

Assessment of Change in Urban Green Spaces Using Sentinel 2 MSI Data and GIS Techniques: A Case Study in Thanh Hoa City, Vietnam

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Abstract. This paper presents the results of an assessment of change in urban green spaces in Thanh Hoa city (Vietnam). Sentinel 2 MSI data in 2015 and 2021 are used to calculate 3 parameters: percentage of green, weight of green types, and weight of proximity to green. These parameters are used to calculate the Weighted Urban Green Space Index (WUGSI). The final result shows the distribution of green space in the study area consisted of very high-quality green, high-quality green, moderate quality green, and low quality green. The obtained results show that the quality of urban green space in Thanh Hoa city has changed significantly in the period 2015-2021, in which the area with category “low quality green space” increased from 7.17% up to 9.48%; areas with category “very high-quality green space” reduced from 65.02% to 47.39%.

Keywords: Urban green space, Weighted Urban Green Space Index, Sentinel 2, Thanh Hoa city

1. Introduction

Urbanization is an inevitable development trend of all countries in the world, especially for developing countries like Vietnam. In general, urbanization contributes to economic growth, changes the economic and labor structure, and to changes the population distribution. However, besides these positives, the urbanization process also creates many challenges for the development of big cities, such as high population density, traffic congestion, and environmental pollution. Urbanization has also led to a drastic change in land cover/land use, with an increase in built-up land and a decrease in vegetative cover.

Urban green spaces are one of the indispensable elements for design and development of cities. UGS are considered as “lung” of cities as well as one of the elements reflecting the quality of life [1]. Therefore, the quantity and quality of UGS are of prime concern for planners and city administrators [2]. Recently, researchers have objectively measured UGS using remote sensing data by estimating the percentage of green and built-up density in many cities of the world. The percentage of green is usually estimated from the Normalized Difference Vegetative Index (NDVI) using multi-spectral remote sensing image [3]. This index has been used in various studies to distinguish between vegetated and non-vegetated areas. Meanwhile, several urban indices have been proposed to classify urban land use/land cover from multispectral satellite imagery, such as UI (Urban index), IBI (Index based built-up index), NDBI (Normalized Difference Built-up Index), NDBaI (Normalized Difference Bareness Index), EBBI (Enhanced Built-up and Bareness Index), etc [4-10].

Gupta et al. (2012) developed the Urban Neighborhood Green Index (UNGI), which considers four parameters: percentage of green, built-up density, proximity to green, and height of structures to assess the quality of UGS [2]. In a study (Gupta et al., 2012), the type of green was used for defining the proximity to green by applying a single buffer of 20 m. Li et al. (2014) estimated the green spaces at the building level using Building Proximity to Green Spaces Index (BPGI) [11]. However, in this study, the authors used only one parameter (proximity to green) to assess the greens without using other parameters.

In this study, we use 03 parameters, including the percentage of green, weight of green types, and weight of proximity to green to assess urban green space. Two Sentinel 2 MSI images taken on December 21, 2015, and January 13, 2021, are used to evaluate the change in green space quality in Thanh Hoa city, Vietnam. The NDVI index is used to calculate the percentage of green based on the green/non-green classification. The weight of green types and weight of proximity to green parameters are determined on the basis of the results of the urban land cover classification. Finally, the Analytic Hierarchy Process method (AHP) of Saaty (1980) has been used for determining the weights of individual parameters and calculating the Weighted Urban Green Space Index (WUGSI) map.

2. Materials and Methodology

2.1 Study areas and Materials

Thanh Hoa city is the administrative, economic, cultural, political, and scientific-technical center of Thanh Hoa province. The city is an urban gateway linking the northern Vietnam key economic region with the North Central region. After nearly 30 years since its establishment, Thanh Hoa city has grown strongly with a high rate of urbanization and became a class I city in 2014. Currently, Thanh Hoa city has a natural area of 146.77 km² with 20 wards and 17 communes, a population of more than 400 thousand people. This is one of the cities with a large population and area in the Northern region of Vietnam. The location map of the study area is presented in Figure 1 [12].

In this study, two multispectral cloud - free Sentinel 2A images acquired from December 21, 2015, and January 13, 2021 (Fig. 2) were used to calculate 3 parameters: the percentage of green, weight of green types, and weight of proximity to green to assess urban green space.

