International Information and Engineering Technology Association
Advancing the World of Information and Engineering

International Journal of Sustainable Development and Planning
Vol. 20, No. 3, March, 2025, pp. 1061-1075
Journal homepage: http://iieta.org/journals/ijsdp

Integrating Urban Design with Natural Dynamics: Enhancing Ecological Resilience in Malang City over a Decade

Andik Isdianto[1], Abdul Wahid Hasyim[2*], Bangun Muljo Sukojo[3], Ilham Alimuddin[4], Intan Astritya Anggraini[2], Erland Raziqin Fatahillah[2]

[1] Department of Marine Science, Faculty of Fisheries and Marine Science, Brawijaya University, Malang 65145, Indonesia
[2] Department of Urban and Regional Planning, Faculty of Engineering, Brawijaya University, Malang 65145, Indonesia
[3] Department of Geomatics Engineering, Faculty of Civil, Planning and Geo-Engineering, Institut Teknologi Sepuluh Nopember, Surabaya 60111, Indonesia
[4] Department of Geological Engineering, Faculty of Engineering, Universitas Hasanuddin, Gowa 92171, Indonesia

Corresponding Author Email: awahidhs@ub.ac.id

https://doi.org/10.18280/ijsdp.200313

Received: 27 January 2025
Revised: 6 March 2025
Accepted: 11 March 2025
Available online: 31 March 2025

Keywords:
eco-sustainable development, green infrastructure, LST, land use change, remote sensing, urban expansion, UHI, vegetation cover

ABSTRACT

This study explores the ecological consequences of urban expansion in Malang City from 2014 to 2024, highlighting how integrating urban design with natural dynamics can enhance a city's resilience to ecological change. Using advanced remote sensing techniques with Landsat 8 OLI/TIRS and Sentinel-2 imagery, the analysis measures changes in key environmental indicators such as Land Surface Temperature (LST), Normalized Building Index (NDBI), and Normalized Vegetation Index (NDVI). Findings show significant ecological changes, including an average increase in LST of 4.72°C, an increase in built-up area of approximately 1.19 km², and a decrease in high-density vegetation cover of 21.47 km². These changes underscore the need for urban design and planning that is not only responsive to current needs but also able to adapt and mitigate long-term ecological impacts. This study proposes a sustainable urban design approach that integrates ecodynamic principles to strengthen urban resilience, relevant not only to Malang but also as a model for global cities in facing the challenges of urbanization and climate change. It emphasizes the importance of green infrastructure development and sustainable zoning practices as key strategies to strengthen the ecological and social resilience of future cities.

1. INTRODUCTION

Urban growth in terms of population, area expansion, landscape change, conversion of non-building land into impermeable built-up areas has become an increasing trend around the world today [1]. A city's growth and development are mostly determined by its population, as the city serves as a physical hub for the activities of its urban community [2]. There has been an increase in the transformation of natural landscapes into human settlements [3] which can directly influence on the built environment and global and local climate.

While the activity of converting natural surfaces to artificial surfaces can reduce evapotranspiration and change the nature of surface radiation ultimately changing the quality of the surrounding thermal environment such as temperature changes. Changes in thermal quality in urban environments can create a more sensitive environment and increase human health risks [4]. Since the urban heat island (UHI) effect can have major ecological and social repercussions, it has been a source of worry for over 40 years and is a popular topic of study in the fields of urban climatology and urban ecology [5]. Changes in the spatial extent and composition of built-up areas or vegetation, as well as changes in spatial planning, all have an impact on the severity of UHI [6].

Malang City is the second largest city in East Java after Surabaya City [7]. Rapid development in various development sectors has an impact on high urbanization. Every year, the average population of Malang City has increased where in 2020-2023 the population growth rate was 0.13% [8]. Additionally, a sizable amount of in-migration 22.397 individuals in 2023 contributes to the population growth. The growth in population certainly has an impact on the physical development of the Malang City.

However, the physical development of Malang City has not been balanced with the right development concept so that it reduces the area of green open space as a vital land use in maintaining environmental quality. The area of green open space in Malang City continues to decrease every year due to land conversion into residential and industrial areas [9]. This is shown by the area of rice fields which decreased in 2011-2023 to 305 hectares [8]. In addition, there was a significant increase in the area of built-up land where in 2012-2020, there was an increase of 6% to 56.05 km^2 or 51% of the total area of Malang City [10]. In addition, land use change activities also have implications for increasing the average LST of Malang

City. Malang City's average LST rose by more than 2°C over the previous 21 years (1997-2018) [9]. Based on this increase, it can be predicted that there will continue to be an increase in average LST in the following years given the increasing population and land needs.

In general, the LST pattern of Malang City follows the land cover pattern. When analyzing high- to low-resolution imagery connected to changes in land use or land cover, remote sensing or geographic information systems are crucial tools for identifying LST patterns [11]. With its versatility, geospatial technology can be used to map patterns of urban growth, track changes in land cover, and offer information on the distribution of the physical characteristics of land [1]. LST distribution data obtained from remote sensing methods may be able to better indicate the hottest and coldest areas compared to temperature data by local meteorological stations [12].

This study has the main objective to investigate the ecological impacts of urban expansion in Malang City from 2014 to 2024, with a primary focus on how urban design principles can be integrated with natural dynamics to enhance ecological resilience and sustainability. This involves data on LST change, building density index, vegetation density index and population distribution as a reflection of the interaction of urban design with natural processes. The use of the population distribution variable shows the novelty of this study as most studies on UHI only include building index and vegetation index as some of the variables that affect LST. In addition to land use index, population size may also affect LST as dense population is directly proportional to building density. The correlation between LST and NDBI, NDVI, and population was then analyzed using the regression method to strengthen the claim of the relationship between these variables.

This study aims to propose sustainable urban design strategies that not only address the immediate impacts of urban expansion but also contribute to the long-term sustainability and resilience of urban ecosystems. The final outcome of this study seeks to provide insights that can guide the design and development of urban environments in a way that is in harmony with and supportive of natural ecological dynamics.

2. METHODOLOGY

2.1 Study area and data collection

Malang City is a city in East Java Province covering an area of 111,077 km^2 which is at an altitude of 445-526 meters above sea level [8]. Malang City has 5 districts, namely Klojen district, Lowokwaru district, Blimbing district, Sukun district, and Kedungkandang district. One of the criteria for selecting Malang City as the study area is based on the population aspect where the population growth rate in Malang City generally always increases every year. In 2015, the population of Malang City was 851,298 people and in 2024 the first semester was 880,787 people [8].

Based on BPS Malang City, in 2023 the minimum temperature of Malang City occurs in September, which was 14.80 degrees Celsius. While the maximum temperature occurs in October, which was 34.00 degrees Celsius. The lowest average temperature occurs in July with an average temperature of 24 degrees Celsius and the highest average temperature occurs in October with an average temperature of 27.30 degrees Celsius. Then for the lowest average air humidity occurred in October with an average humidity of 60.80% and the highest average air humidity occurred in February with an average humidity of 80.40%. Based on rainfall conditions, The highest amount of rainfall occurred in December at 314.60 mm/month and the lowest was in August at 3.40 mm/month [8].

Figures 1 and 2 show the place of this research, Malang City, East Java Province. Figure 1 shows the location map of Malang City with East Java Province. Figure 2 shows the administrative map of Malang City, which consists of 5 districts namely the districts of Klojen, Lowokwaru, Blimbing, Kedungkandang, and Sukun.

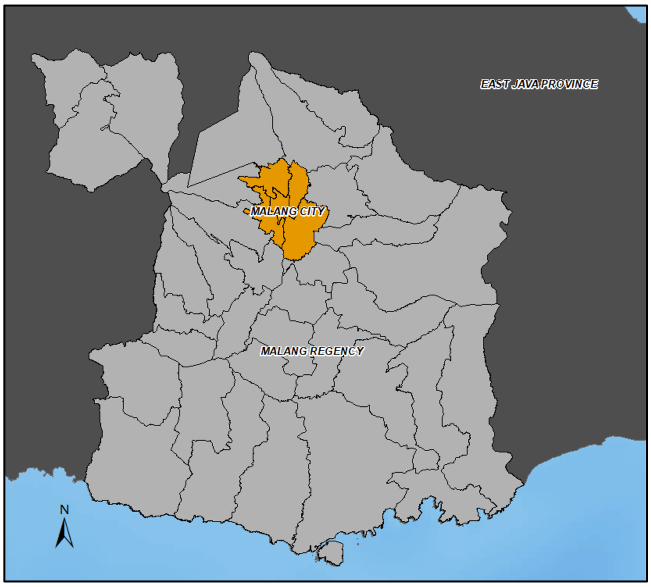

Figure 1. Orientation map of Malang City

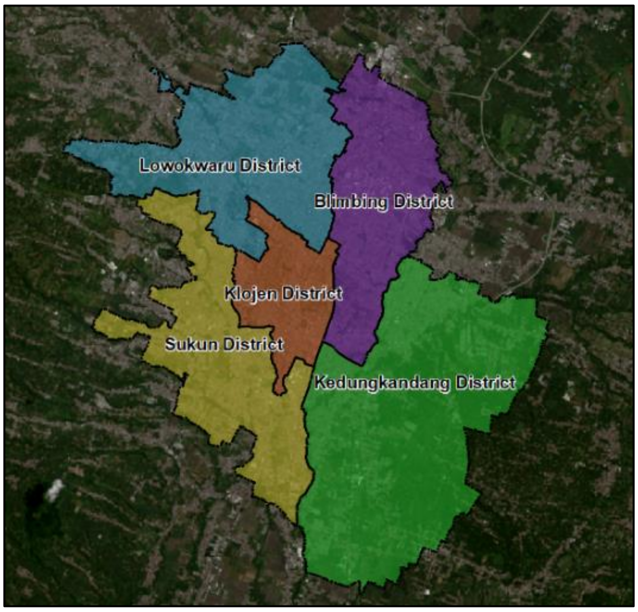

Figure 2. Administrative map of Malang City

The analysis technique used in this research is the time series technique. Time series is a series of data sorted by observation time taken at fixed intervals such as daily, monthly, and annually. The purpose of the time series analysis technique is to identify patterns or trends in the data under study over time. Understanding the characteristic patterns based on time series data can strengthen findings related to factors that can affect changes in the data so as to make better decisions [13].

