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The impact of changes in land use on green open space and Comfort Index in Semarang City, Indonesia

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Abstract*. Semarang City is one of the cities with the most dense population in Indonesia. The increase in the population of Semarang City causes land conversion which has an impact on increasing heat and can cause environmental problems. The results of the random classification of forests for land use in 2013–2022 are dominated by the built-up land class. Use of built-up land continues to increase from 2013–2022 by 8.84% or an area of 3,410 ha. This causes a reduction in green open space by 7.59% or an area of 2,928.49 ha and is still sufficient by 30%. In the predicted use of land in 2032, the dominance of the built-up land class is 61% (23,575 ha). The availability of green open space (RTH) in Semarang City continues to decline from 2013–2032 by 9%. Where in 2032 the availability of green open space will be 29.62% or less than 30%. The relationship between green open space and comfort levels influences each other, where a reduction in green open space causes an increase in comfort levels. Directions need to be made for developing green open spaces consisting of priority 1 areas, namely adding green open spaces in each sub-district, maintaining existing green open spaces, and creating roof gardens and vertical gardens to reduce temperatures in densely populated areas. Meanwhile, priority area 2 is maintaining existing green open space in the form of urban forests and plantation areas.*

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INTRODUCTION

Urban areas are generally not vegetated because they have experienced a lot of conversion of green open land into places of population activity. Semarang City is one of the largest cities in Indonesia in terms of both population and area. The area of Semarang City is around 377 km², with a population of 1,656,564 people, which means that every km² is occupied by a population of 4,425 people in 2022, and will continue to increase in the following years. The increase in population growth rate from 2013–2022 was 1.57% (BPS Semarang City 2022). An increase in population is usually followed by high land conversion from non-built-up land to built-up land, which has an impact on increasing artificial heat sources originating from industrial activities and buildings, which can cause environmental problems and affect the urban climate.

Green Open Space (GOS), is an elongated area/lane and/or clustered, whose use is more open, where plants grow, both plants growing naturally and those planted deliberately. GOS in Semarang City based on the 2010–2030 Regional Spatial Planning has a planned area of 11,211 ha. Based on data from the Ministry of Environment, the area of GOS in 2013 was 15,894 ha and will decrease by 4,911 ha in 2022, so that in 2022 the area of green open space will be 10,983 ha. If this continues, the green open space in 2030 will be lower than planned. Reducing 50% green space causes an increase in air temperature by 0.4 to 1.8 ºC, while the addition of 50% green space only reduces air temperature by 0.2 to 0.5 ºC (Effendy 2009). Changes in land use in areas that are not planned will create problems in spatial planning. Therefore, it is necessary to formulate policies for the management and development of urban green spatial planning to improve the quality of the urban living environment (Aryaguna et al. 2022).

Thermal comfort is a very important element of comfort because it involves comfortable room-temperature conditions. As is well known, humans feel hot or cold as a sensory sensation on the skin to the surrounding temperature stimuli (Rilatupa 2008). The level of thermal comfort for humans in various regions has been formulated using climate parameters, such as air temperature, relative humidity, solar radiation, and wind speed. Other parameters that affect comfort include the metabolic conditions of the body (Hawa 2016). This condition illustrates that GOS is related to the environmental comfort index, particularly the air temperature parameter. The Temperature Humidity Index can be used to assess the level of thermal comfort in an area. This method produces an index to determine the effect of hot conditions on human comfort, which combines the elements of temperature and humidity (Kalfuadi 2009). Remote sensing data modeling can be used to obtain air temperature data, which can be indicated by the presence of vegetation and open spaces included in the green open space classification. Remote sensing technology can assist in estimating climate elements, namely surface temperature, air temperature, relative air humidity, and in observing land changes.

Predictions of future land use and development of Semarang City can be predicted using the Cellular Automata (CA) approach. Cellular Automata modeling in this study can also determine the opportunities for changing one land use to another land use. Meanwhile, Geographic Information System (GIS) is used to build a spatial aspect and develop driving variables that affect change (Mushore et al. 2017). The study of built-up land should also predict future conditions and the need for GOS to make evaluation easier using existing spatial patterns. Based on the description above, research is needed that aims to; 1) identify patterns of land-use change and green open space, 2) analyze predictions of land use, 3) analyze the availability of green open space, and 4) analyze the level of thermal comfort based on the calculation of the Temperature Humidity Index.

METHODS

Study Area

This research was carried out in Semarang City, Central Java Province. Geographically, Semarang City is located between 109º50'–110º35' E and 6º50'–7º10' S. The Semarang city area is divided into 16 subdistricts and 177 sub-districts. The largest sub-district is Gunungpati District, namely 5,974 ha and the smallest sub-district is Central Semarang District with an area of 536 ha. The increase in the population growth rate of the city of Semarang for the 2013–2022 period was 1.57%. The increase in the population of Semarang City is followed by the high conversion of land from non-buildings to construction which has an impact on decreasing green open space in the city of Semarang every year. For this reason, future green open space research is needed. Research implementation begins in July 2021–December 2022.