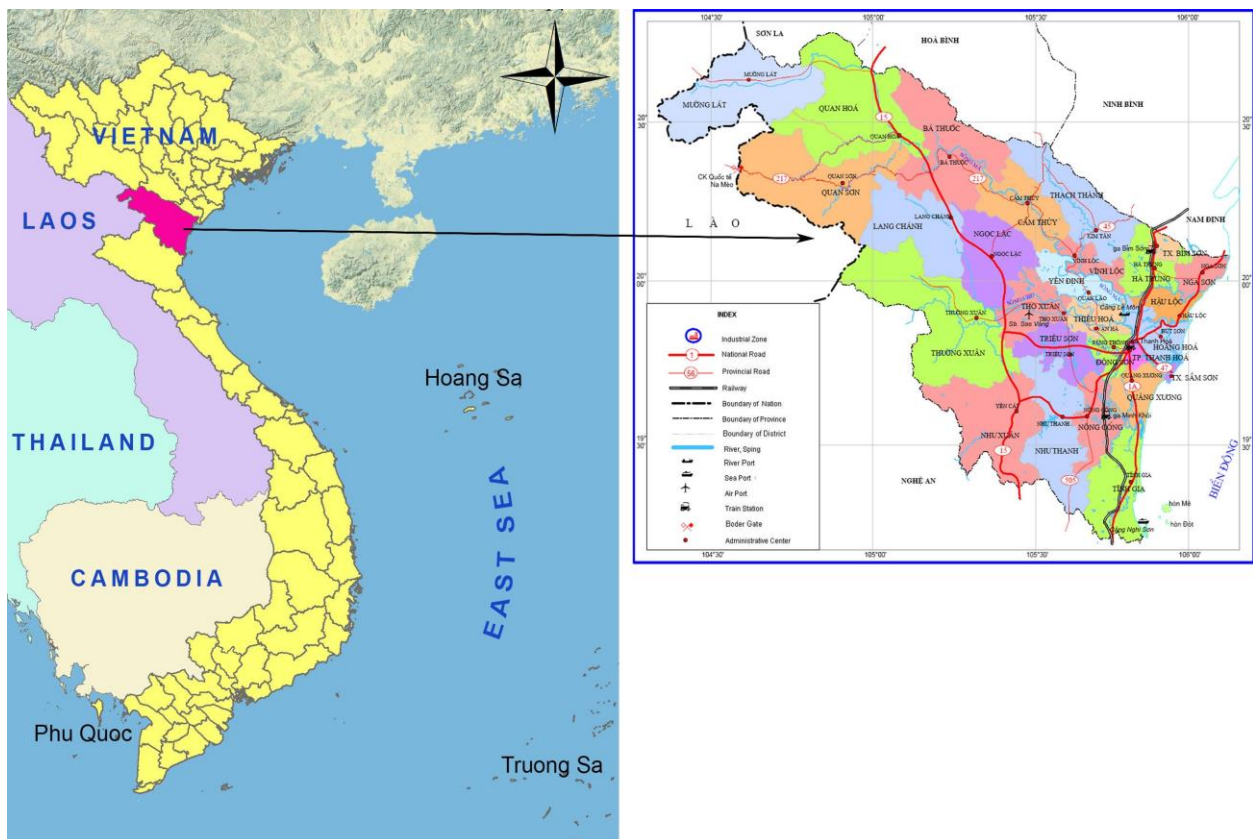


Fig. 1. Study areas in Thanh Hoa city, Vietnam.

The Sentinel-2 mission consists of two satellites developed to support vegetation, land cover, and environmental monitoring. The Sentinel-2A satellite was launched by ESA on June 23, 2015 and operates in a sun-synchronous orbit with a 10-day repeat cycle. A second identical satellite (Sentinel-2B) was launched on March 7, 2017. Together they cover all Earth’s land surfaces, large islands, and inland and coastal waters every five days. The Sentinel-2 Multispectral Instrument (MSI) acquires 13 spectral bands ranging from Visible and Near-Infrared (VNIR) to Shortwave Infrared (SWIR) wavelengths along a 290 km orbital swath [13]. The spectral bands used to calculate the NDVI index have a spatial resolution of 10 m, consistent with studies at a detailed level.

