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Vegetation coverage variation in relation to urbanization process in Vietnam

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Abstract. ***Relevance.*** The phenomenon of urbanization, driven by the socio-economic development requirements in various regions globally, is increasingly contributing to reductions in vegetation cover and intensifying ecological and environmental complexities. As a result, monitoring urban expansion has become indispensable for enhancing efficient urban management and facilitating planning regarding ecological and environmental issues. ***Aim.*** To assess the spatial-temporal variations in vegetation cover in Thai Nguyen City, Vietnam over the past two decades under the impacts of urbanization. ***Methods.*** The spatial-temporal changes in vegetation cover were analyzed using the maximum value composite algorithm integrated into the Google Earth Engine platform. The accuracy assessment of the applied classification method yielded high accuracy levels ranging from 91 to 94%. ***Results.*** For 2001–2023, the urban land area increased by 4024 hectares, with an average annual growth rate of 0.78%, rising from 386 hectares in 2001 to 4.410 hectares in 2023. The findings indicate a slight decrease of approximately 773 hectares in vegetation cover during 2001–2010 but a significant increase of up to 2696 hectares during 2010–2023. These findings highlight the potential risks associated with increasing urban land areas within the study area and emphasize the urgent need for appropriate measures to address this issue.

Keywords: environment, forest, Google Earth Engine, urbanization, satellite imagery

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Изменения растительного покрытия в связи с процессом урбанизации во Вьетнаме

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Аннотация. ***Актуальность.*** Феномен урбанизации, обусловленный потребностями социально-экономического развития в различных регионах мира, все больше способствует сокращению растительного покрова и усугублению экологических проблем. В результате мониторинг расширения городов стал незаменимым для повышения эффективности городского управления и облегчения планирования по экологическим вопросам. ***Цель.*** Оценка пространственно-временных изменений растительного покрова в городе Тхай Нгуен, Вьетнам, за последние два десятилетия под воздействием процесса урбанизации. ***Методы.*** Пространственно-временные изменения растительного покрова анализировались с использованием алгоритма композита максимального значения, интегрированного в платформу Google Earth Engine. Оценка точности примененного метода классификации дала высокие уровни точности – от 91 до

94 %. ***Результаты.*** В период с 2001 по 2023 гг. площадь городских земель выросла на 4024 га при среднегодовых темпах роста 0,78 %, увеличившись с 386 га в 2001 г. до 4410 га в 2023 г. За уменьшением на 773 га растительного покрова в 2001–2010 гг. последовало значительное увеличение до 2696 га в 2010–2023 гг. Эти результаты подчеркивают потенциальные риски, связанные с увеличением городских земельных площадей на территории исследования, и подчеркивают острую необходимость принятия соответствующих мер для решения этой проблемы.

Ключевые слова: окружающая среда, лес, Google Earth Engine, урбанизация, спутниковые снимки

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Introduction

The process of urbanization, driven by rapid population growth over the past few decades, has significantly impacted forest coverage on a global scale [1–3]. This phenomenon has exacerbated ecological and environmental challenges that require immediate attention [4, 5]. While urbanization has the potential to stimulate socio-economic development and improve quality of life [6, 7], it also presents inherent risks to ecological well-being and public health, necessitating prudent consideration [1, 8]. Currently, more than half of the global population resides in urban areas, and this percentage is projected to increase to 65% by 2050 [9, 10]. The expansion of urban land areas not only impacts regional air quality but also has wide-ranging implications for the overall global environment, demanding global attention [2, 7]. Rapid urbanization can quickly cause irreversible damage to the environment [9, 11].

