

ANALYZING URBAN GREEN SPACE IN SOUTHERN CITIES OF BINH DUONG PROVINCE, VIETNAM USING REMOTE SENSING AND GIS TECHNIQUES

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DOIs: <https://www.doi.org/10.46242/jstiuh.v79i1.5805>

Abstract. This study evaluated the spatial and temporal change in urban green space (UGS) in the southern cities of Binh Duong province. Landsat multi-temporal images from 2001 to 2020 were analyzed. The random forest algorithm was used to generate land cover maps, which were then reclassified to UGS maps. The results showed that UGS continuously decreased in the period 2001 – 2020 in the study area. About 67.3% of UGS in the entire study area have been lost during this time. As of 2020, the remaining UGS of the study area was 6,707 hectares, corresponding to an average coverage rate of 25.6% and a ratio of 46.1 m² UGS per capita. Although the overall UGS was still guaranteed to be above the minimum of 9 m² per capita, only 79.2% of the urban area was within a distance of 300 m from UGS of at least 0.5 ha. This can reduce the ability of urban residents in this area to benefit from green spaces.

Keywords. change analysis, GIS, Landsat, remote sensing, urban green space.

1 INTRODUCTION

Urban green space (UGS) is the area covered by vegetation in urban areas. It includes parks, trees, lawns, gardens, urban agricultural parcels, green roofs and balconies, recreation areas, unused vacant lots covered with vegetation, etc. UGS plays a vital role in improving urban environmental quality and human well-being [1-5]. It provides ecological and environmental benefits such as regulating climate, reducing urban heat island effects, preventing dust, absorbing harmful gases, limiting noise, reducing stormwater runoff, etc. It is also a place for people's entertainment, cultural, sports, experience, and communication activities.

Binh Duong province, located in the Southeast region of Vietnam, has experienced a rapid urbanization process from 1995 to the present, especially in the southern region including the cities of Thu Dau Mot, Thuan An, and Di An. The urbanization process has significantly changed land use and land cover in this area [6]. As a result, UGS was gradually shrinking significantly to make way for residential, commercial, and industrial areas. The decline of UGS may cause negative impacts on environmental quality and human well-being. Therefore, monitoring the spatial and temporal change of UGS in this region is necessary. It can support urban planning and monitoring as well as ensuring the quality of human life.

Remote sensing is an effective tool for monitoring UGS [7]. With spatial resolution ranging from coarse to fine, remote sensing images are suitable for monitoring UGS at different scales [8]. Many studies used remote sensing combined with geographic information systems to monitor and evaluate issues related to UGS for different purposes such as change detection [9], [10], environmental management [11], [12], landscape fragmentation monitoring [13], development planning [14], social functional mapping [15], relationship with human health [16].

With these issues in mind, this study aimed to evaluate spatial and temporal changes in UGS in the three southern urban cities of Binh Duong province from 2001 to 2020. Landsat images and GIS-based spatial analysis tools were used for analysis. This study evaluated each period at approximately 5-year intervals. Since the population of 2024 and 2025 has not been updated, the calculations for this year are not included.

2 MATERIALS AND METHODS

2.1 Study area

This study focuses on Thu Dau Mot, Thuan An, and Di An, which are three cities located adjacent to each other in the south of Binh Duong province (Fig. 1). The total area of the three cities is about 26,267 ha, accounting for 9.75% of the entire province's area (Table 1). However, their total population in 2020 is over 1.45 million people, accounting for 56.33% of the province's population [17]. This is the area where

the province's most dynamic service, industrial, and commercial activities take place.

Table 1. Summary of area and population of the study area

Region	Area (hectares)	Population (person)				
		2001	2005	2010	2015	2020
Di An	6,005	106,767	207,262	320,446	394,433	491,051
Thu Dau Mot	11,891	152,050	178,067	241,276	284,181	345,018
Thuan An	8,371	121,863	248,452	410,818	476,221	617,587
Total of three cities	26,267	380,680	633,781	972,540	1,154,835	1,453,656
Binh Duong	269,464	769,946	1,109,318	1,619,930	1,947,220	2,580,550

Source: Binh Duong Statistical Office [17, 18]