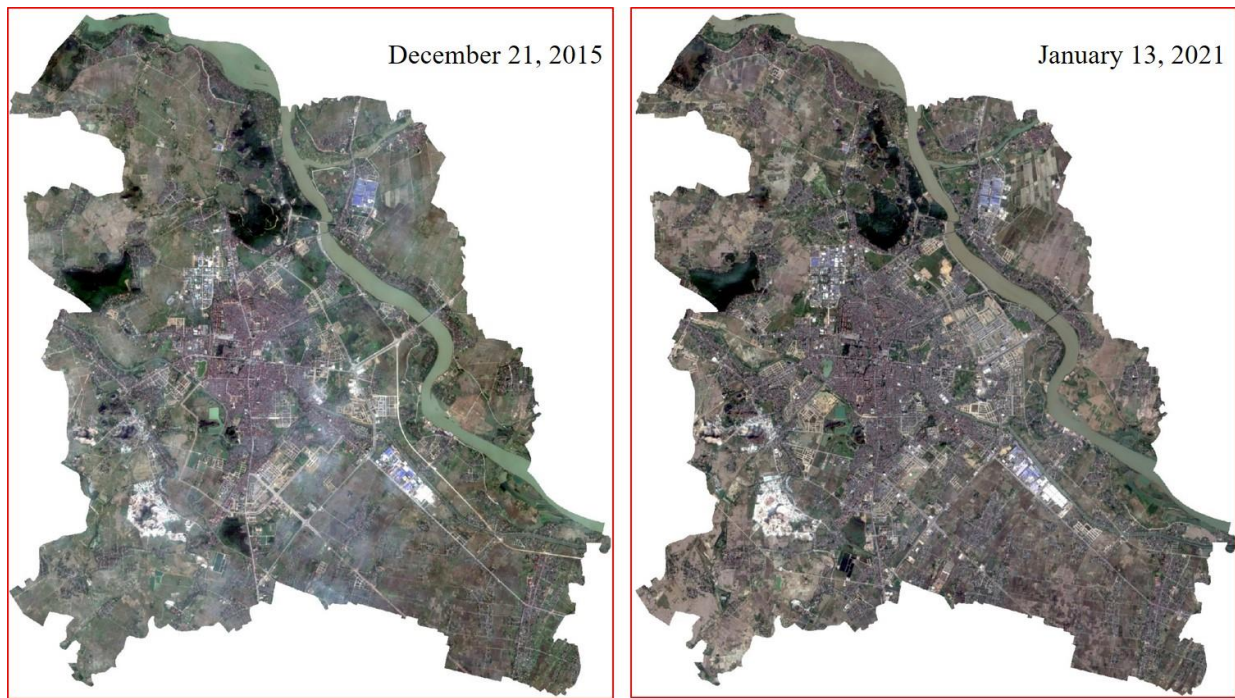


Fig. 2. Sentinel 2 MSI data in Thanh Hoa city, Vietnam, RGB=RED:GREEN:BLUE.

Characteristics of Sentinel 2 satellite bands are showed in Table 1 [14].

Tab. 1. Characteristic of Sentinel 2 satellite imagery.

Sentinel - 2 Bands	Central wavelength (µm)	Resolution (m)
Band 1 - Coastal aerosol	0.443	60
Band 2 - Blue	0.490	10
Band 3 - Green	0.560	10
Band 4 - Red	0.665	10
Band 5 - Vegetation Red Edge	0.705	20
Band 6 - Vegetation Red Edge	0.740	20
Band 7 - Vegetation Red Edge	0.783	20
Band 8 - NIR	0.842	10
Band 8A - Vegetation Red Edge	0.865	20
Band 9 - Water vapour	0.945	60
Band 10 - SWIR-Cirrus	1.375	60
Band 11 - SWIR	1.610	20
Band 12 - SWIR	2.190	20

2.2 Methodology

The Sentinel 2 MSI images after collection and pre-interpreter were cut according to the study area boundary. Spectral reflectance at the red, near-infrared (NIR), and shortwave infrared (SWIR1) bands was used to calculate the NDVI [3] using the following formula:

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}} \tag{1}$$

where: ρ_{RED} , ρ_{NIR} - the spectral reflectance values of red (band 4) and near-infrared (band 8) of Sentinel 2 image.

The thresholding method is used to classify green and non-green classes from NDVI. Then, the 100m × 100m grid was overlaid over the binary image, and the percentage of green was calculated as the ratio between the green area in each cell and the area of 1 cell. The buffer zone at a distance of 100 m was chosen because it is consistent with the 10m spatial resolution of the Sentinel 2 MSI data (visible and NIR bands) used in the study. Based on the percentage of green, each cell has been classified into four green quality classes: low (GI value less than 25%), moderate (25-50%), high (50-75%), and very high green quality (>75%). These classes are assigned values of 0.25, 0.50, 0.75 and 1.00, respectively [2].

