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Study of urban green space changes using Sentinel-2 data in Thai Binh City, Vietnam

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Abstract. Urban green spaces play a crucial role in regulating the environment, improving the quality of life, and contributing significantly to achieving the goals of sustainable urban development. However, the rapid pace of urbanization in recent years has led to substantial changes in land use, particularly a reduction in the area of vegetation and urban green zones. This study utilizes Sentinel-2 L2A satellite data, which offer advantages in spatial resolution and multitemporal observation capabilities. To complement information on vegetation conditions, the Normalized Difference Vegetation Index (NDVI) was calculated. For the classification of major land-cover categories, including water bodies, vegetation, urban areas, and bare land, the Random Forest machine learning algorithm was applied. The analysis results show that urban green spaces in Thai Binh have undergone significant temporal changes, with urban expansion identified as the main factor contributing to the decline of vegetation cover. The findings provide a clear understanding of the development and degradation of urban greenery at the local level and have practical significance for management and planning. They contribute to forming sustainable urban development strategies that balance urban growth and environmental protection, applicable not only to Thai Binh but also to other cities in Vietnam.

Keywords: green areas of the city, remote sensing, satellite images, Random Forest, NDVI

Authors' contribution. *T.P. Nguyen* — conducting research, visualization, analysis of research, creation of a manuscript. *E.A. Parakhina* — concept development, text analysis, supervision. All authors have read and approved the final version of the manuscript.

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Исследование изменений городских зеленых насаждений с использованием данных Sentinel-2 в городе Тхайбинь, Вьетнам

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Аннотация. Городские зеленые насаждения играют важнейшую роль в регулировании окружающей среды, повышении качества жизни населения и вносят значительный вклад в достижение целей устойчивого городского развития. Однако быстрые темпы урбанизации в последние годы вызвали существенные изменения в землепользовании, в частности сокращение площади зеленых насаждений и городских зеленых зон. В исследовании использованы спутниковые данные Sentinel-2 L2A, обладающие преимуществами пространственного разрешения и возможностью многовременных наблюдений. Для дополнения информации о состоянии растительного покрова был рассчитан индекс NDVI. Для классификации основных категорий объектов, включая водные поверхности, растительность, городские территории и открытые земли, применен алгоритм машинного обучения Random Forest. Результаты анализа показали, что городские зеленые насаждения в Тхайбине претерпели значительные изменения во времени, при этом главным фактором сокращения площади растительного покрова является расширение городской застройки. Полученные выводы не только дают четкое представление о развитии и деградации зеленых насаждений на местном уровне, но и имеют практическое значение для управления и планирования, способствуя формированию стратегий устойчивого городского развития, обеспечивающих баланс между ростом городов и охраной окружающей среды, применимых как для Тхайбина, так и для других городов Вьетнама.

Ключевые слова: зеленые зоны города, дистанционное зондирование, космические снимки, Random Forest, NDVI

Вклад авторов. *Нгуен Т.Ф.* — проведение исследования, визуализация, анализ исследования, создание рукописи. *Парахина Е.А.* — разработка концепции, анализ текста, руководство исследованием. Все авторы ознакомлены с окончательной версией статьи и одобрили ее.

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Introduction

Maintaining and expanding urban green areas in the present time is becoming a serious problem in the context of rapid urbanization and the increasing impact of climate change. Green planting not only contributes to improving air quality, reducing the heat effect of the urban island, increasing biodiversity and protecting public health, but is also considered as one of the important factors reflecting the appearance and level of sustainable development of each city. At the same time, the expansion of urban development, the development of agriculture and industry are accompanied by a tendency to reduce natural green areas, forming an additional load on the urban environment and ecosystems. [1–3]

In Vietnam, large cities such as Hanoi, Ho Chi Minh and Da Nang are facing serious difficulties in maintaining green areas against the backdrop of intense socio-economic development. The city of Thai Binh, despite belonging to the category of medium and small cities, is also under similar pressure. The present study looks for green plantations in the administrative boundaries of the city of Thai Binh. The increasing processes of urbanization and industrialization have an impact on green spaces, quality of urban environment and population. Despite growing environmental awareness among local governments and residents, monitoring and management of green areas remains limited, including due to the cost of traditional observational methods and planning difficulties in large areas. [4–5]

Earth remote sensing technologies and satellite data, in particular data from the multispectral instrument MSI of the Sentinel-2 satellite, have proved to be effective for monitoring and assessment of green areas. With the advantages of spatial diversity, time-lapse data and multi-spectral analysis capabilities, Sentinel-2 provides detailed information on the distribution and current state of vegetation cover, which allows to identify the trend of its changes in the urban environment. The interpretation of time dynamics of vegetation cover also takes into account possible seasonal fluctuations of crop indices. Based on this, a study has been conducted in the city of Thai Binh to analyze the dynamics of urban green plantations over time and provide reference data for spatial planning and development of sustainable urban development directions [7].

