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Impact of Urbanization Processes on Vegetation Cover in the Cities Over the Last Two Decades

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ABSTRACT

Background: The process of urbanization serves as a prominent factor leading to the vegetation cover decline in major cities worldwide. This issue has significant consequences for the living environment on a global scale.

Methods: Leveraging the latest advancements in remote sensing techniques (RSTs) and utilizing high-resolution satellite imagery, this study aims to assess the vegetation cover alteration (VCA) in correlation with the urbanization process in Thai Nguyen City, Vietnam. Landsat 5 TM and Sentinel 2A satellite imagery were used to analyze the VCA in Thai Nguyen City during the period from 2001 to 2023. Thai Nguyen city is recognized as the third largest in Northern Vietnam, following the capital city of Hanoi and Hai Phong City and ranks as the tenth most populous city in Vietnam.

Result: The results obtained from this study demonstrate a substantial overall expansion, with the total urban land increasing from 386 hectares in 2001 to 1045 hectares in 2010 and experiencing a rapid surge in 2023, reaching a remarkable 4409 hectares. In general, analyzed results based on VCA maps indicated an overall vegetation cover reduction across the study area. This indicates that the study area has reached a critically high level of degradation in terms of vegetation cover. These findings emphasize the escalating risks associated with the diminishing vegetation cover detected across the study area.

Key words: NDVI, Risk, Satellite image, Sentinel, Vegetation cover.

INTRODUCTION

In recent decades, the rapid urbanization observed in developing nations, particularly in major cities, has led to a significant decline in vegetation cover (MacLachlan *et al*., 2017; Westinga *et al*., 2020). As urban areas expand and infrastructure development takes place, the extent of vegetation cover has notably decreased (Mu *et al*., 2015; Song *et al*., 2017). While urbanization is essential for economic and social progress, its consequences have had a profound impact on the environment, exacerbating issues such as the urban heat island effect (Chatterjee and Majumdar, 2022) and urban flooding (Dang, 2020; Dang, 2022). Understanding the influence of human activities on vegetation ecosystems requires a comprehensive evaluation of VCA (Almalki *et al*., 2022; Deval and Joshi, 2022; Rajalakshimi *et al*., 2023).

Various methods, including the utilization of indices such as the Normalized Difference Vegetation Index (NDVI), Atmospherically Resistant Vegetation Index (ARVI), Enhanced Vegetation Index (EVI) and Soil Adjusted Vegetation Index (SAVI), are commonly employed to monitor the VCA using data derived from remote sensing images (RSIs) (Ravibabu and Vani, 2017; Westinga *et al*., 2020; Buraka *et al*., 2022). RSIs, obtained from satellites or unmanned aerial vehicles (UAVs), play a crucial role in detecting VCA using advanced tools (Almalki *et al*., 2022; Chatterjee and Majumdar, 2022). Additionally, RSIs incorporating spectral, temperature and moisture sensors are employed for comprehensive vegetation data analysis (Almalki *et al*., 2022; Nguyen *et al*., 2023). Geographic Information System (GIS) is also utilized to collect, store and analyze data on vegetation cover (Nguyen *et al*., 2023; Jeyasingh *et al*., 2023; Morrison *et al*., 2018). The percentage of VCA is determined by applying vegetation indices and other reflectance-based indices derived from satellite data (Westinga *et al*., 2020). By digitizing specific sites and utilizing satellite imagery, it is possible to detect the annual loss of vegetation cover, thereby highlighting the rapid increase in the urbanization process over time (Dinh and Dang, 2022; Westinga *et al*., 2020). The primary objective of this study is to analyze RSIs to identify the trends in VCA between 2001 and 2023, providing insights into the impacts of urban processes on the reduction of vegetation cover in Thai Nguyen City. By analyzing the changes in VCA, this study aims to contribute to a better understanding of the consequences of urbanization and support sustainable urban planning and ecosystem management efforts.