Data Collection

This research uses data consisting of two types, namely primary data and secondary data collected from various sources. The data used included Landsat 8 imagery for 2013, 2017, and 2022, Demnas, Administration Map, Population Map, and Semarang City Road Network Map. Tools for processing research data include software ArcGis 10.8, QGis 2.18 with MOLUSCE (Modules For Land Use Change Evaluation) plugins for data analysis, and Microsoft Office for reporting.

Data Analysis

Land Use Analysis

Land use classification in this study was conducted using the random forest classification method to obtain land use data for 2013, 2017, and 2022. Random Forest is a machine learning algorithm that combines the output of several decision trees to achieve a single result. The Random Forest method produces many trees that are used as the basis for a majority vote (the bagging ensemble method). This majority vote was used to determine the label class in the output. The advantage of the Random Forest is that it is very effective in dealing with the problem of overfitting because the trees or classifiers produced by the Random Forest are mapped randomly, so they will not be affected by overfitting.

This study used the dzetsaka plugin with the Random Forest method installed in the QGIS Application. During the classification process, the data were divided (splitting) into training data and test data with a proportion of 70% for training data and 30% for testing data (Zulfajri et al. 2021). The final output of this process was a land use map. Thus, to improve the accuracy of the classification results, it is necessary to use spatial information because the more remote sensing information is used, the more the accuracy will also increase. It is necessary to carry out verification and validation to determine the truth level of the classification process. The results of the land use classification were verified with ground truth points (reality in the field) that were randomly stratified based on the grouping of land use types (Wang and Liu 2009). The classification results are validated using an accuracy test. A higher image resolution was used to validate past land use (2013 and 2022).

Land Use Prediction Analysis

Land use prediction modeling using Cellular Automata (CA) was carried out with QGIS 2.18.2 Software using the MOLUSCE plugin. Quantitatively, changes in land use can be predicted by considering physical, social, economic, and policy factors (Sun et al. 2022). The land use maps used were those for 2013 and 2022. The complete prediction modeling stages are shown in Figure 1 below.

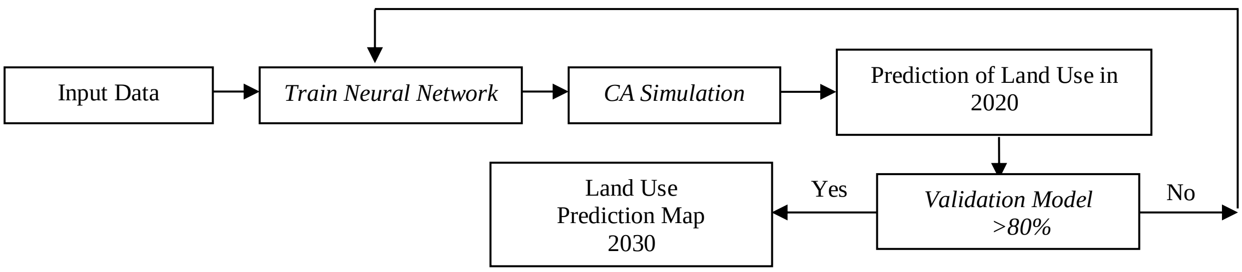

Figure 1 Modeling of land use change

Analysis of Availability of Green Open Space (GOS)

The availability of green open space was calculated to determine the green open space contained in urban area functions. The availability of green open space can be analyzed by calculating the Green Open Space Needs Based on Area. According to Spatial Planning Law Number 26 of 2007, the proportion of green open spaces in an area is 30% of the administrative area of the area. The GOS calculation formula is shown in Equation:

$$\text{Availability of GOS} = (\text{GOS area} / \text{Total Area}) \times 100\%$$

Analysis of Temperature Humidity Index (THI)

The Temperature Humidity Index (THI) was calculated to determine the level of comfort in urban areas. The analysis can be done in 2 ways, namely:

Comfort level according to niuwolt

The classification of comfort levels for low latitudes with tropical climates, namely is classified into four comfort classes: THI < 19 (very comfortable), THI 20–22 (convenient), THI 23–26 (moderate), THI > 27 (uncomfortable). The thermal comfort index according to Nieuwolt can be obtained by the formula:

$$THI = 0.8\ T + (RH \times T) : 500$$

Description:
T = Air Temperature (^{o}C)
RH = Relative humidity (%)

Convenience level based on remote sensing data processing

The level of comfort based on remote sensing data processing is carried out using the overlay technique. The data used are vegetation density data, building density, relative humidity, and surface temperature (Utami et al. 2012). The processing process is based on Figure 2 below.