This article aims to use Sentinel-2 data for the degree of change in green vegetation in the city, combining quantitative indicators and illustrative illustrations to clarify transformation trends, and offers recommendations for conservation and developmentdomestic green infrastructure. The results of the study are important not only for supporting spatial planning, but also for improving environmental quality and public health in the context of global climate change.

The aim of this study is to identify and quantify changes in urban green areas in the city of Thai Binh on the basis of multispectral satellite data from Sentinel-2 for the period 2020–2025. The following objectives have been formulated to achieve this goal:

- To analyze the dynamics of NDVI and spatial redistribution of land cover classes within urban areas in 2020 and 2025.
- To assess the impact of urbanization processes on the reduction and transition of green zones, including the identification of spatial dimensions of vegetation loss.
- To compare the accuracy of two classification schemes (Sentinel-2 and Sentinel-2 + NDVI) and determine their applicability for the monitoring of vegetation in rapidly changing urban landscapes.

Subject and methods of investigation

Study area and data used

The city of Thai Binh was previously the administrative center of the same-named province. Following the adoption of Resolution 60-NQ/TW in 2025, Thai Binh Province was merged with Hung Yen Province, and is now administered by Hung Yen Province. Thai Binh is located in the Hong Delta and covers an area of about 67 km² (Figure 1). Its strategic location provides transport links to Hanoi, Hai Phong and Nam Dinh through the national highway network 10, 39, as well as river routes. Relief of the territory is mainly flat, with fertile alluvial soils favorable for agriculture. The climate is tropical monsoon, which promotes the cultivation of rice and vegetables and at the same time has a significant impact on the way of life of the population. The ecosystem is characterized by extensive rice fields interspersed with aquaculture areas along the Traly River. However, the processes of urbanization and climate change are leading to a reduction in agricultural land area, creating serious challenges for the sustainable development of cities.[1]

Sentinel-2 data is part of the Copernicus programme implemented by the European Space Agency and provides high quality satellite images for a wide range of studies — from environmental and agricultural monitoring to disaster prevention and urban planning. The system consists of two satellites: Sentinel-2A, launched in 2015, and Sentinel-2B, launched in 2017. Both satellites are equipped with a multispectral device (MSI), which allows data to be obtained in 13 spectral ranges with a spatial resolution of 10 to 60 m and a coverage area

[1] Official portal of Hung Yen Province. Available from: https://thaibinh.gov.vn/ (accessed: 01.05.2025).

of one scene of about 290 290 km. Due to the short rebanding period, Sentinel-2 provides almost continuous data over time, making it an effective tool for monitoring the state and dynamics of the environment, including land use, vegetation, water resources and urban areas, and also plays an important role in the assessment of water resources and the study of urbanization processes. In the present study, the analysis was carried out strictly within the administrative boundaries of the city of Thai Binh city. The city boundary was obtained as a vector layer (shapefile) from official administrative data and used for clipping (clip) of Sentinel-2 satellite images during pre-processing.

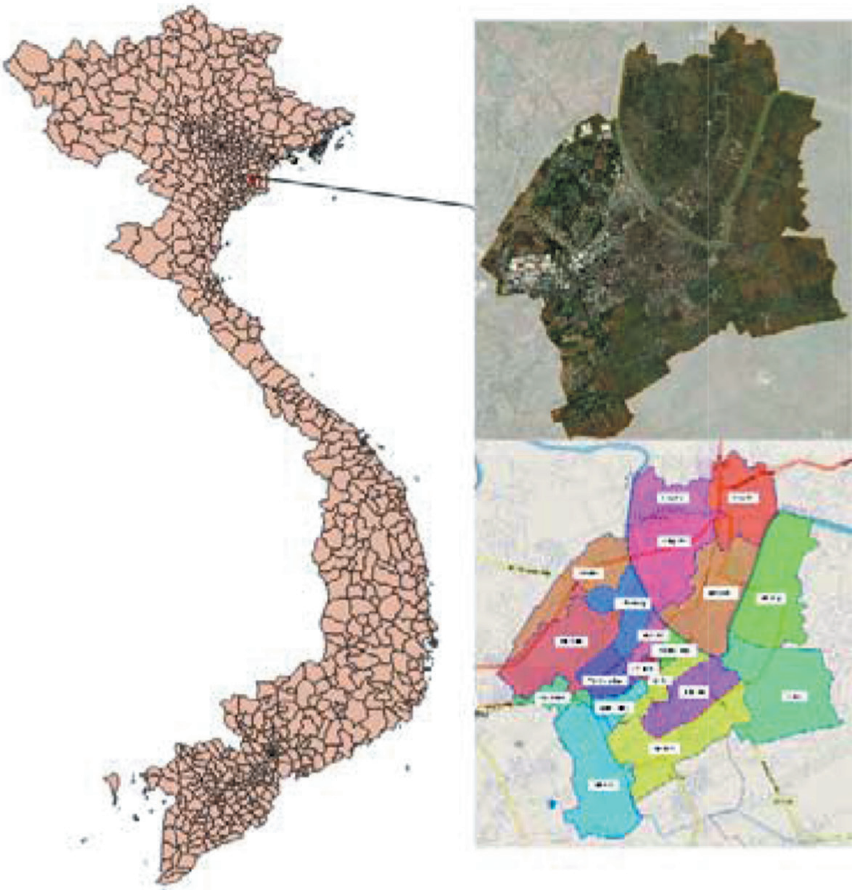


Figure 1. Geographic location of Thai Binh City
Source: compiled by T.F. Nguyen using QGIS software.