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MATERIALS AND METHODS

Thai Nguyen City, strategically located in the northern region of Vietnam between the coordinates 21°28′48″-21°37′ 22″N and 105°42′3″-105°54′54″E, holds immense significance as a hub for economic and social advancement within Thai Nguyen province (Fig 1). It plays a pivotal role in the comprehensive socio-economic development strategy of the northern economic region of Vietnam, as highlighted by Le and Nguyen (2022). With a sprawling land area of 222.93 km², Thai Nguyen City has evolved into a vibrant urban center, accommodating an approximate population of 362,921 individuals as of 2021 (Le and Nguyen, 2022). The city experiences a humid subtropical climate characterized by four distinct seasons that include spring, summer, autumn and winter. These seasonal variations contribute to the diversity and richness of the city's natural environment. The average temperatures in Thai Nguyen City hover around 22.4°C, allowing for comfortable living conditions throughout the year (Le and Nguyen, 2022). Moreover, the region receives an average annual rainfall ranging from 2,000 to 2,500 mm (Phung *et al*., 2019). This generous rainfall sustains the lush greenery and contributes to the overall ecological balance of the area. Thai Nguyen City's geographical location and favorable climate provide a solid foundation for its economic growth and development (Phung *et al*., 2019). The city serves as a thriving center for various industries, including manufacturing, textiles and metallurgy (Le and Nguyen, 2022). Its strategic position within the northern economic region of Vietnam positions Thai Nguyen City as a key contributor to the region's economic progress (Phung *et al*., 2019).

The study utilized satellite imagery from different sources and periods to assess the VCA changes. Landsat 5 TM (Thematic Mapper) images for May 2001 and 2010 were obtained from the United States Geological Survey (USGS) Earth Explorer website (https://glovis.usgs.gov). Sentinel 2A images for May 2023 were acquired from the Open Access Hub (https://scihub.copernicus.eu) (Table 1) (Congedo, 2021; Zhang *et al*., 2021). All satellite images underwent geometric correction and rectification to UTM zone 48N. To analyze the VCA over time, the RDAS IMAGINE 2020 software (Version 16.6) was used. In addition, ArcGIS (Version 10.2) played a role in digitizing, indexing, image analysis, geo-referencing and database creation (Deval and Joshi, 2022; Huang *et al*., 2021). The combination of these software tools enabled efficient handling and processing of satellite imagery data, ensuring accurate results (Thakkar *et al*., 2016; Zhang *et al*., 2021).

To ensure reliable and accurate analysis of the digital images, a thorough process of geometric and radiometric

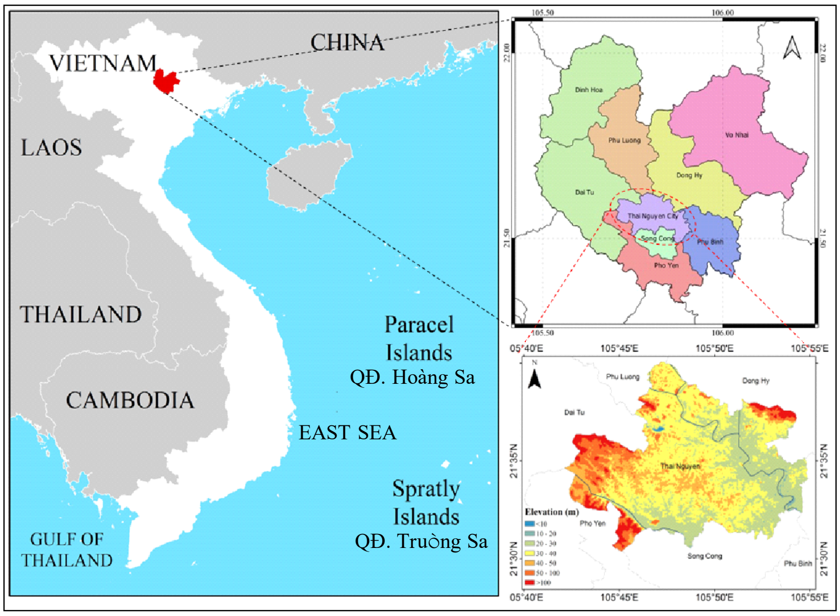

Fig 1: Illustration of topographic map of the study area.

Table 1: Data of multispectral satellite sensors used for the purpose of the study.

Imagery data	Projection	Year	Spatial resolution	Data source
Landsat 5 TM	UTM-Zone-48N	2001	30 m	https://glovis.usgs.gov/
Landsat 5 TM	UTM-Zone-48N	2005	30 m	https://glovis.usgs.gov/
Landsat 5 TM	UTM-Zone-48N	2010	30 m	https://glovis.usgs.gov/
Landsat 8 OLI	UTM-Zone-48N	2015	30 m	https://glovis.usgs.gov/
Sentinel 2A	UTM-Zone-48N	2020	10 m	https://scihub.copernicus.eu/
Sentinel 2A	UTM-Zone-48N	2023	10 m	https://scihub.copernicus.eu