Remote sensing data has been applied in various studies to detect changes in vegetation cover [12, 13]. However, traditional remote sensing approaches are resource-intensive and time-consuming [11, 14]. In contrast, Google Earth Engine (GEE) has emerged as a valuable tool for analyzing remote sensing information [15, 16]. With its cloud-based geospatial platform, GEE revolutionizes remote sensing techniques by providing access to a vast repository of data, including Landsat and Sentinel imagery, as well as climate and meteorological datasets [14, 17]. Its high-speed parallel processing and machine learning algorithms, combined with Google's computational infrastructure, allow for efficient analysis and visualization of geospatial bigdata without the need for supercomputers or specialized coding expertise [18, 19]. GEE has demonstrated great potential for land cover classification [5, 20]. It offers various functions to support vegetation cover classification, including the detection of vegetation cover changes, habitat tracking, urban land mapping, and anthropogenic activities analysis [2, 3]. Numerous studies have utilized GEE to explore vegetation cover changes [21–23] such as the detection of industrial oil palm plantations by Lee et al. [17], monitoring coastal land reclamation activities in the Nine Delta by Sengupta et al. [19], assessing land use changes in Cambodia by Venkatappa et al. [16], and examining land use change in the Savannah River Basin by Zurqani et al. [20, 21].

Building upon these advancements, this study aims to explore the vegetation cover change in Thai Nguyen City over the past two decades, specifically in relation to urban expansion. By using the GEE approach, this study seeks to provide comprehensive insights into the environmental consequences of urbanization and contribute to informed decision-making in land use planning and management in the region.

Study area and method

Study area

Thai Nguyen province holds an important position within northern Vietnam economic region due to its advantageous geographical location and climate [4, 7]. It covers an area of 3526.64 square kilometers and is bordered by Lang Son and Bac Giang provinces to the east, Vinh Phuc and Tuyen Quang to the west, the capital city of Hanoi to the south, and Bac Can province to the north (Fig. 1). The terrain predominantly consists of low hills and mountains, with altitudes averaging over 100 m above sea level across approximately two-thirds of the land [4, 13]. Topography gently slopes downward from north to south and west to east [13].

The climate is humid subtropical, characterized by distinct wet and dry seasons [4]. Rainfall exceeds 2000 mm annually and is the heaviest between May and October, the rainy season. The driest months are November through April, which comprise the dry season [4, 13]. Average temperatures range from 21.5 to 23.0°C, with the warmest month being August and the coolest being January [4, 7]. This climate supports a variety of agricultural activities throughout the province.

Approach method

To examine the variation in vegetation coverage, we utilized satellite imagery from Landsat 5 TM and Sentinel 2A. The specific details and quality of each satellite are provided in Table 1. The satellite images of Thai Nguyen City from the GEE database were extracted for the period 2001–2023 (Table 1).

