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THE INTEGRATED MODEL DEVELOPMENT FOR ASSESSING URBAN GREEN SPACE QUALITY. A CASE STUDY IN HANOI INNER CITY, VIETNAM

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Abstract: Urban Green Space (UGS) is considered fundamental for the sustainable development of the urban economy. The purpose of this study is to assess the quality of urban green space in the Hanoi inner city using the integration of GIS technology, remote sensing, and AHP model. Sentinel 2-MSI data taken in 2020 were utilized to identify three criteria, namely percentage of green, type of green types, and proximity to green. AHP was used to determine the weighted correlation among parameters based on their importance to this phenomenon. As the result, the quality of UGS was classified into four classes, namely very high-quality green, high-quality green, moderate quality green, and low-quality green. The results showed an imbalance in the quality of green space in the study area. In which, areas with high and very high-quality green were distributed mainly on the edge of the city center, accounting for 41% while low quality urban green space was found in the center with 22.4 %.

Key words: urban green space, quality of urban green space, Hanoi Inner City, AHP, Sentinel-2MSI

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INTRODUCTION

Urbanization is an inevitable development trend in most countries in the world. This process contributes to economic growth, creates employment opportunities, develops the infrastructure, and improves standards of living (David, 2008; Nghia et al., 2021). However, besides these positives, urbanization also creates many challenges for the development of cities, such as uneven demographic densities, traffic congestion, and environmental pollution (Davies et al., 2008; Saulle and La, 2011; Nghia et al., 2021). Urbanization has also led to a significant change in the structure of land use, with an increase in built-up land and a decrease in the vegetative cover which poses a great challenge to balanced and sustainable urban planning (Shruti et al., 2019). UGS is defined as urban land, partly or completely covered with grass, trees, shrubs, or other vegetation. It also includes blue-green zone such as ditches, canals, inland waterways, and rivers and riverbanks (De et al., 2021). UGS plays an extremely important role in the sustainable development of the city. It brings numerous valuable benefits e.g improving air and water quality, mitigating noise pollution, and reducing environmental health risks associated with urban living (Thompson, 2002; Gupta et al., 2012; Liu et al., 2014). In addition, it helps stress alleviation and relaxation, physical activity, improved social interaction, and community cohesiveness (Saulle and La, 2011; Maryanti et al., 2016; De, 2021). Although UGS is considered an indispensable factor for the sustainable development of urban areas, a serious decline in the area and quality of urban green space has been taking place in many cities in the world, especially in developing countries (Liou et al., 2021). Therefore, the assessment of the quality of urban green space is considered one of the top concerns of managers and planners in the urban development strategy.

The case study is Hanoi inner city located in the north of Vietnam (Figure 1). It covers an area of 25840 hectares, and the population reaches 3.27 million people (as of the 2020 census). It is known as the second most populous administrative unit in Vietnam. Hanoi is featured by a humid tropical monsoon climate with plentiful precipitation. Because of the recent socio-economic changes, population growth, and urbanization, Hanoi city is witnessing spatial expansion in administrative boundaries and a significant change in the urban landscape. The area of green space is significantly reduced and replaced by residential and construction land (Nong et al., 2018). Owing to urban sprawl with subsequent land-use changes, Hanoi inner city is facing increased environmental pollution, increased floods due to decreased green space, and the emergence of the urban heat islands effect (Uy and Nakagoshi, 2007). Meanwhile, the area of UGS is too small, with only 1 square meter of urban green space for each person, much lower than the WHO standard (9 square meters for each person) (Maryanti et al., 2016). This poses a big warning, threatening the future sustainable development of the city. However, there is too little thorough research on UGS in Hanoi so far. Therefore, assessing the current status of urban green space quality in Hanoi inner city is very necessary, making an important contribution to the planning and development of the city in a sustainable way. Based on these findings, the key objective of this study is to develop a simple model to quantify the quality of urban green space in the study area. Satellite data combined with spatial analysis tools in GIS are

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used to determine three criteria in green space quality assessment including the percentage of green, weighted type of green, and proximity to green. The multi-criteria analysis method is used to determine the correlation between the above criteria, from which an integrated model was built to calculate the quality of green space in the study area.