The object-oriented method was applied for urban land cover classification, then calculate 2 parameters: weight of green types and weight of proximity to green. In this study, 6 basic urban land cover classes were classified: dense vegetation; shrubs, sparse vegetation; agricultural land; vacant; water body, and built-up land, then each class will be weighted according to studies. In addition, the buffer distance 100 m was created based on the land cover map to calculate the weight of proximity to green parameter. A grid of 100m × 100m size was overlaid on buffers for each land cover class and the weight of proximity to green map generated [1, 15].

To assess the change in urban green spaces quality in Thanh Hoa city, the study was used the Weighted Urban Green Space Index (WUGSI), which proposed by Duong et al. (2015) follow the formula:

$$WUGSI_i = \sum_{j=1}^{i=1 \text{ to } n} W_j \times P_{ij} \tag{2}$$

Where: W_j - the relative weight of j^{th} parameter ($j = 1$ to 3); P_{ij} - the value of j^{th} parameter in the i^{th} cell.

Flowchart for the methodology used in this study to assess urban green spaces based on Sentinel 2 MSI data is shown in Figure 3.

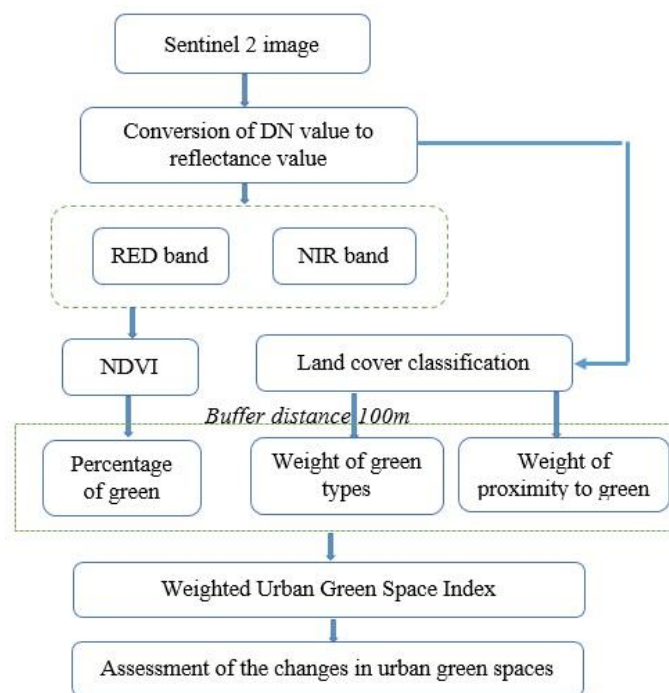


Fig. 3. Flowchart of the methodology for urban green spaces assessment.

3. Result and Discussion

After pre-processing, the reflectance values of red and NIR bands of Sentinel 2 multispectral imagery were used to calculate the NDVI index (Eq. 1). These indices will continue to be used to calculate percentage of the green parameter. The obtained percentage of the green parameter is presented in Figure 4.