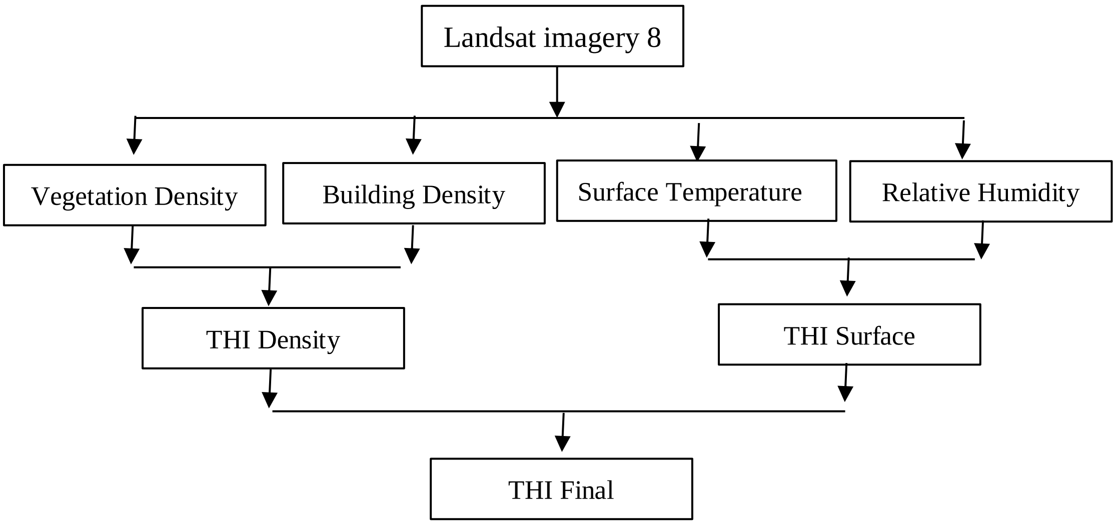

Figure 2 Image processing THI modeling

a. Vegetation Density

Vegetation density is the percentage of species of vegetation or plants that live in a certain area. One of the vegetation densities was determined using NDVI. Techniques that can be used to analyze vegetation. Vegetation density formula is in Table 1:

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

Where:
NIR = Band that has a near infrared wavelength
RED = Band that has a red wavelength

Table 1 NDVI classification

No	Class	Value	Remark
1	Class 1	–1– (–0.03)	Unvegetated land
2	Class 2	–0.03–0.15	Very low greenness
3	Class 3	0.15–0.25	Low greenness
4	Class 4	0.26–0.35	Moderate greenery
5	Class 5	0.36–1.00	High green

b. Building Density

The Normalized Difference Built Index (NDBI) is an algorithmic method that uses mid-infrared and near-infrared (NIR) waves, namely by using band 5 and band 6. The NDBI spectral range ranges from 0.1–0.3. NDBI classification is in Table 2.

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

Where:
SWIR = Band that has middle infrared wavelength
NIR = Band that has a near infrared wavelength

Table 2 NDBI classification

No	Class	Value	Remark
1	Class 1	–1–0	Non-building
2	Class 2	0–0.1	Low building density
3	Class 3	0.1–0.2	Medium building density
4	Class 4	0.2–0.3	High building density
5	Class 5	0.3–1.0	Very high building density

c. Surface Temperature

The surface temperature can be defined as the temperature of the outermost part of an object. while for vegetation it can be seen as the surface temperature of the plant canopy, and in bodies of water it is the temperature of the water's surface (Dahlan 2004). Surface Temperature Formula:

$$LST = BT / (1+ ((\pi BT / c2) * \ln \mathcal{E} \pi))$$

Where:
BT: Temperature brightness (^{o}C)
π : Central wavelength of emitted radiance
c2 : h*c/s = 1.4388*10^{-2} mK = 14388 µm K

d. Relative Humidity

Relative humidity is the percentage of the partial pressure of vapor divided by the saturated vapor pressure at a given temperature. So, it's in percentage form. This is a useful amount in conveying the true feeling of humidity. NDMI is a measurement index used to detect the level of inertia of a land surface. NDMI (Normalized Difference Moisture Index) is an index that works on Near Infrared (NIR) and Short Wavelength Infrared (SWIR) channels (Pamungkas and Pramatana 2019). NDMI formula:

$$NDMI = (NIR – SWIR) / (NIR + SWIR)$$

Where:
SWIR = Band that has Middle Infrared Wavelength
NIR = Band that has a Near Infrared Wavelength

e. Temperature Humidity Index (THI)

The results of remote sensing data processing produce several parameters, namely vegetation density (NDVI), building density (NDBI), surface temperature (LST), and humidity (NDMI). From these several parameters, overlapping is done using qualitative data analysis through the matching method. The profile matching method is a decision-making method by assuming an ideal level of predictor variables that must be met in the subjects studied (Kusrini 2021). The following Table 3 matrix determines the comfort level based on Landsat image processing.