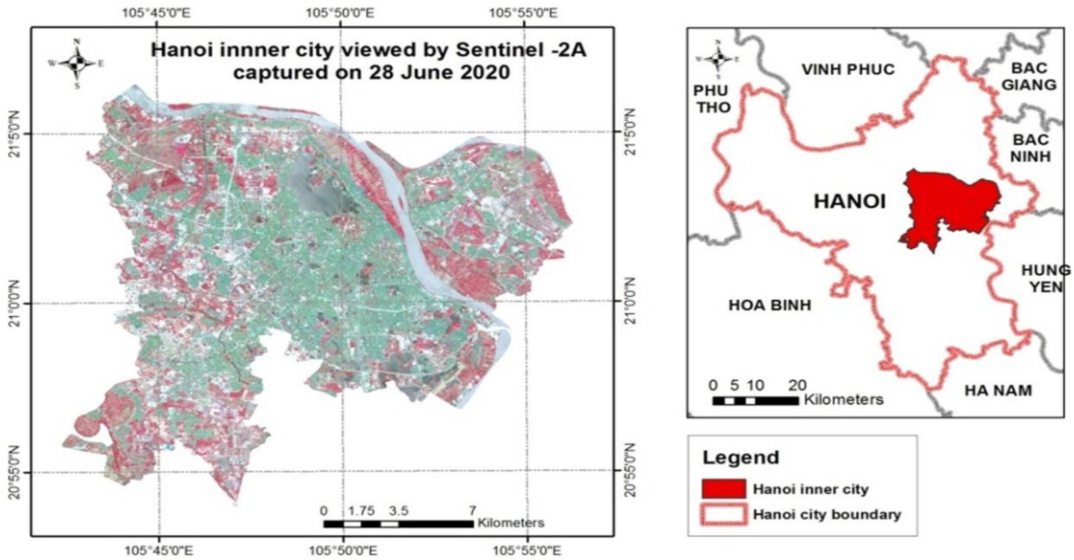

Figure 1. Location of the study area (Source: Author)

MATERIALS AND METHODS

1. Materials

Various criteria in this study are computed by using Sentinel 2A level 1C image. This image was taken on 28 June 2020 and freely downloaded from the website of the European Space Agency (https://scihub.copernicus.eu/). Sentinel 2A satellite was launched in 2015 and carried a single multi-spectral instrument (MSI) with 13 spectral bands in the visible/near-infrared (VNIR) and short wave infrared spectral range (SWIR) at high spatial resolution (10 m to 60 m). To avoid cloud and unwanted shade-free imagery, the images are selected at times with the cleanest sky in June.

The second data is the administrative map at a 1:550,000 scale provided by the Ministry of Natural Resources and Environment. The map is used to define the scope of the study territory and administrative units. Moreover, the map is considered as the background data to determine the location for fieldwork.

2. Methods

The methodology is illustrated in the flowchart, as shown in Figure 2.

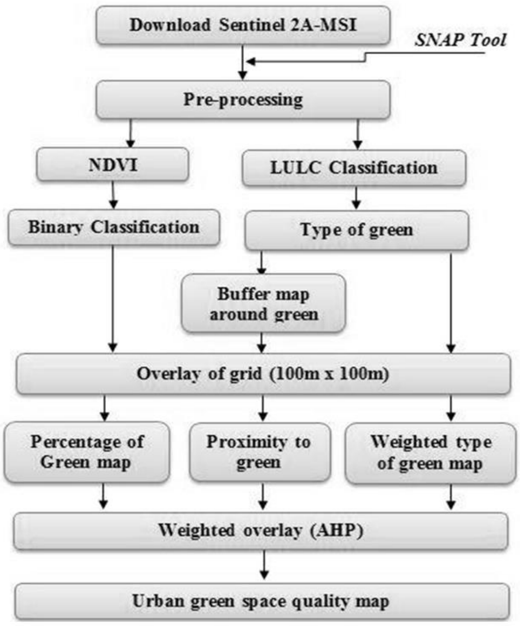

Figure 2. Flowchart of methodology (Source: Authors)

