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Analysis of the Relationship between Thermal Comfort Levels and Green Open Space in Semarang City, Using the Humidex Method

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Abstract

The rapid urbanization of Semarang City has led to an increase in building density and a reduction in Green Open Space (GOS), impacting the thermal comfort of the area. Thermal comfort is determined by air temperature and humidity levels, which are assessed using the Humidex method in Semarang. Recent calculations indicate that Humidex values range from 38.83°C to 41.10°C, categorized from uncomfortable to very uncomfortable. The highest readings in 2023 were recorded at the Semarang Climatology Station, with the lowest at the Ahmad Yani Semarang Meteorological Station. Land cover analysis via Landsat 8 imagery from 2014 to 2023 reveals significant changes: built-up areas increased to 68,541 km², tree-covered areas to 63,104 km², other vegetation types covered 1,353 km², and water bodies spanned 6,784 km². By 2023, the total area of tree vegetation reached 91,187 km². The study shows a strong correlation (0.87) between increased building coverage and higher Humidex values, indicating that urban development elevates thermal discomfort. Conversely, a correlation of -0.83 between GOS and Humidex values suggests that more extensive green spaces contribute to lower Humidex readings, enhancing thermal comfort. To improve or maintain thermal comfort, it is essential to strategically increase GOS, particularly in the northern and eastern parts of the city. Recommendations for the Semarang City Government include optimizing the selection and maintenance of vegetation, enhancing facilities and services in green areas, and educating the community about the benefits of GOS. These measures are crucial for offsetting the thermal discomfort caused by urban density and supporting sustainable urban living in Semarang City.

1. Introduction

Semarang City is one of the Metropolitan Cities in Indonesia. In addition to being the center of government, it is also the center of economic activities in Central Java Province. Due to this strategic role, Semarang City has been converting green open space (GOS) to develop office, industrial, residential, and other infrastructure facilities.

With an area of 373.8 km2, according to the Minister of Agrarian Affairs and Spatial Planning/Head of the National Land Agency of the Republic of Indonesia Number 14 of 2022, Semarang City must have a minimum GOS of 112.14 km2. Reduced GOS area can affect the level of thermal comfort [1].

The lack of thermal comfort also occurs in buildings, as experienced by the people of Seville (Spain). It increased the utilization of urban open space. However, climate change has negatively impacted the comfort level of urban open spaces. In this regard, Teresa et al, (2023) [2] conducted research to design, simulate, and assess infrastructure to improve thermal conditions in their area. The study's results showed that the air temperature value decreased, and the number of uncomfortable hours decreased by 21%. Urban spaces can regenerate with vegetation without waiting 20 or 30 years. People are also encouraged to spend more time outdoors.

Comparatively, The Kalijodo area in Jakarta provides another instance of urban open space utilization. It consists of 47.91% vegetated and 52.09% non-vegetated land. The region struggles with poor water absorption and storage, elevated average air temperatures, a high Thermal Moisture Index (THI), and limited economic prospects. In response, Ignasius et al. (2023) [3] have proposed several enhancements, including increasing the area of vegetated land, upgrading road surfaces, implementing bio pores, and constructing water features such as ponds and wetlands. Furthermore, they focused on boosting community engagement and refining local government policies. These initiatives have led to lower average air temperatures, enhanced water absorption, improved economic potential, and greater community visitation rates.

Sarah Scheiber (2022) [4] stated that the low quality of urban open space also occurs in Malta. According to her, there is a spatial integration gap in planning and governance requirements. Urban open spaces depend not only on design but also on the planning process, stakeholder engagement, and appropriate governance systems.

Jamshid et al. (2020) [5] said that planting plants in urban areas can change the heat balance and lower the temperature. It is referred to Sistan's (Zabol) research in the East of Iran. The results of his study stated that the physiologically equivalent temperature index is related to the average air temperature and radiation among all microclimate parameters. The research also revealed that, in vegetated areas, the average air temperature was 1 °C lower, the average radiation temperature was 6 °C lower, and the PET index was 7 °C lower compared to areas without vegetation.