calibration was conducted (Thakkar *et al*., 2016). Geometric rectification, in particular, plays a crucial role in detecting VCA. By precisely aligning the pixels of multi-temporal remote sensing data, it minimizes the risk of misinterpreting registration errors as VCA (Congedo, 2021; Thakkar *et al*., 2016). Geometric rectification is essential for achieving consistency and facilitating the comparison of images over time. It ensures that each pixel is accurately registered, allowing for a reliable assessment of actual vegetation cover changes. By eliminating discrepancies caused by misalignment, the analysis can provide valuable insights into the dynamics of the VCA. The meticulous calibration process guarantees the integrity and consistency of the digital images, enhancing the accuracy of the subsequent analysis. It enables researchers to confidently identify and quantify changes in the VCA, contributing to a better understanding of the evolving vegetation patterns and their underlying factors. The application of geometric rectification techniques is therefore a fundamental step in conducting comprehensive and reliable studies of vegetation dynamics.

In this study, the NDVI approach, widely used in VCA studies, was employed (Huang *et al*., 2021; Jeevalakshmi *et al*., 2016). The NDVI calculates the normalized ratio of red and near-infrared reflectance, which has proven to be effective in detecting VCA over time (Bhandari *et al*., 2012). To classify pixels with unknown identity, a supervised classification process was implemented, utilizing marked samples of known identity (Bhandari *et al*., 2012; Jeevalakshmi *et al*., 2016). This process aimed to quantify the amount of vegetation and compare vegetation levels between two different periods. The NDVI values theoretically range from -1 to 1 and different land cover types are associated with specific ranges (Huang *et al*., 2021; Jeevalakshmi *et al*., 2016). Extremely negative NDVI values typically correspond to water bodies and built-up areas, while values ranging from 0.006 to 0.467 indicate areas of bare land or non-vegetated surfaces (Jeevalakshmi *et al*., 2016). NDVI values close to zero and up to 0.657 represent varying levels of vegetation cover, including both sparse and dense vegetation (Table 2). By analyzing the NDVI values, the study

Table 2: The classes of vegetation cover category and other types for analysis purposes.

Category	Minimum	Mean	Maximum
Water	-0.332	-0.175	-0.011
Built-up	-0.273	-0.019	0.287
Bare land	0.006	0.166	0.467
Sparse vegetation	0.00	0.404	0.629
Dense vegetation	0.445	0.575	0.657

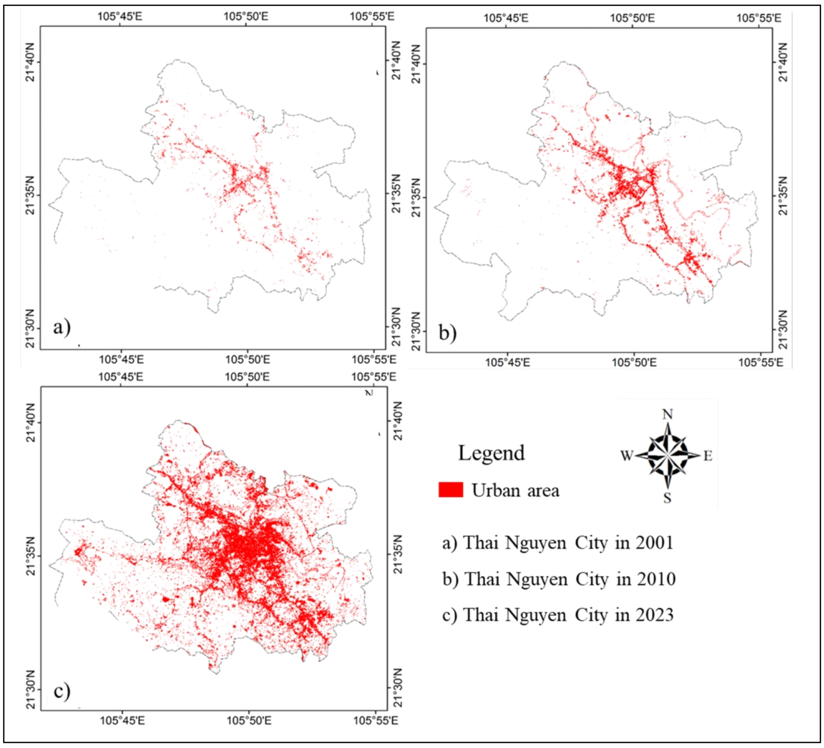

Fig 2: The classification maps of the change in urban land areas across Thai Nguyen City during 2001-2023.

aimed to assess and characterize the VCA, providing valuable insights into the dynamics of the studied area.