2.1. Pre-processing

After downloading Sentinel 2A-MSI, the image was preprocessed with geometric correction and atmospheric corrections using SNAP software.

Geometric correction: Because the spectral bands are stored as jpg-files in three different geometric resolutions (10 m, 20 m, and 60 m), the images were stacked into a single Geo-tiff file of a uniform pixel size of 10 m by using resample tool in SNAP software. The image projection was kept projection at Universal Transverse Mercator (UTM) WGS- 84 Datum, Zone 48.

Atmospheric correction: It is an essential step to eliminate negative effects on the accuracy of results caused by the atmosphere. Sen2Cor (http://step.esa.int/main/third-party-plugins-2/sen2cor/), was used to convert the Top-Of-Atmosphere (TOA) reflectance to Bottom of Atmosphere (BOA) reflectance. The subset steps were also carried out to reduce the size of the scene to include only the study area and speed up processing.

2.2. Identify criteria for UGS

a) Identify the percentage of green

Normalized Difference Vegetation Index (NDVI) was used to identify the percentage of green. This is one of the most popular indices to quickly identify vegetated areas and the health of vegetation with the value from -1 to +1 (Tung and Wai-Lok, 2010). NDVI was determined based on the difference between the Red band and Near-Infrared as equation 1. In the next step, a threshold of NDVI was identified to create a binary classification map including two classes, namely green and non-green classes. The 100m × 100m grid was overlaid on the binary map, and the percentage of green in each cell was calculated using ArcGIS software version 10.8. Based on the percentage of green in each cell, the percentage of green map was classified into four classes, namely low, moderate, high, and very high green quality. In which, the percentage of green in each cell less than 25% was assigned at a low level. In the same manner, moderate green quality, high green quality, and very high green quality values were given to cells where the percentage of green is 25–50%, 50–75%, and more than 75%, respectively (Table 1).

NDVI = (NIR – Red) / (NIR + Red) (1)

Where: NIR: Reflection in the near-infrared spectrum (Band 8)

Red: Reflection in the red range of the spectrum (Band 4)

b) Identify the weighted type of green

The basic types of urban green classes (dense urban vegetation, agricultural land, low/grass vegetation land, open space land, water, and built-up areas) were identified as target classes in SNAP software. Characteristic of features on the ground was identified by interpretation key and the Maximum likelihood method was utilized to classify the urban green space. The field survey was carried out to verify the accuracy of the classification results. The overall accuracy for the classified image was found to be 90.7%, which was more than the minimum accuracy criteria of 85% (Anderson et al., 1976). A 100 m x100 m grid was overlaid on the type of green map. The criteria for defining the green quality classes in the type of green map were identified based on tree canopy density (Gupta et al., 2012) and shown in Table 1. The cells which have an area of dense urban vegetation of equal to or more than 50% were assigned as very high quality (1). The cells which have an area of low/grass vegetation land of equal to or more than 50% were given as high quality (0.75). The cells which have an area of open space or water of equal or more than 50% were given as moderate green quality. The low green quality corresponds to cells with a built-up area of over 50% (0.25).

c) Identify proximity to green

Based on the type of green map, the multi-ring buffers were created with buffer distances of 100m, 200m, and above 300m for each type of green using ArcGIS software. Similar to the two above criteria, a grid of 100 m × 100 m size was overlaid on the type of green buffer map and proximity to green map generated using ArcGIS software. The criteria for defining the green quality classes in proximity to green map are classified into four classes as Table 1. In which, the cells located in a radius of less than 100m around dense urban vegetation were given as very high quality (1). The cells located in a radius of 100 - 200 m around dense urban vegetation or less than 100m around low/grass vegetation were assigned as high green quality (0.75). The cells located in a radius of less than 300 m around low/grass vegetation, open spaces, and water were given as moderate green quality (0.5). The cells located in a radius less than 100 m around built-up were assigned low green quality (0.25). The methodology is illustrated in the flowchart, as shown in Figure 2.