Paz et al. (2024) [6] mentioned that heat waves due to the effects of climate change have made urban areas uninhabitable. Therefore, research was conducted to study the characteristics of thermal behavior. The Research proves that cold water temperatures lower surface temperatures by 15 °C. Water reservoirs can maintain daytime temperatures between 18 and 25 °C, even in heat waves exceeding 7 days and air temperatures of 45 °C.

Air temperature and humidity are crucial factors determining thermal comfort in urban settings, as identified by Feng et al. (2020) [7]. Heat stress indices such as the Discomfort Index, the Tropical Summer Index, and the Thermal Humidity Index (THI) integrate these parameters to assess thermal conditions.

THI specifically gauges heat stress during warm conditions based on human biometeorological principles. It reflects how human bodies respond to the combined effects of temperature (T) and relative humidity (RH), which is why the National Weather Service of the United States employs THI. However, THI does not account for radiant heat, potentially leading to misjudged thermal perceptions by either underestimating or overestimating the environmental heat load.

Another widely used index, the Wet-Bulb Globe Temperature (WBGT), includes measurements of natural wet bulb temperature, black bulb temperature, and dry bulb temperature, thus considering both T and RH and estimated radiant heat impacts. Despite its comprehensive approach, achieving a stable measurement state for the black bulb temperature can be time-consuming, limiting WBGT's application primarily to urgent or temporary assessments.

Besides the heat pressure index, various human energy balance indices are also commonly used, including the Physiologically Equivalent Temperature, Standard Effective Temperature, and Universal Thermal Climate Index. These indices are beneficial as they link thermal comfort to the insulation properties of clothing and the metabolic rate of individuals during physical activity. However, like the WBGT, these indices come with their own set of limitations.

Another straightforward index frequently used in research is the Humidex. This index measures thermal comfort using temperature (T) and relative humidity (RH) parameters, which meteorological stations routinely record. The Humidex formula outputs a value directly related to the perceived temperature in degrees Celsius, indicating comfort levels. This study analyzed thermal comfort using Humidex values in relation to the presence of Green Open Space (GOS), based on data from Landsat 8 imagery.

Yumeng et al. (2023) [8] also applied the Humidex approach in their investigation of the impact of temperature fluctuations on mental health, particularly depression, in Chongqing, one of China's largest, hottest, and most humid cities. Their findings indicated a strong correlation between high Humidex levels (≥40) and increased depression-related outpatient visits from 2014 to 2019. The analysis further revealed that women and older adults (aged 60 and above) were particularly vulnerable to these conditions. The study noted that among outpatients with depression, the incidence rate was significantly elevated, with a Humidex rate of 1709 representing 1.10% of cases.

In response to the challenges of ongoing urbanization and increasing temperatures, this study aims to comprehensively investigate the impact of green space coverage on thermal comfort in Semarang City using the Humidex method. Specifically, the objectives of this research are to: (1) identify the relationship between Humidex values and the increase in built-up areas as well as the decrease in green open spaces, (2) analyze the impact of land use changes on Humidex values from 2014 to 2023, and (3) provide strategic recommendations for the city government on more effective green space management to enhance thermal comfort quality. The study expects to offer valuable insights for more sustainable and environmentally friendly urban planning in Semarang through this approach.

2. Methodology

2.1. Types and Data Sources

The research data includes air temperature parameters and air relative humidity from 2014-2023. Data was obtained from the Ahmad Yani Semarang Meteorological Station (STAMET), the Semarang Climatology Station (STAKLIM), and the Tanjung Emas Semarang Maritime Meteorological Station (STAMAR).