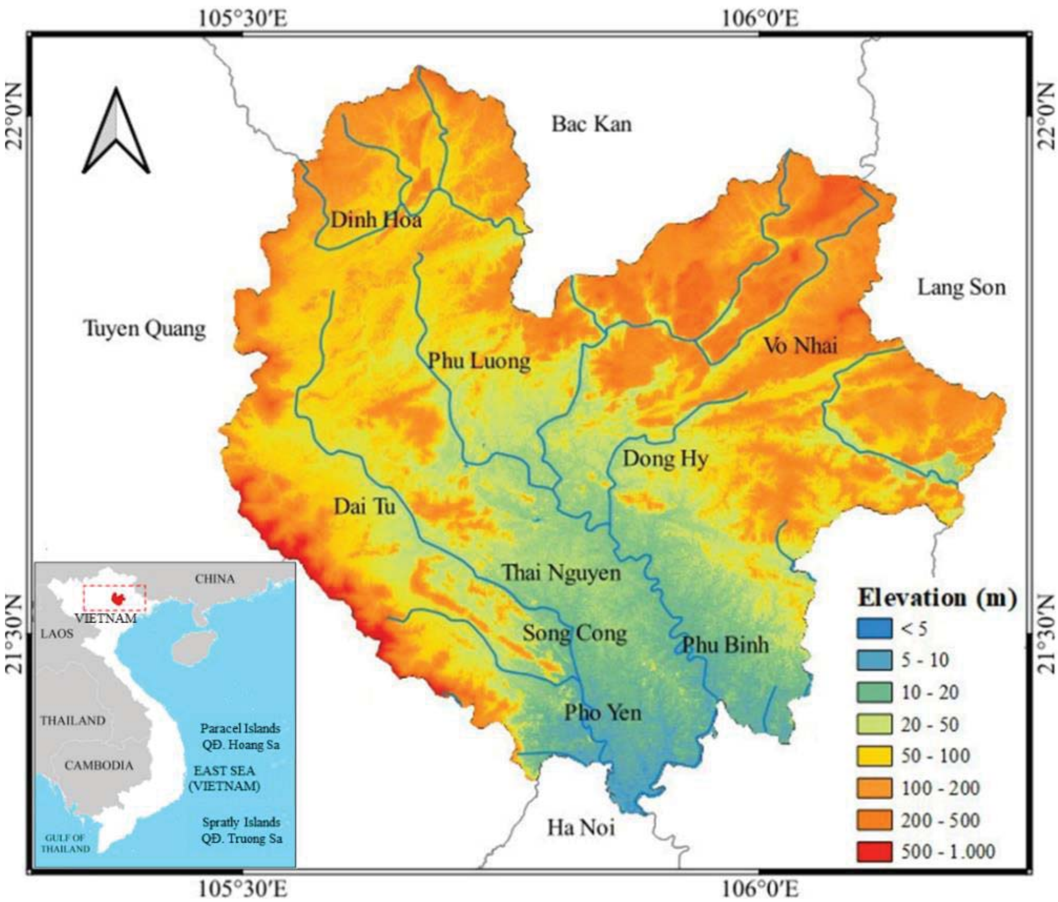

Fig. 1. *Map of the study area*
Рис. 1. *Карта района исследований*

Table 1. *Data of multispectral satellite sensors used for the study*
Таблица 1. *Данные мультиспектральных спутниковых датчиков, использованных для исследования*

Imagery data Данные изображений	Projection Проекция	Acquisition data Данные о приобретении	Spatial resolution, m Пространственное разрешение, m	Data source Источник данных
Landsat 5 TM	UTM-Zone-48N	2001	30	[11, 23]
Landsat 5 TM	UTM-Zone-48N	2010	30	[11, 23]
Sentinel 2A	UTM-Zone-48N	2023	10	[11, 23]

For this study, we used Landsat 5 images from 2001, obtained from USGS Landsat 5 Surface Reflectance Tier 1, and Sentinel 2A images from 2023. The Landsat 5 images underwent atmospheric correction using LEDAPS and included masks for cloud, shadow, water, snow, and per-pixel saturation.

Before conducting remote sensing image classification, we processed the downloaded images using ENVI software. Our objective was to obtain a high-precision image that covers the entire study area. To ensure that the vegetation spectrum curve closely aligns with the actual vegetation spectrum, we performed atmospheric correction. Additionally, we carried out various image processing procedures, including radiometric, atmospheric, geometric, and topographic corrections. These preprocessing steps were implemented to meet the quality requirements for satellite images. They involved converting the digital number values of the image to top-of-atmosphere reflectance through atmospheric correction and resampling the resolution from 30 to 10 m.

For the atmospheric correction of Sentinel-2A images, we applied the semi-automatic classification plugin tool in QGIS software [11, 17]. In addition to the spectral bands, we calculated five indexes for all the selected images: NDVI (Normalized Difference Vegetation Index), NDWI (Normalized Difference Water Index), NDBI (Normalized Difference Built-up Index), Urban Index (UI), and bare index (BI) (Table 2). The maximum value composite (MVC) algorithm was applied to calculate each index. This algorithm examines the value of each index for each pixel and considers only the highest value.