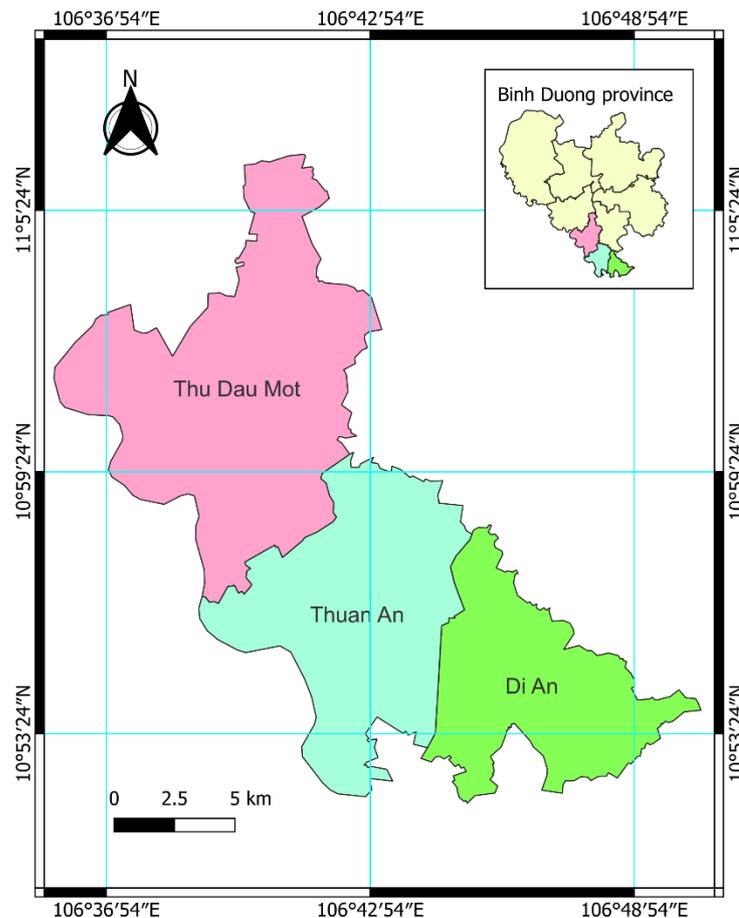


Fig. 1. Study area

According to Bui & Mucsi [6], the urban area in Binh Duong has increased 65 times from 1995 to 2020. Initially, urbanization mainly took place in these three cities, then gradually spread, and shifted to the east and north of the province. During this period, the urbanization rate of the province, which was calculated as a percentage of the urban population per total population of the province, increased from 17.51% to 84.41% in 2020 [19]. The urbanization process has led to significant changes in land use and land cover in the study area.

2.2 Data

Landsat Collection 1 Level 2 surface reflectance images in the years 2001, 2005, 2010, 2015, and 2020 were downloaded from the United States Geological Survey website [20]. The 30-m bands were used, including bands 2, 3, 4, 5, 6, and 7 for Landsat 8 images, and 1, 2, 3, 4, 5, and 7 for Landsat 5 images. In

this study, the panchromatic band in Landsat 8 images was not used to be consistent in spatial resolution, image processing, and classification with Landsat 5 images.

The administrative boundary downloaded from the website of the Database of Global Administrative Areas project [21]. Training and validation data for the classification process were collected and interpreted by the author. Meanwhile, population data were taken from the statistical yearbooks of Binh Duong province [17, 18].

2.3 UGS classification and analysis

The overall workflow is illustrated in Fig. 2. These steps are conducted on QGIS and R software.

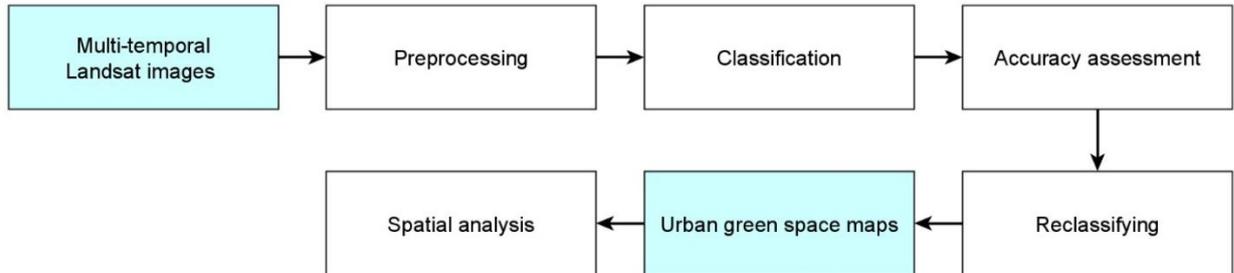


Fig. 2. Overall workflow

In the preprocessing step, two cloud-free images of each year were selected or mosaiced and stacked to create a multitemporal image with 12 bands. Then, they were subset to the study area by using the administrative boundary. These subsetted images were the input for the classification step.