RESULTS AND DISCUSSION

Fig 2 and Table 3 present visually and quantitatively represent the changes in land cover areas during the period of 2001-2023. Table 3 specifically depicted the changes in vegetation cover in the stage of 2001-2010 and 2010-2023. The findings revealed a significant increase in urban land areas, with urban land occupying 1.79% (386 hectares) of the total land area in 2001, 5.51% (1045 hectares) in 2010 and 22.26% (4409 hectares) in 2023. Overall, there was a significant 20.47% (4023 hectares) increase in urban land area during the period of 2001-2023, indicating the expansion and development of Thai Nguyen City due to urbanization processes. The conversion of vegetation cover areas into urban spaces resulted in a considerable loss of vegetation cover areas. These changes can have detrimental environmental effects such as intensified urban heat island phenomena and diminished air quality. A study by Chatterjee and Majumdar (2022) examined the impact of urban expansion on vegetation cover, revealing a consistent decrease in vegetation extent towards the city's central regions. Additionally, the core areas of the city exhibited higher surface temperatures compared to neighboring areas. Another study by Du *et al*. (2019) investigated the spatio-temporal patterns of vegetation cover and the influence of urbanization on vegetation in Chinese metropolises. The findings consistently demonstrated a decline in vegetation cover within increasing built-up areas due to urbanization (Fig 3). The study also highlighted the expansion of bare land areas, which accounted for approximately 19.37% of the total land area during the period of 2001-2010. Table 3 summarized the changes in vegetation cover, indicating a strong reduction from 15424 hectares (71.39% of total land area) in 2001 to 8863 hectares (46.76%) in 2010 and a slight increase of approximately 13.02% in 2023. The loss of vegetation cover during the period of 2001-2010 amounted to 6561 hectares, with an average annual loss of 656.1 hectares in Thai Nguyen City. However, in the subsequent period of 2010-2023, there has been a deep awareness of the harmful effects of reduced vegetation cover on urban

Table 3: Results of cover land classification for 2001, 2010 and 2023 for study area.

Land cover	2001		2010		2023		Cover change trends		
feature	Area (ha)	Rate (%)	Area (ha)	Rate (%)	Area (ha)	Rate (%)	2001-2010	2010-2023	2001-2023
Urban land	386	1.79	1045	5.51	4409	22.26	+3.72	+16.75	+20.47
Vegetation cover	15424	71.39	8863	46.76	11559	58.37	-24.63	-11.61	-13.02
Bare land	5796	26.83	9048	47.73	3836	19.37	+20.91	-28.36	-7.46
Total	21606	100	18956	100	19804	22.26	-	-	-

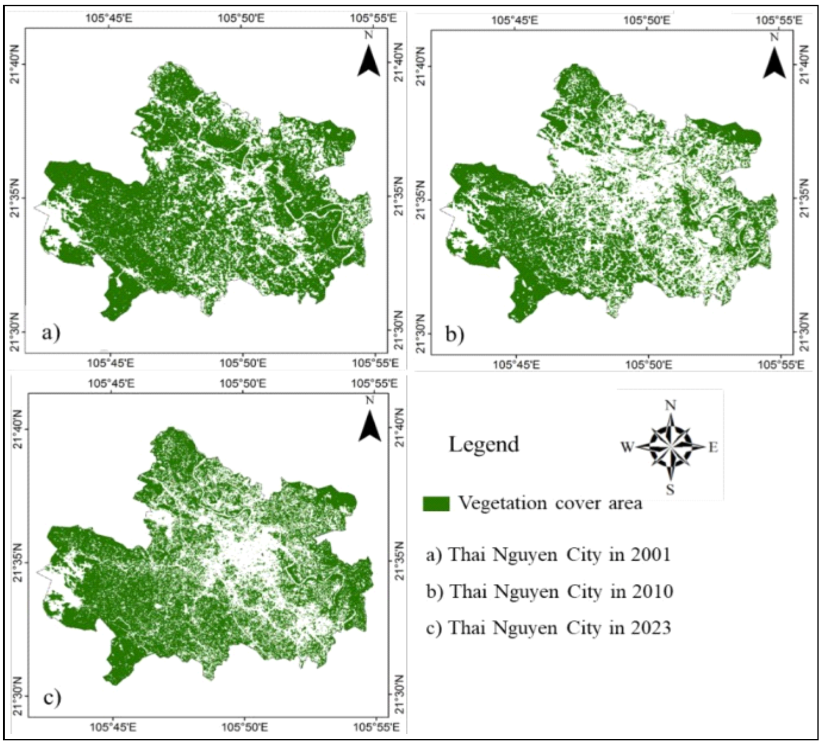

Fig 3: Vegetation cover alteration over time under the impacts of urban expansion across Thai Nguyen City during 2001-2023.