Research methods

The process of analysing urban green areas using multi-frame satellite images from Sentinel-2 is shown in the Figure 2. In the first stage, images corresponding to the area of study are selected with full coverage and a time-frame for analysis per year depending on the purpose of the study. To improve the quality of the analysis, images with minimum cloud were chosen. The data used was loaded and corrected using Microsoft STAC API plug-ins and Semi-Automatic Classification in the QGIS software environment, after which the preliminary processing required for subsequent analysis steps was performed.

Scheme: The process of creating thematic maps using Sentinel-2 satellite images

Start → Selection and verification of input parameters: Sentinel-2 L2A data – study area, observation period, cloudiness → Preliminary image processing → Calculation of the vegetation index → Creation of training points/areas (ROIs — Regions of Interest) → Selection of the classification algorithm and carrying out the classification of objects → Definition of reference model → Accuracy evaluation of → Completion.

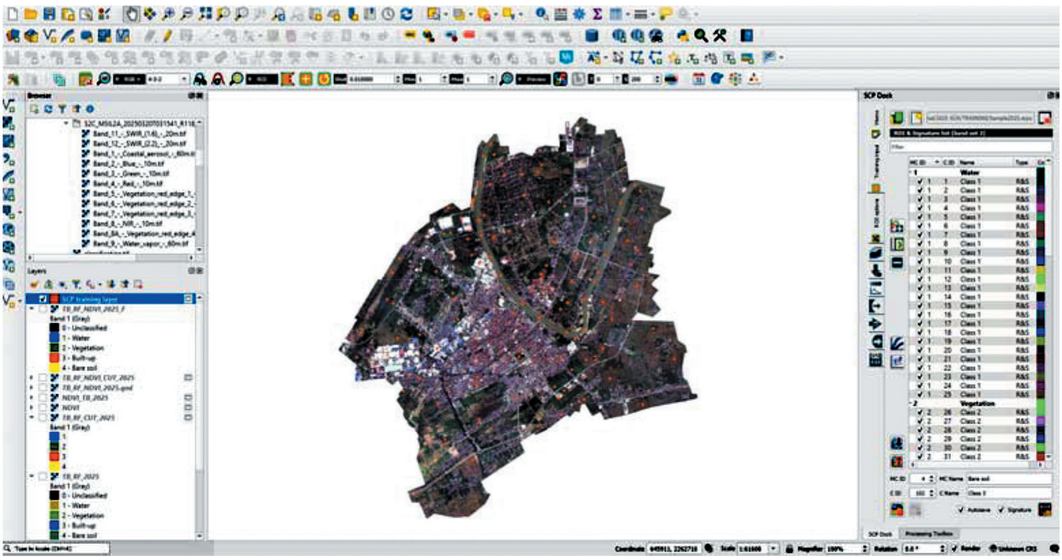


Figure 2. Formation of training points/regions (ROIs — Regions of Interest)

Source: compiled by T.F. Nguyen using QGIS software.

Selection and validation of input parameters. For the correct analysis of vegetation dynamics were used satellite images Sentinel-2, selected for similar seasonal periods — 18.02.2020 and 20.03.2025. The images were selected with regard to high quality and minimum cloudiness, which ensures the accuracy of subsequent calculations of crop indices and classification procedures. This approach allows to minimize seasonal fluctuations and reliability of comparison of NDVI values, with the identified differences are interpreted as a result of the combined influence of urbanization processes and natural factors. The characteristics of the satellite data used are presented in Table 1.

Table 1. **Characteristics of Sentinel-2 data used for creating thematic maps in the study area**

Research region	Path of the zone	Cloud cover	Date of receipt	ID Scene/Product
Thai Binh	T48QXH	4.92%	18.02.2020	S2A_MSIL2A_20200218T032811_R018_T48QXH_20200929T182117
	T48QXH	9.1%	20.03.2025	S2C_MSIL2A_20250320T031541_R118_T48QXH_20250320T090115

Source: compiled by T.P. Nguyen.

The NDVI calculation method

The NDVI index is determined by differences in the spectral reflection of vegetation in the red and near-infrared ranges. The formula is the following:

$$NDVI = \frac{B8 - B4}{B8 + B4},$$

where B8 (NIR) и B4 (RED) — the spectral reflection values in the near infrared and red satellite image channels respectively (for Sentinel-2 satellites these are channels 8 and 4). [2; 6]

NDVI values vary in the range from –1 to 1. Low NDVI values indicate plots with low vegetation cover; high NDVI values correspond to areas with dense vegetation; negative values reflect moist soils and water surfaces. The NDVI index is widely used to assess the state of vegetation, water resource management, classification of green areas and urbanization. It provides reliable information for sustainable planning and effective environmental monitoring. [2; 8-10]

Based on Sentinel-2 data and NDVI index, an analytical model was built:

use only Sentinel-2 channels;

use of Sentinel-2 in combination with NDVI.