This study used a classification scheme of six categories including barren land, impervious surface, annual plants, perennials plants, grasses, and water surfaces. The training samples were manually collected as polygons by a convenience approach based on Landsat images, Google Earth history images, field trips and the author's personal experience. In particular, the Historical Imagery function on Google Earth Pro software was a useful support tool in interpreting and collecting samples from the past years. The random forest algorithm [22] is used for the classification process because of its advantages [23]. The randomForest package [24] on the R environment was used in this task. The parameters are set by default, including a ntree of 500 and mtry of the square root of the total number of variables. In addition, to reduce the salt-and-pepper noise of the classified maps, a 3x3 majority filter was applied.

A set of 1000 validation points was randomly generated in each classified map. The number of points assigned to each land cover class was based on its proportional area on the map, with a minimum of 50 points for each class. Then, these points were manually interpreted and labelled on each land cover map based on the same sources as when collecting training samples. After that, the accuracy of each map was evaluated using a confusion matrix. Overall accuracy is calculated as the ratio of the total number of correctly classified samples (i.e., diagonal of the confusion matrix) to the total number of validation samples.

These land cover maps were then reclassified into UGS maps with two classes. The first one is the green space category, which includes grasses, annual plants, and perennial plants. The second one is the non-green space category, which includes the remaining classes.

From the UGS maps created combined with population data, spatial analyses to calculate UGS indicators were performed. The indicators included green space area, coverage rate, and ratio of area per capita. They were calculated for both the entire study area and each city.

In addition, according to the World Health Organization (WHO) recommendation, urban residents should be able to access public UGS of at least 0.5-1 ha within 300 m linear distance (or around 5 walking minutes) of their homes [25, 26]. Therefore, residential area was extracted from the impervious surface category in land cover maps by excluding industrial zones and quarries. Then, an analysis of residential areas within 300 m of urban green spaces of 0.5 hectares or more was also conducted.

3 RESULTS

After the classification process, the overall accuracy of the maps in 2001, 2005, 2010, 2015, and 2020

gained 90.1%, 88.6%, 91.1%, 91.9%, and 91.7%, respectively. Therefore, it was appropriate to use these maps for further analysis. The UGS maps from 2001 to 2020 are illustrated in Fig. 3.