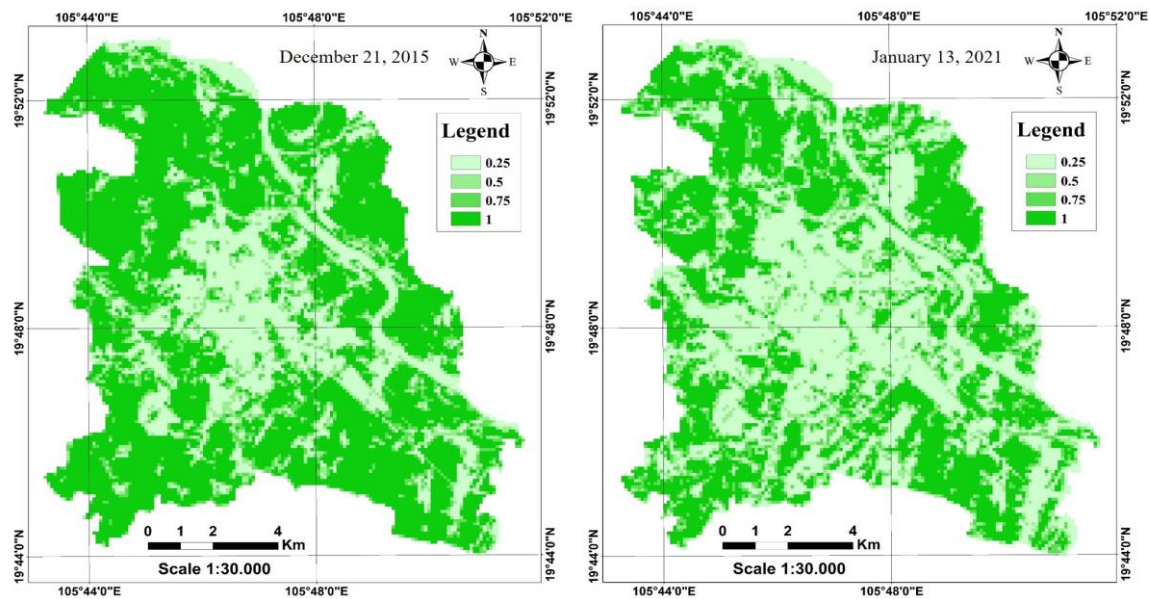


Fig. 4. The percentage of green parameter in Thanh Hoa city, December 21, 2015, and January 13, 2021.

The land cover in Thanh Hoa city is classified into 6 types (dense vegetation; shrubs, sparse vegetation; agricultural land; vacant; water body and built-up land), then create the buffer at a distance of 100 m. In this study, we use the eCognition Developer program to classify the land cover by using an object-oriented method. The land cover maps of Thanh Hoa city established from the Sentinel 2 MSI image on December 21, 2015, and January 13, 2021, are presented in Fig. 6. In this case, the overall accuracy of land cover classification reached 90.8% and 92.0%, the Kappa values were 0.86 and 0.89 respectively for Sentinel 2 images in 2015 and 2021.

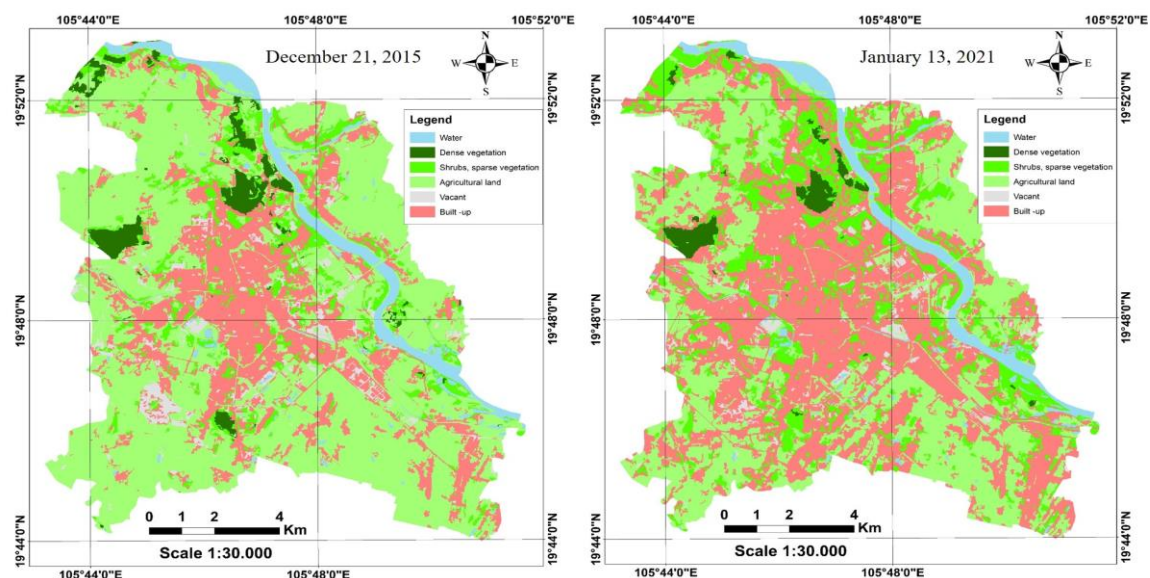


Fig. 5. Land cover maps in Thanh Hoa city, December 21, 2015, and January 13, 2021.