The learning sample was formed by study area and included four main land cover classes: water bodies, vegetation, urbanized areas and open lands. The “vegetation” class included dense woodland, farmland and shrubs; the “non-vegetation” class covered built-up areas and open soils; the “water features” class included rivers, lakes, ponds and water bodies, providing training and validation of the classification model. An independent set of control points not involved in model training was used to assess accuracy, followed by the construction of error matrices and calculation of overall and class-specific accuracy.

The study used a Random Forest (RF) machine learning algorithm in combination with an object-oriented classification method to ensure high accuracy of ground cover classes. During the segmentation phase, an SNIC algorithm was used to group pixels into objects, which reduces errors and improves compliance with the real spatial structure [11].

The results of the classification were evaluated by overall accuracy (OA) and Kappa coefficient. The best model was selected for further analysis. Class "vegetation" was interpreted as urban green plantations, the other classes were related to other types of objects. Based on the data obtained, the total area and proportion of green areas in different time periods were calculated, which made it possible to identify the trends and dynamics of development of urban green spaces.

Study results and discussion

Pretreatment results and NDVI vegetation index

The Sentinel-2 (L2A) data for 2020 and 2025 (Figures 3 and 4 respectively) have been subjected to atmospheric correction, clipped along the administrative boundaries of the city of Thai Binh city and combined into a set of spectral channels for subsequent analysis. In all stages of the analysis, only pixels were used that fall into the city boundaries. After the pre-processing stage, the surface reflection map revealed clear differences between the central part of the city and the suburban areas: residential neighborhoods are characterized by high reflection in red and near-infrared, whereas green arrays show typical reflection values in the near infrared (NIR) channel.

Based on the selected spectral channels, the NDVI index was calculated, reflecting the degree of coverage and the state of vegetation cover. The results showed that in 2020, NDVI values within the urban area ranged from –0.284341 to 0.770541 (Figure 3). The green plantations had a mosaic distribution, forming individual clusters, mainly along river valleys and on agricultural lands. By 2025, the NDVI range had shrunk to a range of –0.105477 to 0.530818 (Figure 4), indicating a declining trend in both area and quality of vegetation cover.

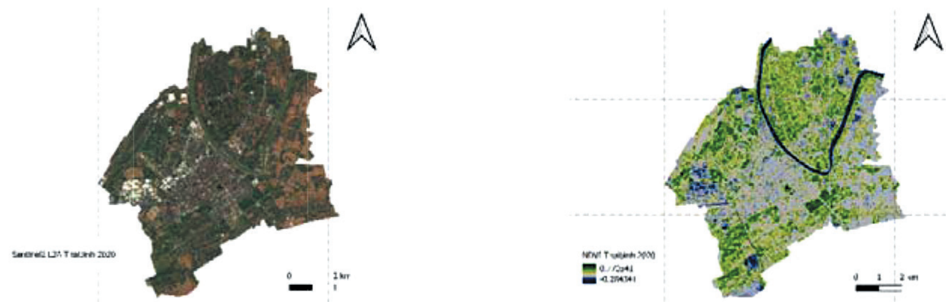


Figure 3. Sentinel-2 satellite image of the study area, obtained on 18.02.2020 and calculated vegetation indices.

Source: compiled by T.P. Nguyen.

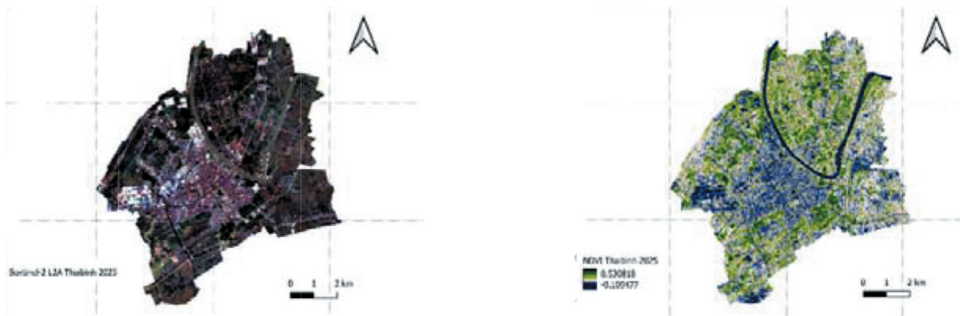


Figure 4. Sentinel-2 satellite image of the study area obtained on 20.03.2025 and calculated vegetation indices.

Source: compiled by T.P. Nguyen.