2.2. Data Processing

The thermal comfort index is calculated by the Humidex method with the following empirical equation.

$$Humidex = T + \frac{5}{9}(e - 10) \quad \text{........................(1)}$$

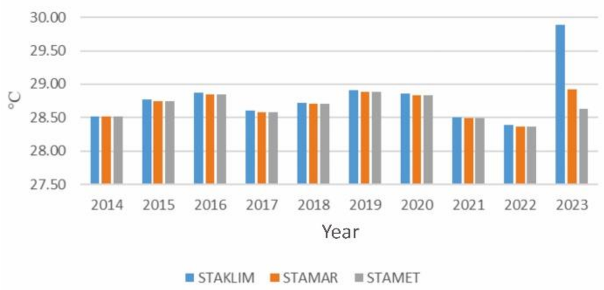
$$e = 6{,}112\ x\ 10^{\left(\frac{7{,}5T}{(237{,}7+T)}\right)} x\ \frac{RH}{100} \quad \text{........................(2)}$$

Humidex = Heat indeks (ºC)
T = Average air temperature (ºC)
RH = Relative humidity (%)

Humidex has no special unit, but it can be associated with the temperature unit °C. The analysis was carried out by determining the level of discomfort at each measurement point, according to the classification of Spridonov et al. (2013) [8] as listed in Table 1.

Table 1. Interpretation of Humidex values according to the sensation of heat [9]

Category	Humidex Index	Information
• Comfortable	≤ 29 ºC	
• A little uncomfortable	30-34 ºC	
• Uncomfortable	35-39 ºC	Limit strenuous physical activity
• very uncomfortable that it causes a feeling of heat sting	40-45 ºC	Carry out the activity in the colder area
• very uncomfortable and almost lead to illness due to heat stroke	46-53 ºC	Stop all physical activity
• Heat death	≥ 54 ºC	



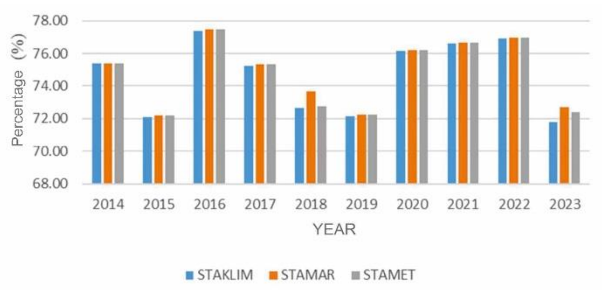


Figure 1. Average Air Temperature 2014-2023. **Figure 2.** Average Relative Humidity 2014-2023

Landsat 8 image data from 2014, 2017, 2020, and 2023 are used to determine the change in land cover in Semarang City. The image is classified to obtain the area in the GOS category. The GOS-wide data was analyzed to determine its relationship with thermal comfort.

3. Results and discussions

3.1. Trends in Air Temperature and Relative Humidity Change

The data on average air temperatures depicted in Figure 1 indicates a rising trend from 2014 to 2023, with noticeable drops in temperatures occurring in 2017, 2021, and 2022, coinciding with active La Niña events. During La Niña, sea surface temperatures in the Eastern Equatorial Pacific drop below normal levels, while those around Indonesia tend to rise. This differential heating causes enhanced convection, accumulating air masses over Indonesia, including those from the Eastern Equatorial Pacific. Consequently, the increased cloud formation and precipitation, driven by rapid surface evaporation, lead to the generation of cooler air. Such intense rainfall effectively cools the air.

In line with the influence of La Nina, relatively high humidity data occurred in 2016, 2020, 2021, and 2022, as shown in Figure 2. Conversely, relatively low humidity occurred in 2015, 2018, 2019, and 2023. In those years, Indonesia experienced the El Nino phenomenon, so the temperature of the sea face became colder, evaporation decreased, or there was a deficit in the water vapor supply. If water vapor decreases, the weather tends to be cold and dry (Siregar et al, 2020) [10]. The history of the El Nino and La Nina phenomena from 1990 to 2024 is shown in Figure 3.