The results of land cover classification in Thanh Hoa city from Sentinel 2 images in 2015 and 2021 are presented in Table 2. It can be seen that the built-up land in Thanh Hoa city has increased significantly in

the period 2015-2021, from 3,554.38 ha in 2015 to 6,433.81 ha in 2021, equivalent to nearly 2 times. The agricultural land has decreased markedly, from 8,741.91 ha in 2015 to 5,151.57 ha in 2021, equivalent to more than 41%. Bare land (vacant) and dense vegetation classes also decreased, while the area of shrubs and sparse vegetation increased about 2 times.

Tab. 2. Land cover classification in Thanh Hoa city from Sentinel 2 MSI images.

No.	Land cover types	Area (ha)	
		December 21, 2015	January 13, 2021
1	Dense vegetation	476.89	293.90
2	Shrubs, sparse vegetation	1,218.13	2,412.60
3	Agricultural land	8,741.91	5,151.57
4	Vacant	583.14	309.96
5	Water body	772.99	745.63
6	Built-up land	3,554.38	6,433.81

These land cover types will be assigned weight values, then define proximity to green parameters according to studies [1, 2]. The weight of green types and weight of proximity to green parameters created from Sentinel 2 MSI image acquired on December 21, 2015, and January 13, 2021, in Thanh Hoa city, are presented in Figures 7 and 8.

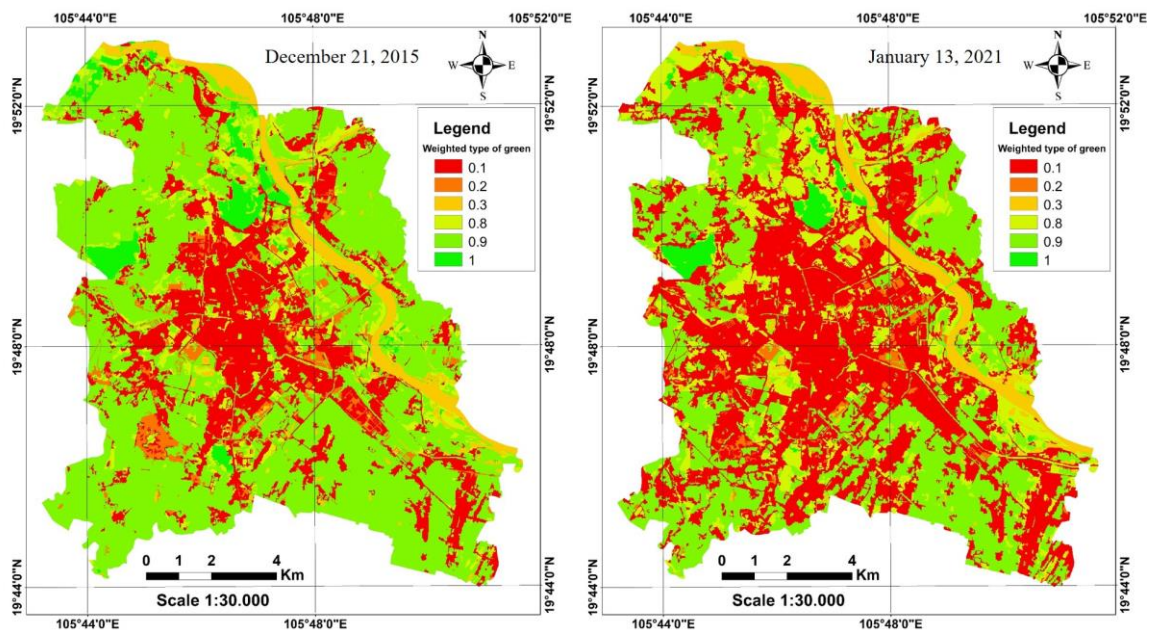


Fig. 6. The weight value of green types calculated from Sentinel 2 MSI data.

To calculate the WUGSI index according to formula 2, it is first necessary to determine the weight value W_j of each parameter: percentage of green, the weight of green types, and weight of proximity to green. The Analytic Hierarchy Process (AHP) method [16] was used to calculate the weights of individual parameters. Saaty’s method describes the level of importance of parameters and their relationship on a scale of 1 to 9. After calculating the weights, the consistency ratio index (CR) was computed to test the consistency of weights. In a study [17], Saaty indicates that the value of CR needs to be less than 0.1. The results of determining the weights of 3 parameters (percentage of green, weigh of green types, the weight of proximity to green) and the CR index values in this study are presented in Table 3. It can be seen that

the green type has the most influence on the quality of green space in urban areas, expressed in the weighted value of 02 parameters: percentage of green (0.590) and weight of green types (0.291). In this case, the CR value reaches 0.042.