Table 3 Determination of the final convenience level

THI	Landsat 8 image		
	Comfortable	**Some are uncomfortable**	**Uncomfortable**
Comfortable	Comfortable	Some are uncomfortable	Some are uncomfortable
Some are uncomfortable	Some are uncomfortable	Some are uncomfortable	Some are uncomfortable
Uncomfortable	Some are uncomfortable	Some are uncomfortable	uncomfortable

RESULTS AND DISCUSSION

Analysis of Land Use Identification and Change

The results of the random forest classification using Landsat satellite imagery for 8 years recorded in 2013 and 2022 produce 9 classes of land use including bodies of water, ponds, built-up land, paddy fields, fields/moors, shrubs, plantations, forests, and mangroves. Validation of land use in 2013, 2017, and 2022 which is the result of random forest classification is shown with a kappa value of 98.40%, 92.76%, and 91.68% respectively. The total accuracy of an image classification result is said to be good or acceptable if it has a kappa accuracy value of 0.80–1.00 (Kubangun et al. 2016). Image interpretation in the random forest classification shows results of more than 80%, which means that the interpretation results are feasible or can be used for further processing and analysis.

The land use class on built-up land dominates in 2013 with 12,892 ha. In 2022 built-up land is the type of land use that dominates in the Semarang City area of 16,302 ha. A decrease in land use was found in the Tambak class of 1.76% or 680.70 ha. The forest class experienced the greatest increase and decrease in land use. The land use that experienced the greatest increase was found in the built-up land class of 8.84% (3,410 ha). The increase in built-up land resulted in land conversion in the city of Semarang and a decrease in green open space. The following is Table 4.

Table 4 Graph of land use change

Land use	Area (ha)			Percentage (%)			Land use change 2013–2022	
	2013	**2017**	**2022**	**2013**	**2017**	**2022**	**ha**	**%**
Forest	7,059.4	9,054.6	5,237.1	18.3	23.5	13.6	–1,822.3	–4.7
Built-up Land	12,892.4	13,933.2	16,302.7	33.4	36.1	42.2	3,410.3	8.8
Mangroves	24.7	48.5	57.7	0.1	0.1	0.1	33.0	0.1
Waters	859.7	1,404.2	1,424.1	2.2	3.6	3.7	564.4	1.5
Plantation	5,214.4	2,707.6	4,253.8	13.5	7.0	11.0	–960.5	–2.5
Ricefield	5,204.9	6,122.0	4,839.4	13.5	15.9	12.5	–365.5	–0.9
Shrubs	2,935.8	1,291.4	3,134.3	7.6	3.3	8.1	198.6	0.5
Ponds	1,846.1	1,361.6	1,165.3	4.8	3.5	3.0	–680.8	–1.8
Moor/Field	2,550.3	2,664.5	2,173.1	6.6	6.9	5.6	–377.2	–1.0

Availability of Green Open Space

Open spaces consist of green and non-green open spaces. Green Open Space is an area elongated/lane or grouped, the use of which is more open, a place for plants to grow, both those that grow naturally or those that are intentionally planted. Based on the number of areas in the city of Semarang, there was a 7.59 % %decrease in green open space from 2013 to 2022. The availability of green open space in 2022 is still sufficient at >30%, with a value of 38.5% or 14,856 ha. Based on the availability of green open space per sub-district, only 5 sub-districts fulfilled > 30%, namely Banyumanik, Mijen, Gunungpati, Ngaliyan, and Tembalang Sub-districts. The lowest availability of green open space was found in Semarang Tengah District at 0.30% and the highest in Gunungpati District at 78% The highest decrease in green open space for 2013–2022 was sub-district Genuk 15% and Ngaliyan 14% Increase in Green Open Space 2013–2022 in sub-district Monument 0.1%. A graph of Green Open Space Availability and Figure 3 graph of Green Open space availability per district is shown in Figure 4.