Table 1. Criteria and their scaling to measure the quality of urban green space (Source: Authors)

No	Criteria	Description	Value	Quality classes
1	Percentage of Green	Less than 25%	1	Low green quality
		From 25 to 50%	2	Moderate green quality
		From 50 to 75%	3	High green quality
		Greater than 75%	4	Very high green quality
2	Weighted type of green	The cells have a built-up area of over 50%	1	Low green quality
		The cells have an area of open space or water equal to or more than 50%	2	Moderate green quality
		The cells have an area of low/grass vegetation equal to or more than 50%	3	High green quality
		The cells have an area of dense urban vegetation equal to or more than 50%	4	Very high green quality
3	Proximity to green	The cells are located in a radius of less than 100 m around built-up	1	Low green quality
		The cells are located in a radius of less than 300 m around low/grass vegetation, open spaces, and water	2	Moderate green quality
		The cells are located in a radius of 100 - 200 m around dense urban vegetation or less than 100m around low/grass vegetation	3	High green quality
		The cells are located in a radius of less than 100m around dense urban vegetation	4	Very high green quality

2.3. Generation of UGS quality map

Table 2. The relative of criteria (Source: Calculated by the authors)

	Percentage of green	Type of green	Proximity to green
Percentage of green	1.00	1/3	1/3
Type of green	3.00	1.00	1/2
Proximity to green	3.00	2.00	1.00
Total	7.00	3.33	1.83

Analytic Hierarchy Process (AHP) was used to determine the weights of the criteria. This method was developed by Thomas Saaty in 1980 and became one of the most famous methods for making multi-criteria decisions. Individual experts' experiences are utilized to estimate the relative magnitudes of factors through pair-wise comparisons with a comparison scale from 1 to 9. The relative preference of one criterion above another is defined. In this study, the relative preference of the three above criteria was assigned based on the opinions of 15 experts including urban planners, geographers, and researchers working in the field of urban planning. The relationship between the pairwise was shown in Table 2. After the computation of weights using Saaty's pairwise comparison method, the Consistency Ratio (CR) was calculated to check the fitness of the weights. If the value of CR is smaller or equal to 0.1, the inconsistency is acceptable. If the consistency ratio is greater than 0.1, we need to revise the subjective judgment (Saaty, 1980). In this case, CR was found at 0.06 and it means that the determined weights were suitable. As the result, proximity to green was considered the most important criteria and given a weight of 0.52. The weights of the percentage of green and type of green were assigned 0.14 and 0.33 respectively, as shown in Table 3.

Table 3. Matrix normalization (Source: Calculated by the authors)

	Percentage of green	Weighted Type of green	Proximity to green	Total	**Average**	Consistency measure	CR
Percentage of green	0.14	0.10	0.18	0.42	**0.14**	1.05	0.06
Weighted Type of green	0.43	0.30	0.27	1.00	**0.33**	0.91	
Proximity to green	0.43	0.60	0.55	1.57	**0.52**	1.04	

A weighted Urban Green Space Index (WUGSI) is generated to assess the quality of UGS in the study area. This index is calculated based on three criteria, namely percentage of green, weight type of green, and proximity to green as equation 3 (Source: authors).

$$WUGSI = \frac{0.14 * X_1 + 0.33 * X_2 + 0.52 * X_3}{3} \quad (3)$$

Where: WUGSI: Weighted Urban Green Space Index; X_1: Percentage of Green; X_2: Type of Green; X_3: Proximity to Green.