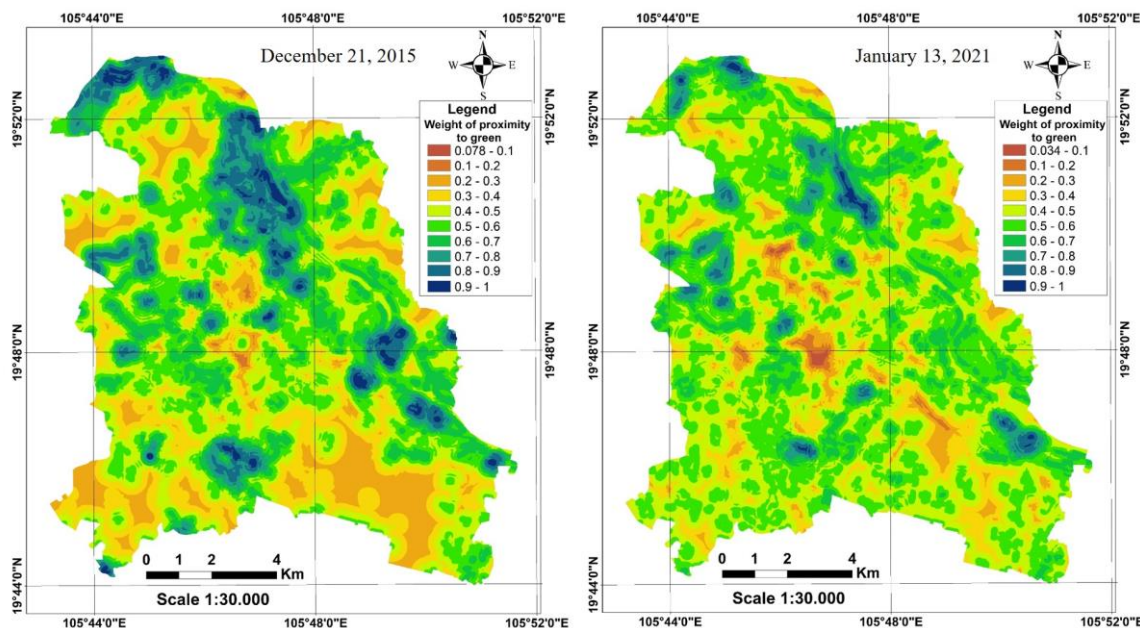


Fig. 7. The weight of proximity to green parameters calculated from Sentinel 2 MSI data.

Tab. 3. The weights of individual parameters and CR index.

No.	Parameter	The weight value	CR index
1	Percentage of green	0.590	0.042
3	Weight of green types	0.291	
4	Weight of proximity to green	0.119	

The result of the WUGSI mapping in Thanh Hoa city from the Sentinel 2 MSI images dated December 21, 2015, and January 13, 2021, are presented in Figure 8. The WUGSI index has a value between 0 and 1, in which the quality of urban green space is divided into 4 categories: low green space quality (< 0.30), moderate green space quality (0.30-0.50), high green space quality (0.50-0.70) and very high green space quality (> 0.70). The results of green space quality zoning in Thanh Hoa city from Sentinel 2 MSI images dated December 21, 2015, and January 13, 2021, are presented in Table 4.

The results obtained show that most of Thanh Hoa city has good green space quality, corresponding to 65.02% and 47.39% of the study area at category “very high green space quality” respectively for 2015 and 2021. The area with the category “high green space quality” also occupies a considerable area, equal to 6.34% and 7.34% of the total study area in 2015 and 2021. This can be explained by the relatively large area of agricultural land and shrubs, sparse vegetation land in Thanh Hoa city, especially after the city was expanded.

In contrast, the areas at categories “low green space quality” and “moderate green space quality” in 2021 both increased compared to 2015. In the 2015-2021 period, the area at category “low quality green space” increased from 7.17% of Thanh Hoa city area to 9.48%; the area at category “moderate level of green space” increased from 21.46% of the total study area to 35.79%. Thus, the area with poor quality of green space (low and moderate quality green space) has increased by more than 1.5 times after more than 5 years, from December 21, 2015 to January 13, 2021. In addition, Figure 7 shows that the area in low green space quality

is mainly concentrated in the central of Thanh Hoa city, mainly in Dong Tho, Dong Huang, Truong Thi, Dong Ve wards. Meanwhile, the wards outside the center city have green space levels ranging from high to very high green space quality. The areas with good green space quality are also similar to areas with a high percentage of green (> 0.5) (Fig. 4).