Figure 4 illustrates the relationship between the increase in building area and the increase in temperature in 2014-2023. The correlation of building area with air temperature is 0.2. This means that both variables have a small amount of value. The relationship is linear positive; the more expansive the building cover, the higher the air temperature.

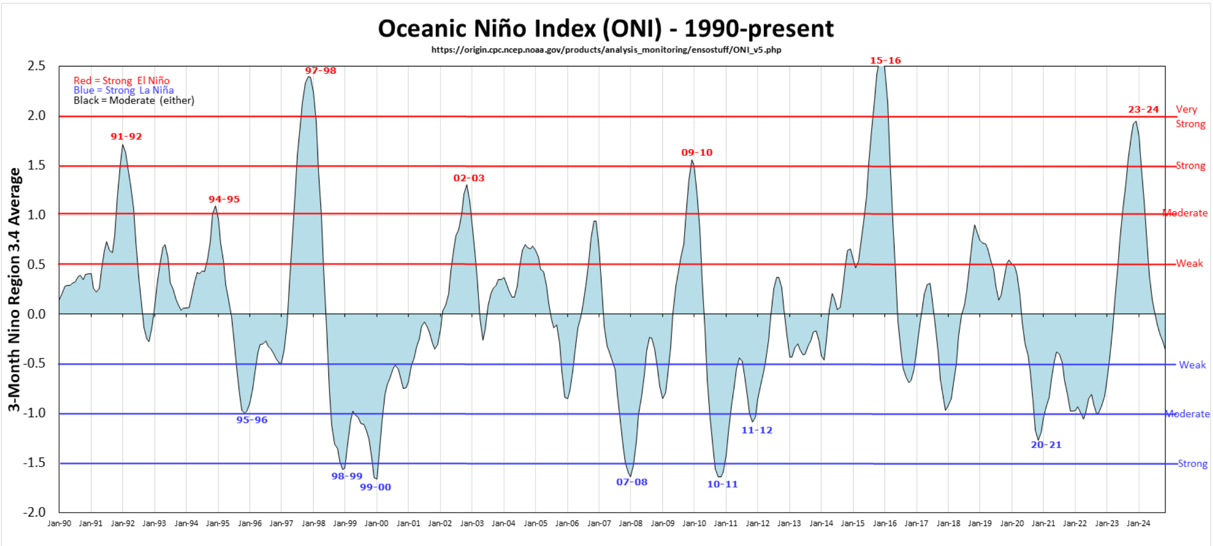


Figure 3. History of El Nino - La Nina Events in 1990-2024 https://ggweather.com/enso/oni.htm [11]

Figure 4. The Relationship Between Building Area and Air Temperature in 2014-2023

3.2. Thermal Comfort Conditions

Based on the interpretation of the humidex values in Table 2. Therefore, the discomfort conditions in Semarang City were relatively evenly distributed throughout the research period. Only a few areas in the uncomfortable category are higher than others.

The results of the calculation of the comfort index show that, in general, thermal discomfort occurred throughout 2014-2013. The heat caused a sting in 2016, 2020, and 2023. In 2015, the best thermal comfort conditions were in STAKLIM and STAMAR, with Humidex indices of 39.00 and 38.99. The best comfort conditions at STAMET occurred in 2023, with a Humidex index of 38.83. Meanwhile, the most challenging comfort conditions occurred in 2023 at STAKLIM, with a Humidex index 41.10.