Table 2. **Area and Changes in Land Cover with NDVI Index in 2020 and 2025**

Value	2020 Area (ha)	2025 Area (ha)
NDVI < 0.4	5123.39	5592.16
NDVI > 0.4	1687.71	1218.94

Source: compiled by T.P. Nguyen.

The area with NDVI > 0.4 (conventionally "dense vegetation") in 2020 was 1687.71 ha, and by 2025 it has decreased to 1218.94 ha (table 2). This indicates a significant reduction of green plantations. It is important to note that the reduction of this area does not mean the disappearance of vegetation, but rather its fragmentation and decrease in density, which is related to the ongoing process of urbanization, construction of new infrastructure and development of land. In tropical climates, many species of vegetation such as lawns, trees along streets, and agricultural plots often have NDVI values ranging from 0.20 to 0.38, especially in high-humidity seasons or under anthropogenic stress. Therefore, the decrease in area with NDVI > 0.4 reflects changes in vegetation structure and does not indicate a complete disappearance of green areas, but rather its weakening in density and area.

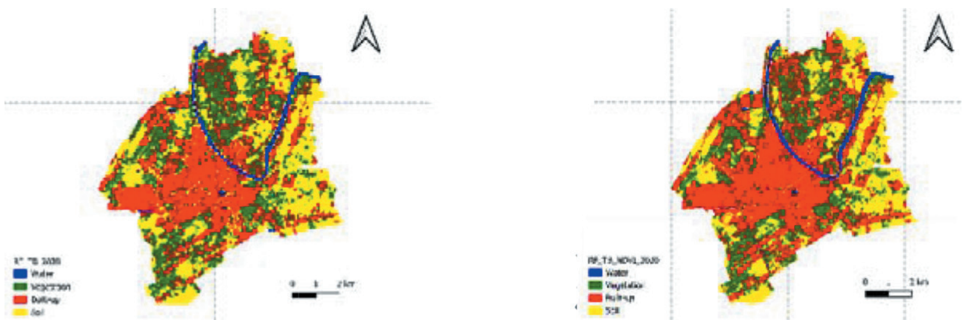
In addition, the reduction of maximum NDVI to 0.53 in 2025 is fully consistent with trends for rapidly urbanizing areas, indicating a decrease in biomass or an increase in anthropogenic load. This is confirmed by the example of the central part of the city and along major highways, where there has been intensive development and land conversion.

Spatial changes in vegetation are particularly noticeable in areas of high urbanization. The decrease in the proportion of areas with NDVI > 0.4 indicates a reduction in large green areas, an expansion of mixed zones where vegetation is adjacent to development, and a reduction in plots with high biomass as a result of construction, road infrastructure and increased density of development.

The NDVI map, presented in the study, clearly demonstrates the process of converting green areas into urban zones and forming new residential areas. These changes are particularly pronounced in the city centre and along key transport corridors, which provides quantitative evidence of reductions in green areas between 2020 and 2025.

Classification results using algorithm Random Forest

An independent sample of 100 control points selected by random stratified sampling was used to assess the accuracy of the classification. For comparability of results and exclusion of bias between land cover classes, 25 points were selected for each class (water, vegetation, built-up areas and open land). The control points were formed on the basis of visual interpretation of high-resolution Sentinel-2 satellite images and auxiliary cartographic data.



a *b*

Figure 5. Results of object-oriented classification for 2020 based on RF algorithm application scenarios:
a — only Sentinel-2 channels; *b* — Sentinel-2 channels and NDVI

Source: compiled by T.P. Nguyen.

a *b*

Figure 6. Results of object-oriented classification for 2025 based on RF algorithm application scenarios:
a — only Sentinel-2 channels; *b* — Sentinel-2 channels and NDVI

Source: compiled by T.P. Nguyen.

Based on the resulting sample, error matrices were constructed and standard classification accuracy indicators were calculated, including overall accuracy (OA), Kappa coefficient as well as metrics for individual classes (User's Accuracy and Producer's Accuracy (Table 3)). This approach is widely used in remote sensing research and provides a reliable and reproducible assessment of classification quality.

Table 3. **Confusion matrices and classification accuracy metrics (Overall Accuracy and Kappa coefficient) for different scenarios and years**

		Classified	1	2	3	4	Total	OA	Kappa coefficient
Only Sentinel-2 channels	2020	**1**	21	1	0	3	25	0.95	0.9333
		2	0	25	0	0	25		
		3	0	0	24	1	25		
		4	0	0	0	25	25		
		Total	21	26	24	29	100		
	2025	**Classified**	**1**	**2**	**3**	**4**	**Total**	0.89	0.8533
		1	22	0	1	2	25		
		2	0	20	1	4	25		
		3	0	0	23	2	25		
		4	0	1	0	24	25		
		Total	22	21	25	32	100		
Sentinel-2 channels and NDVI index	**2020**	**Classified**	**1**	**2**	**3**	**4**	**Total**	0.96	0.9467
		1	23	1	0	1	25		
		2	0	24	1	0	25		
		3	0	0	24	1	25		
		4	0	0	0	25	25		
		Total	23	25	25	27	100		
	2025	**Classified**	**1**	**2**	**3**	**4**	**Total**	0.9	0.8667
		1	24	0	0	1	25		
		2	0	21	0	4	25		
		3	0	0	23	2	25		
		4	1	2	0	22	25		
		Total	25	23	23	29	100		

Note: 1 — water; 2 — vegetation; 3 — built-up; 4 — bare soil.