Table 2. *Information on the indexes considered in this study*

Таблица 2. *Информация об индексах, рассматриваемых в исследовании*

Index type Тип индекса	Symbol Символ	Formula Формула	Note Примечание
Vegetation index Индекс растительности	NDVI	$NDVI = \frac{NIR - RED}{NIR + RED}$	Includes natural, plant forests, mixed forest land and other vegetation covers Включает естественные леса, смешанные лесные массивы и другой растительный покров
Water index Водный индекс	NDWI	$NDWI = \frac{Green - NIR}{Green + NIR}$	Includes rivers, reservoirs, streams and canals Включает реки, водохранилища, ручьи и каналы
Built-up index Накопленный индекс	NDBI	$NDBI = \frac{SWIR1 - NIR}{SWIR1 + NIR}$	Includes industrial zones, houses and other artificial surfaces Включает промышленные зоны, дома и другие искусственные поверхности
Urban index Городской индекс	UI	$UI = \frac{SWIR2 - NIR}{SWIR2 + NIR}$	
Bare index Голый индекс	BI	$BI = \frac{NIR - RED}{NIR + RED}$	Includes bare land, bare hill land, transitional zones and mixed barren land Включает голые земли, голые холмистые земли, переходные зоны и смешанные бесплодные земли

Results and discussion

Fig. 2 provides an overview of the spatial distribution of land use cover types in Vietnam from 2001 to 2023. The study classifies land use into five categories: forest land, annual crop land, urban land, bare land, and water bodies. From the results presented in Table 3, it is revealed that there have been significant changes in land use types over the years. The forest area decreased from 9636 ha in 2001 to 8863 ha in 2010 but increased to 11559 ha in 2023 (Fig. 3). On the other hand, urban land expanded significantly from 386 ha in 2001 to 1046 ha in 2010 and further to 4410 ha in 2023.

In terms of the distribution of land cover types in the study area, forested areas constituted the largest portion in 2001, accounting for 43.30%. Annual crop land and bare land accounted for approximately 26.04% each, followed by water bodies at 2.90% and urban land at 1.70%. In 2010, bare land encompassed the largest area at 40.70%, followed by forest cover at 39.8%, annual crop land at 11.80%, urban land at 4.70%, and water bodies at 3.00% (Fig. 3). Between 2001 and 2010, there was a significant increase in bare land area by 14.61%, urban land area by 2.97%, and water bodies by 0.07%. However, there was a decline in the annual crop land area of 14.17% and forest land area by 3.47%. By 2023, forest land once again dominated, covering 51.9% of the study area, followed by urban land at 19.8%, bare land at 17.2%, annual crop land at 8.1%, and water bodies at 2.90%.

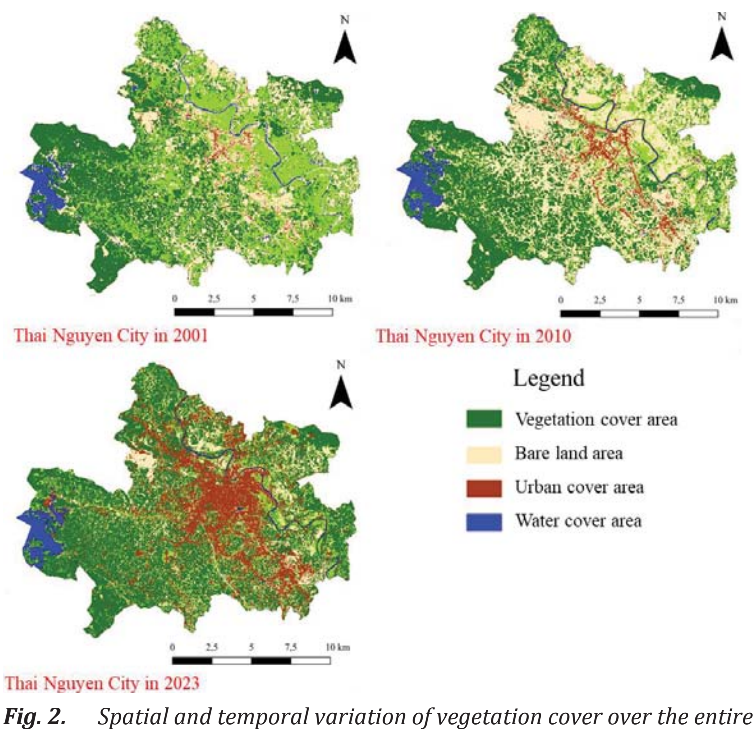

Fig. 2. *Spatial and temporal variation of vegetation cover over the entire study area in the period 2001–2023*