Table 4. Percentage of green by levels (Source: Authors)

Classes	Area (ha)	Percentage (%)
Low green quality	9908.7	32.0
Moderate green quality	4779.2	15.4
High green quality	4714.4	15.2
Very high green quality	11545.4	37.3

RESULTS AND DISCUSSION

1. Percentage of green

Values of NDVI are scaled from -0.232768 to 0.653429 (Figure 3). The green space is extracted from NDVI map. A threshold value is proposed to classify NDVI values into the binary map (Green and Non-green). As the result, the green space area is accounted for 52.6% while the non-green space area is assigned 47.4% (Figure 4). UGS is very sparse in the central area and shows the overall uneven distribution across Hanoi inner city (Figure 5). The percentage of green is classified into four classes, namely less than 25%, from 25 to 50%, from 50% to 75%, and greater than 75%. In which, low green quality with a percentage of green less than 25% covers 32.0 % of the study area and distributes mostly in the central area. Because most of the population is densely lived in the central area of the city, the land here is mainly used for construction purposes with buildings, green space is significantly limited. Areas of high and very high green quality are concentrated around the center with values of 15.2% and 27.2% respectively (Table 4).

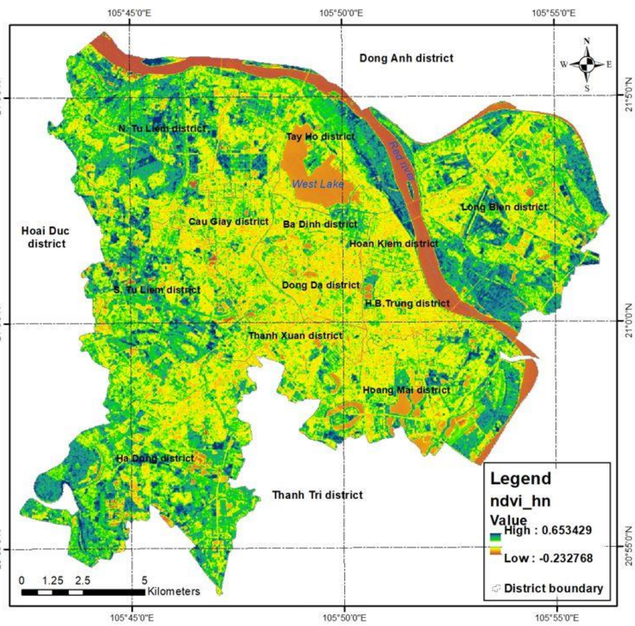

Figure 3. NDVI range (Source: Authors)

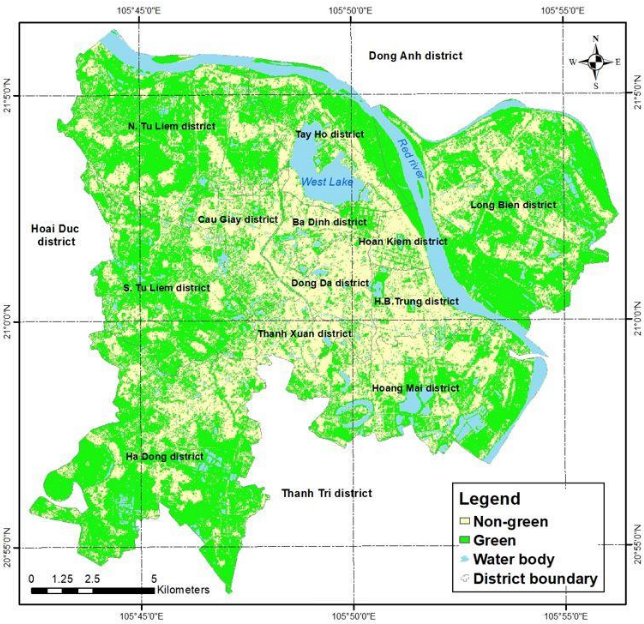

Figure 4. Binary classification (Source: Authors)

2. Weighted type of green

Figure 6 describes the type of green in the study area by the Maximum likelihood method in SNAP software. The overall accuracy for the classified image was found at 87.5%. Table 5 indicates that the built-up accounts for the highest proportion of the land structure with 41.0% while the area of land with dense urban vegetation accounts for 2.4%.