Table 2. Semarang City Humidex Index

Year	**Humidex Index (^{O}C)**			**Comfort Level Category**		
	STAKLIM	**STAMAR**	**STAMET**	**STAKLIM**	**STAMAR**	**STAMET**
2014	39,24	39,23	39,23	Uncomfortable	Uncomfortable	Uncomfortable
2015	39,00	38,99	38,98	Uncomfortable	Uncomfortable	Uncomfortable
2016	40,38	40,35	40,35	very uncomfortable that it causes a feeling of heat sting	very uncomfortable that it causes a feeling of heat sting	very uncomfortable that it causes a feeling of heat sting
2017	39,38	39,35	39,35	Uncomfortable	Uncomfortable	Uncomfortable
2018	39,04	39,22	39,02	Uncomfortable	Uncomfortable	Uncomfortable
2019	39,28	39,26	39,25	Uncomfortable	Uncomfortable	Uncomfortable
2020	40,08	40,05	40,05	very uncomfortable that it causes a feeling of heat sting	very uncomfortable that it causes a feeling of heat sting	very uncomfortable that it causes a feeling of heat sting
2021	39,48	39,46	39,46	Uncomfortable	Uncomfortable	Uncomfortable
2022	39,31	39,28	39,28	Uncomfortable	Uncomfortable	Uncomfortable
2023	41,10	39,45	38,83	very uncomfortable that it causes a feeling of heat sting	Uncomfortable	Uncomfortable

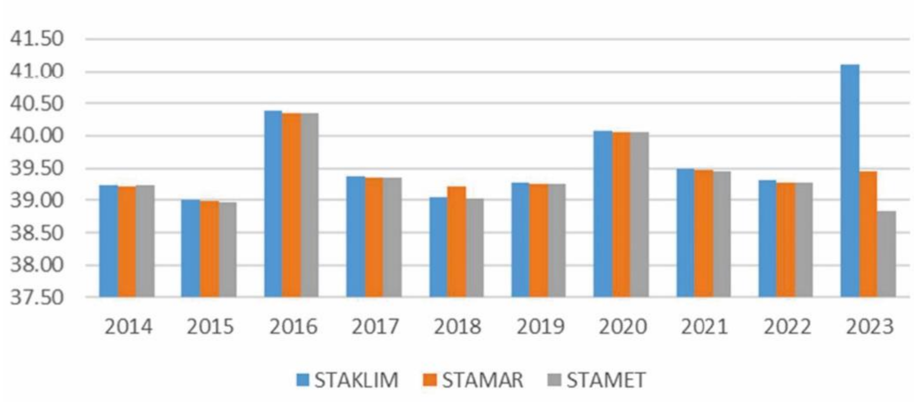


Figure 5. Humidex Values 2014-2023

3.3. Analysis of Spatial Humidex Value

Semarang City Humidex values in 2014-2023 show that the humidex value in STAKLIM is the highest compared to the other two locations (Figure 5). This shows that the level of thermal comfort at STAKLIM is the worst among the three locations. This condition is very likely to occur due to the Urban Heat Island (UHI) phenomenon, considering that the location of STAKLIM is in the middle of an urban area. UHI is an area with a surface temperature higher than its circumference (Agbor and Makinde, 2018) [12]. The main factors of UHI are land cover change, energy utilization, and an increase in waterproof surfaces due to the erection of buildings or land pavements, thus causing heat accumulation (Büyükbeşe and Aslan, 2019) [13]. Meanwhile, the values of Humidex STAMET and STAMAR tend to be the same. This happens because both have the exact location characteristics, namely both are on the outskirts of Semarang City and are closer to the sea than STAKLIM.

During this research, the value of Humidex varied considerably. The peak of discomfort occurred in 2023, especially at STAKLIM. Because of its location in the middle of the heat island, it was exacerbated by the presence of a strong El Nino.

In 2023, the El Nino phenomenon is in a strong category, marked by a sea level anomaly value of 1.5-1.90C. The impact of rising temperatures is felt in urban areas (Tan et al, 2018) [14], namely in STAKLIM. El Niño phenomena have been associated with notably high temperatures in Southeast Asian nations like Malaysia, Thailand, and Vietnam, exemplified by the drought experienced in 2021. These events lead to warmer-than-average conditions and have historically triggered some of the longest and most severe droughts, with record-setting temperature rises observed during the 1997/1998 and 2015/2016 periods (Chen et al, 2018) [15]. Meanwhile, for the two research sites, namely STAMAR and STAMET, the impact of El Nino is not significant. Although the three research sites experienced the El Nino phase, local factors were more influential in the thermal comfort level, as in STAMAR and STAMET [19]. One of the factors that is suspected to affect this is wind and ventilation patterns. The STAMAR and STAMET areas are near the sea, so they have better wind patterns and ventilation, including not many buildings. Such conditions help in maintaining thermal comfort. An increase in wind speed will cause a decrease in the value of Humidex or vice versa. There is an increase in thermal comfort when the value of Humidex decreases or vice versa (Siregar et al, 2019) [16].