The data used in this study are data observed in 2014, 2019, and 2024. The observation period in this study is for 10 years with a time interval of every 5 years. The three years of observation were chosen because Malang City in 2014 to 2024 had a significantly different condition comparison based on the building index, vegetation, and population. By observing the condition of Malang City in a period of 10 years, it is sufficient to analyze the pattern of changes in the condition of Malang City so that it can be further studied regarding the relationship between the research variables. However, observations with a larger amount of time data may result in a clearer identification of change patterns to predict future values.

2.2 Remote sensing theory

Remote sensing is composed of two words, namely remote which means obtaining information without direct contact and sensing which means obtaining information on the condition of the earth's surface (Canada Center for Remote Sensing, 2010) in the study [14]. The tools used are usually satellites, drones or unmanned aircraft, airplanes, hot air balloons, and so onTo comprehend the spatial and temporal variations of fundamental physical attributes depending on various land use patterns, field surveys using remote sensing devices are essential [15]. Planning, management, and monitoring of the environment depend on processing current, accurate data on land cover and environmental conditions [16].

In this research, using Landsat 8 and Sentinel-2 satellite image data. ArcGIS 10.4.1, ENVI 5.3, QGIS 3, IBM SPSS Statistics 25, and Microsoft Excel software were used for image and mapping data processing. ArcGIS 10.4.1 software was used to perform the image pre-processing stage consisting of geometric correction, radiometric correction, and atmospheric correction to improve image quality. The ready images were then processed to obtain NDBI and NDVI values and their classification by entering the relevant formulas using the raster calculator and reclassify tools. ENVI 5.3 software was used to calculate and classify the LST value of the corrected image by entering the related formula using the band math tool. QGIS 3 software is used to calculate the average value of all variables based on administrative boundaries and grids to be further analyzed using zonal statistics tools. Then SPSS and Microsoft Excel software are used for regression analysis by inputting all related data and using linear regression tools.

2.3 LST

The contact between the earth's surface and atmosphere produces heat that is capable of affecting human beings, which is known as LST. Temperature, wind, and surface characteristics are some of the meteorological factors that affect it [17]. For example, areas with low wind speed can cause an increase in LST [18]. In other words, LST has diverse values mainly due to variations in reflectance and ground surface roughness [19]. The distribution of LST in this study is used in describing areas with urban heat spots (UHS) in Malang City and its relation to the land use index. At both local and global sizes, LST can be used as a reliable measure of the energy balance between the surface and the ocean [20]. The earth system's biological, chemical, and physical processes are likewise impacted by LST [21]. Several variables can cause air temperature to differ from surface temperature, including insolation, wind direction and strength, and surface properties [22].

LST data were obtained through data processing from Landsat 8 OLI/TIRS satellite imagery. Landsat 8 imagery was obtained from the U.S. Geological Survey (USGS) website at https://earthexplorer.usgs.gov in geo-tagged image file format (GeoTIFFSensors provided by the USGS data center include Operational Land Imager/Thermal Independent Sensor (OLI/TIRS), Enhanced Thematic Mapper Plus (ETM+), and Thematic Mapper (TM). The OLI sensor has 9 bands while the TIRS sensor has 2 bands, namely band 10 and band 11 with different characteristics [23]. The surface temperature and emissivity response of an item above the surface can be recorded by TIRS sensors in satellite photography, which can assist in getting LST distribution values at low to high resolution scales [1]. Satellite image-based thermal data processing can provide broader spatial coverage on flexible time scales [24].

However, according to Paruntu et al. (2014) cited by Hasyim et al. [25] band 10 in the Landsat 8 TIRS image has a better ability to identify areas with high temperatures compared to band 11 because of the greater calibration uncertainty in band 11. Band 10 is more effectively used to identify thermal anomalies caused by geothermal manifestations. So in this study using band 10 to process LST distribution data. The mean air temperature, atmospheric transmittance, and ground emissivity values needed to process LST are included in the TIRS data on Landsat 8.

The data used in analyzing the distribution of LST in Malang City are data in 2014, 2019, and 2024. The spatial resolution of the LST data is 30 m × 30 m. The LST pixels were then extracted with the administrative boundaries of Malang City for further analysis.

2.4 Normalized difference built-up index (NDBI)

Normalized Difference Built-Up Index (NDBI) is an index to estimate the level of built-up area in an image. A spectral indicator called the NDBI is frequently used to examine the connection between built-up area and LST in metropolitan regions because it has a significant correlation with LST values [23]. NDBI classification data in this study was obtained through data processing results sourced from Sentinel-2 satellite imagery. Sentinel-2 satellite imagery, made available without charge by Copernicus via the website https://scihub.copernicus.eu, is the source of the data used. NDBI values range from -1 to 1 [15]. Negative NDBI values tend to indicate areas of vegetation and water bodies or non-built-up areas. Whereas positive NDBI values tend to indicate the dominance of built-up areas. Denser buildings are indicated by higher NDBI. The Sentinel-2 extraction process uses the Near Infrared (NIR) and Short Wavelength Infrared (SWIR) bands to calculate NDBI values. This formula is used to determine the NDBI value.

$$NDBI = (SWIR - NIR) / (SWIR + NIR)$$

The values of the NDBI index are classified into 4 classes. The classification is based on the level of building density from non-building classes to high-density buildings. The following is the NDBI classification based on [26] (Table 1).

Table 1. NDBI classification

Class	NDBI Value	Building Density Level
1	-1 < NDBI < 0	Non Settlement
2	0 < NDBI < 0.1	Sparse Settlement
3	0.1 < NDBI < 0.2	Dense Settlement
4	0.2 < NDBI < 0.3	Very Dense Settlement

2.5 Normalized difference vegetation index (NDVI)

Normalized Difference Vegetation Index (NDVI) is the most commonly used index for extracting vegetation elements in an image. According to Tucker cited in the study of Guha et al. [27], the NDVI vegetation index is often analyzed together with the LST value because the vegetation index has an effect in reducing the LST value and shows a negative correlation with the LST value. The amount of vegetation in a city can be used as an indicator to determine the type of urban heat present there [28].

NDVI data processing in this study uses data sourced from Sentinel 2-A satellite imagery for 2019 and 2024. The near infrared (NIR) bands 8 and 4 (red and green) are used to calculate the NDVI values. Positive values in these bands correspond to vegetation, whereas negative values correspond to built-up regions, open space, and aquatic bodies [11]. However, the 2014 data uses Landsat 8 OLI/TIRS imagery due to the availability of Sentinel-2 satellite imagery which is available globally starting in December 2018. The processing of NDVI values with Landsat 8 imagery utilizes band 4 Red and band 5 Near Infrared (NIR).

NDVI indicates the magnitude of the vegetation index, which ranges between -1 and 1 [29]. Negative values in NDVI up to <0.1 represent non-vegetated land such as buildings, water bodies and bare land. Positive NDVI values in the range of 0.2 to 0.3 represent grasses and shrubs and positive NDVI values >0.6 represent forests or dense vegetation components. Higher positive NDVI values indicate the presence of healthy and dense vegetation [4]. NDBI values are calculated using the following equation.

$$NDVI = (NIR - RED) / (NIR + RED)$$

The values of the NDVI index are classified into 5 classes (Table 2). The classification is based on the level of vegetation density.

Table 2. NDVI classification

Class	NDVI Value	Greenness Level
1	-1 < NDVI < -0.03	Non Vegetation
2	-0.03 < NDVI < 0.15	Very Low Vegetation
3	0.15 < NDVI < 0.25	Low Vegetation
4	0.25 < NDVI < 0.35	Medium Vegetation
5	0.35 < NDVI < 1	High Vegetation

2.6 Population distribution

Observing population distribution patterns is important so that the government and planners can make the right decisions in carrying out development in the area according to the existing population and future predictions [30]. In this case, it is very important to include indicators of population distribution and density in research that analyzes the distribution of settlements in Malang City. In this research, the source of data on the distribution of the population of Malang City is based on the WorldPop data source which provides high-resolution open geospatial data related to population distribution, demographics, and dynamics. WorldPop is based at the University of Southampton which conducts population mapping around the world. Since 2013, WorldPop has partnered with governments, UN agencies, and others to produce 45,000 demographic datasets to produce high-resolution population distribution data. The spatial demographic data sources from WorldPop has good accuracy [31], due to the following points:

1. Includes population density data;
2. The data is the result of peer-reviewed research;
3. Data based on spatial data or remote sensing with a fairly high resolution of 100 m x 100 m;
4. Data is based on the census database of each country.

2.7 Linear regression

Regression analysis is a statistical procedure that makes use of multiple variable modeling and analysis methods to evaluate the relationship between two or more variables. This process aims to determine the relationship between one dependent variable and one or more independent variables. With specific types of data, multiple regression is used when there are two or more independent variables in the equation; if there is just one independent variable, it is called a simple regression model [32].

Linear regression methods have been commonly used in many studies that examine the relationship between LST and urban landscapes. However, because of seasonal variations in land cover data, intricate landscape architecture, and variety in urban morphology, regression methods' correlation results may not be linear. In this case, linear regression models can be useful for analyzing trends and providing an overview of the relationship between LST and land cover [12].

In this research, the linear regression method used is multiple linear regression. The variable that acts as the dependent variable is the LST value while the independent variables consist of 3 namely NDBI, NDVI, and population. Multiple linear regression is based on the following probabilistic model.

$$Y=a_0+a_1.X_1+a_2.X_2+\ldots+a_n.X_n$$

where, Y=Dependent variable value prediction; a_1=First independent variable; a_2=Second independent variable; a_n=n independent variable; a_0=Constant; X_1=First independent variable coefficient; X_2=Second independent variable coefficient; X_n=n independent variable coefficient.