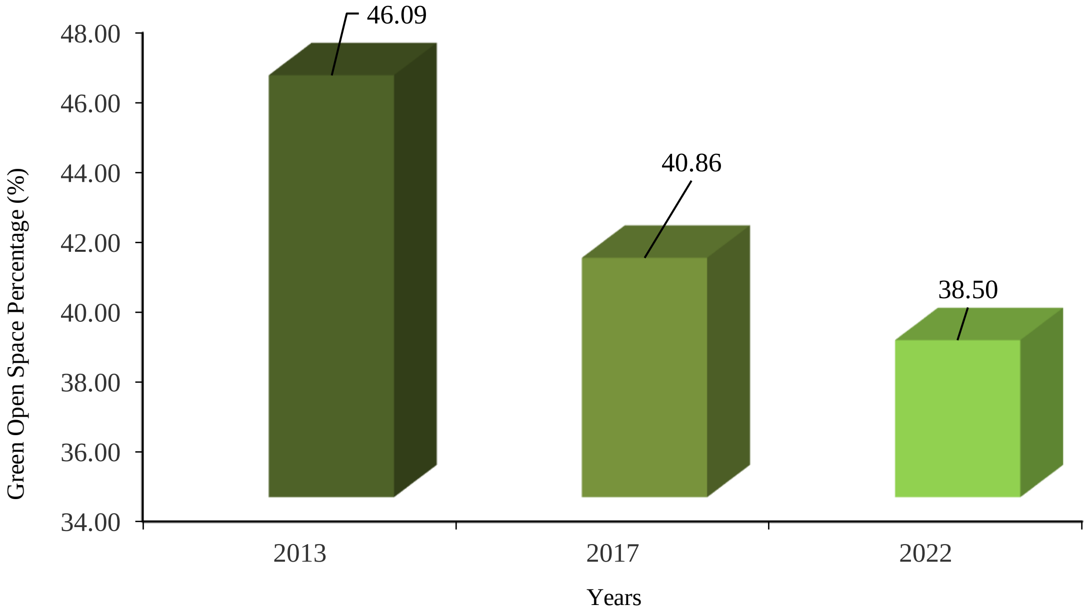

Figure 3 Availability of city green open space 2013–2022

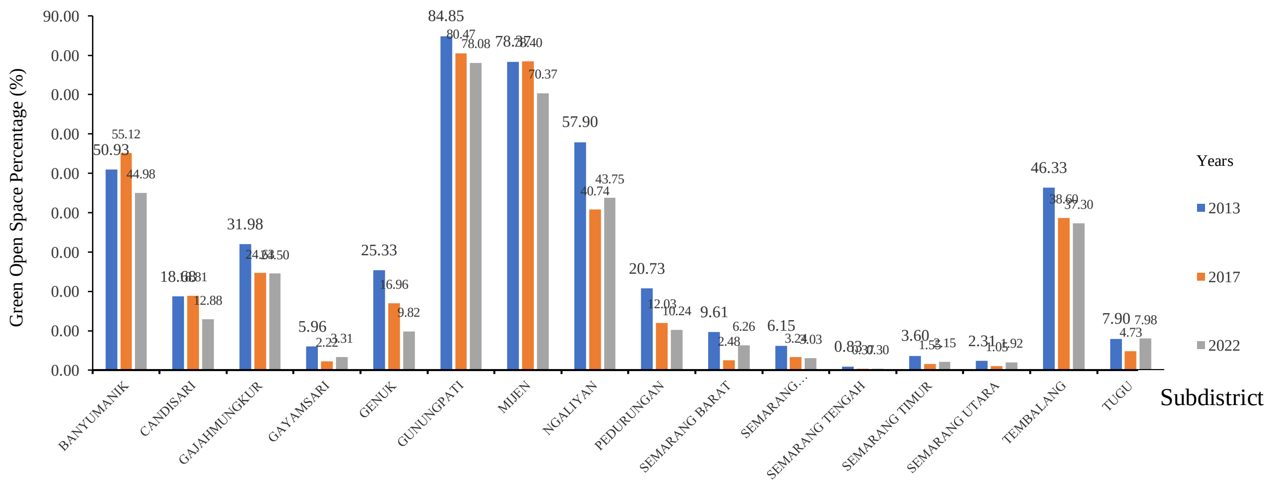

Figure 4 Green open space graph for each district

Prediction of Land Use and Green Open Space

Land use prediction estimates changes in land use at a certain time based on the driving factors. Based on the prediction results of land use in the city of Semarang, driving factors in the form of population growth, distance to roads, and distance to rivers were obtained. For the prediction of land use, a kappa value of 83% was obtained. Land use in 2032 is dominated by a built-up land class of 61% or 23,575 ha. The second largest land use was in the scrubland class (9.46 %), followed by the mangrove class (0.13%). Based on the prediction results for land use, the availability of green open spaces was 29.62%. The following Figure 5 predictions of land use.