Source: compiled by T.P. Nguyen.

In the Sentinel-2 spectral channel only classification scenario, the overall accuracy (OA) was 0.95 in 2020 and 0.89 in 2025, with Kappa coefficients of 0.933 and 0.853 respectively. The values obtained demonstrate the high reliability of the classification and confirm the suitability of the Sentinel-2 data for urban land cover analysis.

When integrating the NDVI index into the set of input features of the Random Forest model, there is an additional improvement in the accuracy indicators. In 2020, the OA value increased from 0.95 to 0.96 and the Kappa coefficient from 0.933 to 0.9467 (Figure 5). In 2025, the OA value increased from 0.89 to 0.9 and the Kappa coefficient from 0.8533 to 0.8667 (Figure 6), indicating a more consistent agreement between classified and reference data compared with the scenario without NDVI.

The improvement of the NDVI accuracy metric is related to the increased ability of the model to distinguish classes with close spectral characteristics, especially between green areas, open lands and built-up areas. This is confirmed by the reduction of mixing errors in the respective classes in the error matrices for both years studied. Thus, the integration of the NDVI index into the input data set for Random Forest not only improves the overall classification accuracy but also ensures stability of the model over the years. These results are scientific evidence that NDVI is a key indicator that should be included in studies to monitor changes in urban green areas using remote sensing data.

Dynamics of land cover classes

The results of the statistical evaluation of the area of classes of land cover, presented in Table 4, show notable changes in the structure of land use in the city of Thai Binh during the period 2020–2025, but the nature and direction of these changes vary according to the classification scheme used.

Table 4. **Area and Area Share of Land Cover Objects**

Object	**Use of Sentinel-2 Channels**			**Use of Sentinel-2 and NDVI**		
	2020, ha	**2025, ha**	**Change**	**2020, ha**	**2025, ha**	**Change**
Water	201.24	229.32	+28.08	214.8	207.55	–7.25
Vegetation	1940.76	1466.64	–474.12	1685.15	1557.2	–127.95
Urbanized Areas	2421.36	2382.12	–39.24	2925.76	2477.49	–448.27
Open Land	2245.32	2730.6	+485.28	1985.35	2568.79	583.44

Source: compiled by T.P. Nguyen.

Using only the Sentinel-2 spectral channels, the area of water bodies increased from 201.24 ha in 2020 to 229.32 ha in 2025 (+28.08 ha). At the same time, with the integration of the NDVI index there is a slight reduction in the water surface — from 214.80 ha to 207.55 ha (–7.25 ha). This difference is due to a more precise division of open water and coastal areas partially covered by aquatic vegetation or with mixed spectral characteristics, which confirms the corrective role of NDVI in the classification of hydrological objects.

For land cover, both methods show a steady trend of area reduction, but the degree of reduction differs significantly. In the scenario using only Sentinel-2 channels, the area of vegetation decreased by 474.12 ha (from 1940.76 ha to 1466.64 ha). When adding NDVI, the reduction was less pronounced — 127.95 ha (from 1685.15 ha to 1557.20 ha), which indicates a more weighted assessment of the state of green areas. This confirms that in the absence of NDVI, part of the thinned vegetation and agricultural land may be mistakenly assigned to other classes of land cover.

The analysis of urbanized areas shows contrasting results of two scenarios. With the classification only by Sentinel-2 channels, the area of built-up areas decreased slightly (–39.24 ha), whereas when using Sentinel-2 together with NDVI a significant decrease in the area of urbanized zones was recorded — 448.31 ha. This discrepancy is due to the more strict separation of dense development from open land and transition zones, which reduces the effect of spectral mixing and highlights the increased reliability of the combined approach.

The area of open land increased in both scenarios: by 485.28 ha when using only Sentinel-2 and by 583.44 ha when using Sentinel-2 with NDVI (Figure 7). This growth reflects the transformation of part of agricultural and green areas into plots with reduced vegetation density, as well as the formation of temporary and transitional spaces in the process of urbanization.

The Sentinel-2 + NDVI classification demonstrates good consistency with other studies on green zone dynamics in areas of intense urbanization in both Vietnam and Asia. In particular, studies by Le et al. in Thanh Hoa Province and Phuong et al. in coastal regions also record the vegetation decline most pronounced in peri-urban areas and along major transport routes. [5; 7] Similar trends are found in Liyaqat et al. and Ali et al., where there is a decline in vegetation cover in the fast-growing cities of Asia. [16; 17] The data obtained in Thai Binh confirms these conclusions: there is an active transformation of agricultural areas and green zones into development plots, which leads to fragmentation of vegetation cover and increase of open land area.

