loi ward has witnessed significant changes in land use over the past two decades. The importance of this change is the result of urban development from the expansion of inhabitants, real estate companies, and the Pleiku government, which has significantly affected agricultural land (Hai et al., 2020). The land use trends of Thang Loi ward are specifically reflected in the following three main contents:

First, the residential land has increased rapidly during the research period, expanding by 40.76 ha, equivalent to a rate of 5.87%. The main reason identified is the rapid increase in population due to family size expansion, free migration to find agricultural production materials for ethnic minorities from the North of Vietnam, and migration from rural to urban areas over more than two decades. Secondly, the use of land for infrastructure has improved rapidly and continuously. In 2002, it accounted for only 2.95% of the total area but rose to 10.67% in 2022 (an increase of 3.62 times). This transition remains the chief trend today, with the reason being the development of infrastructure to transition the economy from agriculture to industry and services according to the progress orientation of Pleiku city. Notable projects contributing to the rise are the upgraded transportation system (Le Duan Street, Nguyen Chi Thanh Street, residential area routes), building new schools (Asia-Pacific school; Nguyen Chi Thanh School), etc. Thirdly, the agricultural land group has decreased significantly to be converted into construction land. Specifically, in 2002, agricultural land accounted for 90.09% of the natural area. But by 2022, it had decreased to 71.36%, a reduction of 1.26 times. The main force driving the decrease in agriculture is the population factor, combined with investment policies, infrastructure development, and housing, requiring people and investors to continue expanding the scale and space of urban areas.

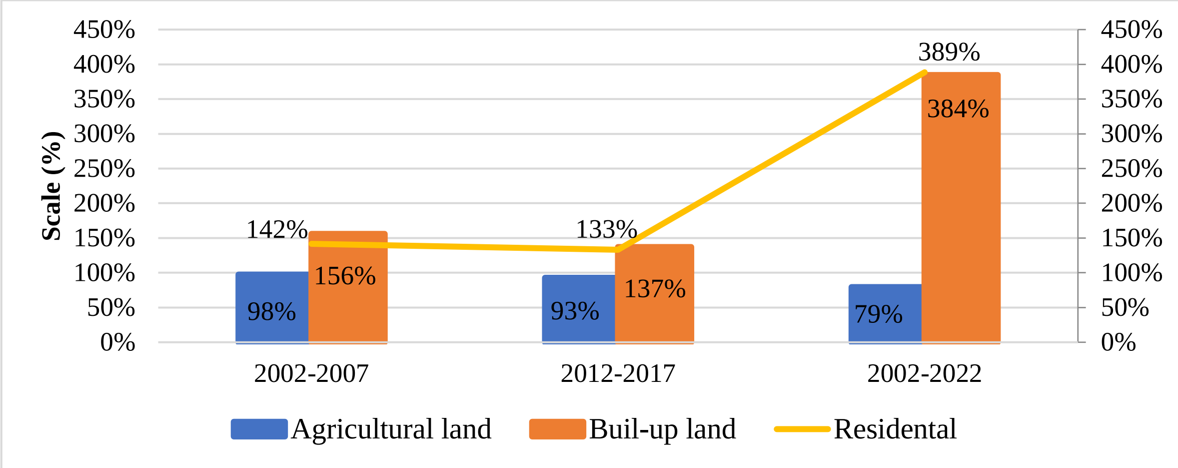


Figure 4. Growth of built-up area in Thang Loi ward (calculated separately from GE).

3.2. The relationship between urban land consumption and population growth

The spatial expansion and inhabitants' growth of Thang Loi ward over the past two decades is a remarkable achievement. The general trend of land use efficiency indicators in the study area is related to land use change, population growth, and urban agglomeration in the future. The results obtained from the comparison of the construction area and digital population evolution show that Thang Loi ward has the fastest resident rate in Pleiku city. The building only used 4.0% of the entire city's people in 2002 (5,400 /135,000 individuals), which has increased to employ 6.15% of the entire population of the Pleiku urban area (18,296/297,500 people). As a consequence, the population has increased by 339%, and cumulative construction has increased by 460% in 20 years (233% and 179% increases between 2002-2012 and 2012-2022), while the boundaries of the study area have not changed. This confirms that the level of land construction growth is higher than the population development.