The research unit used to calculate linear regression in this research is a grid. The grid size used is 300 meters x 300 meters. The number of grids formed is 1117 grids which will then become samples for calculating linear regression to look for correlations between LST, NDBI and NDVI. The use of a 300 m × 300 m grid was chosen by researchers because the grid size is considered to have sufficient level of detail to produce the average value of the data to be calculated to get fairly accurate results.

3. RESULT AND DISCUSSION

3.1 Distribution of LST in Malang City

The data of LST distribution in Malang City using remote sensing with Landsat 8 OLI/TIRS image thermal band 10. The trend of LST value processing results shows variations in LST distribution from 2014 to 2024. LST value in Malang City is classified as 5 class. The following figure shows the LST distribution of Malang City in 2014, 2019, and 2024.

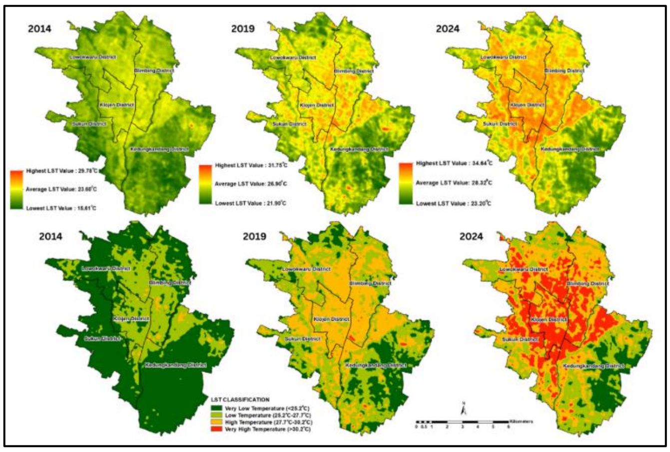

Figure 3. LST distribution of Malang City 2014-2024

Figure 3 shows how the development of LST distribution pattern of Malang City in the 10-year period observed in 2014, 2019, and 2024. In general, the distribution pattern of each district has diverse LST values. There are areas with increasing LST values each year as indicated by the increasing red color in each figure compared to the previous year (especially the central part of Malang City, namely Klojen district and some areas of the other four districts. The Kedungkandang district, in particular, has a region on the outskirts of Malang City with the least variation in LST value as compared to other districts where extremely low temperatures are still prevalent. The eastern and southern regions have continuously been dominated by the lowest temperature class since the beginning of the period (2014) till this year.

Table 3. LST spatial distribution of Malang City 2014-2024

Year	Acquisition Date	Min. (℃)	Max. (℃)	Mean (℃)	Std
2014	June 13, 2014	15.61	29.78	23.60	2.47
2019	July 13, 2019	21.90	31.75	26.90	1.88
2024	August 19, 2024	23.20	34.64	28.32	2.22

The minimum, maximum, and average LST values always increase every year of observation, as shown in Table 3. The maximum LST value increased by 4.86℃ over 10 years (2014-2024). The average LST also increased by 4.72℃. The increase indicates that there are changes in the components that affect the increase in LST, including land cover patterns. The LST value at a location, even with the same land cover characteristics, can vary due to many factors such as vegetation photosynthesis. , albedo, land cover fraction, soil moisture conditions and emissivity [33].

The intensity level of the UHI phenomenon in Malang City based on its LST value can be done by comparing conditions in Malang City with several other cities. However, this is rather difficult because there are differences in characteristics between cities that can affect the conditions of their LST distribution such as geographical conditions. Malang City is one of the big cities with a relatively higher altitude than many cities in Java. As a city with the second highest population density in East Java, the LST value in Malang City shows a pattern of LST change that is not as significant as other cities when compared to cities with similar population density levels. In 2024, Malang City has an average LST value of 28.32℃. Meanwhile, other cities in Java Island that have similar population density levels such as Semarang City based on research [34] in 2024 have an average LST of 33.54. In addition to Semarang City, there is also Surakarta City with an average LST of 36.81%. Even when compared to most cities in East Java, Malang is one of the cities with the lowest average LST value in 2024.

Based on these conditions, it can be said that cities with similar population density characteristics do not always have the same UHI intensity. This may occur due to the many factors that influence LST values such as geographical and weather conditions between cities. The elevation of Malang City, which is above the average city in Java Island, may be a factor in the low UHI intensity in Malang City when compared to other cities. Even so, by looking at the increasing trend in the average LST value of Malang City in the 2014-2024 period, it can be predicted that the value will continue to increase in the future so that control of factors that can cause an increase in UHI must still be carried out.

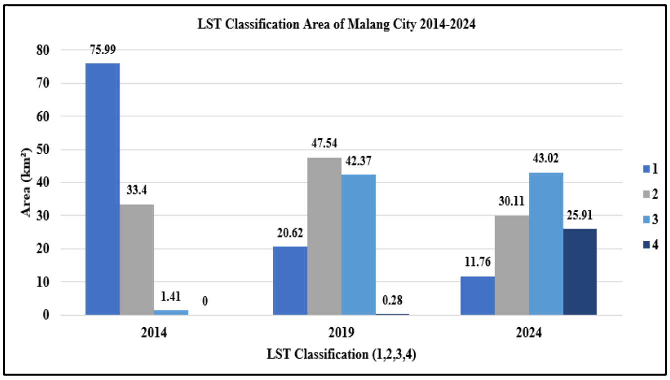

Figure 4. LST classification area of Malang City 2014-2024

Based on the graph in Figure 4, there are temperature classes that have a consistent increase in area and decrease in area. Class 1 (very low temperature) has decreased every year with a total decrease of 64.32 km^2 in 2014-2024. While temperature class 4 (very high temperature) increased by 25.91 km^2 in 2014-2024 from no area with a very high temperature class in 2014. The graph also shows that there was a very significant decrease in the area of the very low temperature class in 2015-2019. An increase in the area with a very high LST classification and a consistent decrease in the area with a very low LST classification every year shows a change in the characteristics of variables that can influence the LST value. These variables include the land use index which will be discussed in the next section.

3.2 NDBI classification in Malang City

The built-up area directly affects the distribution of LST and is the most significant land surface feature for the urban environment. The source of NDBI data is Sentinel-2 imagery for 2019 and 2020. For 2014, Landsat 8 OLI/TIRS imagery was used because Sentinel-2 was not available in 2014. The pixels formed for 2019 and 2020 are 10 m × 10 m and for 2014 are 30 m × 30 m. NDBI values are classified into 4 classes as in the picture below. The following is the NDBI classification of Malang City in 2014, 2019 and 2024.

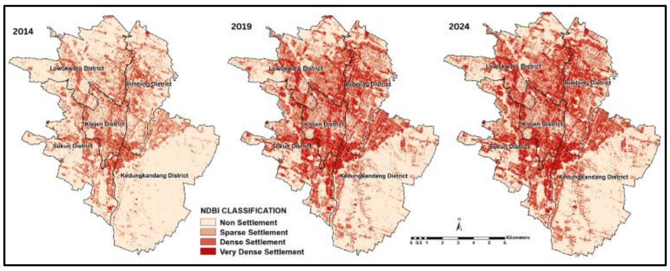

Figure 5. NDBI classification of Malang City 2014-2024

Based on Figure 5, the level of building density in the residential area of Malang City has a varied distribution in each district. However, there is a pattern in the form of an increase in the area of built-up areas marked in red in the figure that continues to grow every year of observation. The addition occurred significantly in 2014-2019. This is due to the rapid development activities in each year.

Klojen district has the highest average building density compared to other districts with a mean NDBI value of 0.102. Meanwhile, the district with the lowest average building density is Kedungkandang district with a mean NDBI of -0.090. The difference in the average building density level of these districts shows that the distribution of buildings in Malang City is not evenly distributed and tends to accumulate in several areas of Malang City.

This picture demonstrates how development activities in Malang City are typically centered in the city's center, which is distinguished by a significant number of structures used for residential, commercial, industrial, and other purposes. Then it can also be seen that from the initial period (2014) until this year the eastern and southern parts of Malang City have been the most consistent in maintaining their land from conversion to built-up areas so it can be said that in these areas development is lower.

Table 4. NDBI spatial distribution of Malang City 2014-2024

Year	Date	Min.	Max.	Mean	Std.
2014	June, 13	-0.829	0.569	-0.277	0.155
2019	July, 25	-0.552	0.648	-0.112	0.161
2024	Aug, 19	-0.557	0.706	-0.109	0.165

The range of NDBI values is -1 to 1 as presented in Table 4, with a higher number indicating a higher building density. Built-up areas are shown by positive values on the NDBI, whereas other types of land cover are indicated by negative values. A high NDBI value generally indicates an area with intensive urban development [35]. In the period 2014-2024, there was a decrease in the minimum NDBI and an increase in land use from unbuilt to built-up, especially in the central part of the city and new residential areas on the edge of the city.

The maximum NDBI. This means that the building density continues to increase every year followed by the addition of new built-up areas. Similarly, the average NDBI also shows an increase.

This should certainly be a concern for the government and planners to overcome the accumulation of buildings that result in high building density in certain locations. This is because there is a big possibility that areas which were not originally dense residential areas can then be transformed into productive urban areas with dense activity. So spatial planning is needed that prioritizes the current condition of the distribution of buildings.

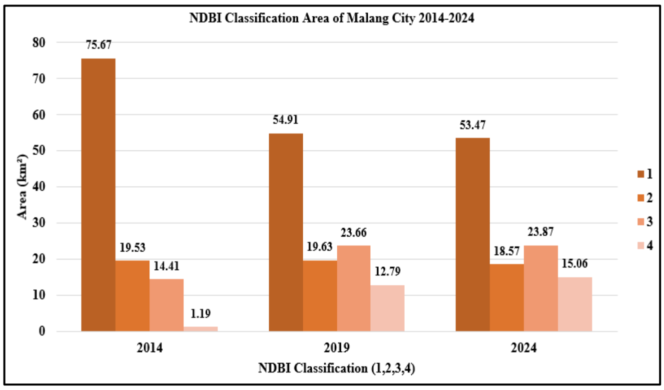

Figure 6. NDBI classification area of Malang City 2014-2024

Based on Figure 6, each NDBI class in 2014, 2019 and 2024 has an increasing or decreasing trend. Class 1 (non-settlement) has an area that continues to decrease every year, reaching 22.2 km^2. While class 4 (very dense settlements) has an area that continues to increase every year, reaching 13.87 km^2 from 2014 to 2024 from only 1.19 km^2 in 2014. Even yet, open space, gardens, and rice fields particularly near the outskirts of the city remain the predominant land uses in Malang City in 2024. This shows that there is rapid development activity in Malang City so that the number of buildings in Malang City continues to increase.