3.4. Land Cover Conditions

The results of running on 25 Landsat 8 sample training are known that in 2014, the building area in Semarang reached 143,867 km^2; the tree vegetation area 154,291 km^2; the area of other vegetation in the form of grasses, shrubs, and so on is 49,504 km^2; and through 35,864 km^2 of water bodies.

Three years later, in 2017, the spread area of the building increased to 156,450 km^2. Meanwhile, the distribution area of tree vegetation decreased to 121,566 km^2, the area of other vegetation to 67,389 km^2; and the area of the water body to 38,122 km^2. The Development continues so that in 2020, the area of the building area has reached 175,088 km^2; the area of tree vegetation is decreasing to 109,734 km^2; other vegetation area is 70,087 km^2; and the area of the water body to 28,618 km^2.

Table 3. Variation of Building Area, Vegetation, and Water Bodies

Year	Building		Tree Vegetation		Other Vegetation		Water Bodies	
	km²	%	km²	%	km²	%	km²	%
2014	143,867	8,75	154,291	21,21	49,504	36,13	35,864	6,30
2017	156,450		121,566		67,389		38,122	
2020	175,088	11,91	109,734	9,73	70,087	4,00	28,618	24,93
2023	212,408	21,31	91,187	16,90	50,857	27,3	29,080	1,61
Total Shift								
%	47,64		40,90		2,73		18,92	
km²	68,541		63,104		1,353		6,784	

The last observation, namely in 2023, is that the building area is expanding, namely to 212,408 km^2; the area of tree vegetation is only 91,187 km^2; the area of other vegetation is 50,857 km^2; and the area of the water body to 29,080 km^2.

From the observation, the total land function transition over 10 years was obtained, which reached 47.64% or around 68,541 km^2 of building area; 40.90% or about 63.104 km^2 of tree vegetation; 2.73% or about 1,353 km^2 of other vegetation; and 18.92% or about 6,784 km^2 for water bodies.

Thus, it can be concluded that the value of land function transition is quite significant. This shows an imbalance between the acceleration of development and the maintenance of green land. The results of Landsat data processing have been verified with an overall accuracy result of 85%. This accumulation level is included in the excellent category on the representation of Landsat 8 satellite imagery (Li et al, 2022) [16]. The percentage change in the area of buildings, vegetation, and water bodies is presented in Table 3. As previously stated, Semarang City spans 373.78 km². Consequently, the city must maintain at least 112.14 km² of Green Open Space (GOS), representing 30% of the total area. A detailed comparison of the area covered by tree vegetation relative to the overall area of Semarang City is provided in Table 4.

It appears that, from 2014 to 2017, the area of tree vegetation still meets the minimum requirement for the availability of urban GOS, which is 41.28%. However, in 2017, it dropped to 32.52%. Even at the final monitoring in 2023, the area of tree vegetation no longer meets the minimum requirement for the availability of urban GOS, which is 24.20%.

The area of tree vegetation, as shown in the image of Landsat in Semarang City in 2023, reaches 91,187 km2. Meanwhile, the area in the form of other vegetation, such as grass, shrubs, or rice field areas, reaches 50,857 km^2. According to the Minister of Agrarian and Spatial Planning/Head of the National Land Agency of the Republic of Indonesia Number 14 of 2022, Semarang City must have a minimum of 112.14 km2 of GOS. Thus, the city of Semarang has fulfilled the minimum requirements for the area of the GOS. Changes in the area of buildings, vegetation, and water bodies are presented in Figure 6. Red indicates the area of the building, green indicates the vegetation area, orange indicates other vegetation areas, and blue indicates the area of the water body.