TABLE 1. Population Growth and Built-up Area Changes

Thang Loi Ward				Change		
Year	2002	2012	2022	2002-2012	2012-2022	2002-2022
Population	5.400	10.188	18.296			
Built-up Area	20,60	48,02	94,74			
Population Growth				189%	180%	339%
Built-up Area Growth				233%	197%	460%
Land Consumption Rate (LCR)				13%	8%	16%
ULUE (LCRPGR) index				0,06	0,04	0,04

The spatial change of LCRPGR from 2002 to 2022 is described in Figure 5. In this study, the averages were calculated by following the LCR, PGR, and LCRPGR formulas based on the total land area and population per year instead of using the statistical mean values. The average LCRPGR initially increased from 0.09 (in 2002) to 0.11 (in 2007), then decreased to 0.08 (in 2012) before continuing to drop to 0.05 in 2022. The highest average of LCR was observed alongside the peak of LCRPGR during the 2002-2012 period. Thus, with a land consumption rate (LCR) of 14.22% over the past 20 years, corresponding to 101.17 ha of agricultural land converted to urban development land, and an average population growth rate of the ward at 1.04% per year. The calculation results show that the average LCRPGR of Thang Loi ward for the period 2002-2022 is 0.14, which is considered an urban area with a high population density increase ($0 < LCRPGR \leq 1$).

The highest LCRPGR rate in the period 2002-2012 was partly due to the impact of the land allocation program for low-income households, mainly converted from agricultural land (Nguyen Ninh et al., 2020). Another part is from commercial housing projects developed by real estate companies, formed by the increase in the wave of migration from other places, especially from rural areas in Gia Lai province to Thang Loi ward, in search of employment and better living conditions. On the contrary, LCRPGR decreased in the period 2012-2022 (the sharpest decrease was in the period 2017-2022) due to the impact of the Covid-19 pandemic as well as the main targeted efforts of the Vietnamese Government and the Pleiku city authority in promoting solutions to reduce the "land fever period" during this time.

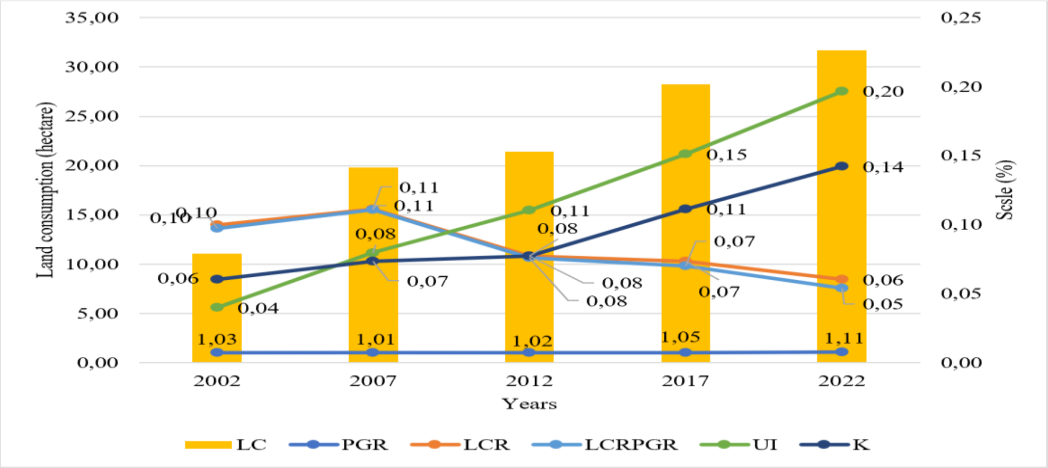


Figure 5. Changes in average population growth rate (PGR), land use ratio (LCR), and LCRPGR of Thang Loi ward during 2002–2022.

3.3. Land Hoarding and Urban Expansion

Data calculated from satellite images show that land hoarding activities are a core reason for fragmented urban expansion. Real estate growth companies hold a significant portion of their land inactive, with numerous projects only about 10% developed. Many plots of land under individual ownership are hoarded for speculation, with an estimated 79 hectares affecting the land use density. GE image analysis reveals that built-up areas (mainly residential points) are 1-2 km far apart, with most of the agricultural land interspersed between residential areas being either vacant or underutilized (Figure 6), once again indicating gaps in land use efficiency.

(a) (b) (c)

Figure 6. Cases of land accumulation (a), urban expansion (b), and land use fragmentation (c) (Google Earth, 2022)

4. Conclusion

The study reveals major gaps in the efficiency of urban land use over the past 20 years. The expansion of building areas has far exceeded the population growth rate. The ULUE index for the research area is low, indicating inefficient land use. The situation is exacerbated as many hectares of land have been converted from agriculture to construction, primarily for residential purposes, resulting in land hoarding. A substantial portion of the transferred land remains vacant or underutilized for several years.

The unsustainable conversion of agricultural land has led to a low building density. This becomes even worse when the conversion is inefficient, resulting in severe consequences for the informal land market and widespread fragmentation of land use. Overemphasis on land conversion while neglecting its utilization efficiency will affect the livelihoods of people tied to agricultural production, impact the ecosystem and urban infrastructure, exacerbate land resource wastage, diminish the effectiveness of state management, and lead to unintended consequences for sustainable urban land use. Therefore, it is recommended that investigation and analysis at a larger urban scale is absolutely necessary to provide a more insightful and comprehensive view of land use efficiency across regions of urban.

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