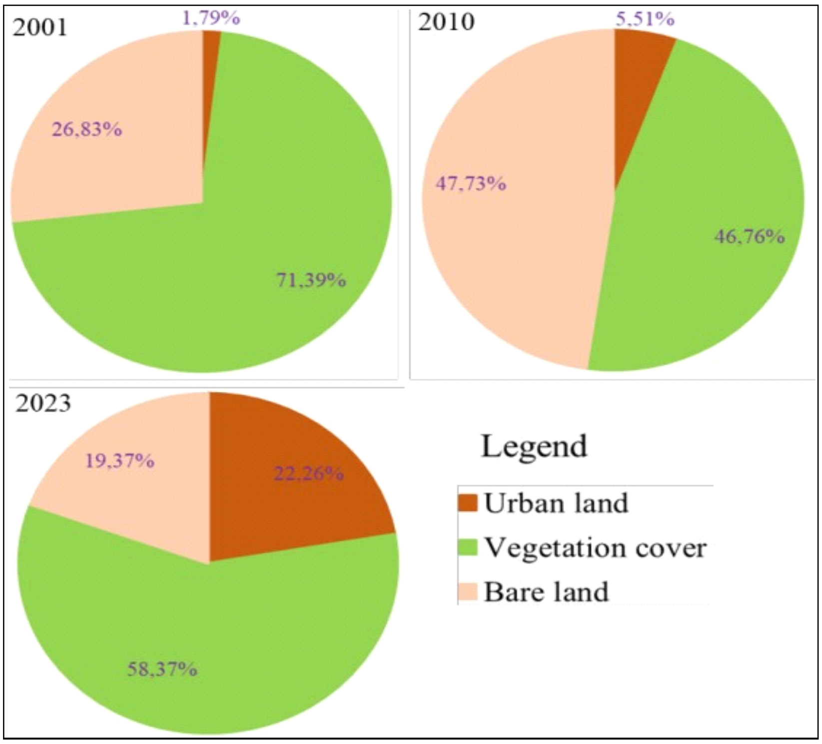

Fig 4: Land area changes across the study area for 2001-2010, 2010-2023 and 2001-2023.

areas, city centers and bare land hills. Government reforestation policies led to a decrease in barren hillsides and the reestablishment of vegetation cover in those areas. Timely policies and measures implemented by local authorities and government agencies contributed to the recovery and improvement of vegetation cover during the period of 2010-2023. The overall area of bare land experienced a strong decrease of approximately 28.36% in the stage of 2010-2023 (Fig 2). The study emphasized the need for sustainable urban planning strategies to mitigate the adverse impacts of urbanization and maintain a balance between urban development and ecological preservation. These strategies should focus on managing and protecting green spaces, as well as promoting conservation and restoration efforts for vegetation areas (Fig 3 and Fig 4). Overall, the study revealed a decline in vegetation cover and a significant increase in urban land and bare land areas in the stage of 2001-2010 (Fig 4). A positive aspect that was also noted through the research is the restoration of vegetation cover during the period of 2010-2023. This is an encouraging sign that contributes to the recovery and maintenance of increased green spaces in Thai Nguyen City and other major urban areas in Vietnam. The findings emphasize the urgency of addressing the reduction in vegetation cover and implementing measures to foster sustainable urban development while preserving ecological balance.

Conclusion

The study utilized NDVI in the ArcGIS software, to analysis of satellite imagery from 2001 to 2023 and to assess the temporal changes in vegetation cover within Thai Nguyen City, Vietnam. The application of the NDVI technique to analyze high-resolution satellite images enabled the accurate quantification of urban land area increase. The precision of the urban land area change maps was confirmed through post-classification comparison, demonstrating high accuracy. Significantly, the findings revealed a notable reduction in vegetation cover, highlighting the substantial impact of urbanization on the ecological landscape. These observations emphasize the growing risk of diminishing vegetation cover in the study area. Ongoing efforts are being made to acquire images from additional periods and further refine the research methodology. These findings have important implications for urban planning and environmental management. It is essential to prioritize the conservation and restoration of green spaces within cities to mitigate the negative environmental impacts associated with urbanization. By doing so, we can foster sustainable development and ensure a greener and healthier living environment for both present and future generations.

Conflict of interest

The author has not received research grants from any agency or organization. The author confirms that I have no conflict of interest.

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