Рис. 2. *Пространственно-временная изменчивость растительного покрова на всей территории исследования в период с 2001 по 2023 гг.*

Table 3. *Temporal variation trend of vegetation covers over the study area for 2001–2023*

Таблица 3. *Динамика временного изменения растительного покрова на территории исследований в период с 2001 по 2023 гг.*

Cover types Типы обложек	2001		2010		2023		Vegetation cover trends Тенденции растительного покрова		
	Area Область (ha)	Ratio Соотношение (%)	Area Область (ha)	Ratio Соотношение (%)	Area Область (ha)	Ratio Соотношение (%)	2001–2010	2010–2023	2001–2023
							(%)		
Forest land Лесные земли	9636	43.3	8863	39.8	11559	51.9	–3.47	+12.12	8.64
Annual crops Однолетние культуры	5789	26.0	2635	11.8	1808	8.1	–14.17	–3.72	–17.89
Urban land Городские земли	386	1.7	1046	4.7	4410	19.8	+2.97	+15.12	+18.08
Bare land Голая земля	5796	26.0	9048	40.7	3836	17.2	+14.61	–23.42	–8.81
Water body Водоем	646	2.9	661	3.0	640	2.9	+0.07	–0.09	–0.03
Total Общий	22,253	100	222,53	100	222,53	100	–	–	–

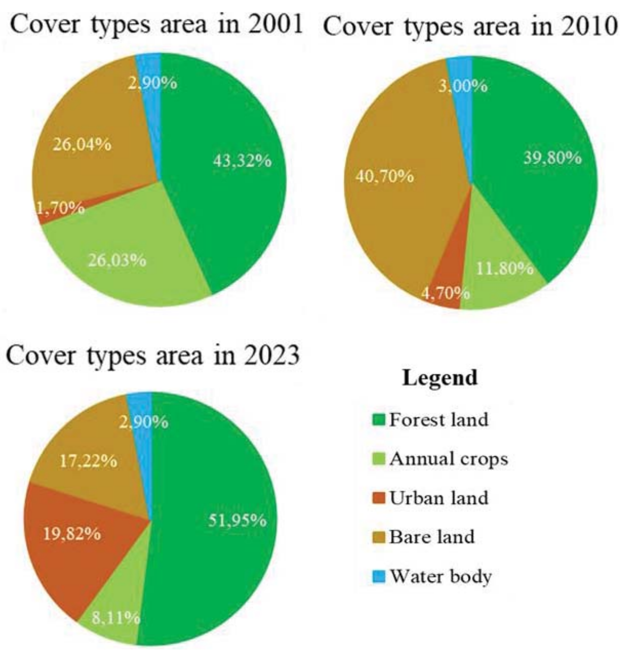

Fig. 3. *Land cover change across Thai Nguyen City for 2001–2023*

Рис. 3. *Изменение растительного покрова города Тхай Нгуен в период с 2001 по 2023 гг.*

The decline in forest land area during the 2001–2010 period raises concerns about potential ecological imbalances in the study area, attributed to urban expansion and deforestation activities. However, there was a subsequent strong increase in forest land area by 12.12% in the 2010–2023 period (Fig. 4). The conversion of vegetation coverage areas into urban spaces has led to a considerable loss of vegetation cover and a decline in ecological areas, which can have detrimental environmental effects such as intensified urban heat island phenomena and diminished air quality. The trend of decreasing annual crop land area continued, declining by 17.89% during the 2001–2023 period.