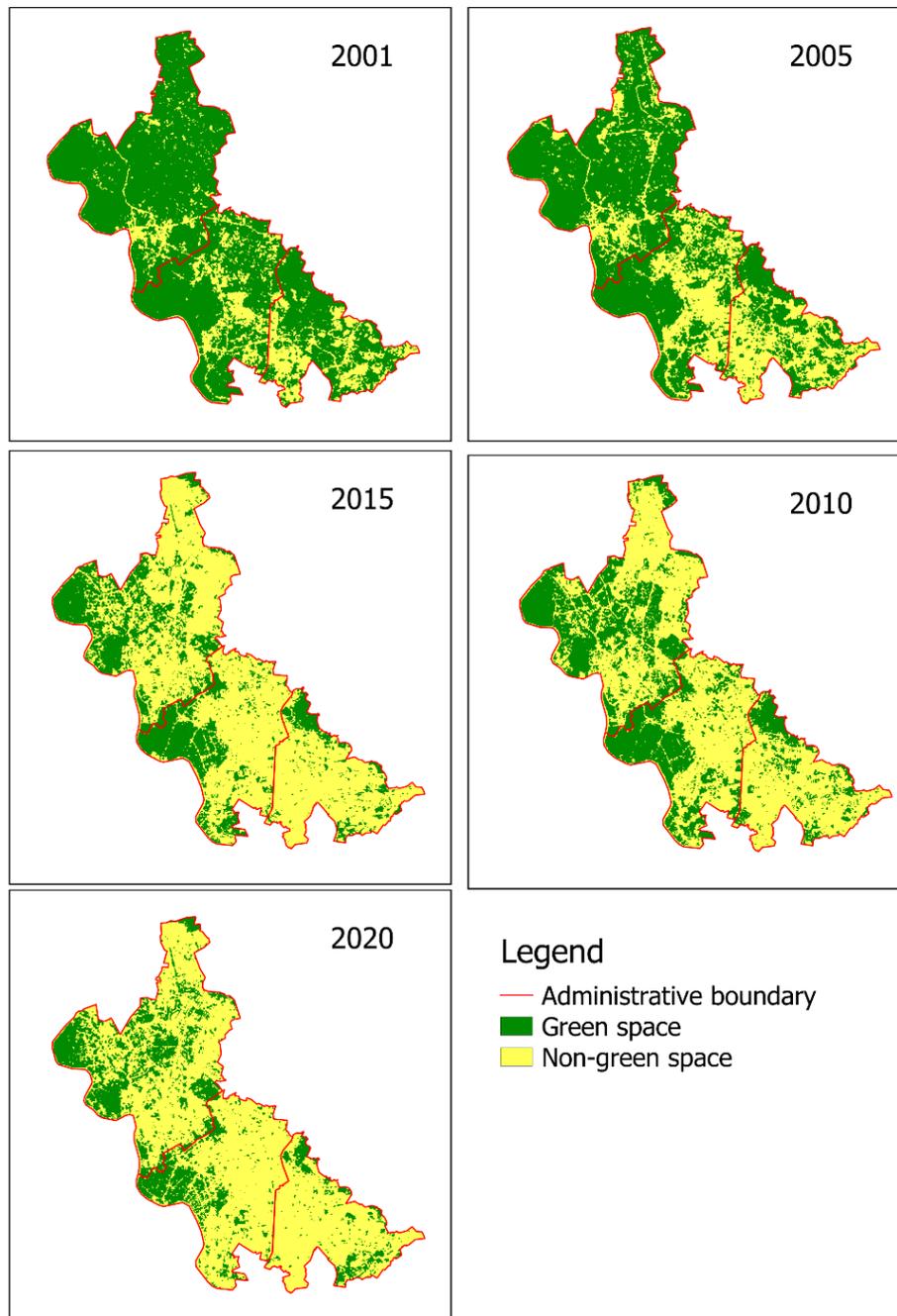


Fig. 3. Urban green space in the study area from 2001 to 2020

The spatial analysis results are illustrated in Figs. 4 and 5. The results showed that the area of UGS, the coverage rate, and the ratio of UGS per capita continuously decreased in the period 2001 – 2020, in which, the period 2001 - 2010 saw a rapid decline.

For the area (Fig. 4), the entire region had 20,496.2 hectares of UGS in 2001. By 2020, only 6,707 hectares remained. Thus, 13,789.3 hectares, corresponding to 67.3%, of UGS were replaced by other types of land cover and land use during the study period. The sharpest decline occurred in the period 2005-2010 with 7,240.1 hectares completely lost. This decreasing trend was also similar in each city.

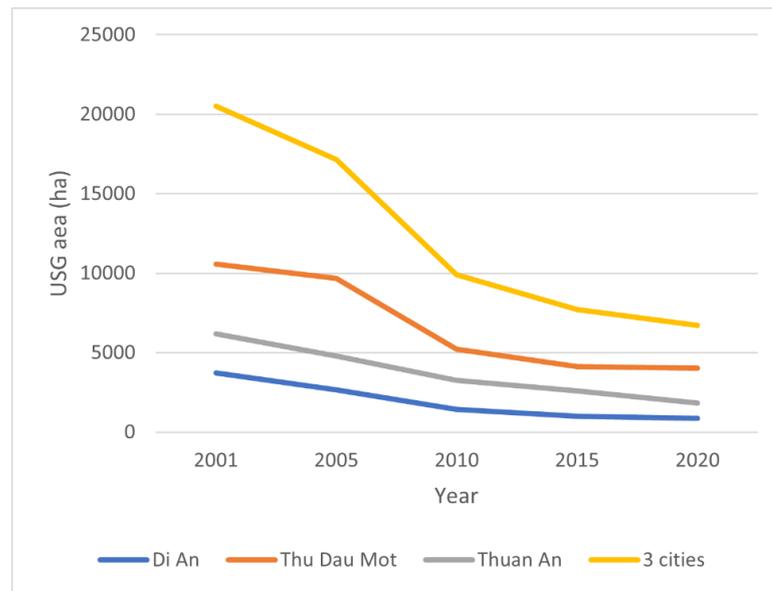


Fig. 4. The change in UGS area from 2001 to 2020

For the coverage rate (Fig. 5a), in 2001, the average rate of UGS of the entire study area reached 78.1%. As of 2020, the average rate of the three cities decreased to 25.6%. On the city scale, the rates of Thu Dau Mot, Thuan An, and Di An decreased from 89%, 74.2%, and 62.2% in 2001 to 33.9%, 21.7%, and 14.3% in 2020, respectively.