Even though it is currently seen that the non-building class still dominates in Malang City with a percentage of 48.18%, this number will likely continue to decrease. This is because the condition of population growth which continues to increase every year certainly has an impact on the need for land which also increases along with the population's need for housing and other supporting facilities. This phenomenon must certainly be managed with a appropriate planning concept to realize more equitable development activities to minimize the problems.

NDBI is an important spectral index that is significantly correlated with LST values. In general, built-up areas that are shown with positive values on the NDBI index indicate high LST values. Conversion of land cover from vegetated land to built-up areas can increase LST values through replacing natural surface materials with sidewalks or urban building construction, thereby reducing the cooling effect of vegetative surfaces [36]. Therefore, studies related to LST and the built index in the form of NDBI are important in urban planning and land use.

3.3 NDVI classification of Malang City

Researchers utilize the Normalized Difference Vegetation Index (NDVI), one of several vegetation indices in remote sensing science, extensively to determine the percentage of vegetation cover on Earth's surface [37]. In this study, the data source used comes from Sentinel-2 satellite images for 2019 and 2024 and Landsat 8 OLI/TIRS images for 2014. The pixel size resulting from NDVI data processing in 2019 and 2024 is 10 meters × 10 meters and for 2014 is 30 meters × 30 meters. The following figure shows the distribution of NDVI in

Malang City in 2014, 2019 and 2024.

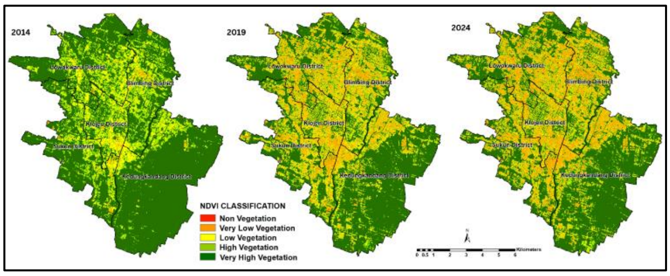

Figure 7. NDVI classification area of Malang City 2014-2024

Based on Figure 7, NDVI values are classified into 5 classes ranging from non-vegetation class to high greenness class. There are changes in the distribution pattern of NDVI classification in each year of observation in Malang City. Especially in 2014-2019 which has a very significant change compared to 2019-2024. Areas with a high greenness classification characterized by dark green color have an area that continues to shrink with uneven distribution and tends to dominate in the eastern and southern Kedungkandang districts. On the other hand, relatively low greenness classes which are primarily built-up or residential land uses dominate the city's center, including the Klojen District and the surroundings around it.. The vegetation components in the central part of the city are generally parks and urban forests as well as vegetation on sidewalks or road medians.

Table 5. NDVI spatial distribution of Malang City 2014-2024

Year	Acquisition Date	Min.	Max.	Mean	Std.
2014	June, 13	-0.067	0.999	0.677	0.174
2019	July, 25	-0.513	0.911	0.536	0.218
2024	August, 19	-0.536	0.912	0.529	0.226

Based on Table 5, there is a decrease in the average NDVI value during 2014-2024 by 0.138. The decrease in the average NDVI indicates that the amount of vegetation area with moderate to high greenness has decreased every year. This shows the opposite pattern to the distribution of the NDBI classification where the average NDBI increases every year. The linear pattern is due to the decrease in vegetation area caused by land conversion into built-up areas.

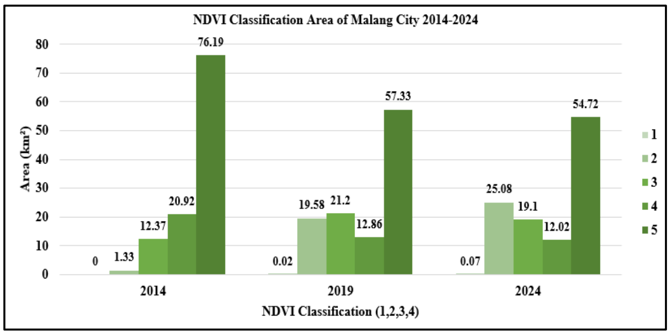

Figure 8. NDVI classification area of Malang 2014-2024

Based on the graph in Figure 8, it is known that each NDVI class shows a diverse pattern of changes in area, there are classes with increasing patterns and decreasing classes. Non-vegetated land and very low greenness classes have an increasing area every year. While the medium greenness and high greenness classes have a decreasing area. As previously stated, the area of the high greenness class experienced a significant decrease in 2019-2024 with a decrease in area reaching 21.47 km^2. This indicates that every year there is an increase in development activities that convert vegetation land into built-up land, resulting in a decrease in the number of vegetation land areas and an increase in the number of non-vegetation land areas and very low greenness in the form of residential land uses.

The high level of development activity which tends to be concentrated in only a few areas can potentially reduce vegetation land in these areas continuously. An imbalance between building land and vegetation land in an urban area can cause sustainable urban problems. This is because vegetation land, which has an important role in maintaining ecosystem balance and environmental quality in urban areas, does not have sufficient area available to handle urban activities. If this is not addressed immediately, it can cause problems such as increasing urban temperatures, increasing hot spot areas, poor air quality, health problems, and others. So the issue of balanced development has now become crucial in realizing sustainable cities.

3.4 Population distribution of Malang City

Data on the distribution of the population of Malang City in 2014, 2019, and 2024 based on remote sensing is sourced from WorldPop through a website that can be accessed at https://hub.worldpop.org/geodata/listing?id=29. The data has a unit value in the form of pixels measuring 90 m × 90 m or on an area scale per 1,800 m^2. Pixel data shows higher data resolution so that it will be more effective to be analyzed together with other variables that are also pixel-based compared to census data with units in the form of villages or districts. The population distribution is then classified into 5 classes based on population size. The following figure shows the population distribution of Malang City in 2014, 2019, and 2024.

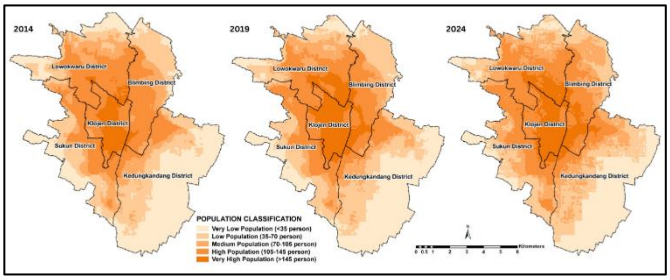

Figure 9. Population classification of Malang City 2014-2024

Figure 9 shows that pixels with a very high population classification (>145 people) marked with the darkest orange color tend to be located in the downtown area and some of the surrounding areas. The pixels with very low population classification (<35 people) marked with the lightest orange color are dominated in Kedungkandang district in the east and south. The population of Malang City is still dispersed unevenly and only tends to cluster in specific places, as evidenced by the density of residential areas and the activity of the local populace, according to the map depicting the distribution of the population. This distribution is in line with the NDBI and NDVI characteristics of this area which were previously explained, where areas with high population levels tend to have high NDBI values and low NDVI values, which indicates dense built-up areas in the area.

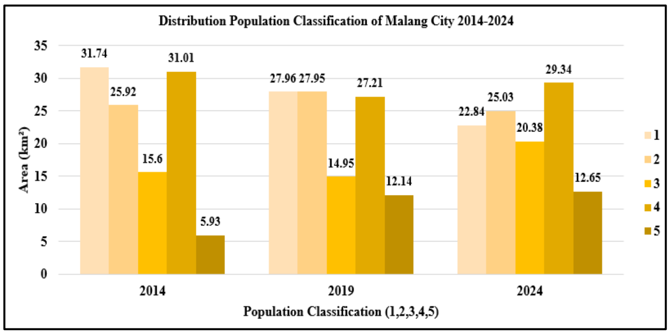

Figure 10. Population classification area of Malang City 2014-2024

Based on the graph in Figure 10, it shows that there are population classes that consistently increase, decrease, or fluctuate. Population class 1 (very low population) experienced a decreasing area from 2014-2014, reaching 8.9 km^2. Meanwhile, class 5 (very high population) experienced an increasing area from 2014-2024, reaching 6.72 km^2.

Based on this data, it is known that every year, the population of Malang City tends to increase every year. This is partly due to the high rate of urbanization to Malang City. The literature survey also states that many regions in the world have experienced an unprecedented rate of urbanization growth over the past century and the population growth rate shows no signs of slowing down. The issue of population increase, especially in Malang City, causes the need for action in the form of solutions in preventing further problems in the urban environment.

3.5 Interconnected dynamics of LST, NDBI, NDVI, and population distribution

Changes in LST distribution patterns in Malang City correlate with the distribution conditions of NDBI, NDVI, and population distribution. The four variables are related to each other. The LST value of the NDBI index, which represents built-up regions, is higher than that of the NDVI, which represents non-built-up areas like vegetated land. The population distribution pattern that shows an increase in population growth rate every year results in the conversion of land from non-built to built-up areas to meet the needs of the population, which in turn the built-up area will increase the LST value if it is not balanced with sufficient vegetation components around it.

The primary effect of urbanization, which also causes the LST to rise, is a change in the properties of the land [38]. Empirically, higher LST is caused by increasing impervious surfaces in urban areas which is closely related to changes in Land Use and Cover (LULC) required by urban development [39]. Furthermore, heat conductivity can be raised by frequently utilized urban infrastructure elements that make surfaces more impermeable, such as parking lots, pedestrian crossings, and bridges [40].