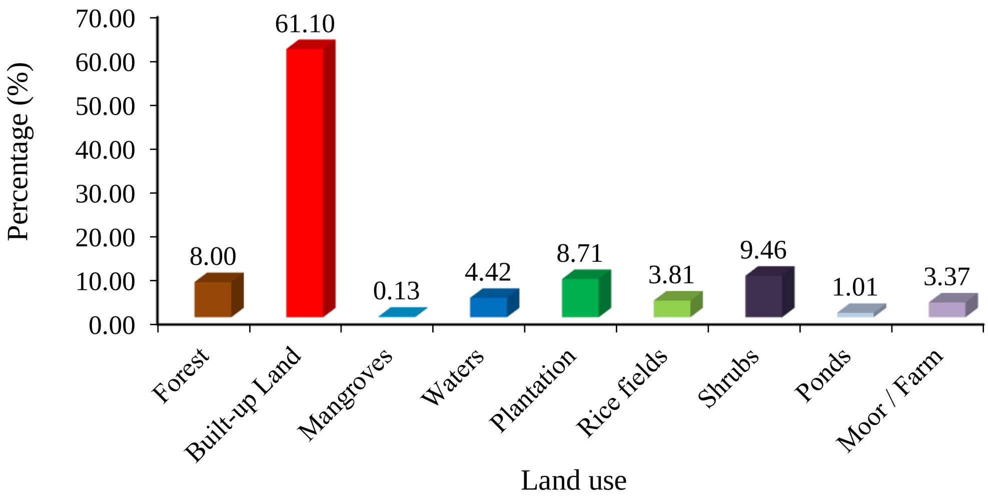

Figure 5 Land use prediction graph in 2023

Temperature Humidity Index (THI)

The comfort level based on niuwolt calculations based on Agency for Meteorology, Climatology and Geophysics climate data obtained an increase in THI from 2013–2022 of 1.2ºC. The increase in the THI makes the comfort condition moderate to uncomfortable. Figure 6 shows a Niuwolt THI chart. The thermal comfort level based on the image processing results was the final comfort level. There is an increase in the comfort level of the uncomfortable class by 19% or 1,694 ha and a decrease in the comfort level of the comfortable class by 6,929 ha (Figure 7).