Table 4. Percentage of Tree Vegetation Area to the Area of Semarang City

Year	Tree Vegetation Area (Km^2)	Percentage (%)
2014	154,291	41,28
2017	121,566	32,52
2020	109,734	29,36
2023	91,184	24,40

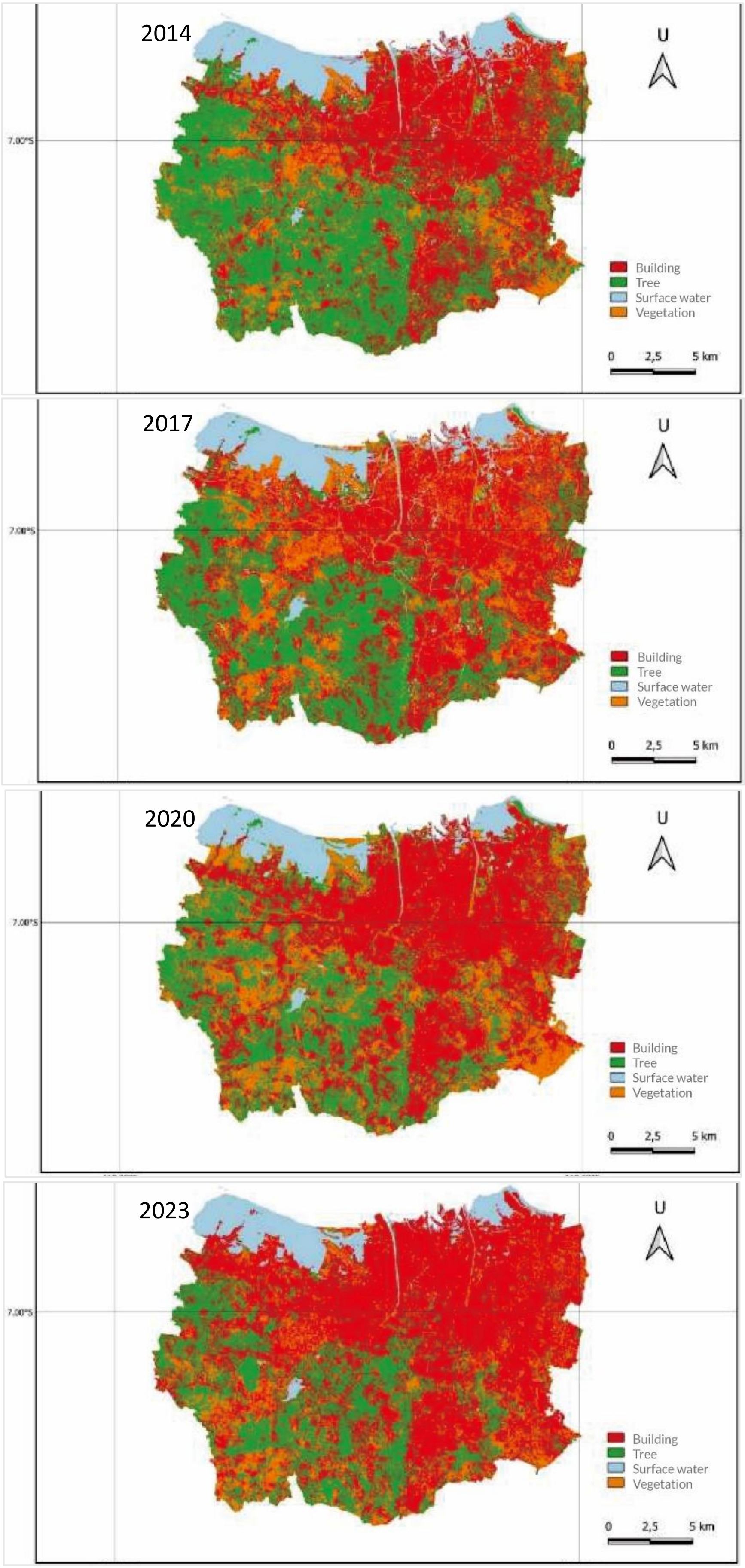


Figure 6. Land use map of Semarang City in various years.