Water bodies and verdant foliage generally exhibit low LST. Conversely, populated regions, exposed rock surfaces, or dry soil exhibit elevated LST. Therefore, Studies connected to LST are crucial for land use and urban development [41]. There are now cool spots in that area of the city as a result of the spread of different kinds of green space, such as parks and gardens [42].

The central part of Malang City which has low NDVI values but the distribution of LST, NDBI and population distribution tends to be higher than other areas shows that development activities in Malang City tend to be concentrated in this area. This area, which is dominated by built-up areas in the form of residential, industrial, and other areas, varies in characteristics. In contrast, areas of the city with high NDVI, low LST, NDBI, and population distribution values are dominated by greenery and devoid of structures, including plantations, open spaces, and rice fields.

In the modern era, rapid urbanization drives land conversion processes and rapid increases in surface temperatures in a very short time [43]. This condition must be a major concern for the government, where if the increase in built-up land area continues to occur massively in the future without good spatial planning to place the additional buildings, there could be too high a density of buildings in some areas and this could cause further problems. In this situation, thorough city planning is required, taking into account the distribution of LST, the building density determined by NDBI, the availability of vegetation determined by NDVI, and the population distribution of the city as reported in this study.

3.6 Regression analysis between LST, NDBI, NDVI, and population values

The purpose of this regression analysis is to identify deeper correlations between LST, NDBI, NDVI, and population of Malang City in the period 2014-2024. The regression analysis technique used to assess the relationship between LST and the three variables was multiple regression for all pixels in the study area except pixels that were outside the grid because the area did not fill the entire grid. The data entered into the SPSS system were the average LST value per grid as the dependent variable, the average NDBI and NDVI index values per grid, and the average population per grid as the independent variables. The multiple regression model developed in this study is as follows.

2014: $Y = 25.585 + 5.449\ NDBI - 3.806\ NDVI + 0.008\ POP$
2019: $Y = 27.116 + 8.267\ NDBI - 0.957\ NDVI + 0.004\ POP$
2024: $Y = 28.808 + 6.493\ NDBI - 4.024\ NDVI + 0.013\ POP$

where, LST: Land surface temperature (℃); NDBI: Normalized Difference Built-Up Index; NDVI: Normalized Difference Vegetation Index; POP: Population.

Based on the three regression models at three different observation times, there is a similar correlation between LST and the three independent variables characterized by positive and negative coefficients. Positive correlation occurs between LST, NDBI, and population. While a negative correlation occurs between LST and NDVI. The positive coefficients on the NDBI and population variables imply that in Malang City, both variables contribute to the increase in LST. While the negative correlation on the NDVI variable implies that the vegetation component contributes to the decrease of LST.

3.7 Policy implications: Enhancing urban green spaces

The decline in the Normalized Difference Vegetation Index (NDVI) within Malang City, as revealed through multi-temporal remote sensing analysis, highlights a pressing need for effective urban green space policies. Urban green spaces play a crucial role not only in enhancing the aesthetic appeal and recreational opportunities within cities but also in mitigating the UHI effect, improving air quality, and bolstering the resilience of urban ecosystems. The relationship between NDVI and urbanization is well-documented; as urban areas expand, vegetation cover often diminishes, leading to increased temperatures and reduced biodiversity.

In Malang City, the NDVI analysis indicates that only 26.60% of the urban area meets the requirements for medium to high-density vegetation, suggesting a significant shortfall in green space [44]. This deficiency is exacerbated by rapid urbanization, which has transformed agricultural land and forests into urban developments, increasing the urban area cover from 21% in 2001 to 40% in 2014 [45]. These changes not only contribute to the UHI effect where urban areas experience higher temperatures than rural areas, but also have negative impacts on air quality and the overall health of urban ecosystems, as is the case in several large cities in Asia and Brussels, Belgium [46, 47]. The UHI phenomenon is particularly concerning as it leads to increased energy consumption, human thermal stress, and exacerbates air pollution.

Moreover, the UHI effect can be mitigated through the strategic enhancement of urban green spaces. Research in Fuping China, indicates that urban green spaces act as biological filters, absorbing pollutants and releasing oxygen, which is vital for maintaining urban ecological balance [48]. Incorporating green spaces into urban development is crucial in enhancing the well-being of inhabitants and cultivating a sustainable urban milieu.

Research conducted in China and the United State, indicates that increasing green open spaces significantly supports biodiversity and ecological resilience, particularly through enhanced vegetation indices such as the Normalized Difference Vegetation Index (NDVI). Elevated NDVI values often correlate with a greater diversity and abundance of vertebrate species, indicating that urban green spaces can foster healthier ecosystems [49]. This phenomenon has been documented in various studies across different regions, demonstrating that policies aimed at expanding green open space can yield tangible benefits for urban biodiversity and, consequently, urban resilience.

3.7.1 Development of green infrastructure

The implementation of robust green infrastructure policies in urban development is essential for addressing the challenges posed by urbanization, particularly in cities like Malang. Urban resilience, the reduction of the UHI impact, and the general quality of the environment can all be greatly increased by requiring the installation of green infrastructure, such as vertical gardens, green roofs, and the maintenance of existing green spaces.

To begin with, the integration of green roofs and vertical gardens into new urban development projects offers a multifaceted approach to urban sustainability. Green roofs, for instance, have been shown to effectively reduce stormwater runoff, lower ambient temperatures, and improve air quality by filtering pollutants [50]. These benefits are particularly crucial in densely populated urban areas where impervious surfaces dominate, leading to increased heat retention and flooding risks. Studies indicate that green roofs can delay the peak runoff time during storm events, thereby alleviating urban flooding issues [51]. Additionally, vegetation on rooftops promotes biodiversity by giving different species places to live, which is essential for preserving ecological balance in urban environments [29].

In addition to green roofs, vertical gardens can also play a significant role in enhancing urban green spaces. These installations not only beautify urban environments but also contribute to energy savings by insulating buildings, thereby reducing the need for heating and cooling [52]. The aesthetic and psychological benefits of green spaces are well-documented, with evidence suggesting that access to greenery can improve mental health and community well-being [53, 54]. Therefore, incorporating vertical gardens into urban planning can create more livable and attractive urban spaces.

3.7.2 Expansion and maintenance of public parks

The expansion and maintenance of public parks are critical components of urban planning that contribute significantly to community well-being, social cohesion, and environmental sustainability. Effective management and development strategies for public parks can enhance their accessibility, usability, and overall impact on urban life.

One of the primary considerations in expanding public parks is ensuring equitable access for all community members. Research indicates that spatial equity in the distribution of public parks is essential for fostering inclusivity and addressing social disparities within urban environments [55]. Parks should be designed with the needs of diverse populations in mind, taking into account factors such as age, mobility, and socio-economic status [56]. For instance, parks that are well-connected to surrounding neighborhoods through pedestrian-friendly pathways and public transport options are more likely to attract a higher number of users [57]. This is particularly important in densely populated urban areas, where the demand for accessible recreational spaces is high [58].

Moreover, the design and maintenance of public parks play a crucial role in their utilization. Features such as age-appropriate playground equipment, sports facilities, and social gathering spaces can significantly influence park visitation rates among children and teenagers [59]. Additionally, the aesthetic appeal and upkeep of these parks are vital; poorly maintained parks can deter visitors and diminish their perceived value [60]. Studies have shown that community involvement in park management and maintenance can enhance user satisfaction and foster a sense of ownership among residents [61]. In addition to enhancing parks' physical condition, this participatory method builds community relationships and promotes more regular use.

Furthermore, the integration of green spaces into urban planning is linked to numerous public health benefits. Urban parks provide essential opportunities for physical activity, which is increasingly recognized as a critical factor in combating urban health issues such as obesity and mental health disorders [62]. The existence of green spaces has been linked to better social interactions among neighbors, lower stress levels, and greater mental health [63]. Therefore, maintaining and expanding public parks should be viewed not merely as an aesthetic or recreational endeavor but as a fundamental public health strategy.

3.7.3 Urban reforestation and tree planting initiatives

Urban reforestation and tree-planting initiatives are increasingly recognized as vital strategies for enhancing urban environments, mitigating climate change, and improving public health. These initiatives not only contribute to carbon sequestration but also provide a multitude of ecological, social, and economic benefits.

One of the primary motivations for urban reforestation is the need to combat climate change. Urban areas, characterized by high levels of impervious surfaces, contribute significantly to greenhouse gas emissions. Tree planting initiatives can help offset these emissions by enhancing carbon sequestration. For instance, studies indicate that urban vegetation can sequester substantial amounts of carbon, with initiatives like Grow Boston Greener aiming to increase tree canopy cover to 35%, potentially enhancing carbon sequestration rates further [64]. However, it is crucial that these initiatives are well-planned; poorly executed tree planting can inadvertently lead to increased emissions and negative impacts on biodiversity [65]. Therefore, comprehensive planning and stakeholder involvement are essential to ensure that tree planting efforts are effective and sustainable.

The ecological benefits of urban forestry extend beyond carbon sequestration. Urban forests are essential for controlling stormwater runoff, mitigating the effects of UHIs, and enhancing air quality. Trees can intercept rainfall, thereby reducing flood risks and improving water quality [66]. Additionally, the presence of trees in urban settings has been linked to enhanced biodiversity, providing habitats for various species and contributing to the overall health of urban ecosystems [67]. The aesthetic and recreational value of urban green spaces also cannot be overlooked, as they offer residents opportunities for leisure and community engagement.

Initiatives for urban forestry can have a big social influence on public health.Research has shown that having access to green spaces is associated with reduced stress levels, increased physical activity, and improved mental and physical health [68]. Urban trees serve as social determinants of health, promoting well-being through their presence in neighborhoods. Furthermore, community involvement in tree planting and maintenance fosters a sense of stewardship and responsibility among residents, which can enhance the success of these initiatives [69]. Participating local communities in the design and implementation of tree planting programs guarantees that the efforts cater to the unique requirements and inclinations of the populace, thus augmenting their efficacy and durability.