In contrast, urban land areas continuously increased over the 23-year study period, with a rise of 15.12% from 2010 to 2023. This indicates a rapid urbanization trend, possibly due to population growth, economic development as well infrastructure expansion. Bare land areas initially experienced a strong upward trend of 14.61% from 2001 to 2010 but then saw a significant decrease of 23.42% from 2010 to 2023. This change is positive for soil conservation and ecosystem health. The water body areas showed relatively minor changes, with slight increase and decreasing trends throughout the study period (Fig. 4).

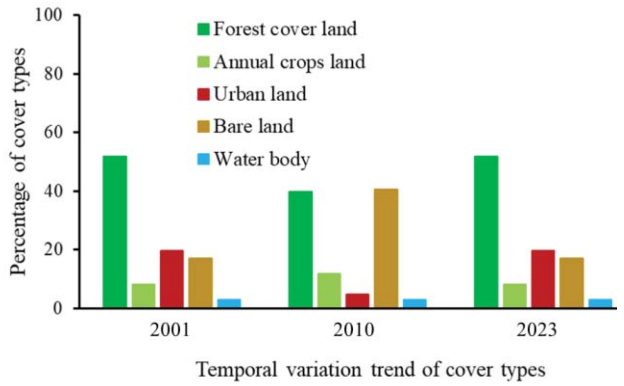

Fig. 4. *Land cover types change trend across Thai Nguyen City for 2001–2023*

Рис. 4. *Тенденция изменения типов земельного покрова в городе Тхай Нгуен в период с 2001 по 2023 гг.*

In general, the analysis of land use changes in the study area reveals a significant decrease in forest land and annual crop land, rapid urbanization, and fluctuations in bare land and water body areas. These findings highlight the need for effective land management strategies to mitigate the negative environmental impacts associated with urbanization and ensure sustainable development in Thai Nguyen City of Vietnam.

Discussion

The study reveals significant changes in vegetation covers within Thai Nguyen City over the past two decades. Specifically, the period from 2001 to 2010 witnessed a decline in forested areas, accompanied by a simultaneous increase in agricultural land and urbanization. These shifts can be attributed to various factors, including population growth, industrial development, and land use policies. However, it is worth noting that since 2010, there has been a noticeable shift towards promoting environmental conservation and sustainable land management practices. As a result, the trend has reversed, showing a gradual increase in forested areas and a decrease in agricultural land and urban sprawl. This positive change signifies a conscious effort to preserve and restore natural ecosystems within the city.

Furthermore, the analysis emphasizes the significance of implementing effective land use policies and conservation strategies. The upward trend in vegetation cover areas is a testament to the success of reforestation initiatives and the protection of existing forests. These efforts have not only enhanced biodiversity but also played a crucial role in mitigating climate change and improving the overall ecological health of Thai Nguyen City. Additionally, the decline in annual crop land areas can be attributed to advancements in agricultural practices. Mechanization and the adoption of advanced agricultural techniques have led to increased productivity and reduced land use requirements. Consequently, this has allowed for the conversion of cultivation land into other land use types.

Overall, the decrease in cultivation and bare land areas and the increase in urban land areas can be attributed to strategic urban planning. This approach prioritizes the integration of green spaces, eco-friendly infrastructure, and sustainable development. By doing so, the city not only enhances its aesthetic appeal but also promotes a healthier and more livable environment for its residents.

Conclusions

The study analyzed vegetation coverage variation in relation to urbanization in Vietnam provides valuable insights into the changing landscape of Thai Nguyen City. The study focused on assessing the spatial-temporal variations in vegetation cover in Thai Nguyen City, Vietnam over the past two decades, under the influence of urbanization. The analysis utilized the maximum value composite algorithm integrated into the Google Earth Engine platform, with high accuracy levels ranging from 91 to 94%. The results revealed an increase in urban land area of 4024 hectares from 2001 to 2023, with an average annual growth rate of 0.78%. Furthermore, there was a slight decrease of approximately 773 hectares in vegetation cover during 2001–2010, followed by a significant increase of up to 2696 hectares during 2010–2023. These findings highlight the potential risks associated with expanding urban areas in the study area and emphasize the urgent need for appropriate measures to address this issue.

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