For the ratio of UGS per capita (Fig. 5b), the average ratio of the entire region was 538.4 m² in 2001. By 2020, the average ratio decreased to 46.1 m² UGS per capita. In which, Di An has the lowest ratio with 17.5 m² per capita, and Thu Dau Mot has the highest ratio with 116.8 m² per capita. The ratio of Thuan An is 29.4 m² per capita.

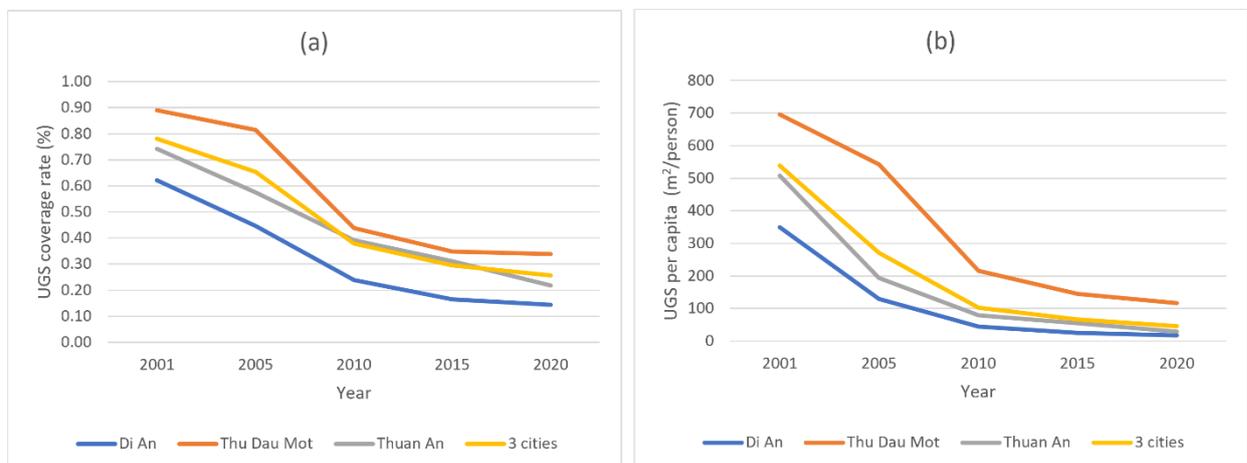


Fig. 5. The change in (a) UGS coverage rate and (b) the ratio of UGS per capita from 2001 to 2020

4 DISCUSSIONS

The cause of the decline mainly stemmed from the socio-economic development strategy of Binh Duong province. In the initial phase of the urbanization and industrialization process (1997-2007), the province focused on development in the southern region, which was this study area. Residential, industrial, and commercial zones were built and expanded here during this period [6]. Consequently, the UGS was significantly reduced to make way for developed areas. The expansion of built-up areas along with the population explosion (Table 1) caused the UGS per capita to decrease very rapidly during this phase. The population explosion in this area was mainly due to migration (i.e., mechanical increase). The reasons were

the development of industrial zones, the job market and high and stable income compared to neighbouring areas [6]. In the next phases of the urbanization and industrialization process, due to changes in the province's development policy from 2007, which focused on urban expansion to the eastern and northern areas, the pace of decline in UGS slowed down in the study area.

Many studies use a common standard that urban areas need to provide a minimum area of 9 m² UGS per capita, and ideally, it should be 50 m² UGS per capita [27-32]. It can be seen that the ratio of UGS per capita in 2020 of our study area fell within the range of these two thresholds. Therefore, this ratio was still acceptable for this standard, especially Thu Dau Mot city fully met the standard with 116.8 m² per capita. The high ratio in Thu Dau Mot and Thuan An was mainly due to the contribution of the agricultural cultivation and orchards along the Saigon River and golf courses. Meanwhile, the ratio of Di An was from the contribution of small farming parcels as well as several green parks. However, if the declining trend of UGS continues in the future, this ratio may soon fall below the threshold of 9 m² per capita. As a result, this can affect the quality of life of people in this area.

In addition, the ability to access green space can improve human health [33-35]. As mentioned, WHO recommends that every citizen should be able to reach a UGS of at least 0.5 hectares within a distance of 300 m (or within 5-minute walkable) [25, 26]. Compared to this standard, the spatial analysis showed that only 79.2% of residential areas in this study met the requirement. It indicated that the spatial distribution of green areas was uneven in the study area. This reduces urban residents' ability to access and benefit from green spaces in the study area. Therefore, the spatial distribution of urban green space should be considered in future urban planning. A dispersed USG pattern is recommended to increase the accessibility of urban citizens. Furthermore, the dispersed USG pattern may also help improve the quality of the urban environment [32].