Despite the numerous benefits, urban forestry initiatives face challenges, particularly in developing regions where resources and infrastructure may be limited [70]. Innovative approaches are needed to foster participation and ensure the successful implementation of tree planting programs in these contexts. This includes adapting strategies to local conditions and involving diverse stakeholders throughout the process.

When analyzing the conditions in Malang City, although the area of vegetation land has decreased every year, the current available vegetation land area still has a large percentage value. Based on land use data in the 2022-2042 Malang City RTRW document, vegetation land in the form of agriculture, plantations, greenways, and green open spaces such as parks and urban forests has a total area of 29.78 km^2. While the need for the provision of green open space per capita based on Public Works Regulation Number 05/PRT/M/2008, the need for green open space per capita is 20 m^2. The population of Malang City in 2024 based on BPS data is 889,359 people. So that the total area of green open space to meet the standard needs of the entire population in Malang City is 17.79 km^2. So that the need for green space per capita in Malang City is still fulfilled.

So the main concern in recommending the development of green open space in Malang City is to equalize the vegetation component, especially in areas that become UHI areas in the form of areas with higher LST values. The distribution of vegetation can be done by planting trees around houses and on sidewalks. In addition, it is also necessary to control and improve the quality of green open spaces, especially parks and urban forests that are currently available. The quality includes the quantity of vegetation components in the form of trees that are effective in performing their functions and roles as supporting the quality of the urban environment. The existence of parks and urban forests that are still dominated by heat-absorbing materials and vegetation that is not effective in absorbing carbon and pollution, the resulting ecosystem services to environmental quality are not optimal. Shade from trees covering urban areas can improve environmental quality while providing comfort to city dwellers. through the reduction of hot spots in Malang City.

3.8 Integration of sustainable development and planning

Malang City, as a rapidly urbanizing area in Indonesia, faces significant challenges related to urban growth, including environmental degradation, loss of green spaces, and increased urban heat. To mitigate these negative impacts, the integration of sustainable practices such as green infrastructure, urban forestry initiatives, and sustainable zoning practices is essential [25]. These strategies can enhance urban resilience, improve public health, and promote biodiversity.

3.8.1 Green infrastructure development

The implementation of green infrastructure is a vital strategy for Malang City to address the adverse effects of urbanizationA range of natural and semi-natural systems that offer ecosystem services, like stormwater management, improved air quality, and urban cooling, are referred to as "green infrastructure" [71]. For example, installing rain gardens, permeable pavements, and green roofs can greatly minimize surface runoff and lessen the impact of the UHI effect, which is especially noticeable in densely populated areas [72]. Studies have shown that urban vegetation can effectively regulate microclimates, leading to cooler urban areas and improved overall livability.

Moreover, integrating green corridors and parks within urban planning can enhance connectivity between green spaces, promoting biodiversity and providing recreational opportunities for residents [73]. This approach aligns with the concept of multifunctional green infrastructure, which aims to optimize the benefits of urban green spaces for both ecological and social purposes [74]. By prioritizing green infrastructure, Malang can create a more sustainable urban landscape that supports both human and ecological health.

3.8.2 Urban forestry initiatives

Urban forestry initiatives are another critical component of sustainable urban development in Malang. The city can enhance its tree canopy cover through targeted tree planting programs, which not only sequester carbon but also improve air quality and provide shade [75]. Research indicates that urban forests can significantly contribute to public health by promoting physical activity and mental well-being through increased access to green spaces [70]. Furthermore, community involvement in tree planting and maintenance fosters a sense of ownership and stewardship, which is essential for the long-term success of urban forestry initiatives.

To effectively implement urban forestry, Malang City should adopt a participatory approach that involves local communities, stakeholders, and experts in the planning and execution of tree planting projects. This collaboration can ensure that the selected species are suitable for the local environment and meet the needs of the community [76]. Additionally, integrating urban forestry into broader urban planning frameworks can enhance the resilience of the city against climate change impacts.

3.8.3 Sustainable zoning practices

Sustainable zoning practices are crucial for managing urban growth in a way that preserves green spaces and promotes sustainable land use. Malang City has the ability to enact zoning laws that restrict the expansion of agricultural land into urban areas and give priority to maintaining the area's current green spaces [75]. This approach not only protects biodiversity but also ensures that residents have access to essential green spaces for recreation and relaxation.

Additionally, the city can enact mixed-use zoning laws that promote the coexistence of commercial, residential, and recreational areas. Such policies can reduce the need for transportation, thereby lowering greenhouse gas emissions and fostering vibrant, walkable neighborhoods [76]. Urban zoning planning should also be carefully considered, rationally planned to control development intensity, reduce the hardland ratio, and expand the presence of green open space in urban areas [77]. By aligning zoning practices with sustainability goals, Malang can create a more cohesive urban environment that supports both economic development and ecological health.

4. CONCLUSIONS

This study specifically uses remote sensing methods aimed at analyzing the interaction between urban development and environmental parameters in Malang City for a decade. The findings in Malang City show a very significant increase in LST along with an increase in the NDBI and a decrease in vegetation cover as indicated by the NDVI. The average LST increase of 4.72℃ from 2014 to 2024, the growth of built-up areas of around 1.19 km², and the decrease in high-density vegetation areas of 21.47 km² indicate the loss of valuable green space.

These findings demonstrate the urgent need for an integrated urban planning approach that not only mitigates the UHI effect but can also significantly enhance the resilience of urban ecosystems through design principles that are in harmony with natural dynamics. These results underscore the potential of Malang's strategy as a model for other cities globally facing similar challenges of urbanization and climate change. These findings demonstrate the urgent need for an integrated urban planning approach that not only mitigates the UHI impact but can also significantly enhance the resilience of urban ecosystems through design principles that are in harmony with natural dynamics. These results underscore the potential of Malang's strategy as a model for other cities around the world facing similar challenges related to urbanization and climate change. This study recommends urban policies with global implications and future research directions, focusing on:

· Enhancing Urban Green Space: Increasing the green cover of Malang through strategic initiatives such as urban reforestation, green roof use, and expanding public parks to offset the impacts of UHI and to improve Malang's air quality. This strategy is highly applicable to cities around the world, which have similar ecological challenges.

· Sustainable Urban Planning: Strict implementation of zoning regulations that encourage sustainable development in Malang, while preventing unnecessary land cover changes, and ultimately there is a balance between growth and environmental sustainability.

· Community Involvement in Urban Greening: Encouraging community engagement in green initiatives in Malang, with the aim of fostering a sense of responsibility among residents and building a more sustainable urban future.

This research has a significant contribution to the ongoing dialogue on sustainable urban development, by providing empirical evidence in Malang City that supports the restructuring of urban planning frameworks towards a more sustainable and resilient urban environment. This aligns with the Sustainable Development Goals, particularly Goal 11 (Climate Action) and Goal 13 (Sustainable Cities and Communities), as it emphasizes the critical role that spatial planning plays in reducing the effects of climate change in urban areas.

This research has limitations in the form of selecting factors that can affect LST. Basically, LST values in an area can be influenced by various factors with complex interrelationships between variables. Some factors that can affect LST values outside of this study include weather factors such as air temperature, humidity, solar radiation, wind speed, and seasonal differences between times. The data in this study was taken at the observation time of 3 years without further attention related to its weather characteristics even though it was in the same season. This condition is very likely to cause bias in the results of data processing. However, reviewing most of the similar studies that have been conducted, land conversion factors involving land use changes between building components and vegetation are the main factors that cause changes in LST conditions in an area. However, adding various other factors besides land use may produce more valid and complex analysis results.

ACKNOWLEDGMENT

The authors would like to express their deepest gratitude to Brawijaya University for the support and facilities provided that greatly assisted this research, so that this research could run smoothly. The resources and guidance from the faculty and technical staff were invaluable in conducting this comprehensive study on the ecological impacts of urban expansion in Malang City. We are also grateful for the continuous encouragement and insight provided by our colleagues at the Department of Urban Planning and Environment, which have significantly enriched this research.

REFERENCES

[1] Das, S., Angadi, D.P. (2020). Land use-land cover

(LULC) transformation and its relation with land surface temperature changes: A case study of barrackpore subdivision. Remote Sensing Applications: Society and Environment, 19: 100322. https://doi.org/10.1016/j.rsase.2020.100322

[2] Akhmetshin, E., Sultanova, S., Shichiyakh, R., Khodjaeva, M., Stepanova, D., Nurgaliyeva, A. (2024). Efficiency in urban management and smart city concepts: A Russian cities case study. International Journal of Sustainable Development and Planning, 19(4): 1379-1387. https://doi.org/10.18280/ijsdp.190415

[3] Najim, S., Alslam, N.A., Albazzaz, I.A. (2021). Environmental influences on the settlements patterns of communities in the marshes of Iraq. International Journal of Design & Nature and Ecodynamics, 16(6): 657-663. https://doi.org/10.18280/ijdne.160606

[4] Roy, S., Pandit, S., Akter, E., Hossain, S., Papia, M., Banik, L., Dube, T., Rahman, F. (2020). Examining the nexus between land surface temperature and urban growth in chattogram metropolitan area of bangladesh using long term landsat series data. Urban Climate, 32: 100593. https://doi.org/10.1016/j.uclim.2020.100593

[5] Li, X., Zhou, W., Ouyang, Z. (2013). Relationship between land surface temperature and spatial pattern of greenspace: What are the effects of spatial resolution? Landscape And Urban Planning, 114: 1-8. https://doi.org/10.1016/j.landurbplan.2013.02.005

[6] Debbage, N., Shepherd, J.M. (2015). The urban heat island effect and city contiguity. Computers, Environment and Urban Systems, 54: 181-194. https://doi.org/10.1016/j.compenvurbsys.2015.08.002

[7] Purnamasari, W.D., Anfansyah, R. (2021). The phenomenon of urban fringe settlements in the south-north region of Malang city. IOP Conference Series: Earth and Enviromental Science, 916(1): 012023. https://doi.org/10.1088/1755-1315/916/1/012023

[8] BPS Kota Malang. (2024). Malang city in figures 2024. https://malangkota.bps.go.id/id/publication/2024/02/28/e7d11012c6940bb521e9c100/kota-malang-dalam-angka-2024.html.