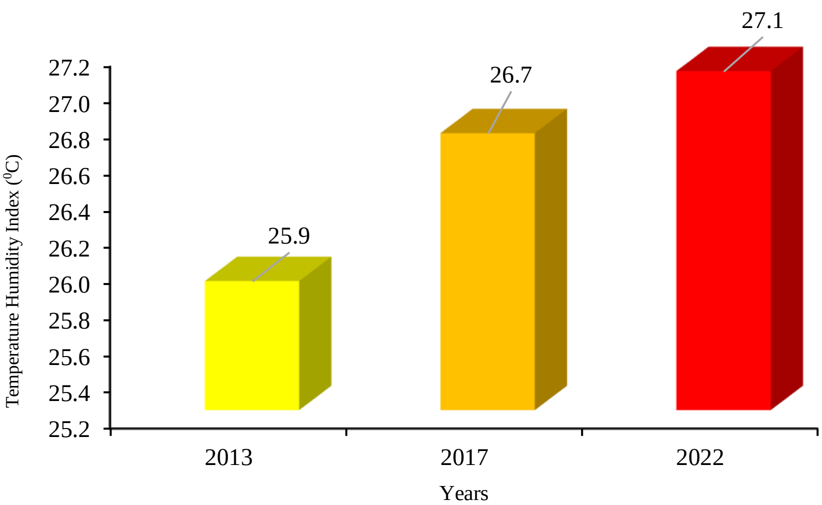

Figure 6 Graph of THI Niuwolt

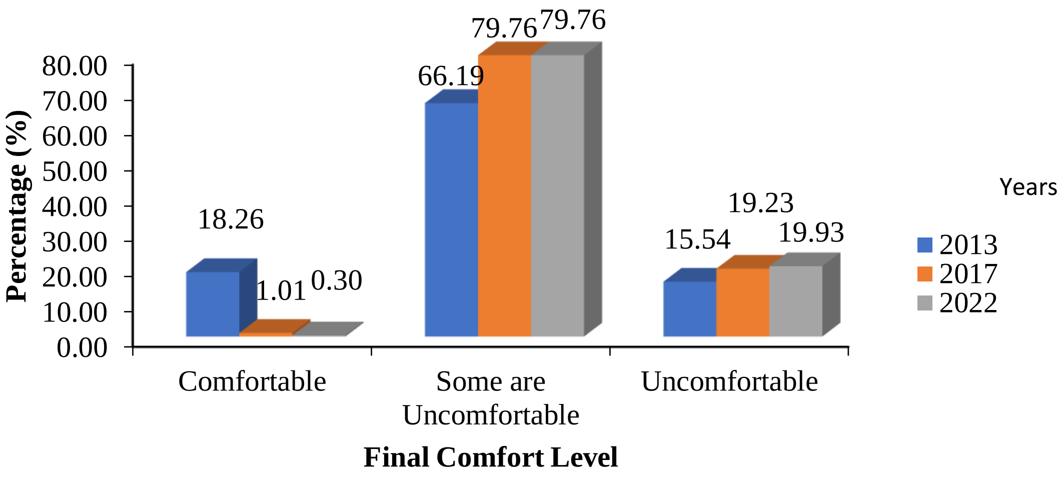

Figure 7 Graph of image processing THI

Impact of Changes in Land Use and Relationship between Green Open Space and THI

Based on the results of this analysis, the following conclusions were drawn: the decrease in the availability of green open space by 16% or 6,336 ha, which resulted in a decrease in the level of comfort in the comfortable class by 18% or 6,979 ha, and an increase in the level of comfort in the uncomfortable class by 4% or 1,655 ha. The relationship between GOS and the level of comfort influences each other, where a decrease in green open space causes an increase in the comfort level and makes comfortable environmental conditions uncomfortable. The proportion of green open space in 2032 < 30%; Therefore, several scenarios are needed to guide the development of green open spaces. Changes in land use are in Figure 8 and the relationship between green open space and comfort level is in Figure 9.

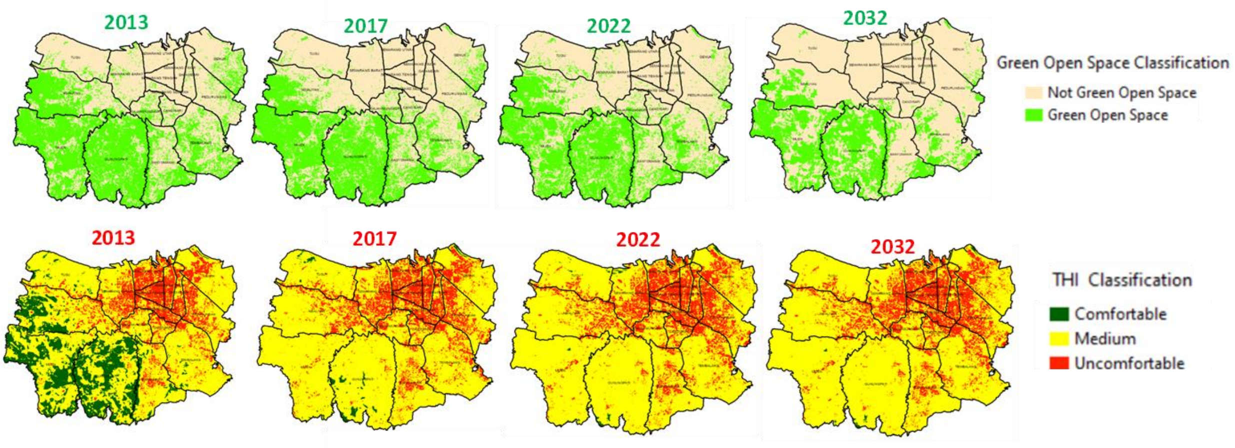

Figure 8 Land use change

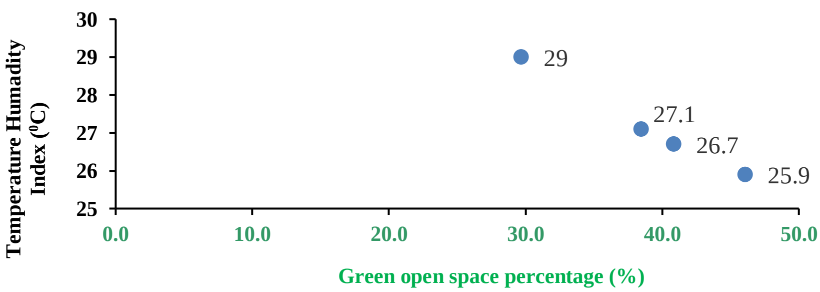

Figure 9 Changes in Comfort Levels 2013–2032

Directions for the Development of Green Open Space

Based on the results of remote sensing data processing and analysis, the relationship between GOS and the level of THI influences each other, where a decrease in green open space causes an increase in thermal comfort. This causes environmental conditions to become uncomfortable. To develop green open space and set comfort levels based on the thermal analysis results, three development directions (THI) are divided into three Priority Areas with several criteria determined based on remote sensing data processing results. The direction of priority area 1 is to maintain the existing green open space and add green open space by building roof gardens and vertical gardens in each house with an ecological function to reduce the ambient temperature by differentiating the area of green open space < 30%, comfort level > 34 °C, and building density > 50%. The direction of priority 2 areas is to maintain existing green open spaces and add green open spaces in each sub-district and sub-district in the form of village parks and sub-district parks in the form of rice fields, mangroves, shrubs, and dry fields/fields with the criteria of open space area green 30–50%, comfort level 32–34 ºC and building density 25–50%. Priority area 3 is maintaining green open spaces in the form of urban forests, and plantation areas and imposing sanctions on fraudulent logging. Directions Priority area 3 has criteria of > 50% green open space, comfort level < 32 ºC, and building density < 25%. Figure 10 Map of the distribution of priority area development directions in the Semarang city.