Finally, in terms of UGS mapping techniques based on remote sensing, the difference of this study is the use of multi-temporal images at each time point instead of single images, compared with some other studies [10, 11, 13]. Multi-temporal images have the advantage of providing information on seasonal changes in vegetation. Therefore, they support more accurate mapping of green areas.

5 CONCLUSION

In summary, this study evaluated the change in UGS in the region of the three cities of Thu Dau Mot, Di An, and Thuan An in Binh Duong province, Vietnam in 2001 – 2020 using multi-temporal Landsat images and spatial analysis.

The results showed a continuous decline trend in UGS area, coverage rate, and ratio of UGS per capita during the study period, in which, the period 2001 – 2010 experienced a rapid decrease. Specifically, the UGS of the entire study area decreased from 20,496.2 hectares in 2001 to 6,707 hectares in 2020, corresponding to a decrease of 67.3%. As a result, the average UGS coverage rate decreased from 78.1% to 25.6%, and the average ratio of UGS per capita decreased from 538.4 m² to 46.1 m² during this period. As of 2020, Thu Dau Mot, Di An, and Thuan An had a coverage rate of 33.9%, 21.7%, and 14.3%, respectively, and a ratio of 116.8 m², 17.5 m², and 29.4 m² USG per capita, respectively. The cause of the decline mainly came from the phases of the urbanization and industrialization process of Binh Duong province. In which the main cause was the expansion of built-up areas and the mechanical population explosion.

This study also compared the analysis results with some common UGS standards. It can be seen that the average ratio of UGS per capita of the three cities all met the minimum area of 9 m² per capita. However, only 79.2% of residential areas were able to reach a UGS of at least 0.5 hectares within a distance of 300 m (or within 5-minute walkable). This reduces the ability of citizens to access and benefit from green spaces in the study area. A dispersed USG pattern is recommended to improve the accessibility of urban citizens as well as the quality of the environment.

This study also has some limitations. Calculating the distance from residential areas to green areas would be better if there were precise data on the exact geographical location of each house in the study area. However, due to the lack of available data, this study only focused on relative residential location at the pixel scale. In addition, some minor adjustments to the administrative boundaries of the three cities in the past were also omitted. These issues may affect the analysis results. Furthermore, analysis of the main drivers leading to UGS loss also needs to be done. These will be considered in future studies.

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PHÂN TÍCH BIẾN ĐỘNG KHÔNG GIAN XANH ĐÔ THỊ Ở CÁC THÀNH PHỐ PHÍA NAM TỈNH BÌNH DƯƠNG, VIỆT NAM BẰNG CÔNG NGHỆ VIỄN THÁM VÀ GIS

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Tóm tắt. Nghiên cứu này đánh giá sự thay đổi theo không gian và thời gian của không gian xanh đô thị tại các thành phố phía Nam tỉnh Bình Dương. Ảnh Landsat đa thời gian từ năm 2001 đến năm 2020 được sử dụng. Thuật toán rừng ngẫu nhiên được sử dụng để tạo các bản đồ lớp phủ, sau đó các bản đồ này được tái phân loại thành các bản đồ không gian xanh. Kết quả cho thấy diện tích không gian xanh liên tục giảm trong giai đoạn 2001 – 2020. Khoảng 67,3% diện tích không gian xanh trên toàn bộ khu vực nghiên cứu đã bị mất đi trong thời gian này. Tính đến năm 2020, diện tích không gian xanh còn lại khoảng 6.707 ha, tương ứng với tỷ lệ che phủ trung bình là 25,7% và tỷ lệ bình quân đầu người là 46,1 m². Mặc dù diện tích không gian xanh vẫn được đảm bảo cao hơn mức tối thiểu là 9 m² bình quân đầu người, nhưng chỉ có 79,2% diện tích đô thị nằm trong khoảng cách 300 m tính từ các mảng xanh từ 0,5 ha trở lên. Điều này có thể làm giảm khả năng thụ hưởng các lợi ích từ không gian xanh của cư dân đô thị trong khu vực này.

Từ khóa. phân tích biến động, GIS, Landsat, viễn thám, không gian xanh đô thị.

Received on May 06, 2025

Revised on June 30, 2025