[9] Azizah, V., Deffinika, I., Arinta, D. (2022). The effect of land use changes on land surface temperature in Malang city's on 2016 - 2020. IOP Conference Series: Earth and Environmental Science, 1066(1): 012006. https://doi.org/10.1088/1755-1315/1066/1/012006

[10] Agustina, S.F., Herwangi, Y. (2023). Pengukuran spasial urban sprawl di kota malang menggunakan shannon's entropy. Jurnal Riset Pembangunan, 5(2): 74-82. https://doi.org/10.36087/jrp.v5i2.131

[11] Khan, M.S., Ullah, S., Chen, L. (2021). Comparison on land-use/land-cover indices in explaining land surface temperature variations in the city of Beijing, China. Land, 10(10): 1018. https://doi.org/10.3390/land10101018

[12] Tran, D.X., Pla, F., Latorre-carmona, P., Myint, S.W., Caetano, M., Kieu, H.V. (2017). Characterizing the relationship between land use land cover change and land surface temperature. ISPRS Journal of Photogrammetry and Remote Sensing, 124: 119-132. https://doi.org/10.1016/j.isprsjprs.2017.01.001

[13] Pangaribuan, J.J., Fanny, F., Barus, O.P., Romindo, R. (2023). Prediksi penjualan bisnis rumah properti dengan menggunakan metode autoregressive integrated moving average (ARIMA). Jurnal Sistem Informasi Bisnis, 13(2): 154-161. https://doi.org/10.21456/vol13iss2pp154-161

[14] Wahid, H.A., Pamungkas, Y.A. (2023). Remote Sensing Technology as a Support for Spatial Aspects in Planning. Malang: UB Press.

[15] Mirchooli, F., Hamidreza, S., Prof, S., Darvishan, A.K. (2020). Remote sensing applications: Society and environment analyzing spatial variations of relationships between land surface temperature and some remotely sensed indices in different land uses. Remote Sensing Applications: Society And Environment, 19: 100359. https://doi.org/10.1016/j.rsase.2020.100359

[16] Zhang, Y., Odeh, I.O.A., Han, C. (2009). Bi-temporal characterization of land surface temperature in relation to impervious surface area, NDVI and NDBI, using a sub-pixel image analysis. International Journal of Applied Earth Observations and Geoinformation, 11(4): 256-264. https://doi.org/10.1016/j.jag.2009.03.001

[17] Ismail, N.A., Abdullah, S., Mansor, A.A., Ahmad, A.N., Ahmed, A.N., Ismail, M. (2024). Trend and interrelationship of PM2.5, gaseous pollutants and meteorological factors in Kuala Terengganu, Malaysia. International Journal of Design & Nature and Ecodynamics, 19(4): 1251-1260. https://doi.org/10.18280/ijdne.190416

[18] Patel, S., Indraganti, M., Jawarneh, R.N. (2024). A comprehensive systematic review: Impact of land use/land cover (LULC) on land surface temperatures (LST) and outdoor thermal comfort. Building and Environment, 249: 111130. https://doi.org/10.1016/j.buildenv.2023.111130

[19] Grimm, N.B., Faeth, S.H., Golubiewski, N.E., Redman, C.L., Wu, J., Bai, X., Briggs, J.M. (2008). Global change and the ecology of cities. Science, 319(5864): 756-760. https://doi.org/10.1126/science.1150195

[20] Mahato, S., Pal, S. (2019). Sciencedirect influence of land surface parameters on the spatio-seasonal land surface temperature regime in Rural West Bengal, India. Advances in Space Research, 63(1): 172-189. https://doi.org/10.1016/j.asr.2018.09.014

[21] El-zeiny, A.M., Hala, A.E. (2017). Environmental monitoring of spatiotemporal change in land use / land cover and its impact on land surface temperature in El-Fayoum governorate, Egypt. Remote Sensing Applications: Society and Environment, 8: 266-277. https://doi.org/10.1016/j.rsase.2017.10.003

[22] Armson, D., Stringer, P., Ennos, A.R. (2012). The effect of tree shade and grass on surface and globe temperatures in an urban area. Urban Forestry & Urban Greening, 11(3): 245-255. https://doi.org/10.1016/j.ufug.2012.05.002

[23] Guha, S., Govil, H., Dey, A., Gill, N. (2018). Analytical study of land surface temperature with NDVI and NDBI using Landsat 8 OLI and TIRS data in Florence and Naples City, Italy. European Journal of Remote Sensing, 51(1): 667-678. https://doi.org/10.1080/22797254.2018.1474494

[24] Myint, S.W., Wentz, E.A., Brazel, A.J., Quattrochi, D.A. (2013). The impact of distinct anthropogenic and vegetation features on urban warming. Landscape Ecology, 28: 959-978. https://doi.org/10.1007/S10980-013-9868-Y

[25] Hasyim, A.W., Sukojo, B.M., Anggraini, I.A., Fatahillah, E.R., Isdianto, A. (2025). Urban heat island effect and sustainable planning: Analysis of land surface temperature and vegetation in Malang City. International

Journal of Sustainable Development and Planning, 20(2): 683-697. https://doi.org/10.18280/ijsdp.200218

[26] Handayani, M.N., Sasmito, B., Putra, A. (2017). Analysis of the relationship between temperature changes and built-up area index using landsat imagery (Case study: Surakarta City). Jurnal Geodesi Undip, 6(4): 208-218. https://doi.org/10.14710/jgundip.2017.18145

[27] Guha, S., Govil, H., Gill, N., Dey, A., Gill, N. (2020). Annals of GIS analytical study on the relationship between land surface temperature and land use / land cover indices. Annals of GIS, 26(2): 201-216. https://doi.org/10.1080/19475683.2020.1754291

[28] Karnieli, A., Agam, N., Pinker, R., Anderson, M., Imhoff, M., Gutman, G., Panov, N., Goldberg, A. (2009). Use of NDVI and land surface temperature for drought assessment: Merits and limitations. Journal of Climate, 23: 618-633. https://doi.org/10.1175/2009JCLI2900.1

[29] Hasyim, A.W., Ari, I.R.D., Kurniawan, E.B., Kriswati, L., Wahid, M.N.I., Isdianto, A. (2024). Integrating object-based classification and multivariate analysis to evaluate flood vulnerability in unplanned settlements of Malang City, Indonesia. International Journal of Design & Nature and Ecodynamics, 19(5): 1611-1625. https://doi.org/10.18280/ijdne.190515

[30] Ariyanto, E., Nugraha, M.K.R. (2024). Population vs. poverty level in the future in Indonesia: Holt's linear trend method. International Journal of Sustainable Development and Planning, 19(7): 2763-2770. https://doi.org/10.18280/ijsdp.190733

[31] Tatem, A.J. (2017). Worldpop, open data for spatial demography. Scientific Data, 4(1): 1-4. https://doi.org/10.1038/sdata.2017.4

[32] Basri, H. (2019). Multiple regression modeling for data in emotional intelligence studies. DIDAKTIKA: Jurnal Kependidikan, 12(2): 103-116. https://doi.org/10.30863/didaktika.v12i2.179

[33] Ghosh, A., Joshi, P.K. (2014). Hyperspectral imagery for disaggregation of land surface temperature with selected regression algorithms over different land use land cover scenes. ISPRS Journal of Photogrammetry and Remote Sensing, 96: 76-93. https://doi.org/10.1016/j.isprsjprs.2014.07.003

[34] Aulya, R., Rakuasa, H., Turi, F., Hidayatullah, M., Latue, P. (2024). Analysis of average land surface temperature of Java Island, Indonesia in 2024 using reduce regions in Google Earth Engine. Journal of Selvicoltura Asean, 1(2): 80-95. https://doi.org/10.70177/jsa.v1i2.1182

[35] Zhou, X., Wang, Y. (2010). Dynamics of land surface temperature in response to land-use / cover change. Geographical Research, 49(1): 23-36. https://doi.org/10.1111/j.1745-5871.2010.00686.x

[36] Santamouris, M. (2013). Using cool pavements as a mitigation strategy to fight urban heat island — A review of the actual developments. Renewable and Sustainable Energy Reviews, 26: 224-240. https://doi.org/10.1016/j.rser.2013.05.047

[37] Gandhi, G.M., Parthiban, S., Thummalu, N., Christy, A. (2015). Ndvi: Vegetation change detection using remote sensing and GIS - A case study of Vellore District. Procedia - Procedia Computer Science, 57: 1199-1210. https://doi.org/10.1016/j.procs.2015.07.415

[38] Guha, S., Govil, H., Gill, N., Dey, A. (2021). A long-term seasonal analysis on the relationship between LST and NDBI using Landsat data. Quaternary International, 575-576: 249-258. https://doi.org/10.1016/j.quaint.2020.06.041

[39] Ali, S.B., Patnaik, S., Madguni, O. (2017). Microclimate land surface temperatures across urban land use / land cover forms. Global Journal of Environmental Science and Management, 3(3): 231-242. https://doi.org/10.22034/gjesm.2017.03.03.001

[40] Emmanuel, R., Krüger, E. (2012). Urban heat island and its impact on climate change resilience in a shrinking city: The case of Glasgow, UK. Building and Environment, 53: 137-149. https://doi.org/10.1016/j.buildenv.2012.01.020

[41] Li, W., Cao, Q., Lang, K., Wu, J. (2017). Linking potential heat source and sink to urban heat island: Heterogeneous effects of landscape pattern on land surface temperature. Science of The Total Environment, 586: 457-465. 10.1016/j.scitotenv.2017.01.191