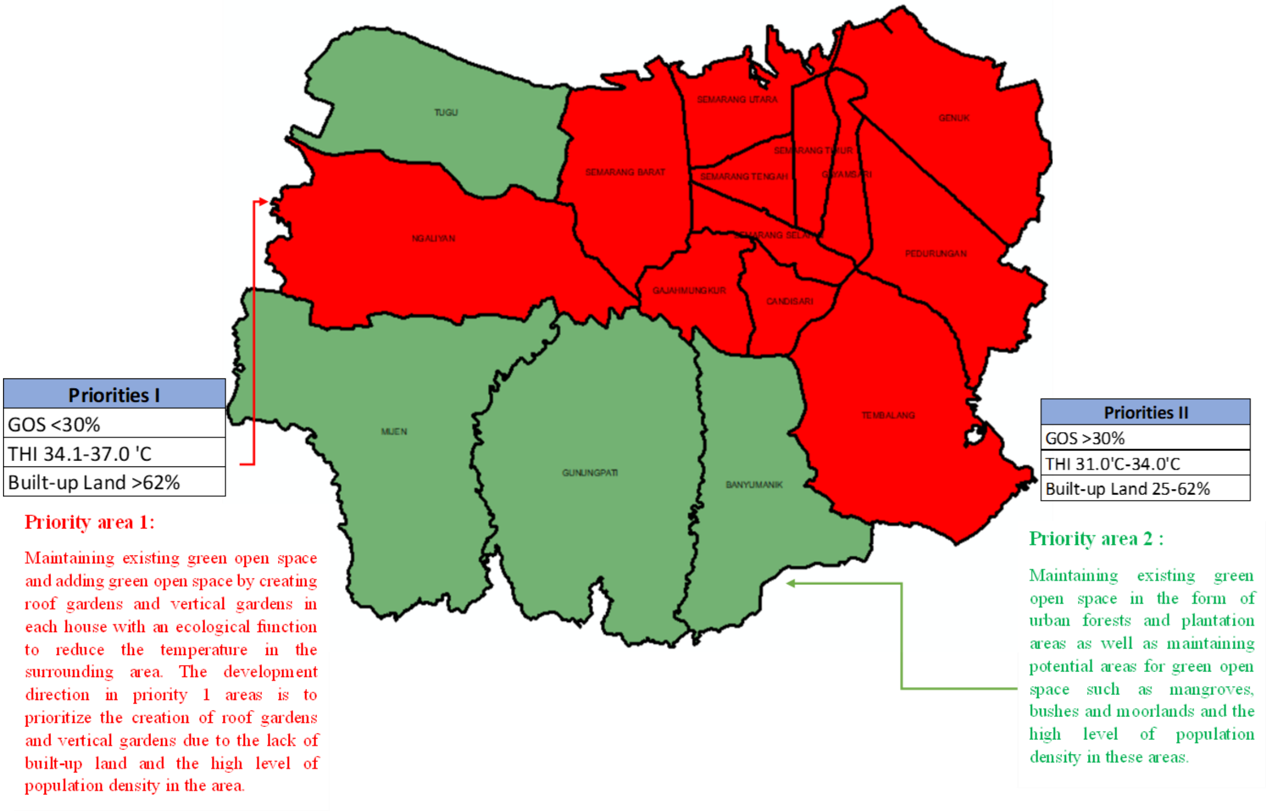

Figure 10 Map of the distribution of priority area development directions in the Semarang City

CONCLUSION

Based on the research that has been carried out, there are the following conclusions: Land use in Semarang City is dominated by built-up land (2013–2022). The increase in built-up land by 8.84% or 3,410 ha resulted in a decrease in green open space by 7.59% or 2,928.49 ha. Even though the area of Semarang City green open space is still > 30% with a value of 38.5% or 14,856 ha. In the prediction of land use, a kappa value of 83% is obtained, where the 2032 land use is dominated by the built-up land class of 61% or 23,575 ha. The second largest land use is in the scrubland class at 9.46% and the smallest land use is in the mangrove class at 0.13%.

The availability of GOS in the city of Semarang continues to decrease from 2013–2022 by 7.59% or 2,928 ha. Where in 2022 the availability GOS in Semarang City is 38.50%, still sufficient > 30%. Based on the availability of green open space per sub-district, only 5 sub-districts fulfilled > 30%, namely Banyumanik, Mijen, Gunungpati, Ngaliyan, and Tembalang Sub-districts. The relationship between GOS and the level of comfort influences each other, where the decrease in green open space causes an increase in the level of comfort and makes comfortable environmental conditions uncomfortable.

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