Table 5. Land use structure (Source: Authors)

Type of land use	Area (ha)	Percentage (%)
Dense urban vegetation	754.3	2.4
Low/grass vegetation	7694.3	24.9
Open space land	6617.4	21.4
Water	3191.2	10.3
Built-up	12687.6	41.0

The results show an imbalance in the land use structure. Accordingly, the percentage of green space is too little, the green area only accounts for 48.7%. The ratio of green space in the study area is estimated to be less than 2 square meters per person on average, much lower than in other countries in the world such as London 40 sq m/person, Washington 38 sq m/person (Maryanti et al., 2016). Figure 7 shows the quality of urban green space based on the canopy density of trees. Areas with high canopy density such as parks and botanical gardens are assigned at a very high green quality and account for 4.7%. Areas with low quality of green occupy a large area in the study area. These are construction land areas with asphalt, concrete, or brick and they cover about 39.8% of the area.

Figure 5. Percentage of green (Source: Authors)

Table 6. Weighted type of green by levels (Source: Authors)

Classes	Area (ha)	Percentage (%)
Low green quality	12327.5	39.8
Moderate green quality	10494.2	33.9
High green quality	6674.8	21.6
Very high green quality	1451.1	4.7

Table 7. Proximity to green by levels (Source: Authors)

Classes	Area	Percentage
Low green quality	6857.9	22.2
Moderate green quality	11190.5	36.3
High green quality	11252.7	36.5
Very high green quality	1523.6	4.9

Table 8. Quality of UGS by levels (Source: Authors)

Classes	Area (hectare)	Percentage (%)
Low	4857.8	22.4
Moderate	11040.4	36.0
High	11252.7	36.7
Very high	1523.6	5.0

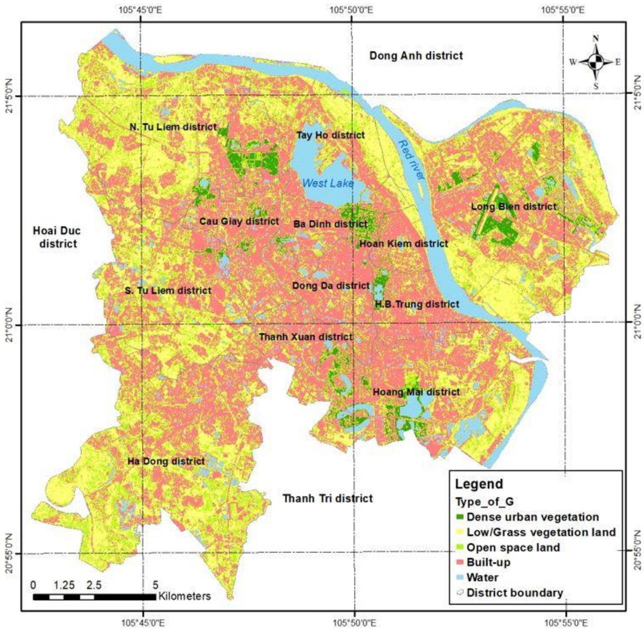

Figure 6. Type of green (Source: Authors)

Figure 7. Weighted type of green (Source: Authors)

3. Proximity to green

Figure 8 shows a clear difference in the degree of proximity to green in the study area. In which, areas with low levels of access to green space are distributed in central Hanoi with 22.2% area of the study area, where densely distributed urban areas coexist with small green spaces. More than 50% of the population is distributed in this area. It means that about half of the population in Hanoi inner city is not sufficiently close to green space (Table 7).