[42] Norton, B.A., Coutts, A.M., Liveley, S.J., Harris, R.J., Hunter, A.M., Williams, N.S. (2015). Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. Landscape and Urban Planning, 134: 127-138. https://doi.org/10.1016/j.landurbplan.2014.10.018

[43] Liu, H., Zhan, Q., Yang, C., Wang, J. (2018). Characterizing the spatio-temporal pattern of land surface temperature through time series clustering: Based on the latent pattern and morphology. Remote Sensing, 10(4): 654. https://doi.org/10.3390/rs10040654

[44] Wikantiyoso, R., Sulaksono, A.G., Suhartono, T. (2021). Detection of potential green open space area using landsat 8 satellite imagery. ARTEKS: Jurnal Teknik Arsitektur, 6(1): 149-154. https://doi.org/10.30822/arteks.v6i1.730

[45] Hartatik, S., Itaya, A. (2019). The current status of green space around elementary schools: A case study of Malang, Indonesia. Journal of Forest Planning, 25(1): 15-20. https://doi.org/10.20659/jfp.2019.001

[46] Lee, K., Kim, Y., Sung, H., Ryu, J. (2019). Trend analysis of urban heat island intensity according to urban area change in Asian Mega Cities. Sustainability, 12(1): 112. https://doi.org/10.3390/su12010112

[47] Lauwaet, D., Ridder, K.D., Saeed, S., Brisson, E., Chatterjee, F., Lipzig, N.V., Maiheu, B., Hooyberghs, H. (2016). Assessing the current and future urban heat island of brussels. Urban Climate, 15: 1-15. https://doi.org/10.1016/j.uclim.2015.11.00

[48] Li, Z., Fan, Z., Shen, S. (2018). Urban green space suitability evaluation based on the AHP-cv combined weight method: A case study of Fuping County, China. Sustainability, 10(8): 2656. https://doi.org/10.3390/su10082656

[49] Cai, D., Fraedrich, K., Guan, Y., Guo, S., Carvalho, L.M.V., Zhu, X. (2019). Causality of biodiversity loss: Climate, vegetation, and urbanization in China and America. Sensors, 19(20): 4499. https://doi.org/10.3390/s19204499

[50] Azis, S.S.A., Razali, M.N., Maimun, N.H.A., Yusoff, N.S.M., Rahman, M.S.A., Zulkifli, N.A.A. (2021). An analysis on the efficiency of green roof in managing urban stormwater runoff. Planning Malaysia, 19(17): 991. https://doi.org/10.21837/pm.v19i17.991

[51] Liu, Z. (2024). Using roof garden to alleviate urbanization problems - A case study of Chengdu city. Applied and Computational Engineering, 58(1): 85-93. https://doi.org/10.54254/2755-2721/58/20240698

[52] Mutani, G., Todeschi, V. (2021). Roof-integrated green technologies, energy saving and outdoor thermal comfort: Insights from a case study in urban environment. International Journal of Sustainable Development and Planning, 16(1): 13-23. https://doi.org/10.18280/ijsdp.160102
[53] Muzakir, M., Wahyuningsih, W., Ponirin, P. (2024). Measurement model of sustainable servicescape and service quality on green space and environmental satisfaction. International Journal of Sustainable Development and Planning, 19(10): 3989-3994. https://doi.org/10.18280/ijsdp.191027
[54] Novalia, I., Prakoso, W.A., Tambunan, R.P., Hasibuan, H.S. (2024). Green roofs in urban underground buildings: Design impact on perceptual comfort. International Journal of Design & Nature and Ecodynamics, 19(5): 1479-1489. https://doi.org/10.18280/ijdne.190502
[55] Almohamad, H., Knaack, A.L., Habib, B.M. (2018). Assessing spatial equity and accessibility of public green spaces in Aleppo City, Syria. Forests, 9(11): 706. https://doi.org/10.3390/f9110706
[56] Guo, X., Wang, J., Wu, X. (2022). Study on residents' satisfaction and green development of city parks in Linfen, China. Polish Journal of Environmental Studies, 31(4): 3051-3062. https://doi.org/10.15244/pjoes/145188
[57] Park, K. (2019). Park and neighborhood attributes associated with park use: An observational study using unmanned aerial vehicles. Environment and Behavior, 52(5): 518-543. https://doi.org/10.1177/0013916518811418
[58] Alamri, S. (2024). Spatial analysis and GIS mapping of public parks adequacy: A case study from Riyadh, Saudi Arabia. Sustainability, 16(8): 3305. https://doi.org/10.3390/su16083305
[59] McCormack, G.R., Rock, M., Swanson, K., Burton, L., Massolo, A. (2014). Physical activity patterns in urban neighbourhood parks: Insights from a multiple case study. BMC Public Health, 14(1): 1-13. https://doi.org/10.1186/1471-2458-14-962
[60] Ahmad, S., Ayob, Z., Hussain, N.H.M., Nayan, N.M. (2022). Assessment of landscape maintenance towards cost planning: Expert validation on the criteria of sustainable landscape maintenance for public park. Planning Malaysia, 20(22): 1129. https://doi.org/10.21837/pm.v20i22.1129
[61] Sonet, U.N., Klufallah, M.M.A., Peters, M., Dixon, T.J. (2021). Indicators of the public participation exercise for designing public parks in Malaysia: A systematic review. Sustainability, 13(21): 12119. https://doi.org/10.3390/su132112119
[62] Zhang, C., Su, Q., Zhu, Y. (2023). Urban park system on public health: Underlying driving mechanism and planning thinking. Frontiers in Public Health, 11: 1193604. https://doi.org/10.3389/fpubh.2023.1193604
[63] Chen, S., Wu, Z., Sleipness, O.R., Wang, H. (2022). Benefits and conflicts: A systematic review of dog park design and management strategies. Animals, 12(17): 2251. https://doi.org/10.3390/ani12172251
[64] Briber, B.M., Hutyra, L.R., Dunn, A.L., Raciti, S.M., Munger, J.W. (2013). Variations in atmospheric CO2 mixing ratios across a Boston, MA urban to rural gradient. Land, 2(3): 304-327. https://doi.org/10.3390/land2030304
[65] Sacco, A.D., Hardwick, K., Blakesley, D., Brancalion, P.H.S., Breman, E., Rebola, L.C., Chomba, S., Dixon, K., Elliott, S., Ruyonga, G., Shaw, K., Smith, P., Smith, R.J., Antonelli, A. (2021). Ten golden rules for reforestation to optimize carbon sequestration, biodiversity recovery and livelihood benefits. Global Change Biology, 27(7): 1328-1348. https://doi.org/10.1111/gcb.15498
[66] Martini, A., Biondi, D., Batista, A.C. (2017). O microclima de diferentes arranjos paisagísticos na arborização de ruas de curitiba - pr. Ciência Florestal, 27(4): 1257-1268. https://doi.org/10.5902/1980509830313
[67] Kodoh, J., Jaunis, O., Maid, M., Lintangah, W., Mojiol, A.R. (2023). Urban forestry in Kota Kinabalu: Home garden practices by urban villages for biodiversity, socio-economic and environmental services. IOP Conference Series: Earth and Environmental Science, 1145(1): 012012. https://doi.org/10.1088/1755-1315/1145/1/012012
[68] Wolf, K.L., Lam, S., McKeen, J., Richardson, G.R.A., van Den Bosch, M., Bardekjian, A.C. (2020). Urban trees and human health: A scoping review. International Journal of Environmental Research and Public Health, 17(12): 4371. https://doi.org/10.3390/ijerph17124371
[69] Roman, L.A., Walker, L.A., Martineau, C.M., Muffly, D.J., MacQueen, S.A., Harris, W. (2015). Stewardship matters: Case studies in establishment success of urban trees. Urban Forestry & Urban Greening, 14(4): 1174-1182. https://doi.org/10.1016/j.ufug.2015.11.001
[70] Yuniarti, E., Damanik, F.H.S., Dewata, I., Nugraha, F.A.D. (2024). Urban green space as a solution for degenerative diseases: A perspective based on a literature review. International Journal of Sustainable Development and Planning, 19(4): 1271-1279. https://doi.org/10.18280/ijsdp.190405
[71] Kang, W., Chon, J., Kim, G. (2020). Urban ecosystem services: A review of the knowledge components and evolution in the 2010s. Sustainability, 12(23): 9839. https://doi.org/10.3390/su12239839
[72] Anderson, V., Gough, W.A. (2021). Nature-based cooling potential: A multi-type green infrastructure evaluation in Toronto, Ontario, Canada. International Journal of Biometeorology, 66(2): 397-410. https://doi.org/10.1007/s00484-021-02100-5
[73] Vasiljevic, N., Radić, B., Gavrilović, S., Šljukić, B., Medarević, M., Ristić, R. (2018). The concept of green infrastructure and urban landscape planning: A challenge for urban forestry planning in Belgrade, Serbia. iForest - Biogeosciences and Forestry, 11(4): 491-498. https://doi.org/10.3832/ifor2683-011
[74] Saleh, H.A., Alrobaee, T.R. (2024). Planning and designing sustainable urban space according to the concept of ecological aesthetics. International Journal of Sustainable Development and Planning, 19(11): 4291-4302. https://doi.org/10.18280/ijsdp.191118
[75] Kamil, M., Romadhan, A.A. (2020). Local geo-politics of urban food resilience to achieve sustainable city development in Malang, Indonesia. In Proceedings of the 1st Borobudur International Symposium on Humanities, Economics and Social Sciences (BIS-HESS 2019), pp. 782-785. https://doi.org/10.2991/assehr.k.200529.165
[76] Kusumaningrum, K.W., Saraswati, R., Wibowo, A. (2022). Green open space development based on urban heat island phenomenon in Malang city. IOP Conference

Series: Earth and Environmental Science, 950(1): 012066. https://doi.org/10.1088/1755-1315/950/1/012066
[77] Al-Jawari, S.M., Kadhim, F.M., Albasri, N.A.R. (2024). Urban safety is a tool for containing slums to reach a sustainable urban structure. International Journal of Safety and Security Engineering, 14(1): 191-200. https://doi.org/10.18280/ijsse.140119