The spatial structure of vegetation changes in the city has the following features:

- **Suburban area:** formerly large green areas become fragmented due to the expansion of residential areas.
- **Main transport corridors:** there is an emerging trend towards more open land, reflecting the modernization of upstream infrastructure**.**
- **Coastal and recreational areas:** a decrease in NDVI would be influenced by changes in hydrological regime, land use conversion or an increase in anthropogenic load.
- **City center:** high degree of development leads to the reduction of small and isolated green areas.

Thus, the use of NDVI in conjunction with Sentinel-2 data not only improves the accuracy of the quantitative assessment but also allows for a better identification of spatial patterns of land cover degradation. The results are consistent with international studies and confirm the applicability of this methodology for monitoring land cover dynamics in conditions of accelerated urbanization.

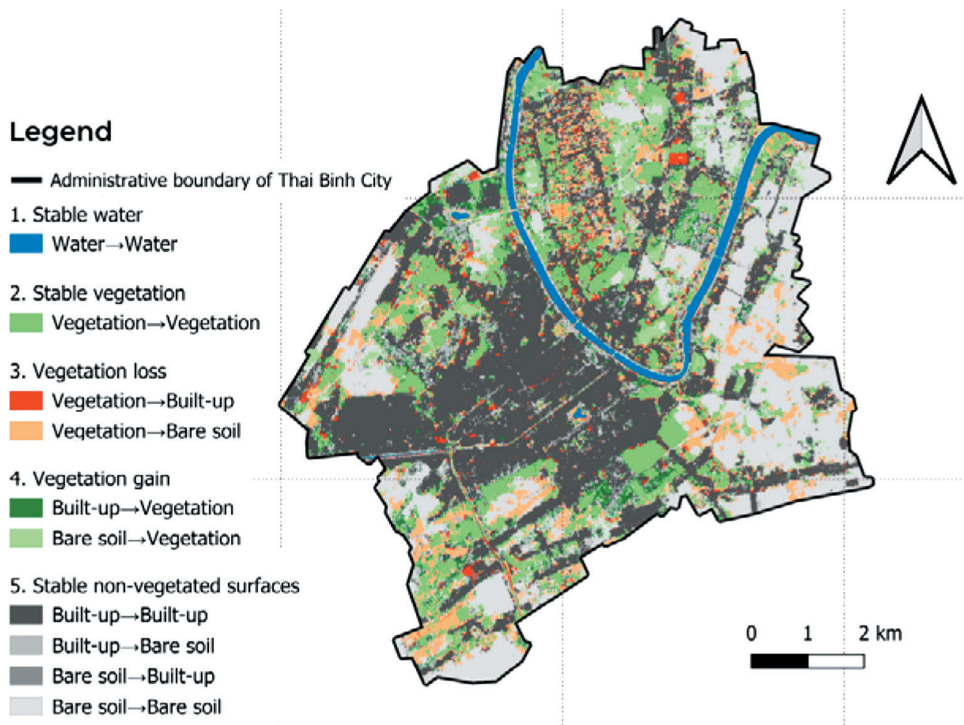


Figure 7. Land cover change map of Thai Binh City for 2020–2025 derived from object-oriented classification of Sentinel-2 data using the Random Forest algorithm and NDVI index.

Source: compiled by T.P. Nguyen.

Conclusion

In the present study, based on data from Sentinel-2 satellites in combination with object-oriented approach and Random Forest algorithm, an analysis of changes in urban green plantations in the city of Thai Binh between 2020 and 2025 was carried out. In order to minimize the seasonal influence, images were selected that refer to comparable time intervals, which allowed to increase the reliability of inter-year comparison.

The results of the classification accuracy assessment showed that when using only Sentinel-2 spectral channels, the overall accuracy (OA) was 95% at a Kappa coefficient of 0.9333 in 2020 and 89% at a Kappa coefficient of 0.8533 in 2025. The integration of the NDVI index resulted in an improvement and stabilization of the classification quality: the OA values reached 96 and 90%, and the Kappa coefficients were 0.9467 and 0.8667 respectively. This confirms that the inclusion of NDVI contributes to a more correct differentiation of classes with close spectral characteristics, especially between vegetation, open lands and built-up areas.

Analysis of the dynamics of land cover revealed a tendency to reduce the area of vegetation in the years of 2020–2025, accompanied by an increase in the area of open land and a change in the configuration of urbanized areas. The Sentinel-2 + NDVI scenario shows more restrained and realistic estimates of changes. The recorded changes reflect land use transformation processes and increasing anthropogenic impact, but the results are interpreted considering the possible influence of seasonal and natural factors.

Overall, the study provides a holistic view of spatial and structural changes in the urban environment of Thai Binh and confirms the effectiveness of combined use of Sentinel-2 data and NDVI index for monitoring green infrastructure dynamics. The findings can serve as a scientifically based information basis for governments and spatial planners in the development of strategies to preserve green areas and sustainable urban development.