4. Quality of Urban green space

Map of UGS quality is built by using an arithmetic weighted overlay approach from three criteria, namely percentage of green, weighted type of green, and proximity to green (Equation 3). The calculated values are further classified into four green quality classes for ease of visualization and comparative evaluation. The quality of UGS is presented in Figure 9. The research results clearly show the imbalance in the quality of green space in the study area, especially the significant difference between the central and suburban areas. As the result, areas with low and very low quality of green space account for 22.4% and are distributed mainly in the central area of the city. Areas with good and very good quality of green space are scattered around the central area, accounting for 36.7% and 5.0%, respectively.

The map shows the current status of green space quality in the whole area. Accordingly, green space in the study area has not been properly planned, which is doing very well in many developed countries (Oh-Hyun et al., 2021). There is a significant imbalance between the central area and the surrounding area. The quantifiable information regarding green structures and their distribution is very important for sustainable planning. The developed index provides a decision support tool to evaluate, quantify and compare various neighborhoods in terms of the amount and distribution of green structure.

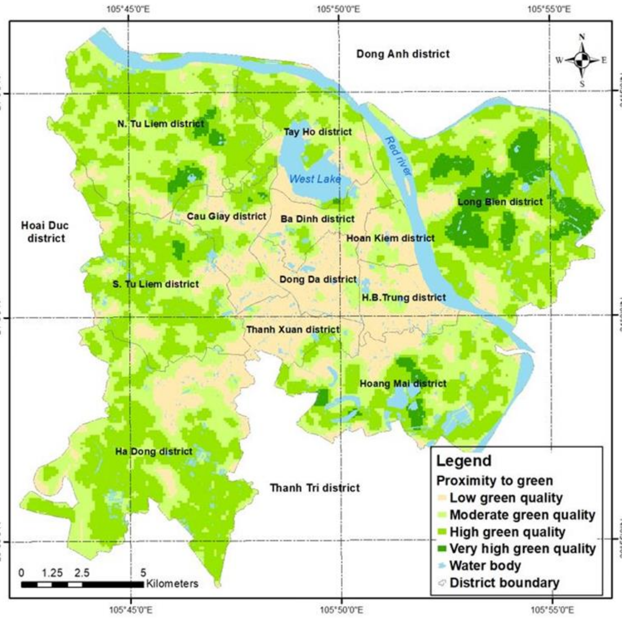

Figure 8. Proximity to green (Source: Authors)

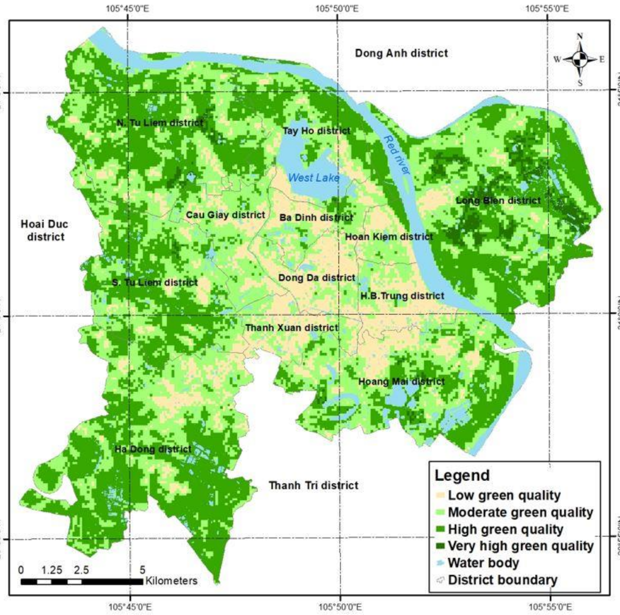

Figure 9. Quality of Urban Green Space (Source: Authors)

The quality of UGS is not only considered based on a percentage of green but also assessed based on the proximity of green space in specific neighborhoods and environments. The type of green with the difference in canopy density is also taken into in this model. The assessment of green space quality in many aspects with the participation of experts makes the research results more reliable. Therefore, this model can be used by spatial planners and urban managers. The application of this index can provide an opportunity to undertake a range of neighborhood greening strategies and will be useful information for the urban planning system in Hanoi inner city.