Tab. 4. The green space quality level in Thanh Hoa city, December 21, 2015, and January 13, 2021.

No.	Green space quality level	Area (%)	
		December 21, 2015	January 13, 2021
1	Low quality green spaces	7.17	9.48
2	Moderate quality green spaces	21.46	35.79
3	High quality green spaces	6.34	7.34
4	Very high quality green spaces	65.02	47.39

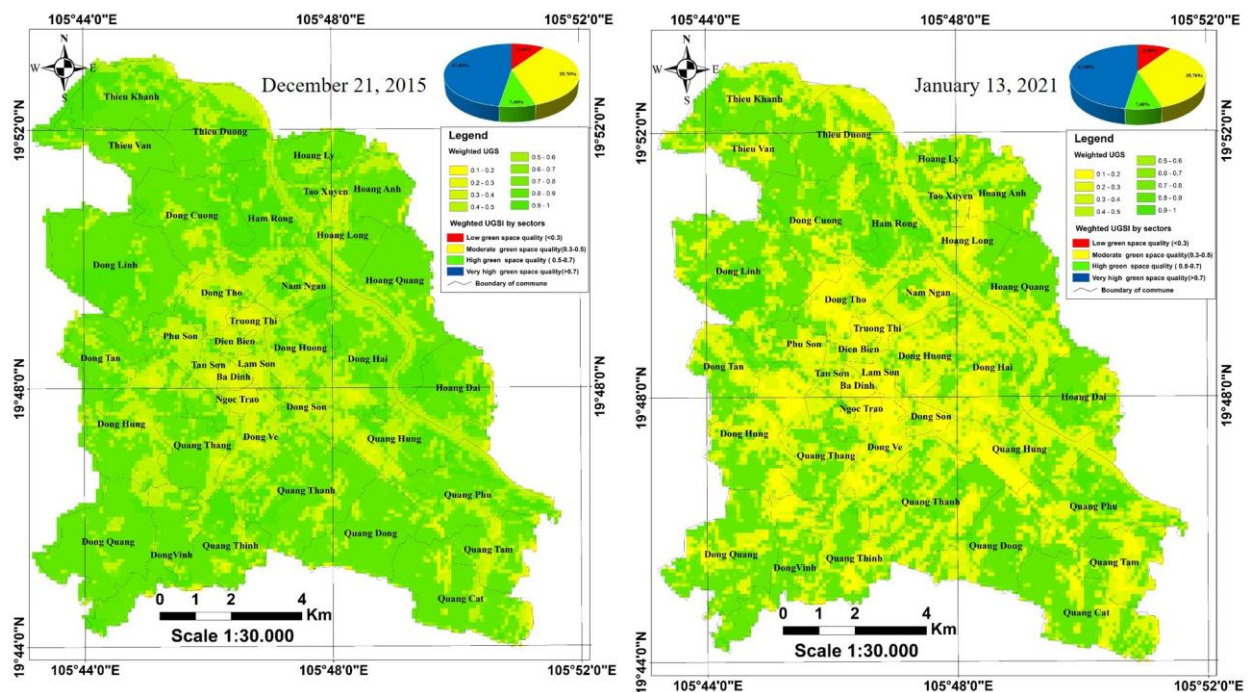


Fig. 8. WUGSI maps in Thanh Hoa city, December 21, 2015, and January 13, 2021.

4. Conclusion

Thanh Hoa is a fast-growing city and has good green space quality due to the relatively large area of agricultural land and shrubs, sparse vegetation land. The results obtained in the study show that most of the city area has very high quality of green space. However, the area with high quality of green space is rapidly decreasing in the period 2015-2021 due to the increase in built-up land. Along with that, the area at category low and moderate green spaces quality have increased significantly.

Remote sensing imagery with high spatial resolution and GIS data can be effectively used in preserving and monitoring green and open spaces in the urban area. Sentinel 2 MSI images with the highest spatial resolution up to 10 m are perfectly suitable for urban cover classification, thereby calculating parameters such as percentage of green, percentage of built-up land, the weight of green types, weight of proximity to green. These are the input parameters to calculate the WUGSI index to classify the quality level of urban green space. The results obtained in the study are objective and timely information, helping managers in

monitoring and planning land use in urban areas.

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