3.5. Analysis of the Relationship of Thermal Comfort Conditions with the Extent of GOS

The correlation of thermal comfort conditions indicated by the Humidex value with the building area shows a positive value of 0.87. This means that both variables have a robust positive linear relationship. In other words, the wider the building cover, the greater Humidex is value. An increase in the humidex value means a decrease in the level of thermal comfort as shown in Figure 8.

The correlation of the Humidex value with the vegetation area shows a value of -0.83. This means that both variables have a powerful negative linear influence, or the wider the vegetation cover, the lower the Humidex value is, and vice versa. A decrease in the value of humidex means increased thermal comfort. A graph of the relationship between Humidex values and vegetation area can be seen in Figure 9.

The relationship between green open spaces and thermal comfort in Semarang City, as analyzed through the Humidex method, echoes findings across various regions. Putri et al. (2023) observed similar dynamics in riparian vegetation affecting local climates within the Central Welang Watershed [20], suggesting that vegetation can significantly impact microclimatic conditions. Furthermore, Harnani and Savira (2023) demonstrated the application of remote sensing techniques to assess vegetation's role in mitigating flood risks, which indirectly supports the cooling effects of green spaces in urban settings [21]. Additionally, Prayuda and Kusuma (2023) used predictive models to analyze land cover changes in Surabaya, further emphasizing the necessity of maintaining green open spaces to manage urban heat effectively [23]. These studies collectively highlight the crucial role of vegetation in urban planning for enhancing thermal comfort in tropical cities like Semarang.

The interplay between the atmosphere and urban vegetation is intricate and necessitates a thoughtful approach to green infrastructure design. The thermal impact of urban vegetation derives from a blend of evapotranspiration and shading, which collectively contribute to cooling effects. Tree shade mitigates the escalation of surface temperatures and markedly lowers the average radiation temperature in urban areas. Additionally, trees serve as barriers against solar radiation. Urban vegetation further aids in cooling through transpiration, where some of the sun's energy is absorbed and converted into latent heat due to plant water evaporation. This not only cools the leaf surfaces but also the air around them. The success of these nature-based solutions in enhancing thermal comfort varies based on factors such as the layout of the urban landscape and the type and extent of green infrastructure implemented, as discussed by Gatto et al. (2023) [18]. The extent of vegetated land correlates with shifts in the thermal comfort index in downtown Semarang

4. Conclusion

From 2014 to 2023, the Humidex values in Semarang City ranged from 38.83°C to 41.10°C, placing them within the uncomfortable to very uncomfortable range, significantly contributing to the sensation of oppressive heat. During this period, the area of green spaces, particularly tree vegetation, has continually diminished, falling short of the minimum requirements set by the Minister of Agrarian Affairs and Spatial Planning/Head of BPN RI in Regulation Number 14 of 2022 concerning the Provision and Utilization of Green Open Space. According to the regulation, Semarang City, which spans 373.8 km², must maintain at least 112.14 km² as GOS. However, data from 2023 indicate that the area of GOS with tree vegetation in Semarang has dwindled to just 91,184 km² or 24.40% of the city's total area. Analysis reveals a clear correlation: more extensive vegetation cover corresponds with lower Humidex values, indicating cooler conditions and enhanced comfort levels. Conversely, reduced green cover leads to higher Humidex values and decreased comfort. Thus, maintaining or increasing green open spaces is crucial for improving thermal comfort in Semarang City.

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