Literature shows that many studies have used multi-criteria analysis based on GIS for assessing the quality of UGS in the world. The integrated model of GIS and AHP has been proven and applied effectively in many studies. The quality of UGS was effectively assessed by using the Urban Neighborhood Green Index which was built by four criteria, namely percentage of green, built-up density, proximity to green, and height of structures in Delhi, India (Gupta et al., 2012). The quality of UGS in some big cities in China was also assessed based on the green index, proximity to green, density of high built-up, and building sparsity (Yuqin et al., 2015; Zhanqiang et al., 2019).

CONCLUSION

The process of urbanization is accelerating the development of urban areas around the world. As of 2021, the urban population accounts for 56.2% of the population. The increasing urban growth rate leads to the rapid decline of urban green in cities. The urban green space quality zoning map provides important documents that contribute to reflecting the current status of green space in the study area. Instead of just looking at a single component like the percentage of green, the WUGSI reflects the quality of urban green space holistically, where the distribution of green space in residential areas has a significant influence on the quality of life of residents and urban structure.

With the increasing impact of global warming, coupled with unsustainable urbanization, many cities around the world are facing new challenges such as intensified Urban heat island effect (Shishegar, 2014; Huang et al., 2018). The important role of UGS provides city planners with important lessons learned in sustainable urban development and improves the human life quality (Michelle et al., 2018). The research results reflect the current status of green space quality in the inner city of Hanoi. On that basis, managers need to have appropriate solutions to rationally use and plan urban green space in Hanoi. Some possible solutions are suggested such as (1) Strengthening cooperation between urban management agencies and the Department of Natural Resources and Environment, (2) Raising people's awareness of protecting green spaces, and (3) relocation of the building structure to reduce the population density in the downtown.

This study takes advantage of Sentinel satellite image data. Our results indicated that Sentinel-2 MSI data with a 10-meter-resolution band may assist decision-makers in the knowledge of the physical features of UGS in the city. Remote sensing imagery with high spatial resolution and GIS data can be effectively used in preserving and monitoring green and open spaces in urban areas. Sentinel 2 MSI images can provide information about the percentage of green, the weight type of green, and proximity to green. The data from the field survey helps to strengthen the research results. The combination of remote sensing with spatial analysis and processing functions in GIS makes correlation assessment easier. The study demonstrates that remote sensing images coupled with GIS can be a valuable tool for evaluating urban green structures. GIS can be an effective tool for preserving and monitoring green and open spaces in an urban area.

GIS technologies play a crucial role in UGS planning. The combination of GIS and AHP brings a flexible and realistic tool for assessing the quality of UGS in the study area. The contribution of experts in the determination of the criteria using AHP improves the reliability of research results. This study can provide a framework for the planning of USG and land use planning in the study area in the future. Improving the quality of urban green space plays an important role in the city's sustainable economic development strategy. This research, however, is subject to several limitations. Firstly, some other parameters can be used to analyze UGS such as density of built-up, the density of high built-up, building sparsity, etc (Zhanqiang et al., 2019). However, this study only evaluates the quality of green space based on three indicators, namely percentage of green, type of green, and proximity to green. Assessing the UGS index based on proximity to surrounding built-up, usability, population to be served and the combination of several other parameters will yield better results. Secondly, using high-resolution satellite images can bring better effectiveness. LIDAR data or stereo pairs can provide useful information about urban structure (Faryadi and Taheri, 2009; Zhanqiang et al., 2019).

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