References

[1] Olivadese M, Dindo ML. Water, ecosystem services, and urban green spaces in the anthropocene. *Land*. 2024;13(11):1948. https://doi.org/10.3390/land13111948 EDN: ZBTKRO

[2] Zhang F, Qian H. A comprehensive review of the environmental benefits of urban green spaces. *Environmental Research*. 2024;252(2):118837. https://doi.org/10.1016/j.envres.2024.118837 EDN: BNVEZS

[3] Zhanwen Q, Islam MZ. Urban equilibrium: legal imperatives for sustainable development and habitat preservation in Shenzhen, China. *Urban Ecosystems.* 2024;27:2223–2243. https://doi.org/10.1007/s11252-024-01588-0 EDN: CKSEBB

[4] Huong PL, Tuan NT. Ecosystem service value in the context of urbanization: Comparison among economic-social regions of Vietnam. *Heliyon*. 2024;10(21):e39878. DOI: 10.1016/j.heliyon.2024.e39878.

[5] Le KT, Le KB, Le VP. Monitoring urban green space changes using multi-temporal Sentinel-2 MSI Data in Thanh Hoa Province, Vietnam. *Journal of Construction*. 2025;(1):202–205. Available from: https://vjol.info.vn/index.php/tcxd/article/view/107316 (accessed: 25.09.2025).

[6] Han H, Liu Z, Li J, Zeng Z. Challenges in remote sensing based climate and crop monitoring: navigating the complexities using AI. *Journal of Cloud Computing*. 2024;13:34. https://doi.org/10.1186/s13677-023-00583-8 EDN: EQGUES

[7] Thi Phuong To, Le Hung T, Thi Giang Le, Xuan Bien T, Van Phu Le. Assessment of land cover changes using sentinel-2 satellite image data: a case study of Thanh Hoa coastal area, Viet Nam. *IOP Conference Series: Earth and Environmental Science*. 2024;1345(1):012026. DOI:10.1088/1755-1315/1345/1/012026 EDN: GVTPKP

[8] Xiong N, Yu R, Yan F, Wang J, Feng Zh. Land use and land cover changes and prediction based on multi-scenario simulation: A case study of Qishan County, China. *Remote Sensing*. 2022;14(16):4041. DOI:10.3390/rs14164041.

[9] Norovsuren B, Tseveen B, Batomunkuev V, Renchin T, Natsagdorj E, Yangiv A, Mart Z. Land cover classification using maximum likelihood method (2000 and 2019) at Khandgait valley in Mongolia. *IOP Conference Series: Earth and Environmental Science*. 2019;381:012054. DOI: 10.1088/1755-1315/381/1/012054.

[10] Chaikaew P. Land use change monitoring and modelling using GIS and remote sensing data for watershed scale in Thailand. In: Loures LC, editor. *Land Use — Assessing the Past, Envisioning the Future*. IntechOpen; 2019. p. 165–181. DOI: 10.5772/intechopen.79167.

[11] Ismayilova I, Timpf S. Classifying Urban Green Spaces using a combined Sentinel-2 and Random Forest approach. *AGILE: GIScience Series*. 2022;3:38. DOI: 10.5194/agile-giss-3-38-2022.

[12] Pham VD, Hoang VK, Nguyen VT. Mapping of green space distribution with random forest algorithm (RF) on the Google Earth Engine cloud platform: case study in Ba Vi district, Hanoi City. *Vietnam National University of Forestry*. 2022;(6):58–67. DOI: 10.55250/jo.vnuf.2022.6.058-067.

[13] Manika N, Dhyani S. Rampant urbanization, loss of green spaces, depleting foraging wisdom for nutrition, health, and protecting urban greenscapes: lessons from populous Uttar Pradesh, India. In: Dhyani S, Sardeshpande M, editors. *Urban Foraging in the Changing World.* Singapore: Springer; 2024. p. 79–102. https://doi.org/10.1007/978-981-97-0345-6_6

[14] Sadler J, Bates A, Hale J, James P. Bringing cities alive: the importance of urban green spaces for people and biodiversity. In: Gaston KJ, ed. *Urban Ecology*. 2010;230–260. DOI:10.1017/CBO9780511778483.011.

[15] Wang J, Zhou W, Wang J, Qian Y. From quantity to quality: enhanced understanding of the changes in urban greenspace. *Landscape Ecology*. 2019;34:1145–1160. https://doi.org/10.1007/s10980-019-00828-5

[16] Liyaqat S, Dasti MYS, Hussain E, Mumtaz F, Kucher DE, Tariq A. Urban heat island dynamics in Rawalpindi: a 30-year remote sensing analysis and future projections. *Scientific Reports.* 2025;15:32760. https://doi.org/10.1038/s41598-025-13844-0 EDN: SQXVXG

[17] Ali MA, Jamal S, Ahmad WS, Rafi S, Kucher DE. Integrating earth observation and CA-ANN modelling to predict LULC dynamics in wetland ecosystem under urban pressure. *GeoJournal*. 2025;90:236. DOI: 10.1007/s10708-025-11482-7 EDN: MVCAJB

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