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[Research Article]

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Spatial and Temporal Variations in Land Surface Temperature as an Indicator of Learning Comfort Level in Banten Province

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Abstract

Increasing population and rapid development of built-up land can cause an increase in land surface temperature. These changes are often associated with many factors, including changes in land use, and surface parameters, economic development, and vegetation. This research aims to analyze the temperature factor as an indicator of indoor thermal comfort to support the learning process in schools in the Banten Province area. This research uses a spatial temporal approach with descriptive statistical analysis. Based on the results, show that the land surface temperature at each school location in Banten province shows conditions that are not constant. The number of schools with uncomfortable conditions varies from 2019 (89.07%), 2020 (42.65%), 2021 (45.66%), 2022 (82.66%), and 2023 (52.44%). This shows that there has been a decrease in uncomfortable conditions for studying by 36.63% in the last 5 years.

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Abstrak

Meningkatnya jumlah populasi dan pesatnya perkembangan lahan terbangun dapat menyebabkan terjadinya peningkatan Suhu Permukaan Daratan. Perubahan ini sering dikaitkan dengan banyak faktor, termasuk perubahan penggunaan lahan, dan parameter permukaan, perkembangan ekonomi, dan vegetasi. Penelitian ini bertujuan menganalisis faktor suhu sebagai indikator kenyaman termal dalam ruangan untuk mendukung proses pembelajaran disekolah di wilayah Provinsi Banten. Penelitian ini menggunakan pendekatan spasial temporal dengan analisis statistik deskriptif. Berdasarkan hasil menunjukan suhu permukaan daratan di setiap lokasi sekolah di provinsi Banten menunjukan kondisi yang tidak konstan. Jumlah sekolah dengan kondisi kurang nyaman bervariasi dari 2019 (89.07%), 2020 (42.65%), 2021 (45.66%), 2022 (82.66%), dan 2023 (52.44%). Hal ini menunjukkan terdapat penurunan kondisi kurang nyaman untuk belajar sebesar 36.63% dalam 5 tahun terakhir.

INTRODUCTION

In the 21st century, half of the global population is urban, so this century is also called the "urban century". This number is estimated to continue to increase to reach more than 70% in 2050. Cities are considered places to reduce consumption from various sources and increase the release of pollutants. It also poses a serious threat to ecological resources and can limit urban facilities and the rapid growth of urbanization (Mirkatouli et al., 2015). The rapid growth of urbanization and regional development due to the transformation of artificial land into low levels of natural land cover is one of the main causes of global climate change (Touchaei & Wang, 2015; Insan & Prasetya, 2021). Population growth in urban areas, especially in developing countries, contributes to putting a lot of pressure on natural resources and causes the gradual loss of these resources (Peron et al., 2015; Aldiansyah & Wardani, 2023).

Land surface temperature (LST) is an important parameter in the physical processes of surface energy and water balance at local to global scales (Solanky et al., 2018). Changes in LST are related to many factors, including changes in land use, economic development, changes in vegetation, and so on (Rajendran & Mani, 2015). In urban areas, temperature variations due to high LST are strongly influenced by the high ratio of impervious surfaces reaching 5°C which poses concerns for the environment and human health (Emmanuel & Krüger, 2012; Chen et al., 2021). This phenomenon is most commonly associated with increased impervious surfaces due to changes in land use and cover required by development (Buchin et al., 2016; Traore et al., 2021).

In densely built areas, the poor layout can create a “canyon effect” where airflow is restricted and causes heat to be trapped, creating higher temperatures (Chen et al., 2022). Darker building colors and building surfaces that do not reflect light can produce higher temperatures (Pu et al., 2006). Building infrastructure such as parking lots and pedestrian walkways are considered to increase thermal conductivity (Tahooni et al., 2023).

Buildings that are too hot will cause occupants to feel uncomfortable (Gunawan & Ananda, 2017). Many experts have analyzed the negative impact of poor room conditions on the effectiveness of the occupants, for example, uncomfortable study room conditions will affect the success of receiving learning material (Haynes, 2008). Room conditions are good if 80% of the occupants feel comfortable in the room (Kwok, 1997).

A school building is an educational facility where the teaching and learning process takes place between teaching staff and students. Schoolrooms must pay attention to the level of thermal comfort so that the teaching and learning process can run optimally. The temperature factor as an indicator of thermal comfort is an important thing to analyze, especially in the learning process at school (Aienna et al., 2016). Therefore, evaluation of LST is important for designing indoor spaces that are thermally comfortable and create a conducive learning environment.

Weather/climate information can be obtained using remote sensing systems (Wardhani, 2006). The advantage of using remote sensing is that it allows measuring natural conditions via satellite with wide area coverage without having direct contact with the area being studied (Lillesand & Kiefer, 1987). Compared with in situ measurements, traditionally considered the most reliable observations (Dubovik et al., 2002), but due to the limited number of weather stations, the resulting data is limited (Wardhani, 2006). Therefore, remote sensing is needed to minimize these data limitations. Research conducted by Goldblatt et al. (2021) at the King Abdulaziz University campus (Jeddah, Saudi Arabia) and four surrounding neighborhoods using Landsat 8 found that using only remote sensing data, including LST, Normalized Difference Vegetation Index (NDVI), and Normalized Difference Built-Up Index (NDBI), random forest classifiers can detect locations with classification “very hot” thermal comfort was nearly as effective as estimates using in situ data, with one of the models achieving an F1 Score of 0.65. Research conducted by Imran et al. (2021) during summer in Dhaka City shows that the distribution of land use (especially built-up land and bare land) is spatially correlated with LST distribution and causes thermal discomfort in humans. This study aims to understand the spatial and temporal patterns of Land Surface Temperature (LST) variations to identify indicators of learning comfort levels in 2019-2023 in Banten Province using Landsat 8 Imagery.

METHOD

Study Area

This study is located in Banten Province between 5º7'50"-7º1'11" South Latitude and 105º1'11"-106º7'12" East Longitude (Figure 1). Based on the 2022 Central Statistics Agency report, the population of Banten reached 12,251,985 people with an area of 9,663 km² (BPS Banten Province, 2023). This region is dominated by flat areas with a slope of 0-2% covering an area of 574,090 hectares. This situation allows for significant extraction of forest cover because it is considered suitable for development.

Preprocessing

The data used in this research is satellite image data and school point distribution. Landsat 8 OLI/TIRS image data was downloaded from United States Geological Survey (USGS) metadata via https://earthexplorer.usgs.gov/. The Landsat 8 OLI/TIRS satellite has two sensors, namely the Operational Land Imager (OLI) sensor and the Thermal Infrared Sensor (TIRS). These two sensors provide a spatial resolution of 30 meters (visible, NIR, SWIR), 100 meters (thermal), and 15 meters (panchromatic). This satellite has a temporal resolution of 16 days.

Landsat imagery is used to extract thermal comfort information using the Land Surface Temperature algorithm. Considering the wide area coverage compared to Landsat 8 OLI/TIRS recording coverage, the mosaic technique was used in this study. A mosaic image is a combination of several images that have matching parts to form an image with a wider visualization. The stages in mosaic images are carried out in three stages, namely point initialization in image pairs, image warping, and image merging. Image acquisition criteria were set to have cloud cover < 10%. Image acquisition is determined by the climate of Banten Province. Banten Province receives less rainfall from April to October, so the imagery is taken in July respectively (BPS Banten Province, 2024). Meanwhile, school distribution points were obtained from the Banten Province Geospatial Information Agency (BIG). School distribution data can be downloaded via https://geoportal.big.go.id/#/.

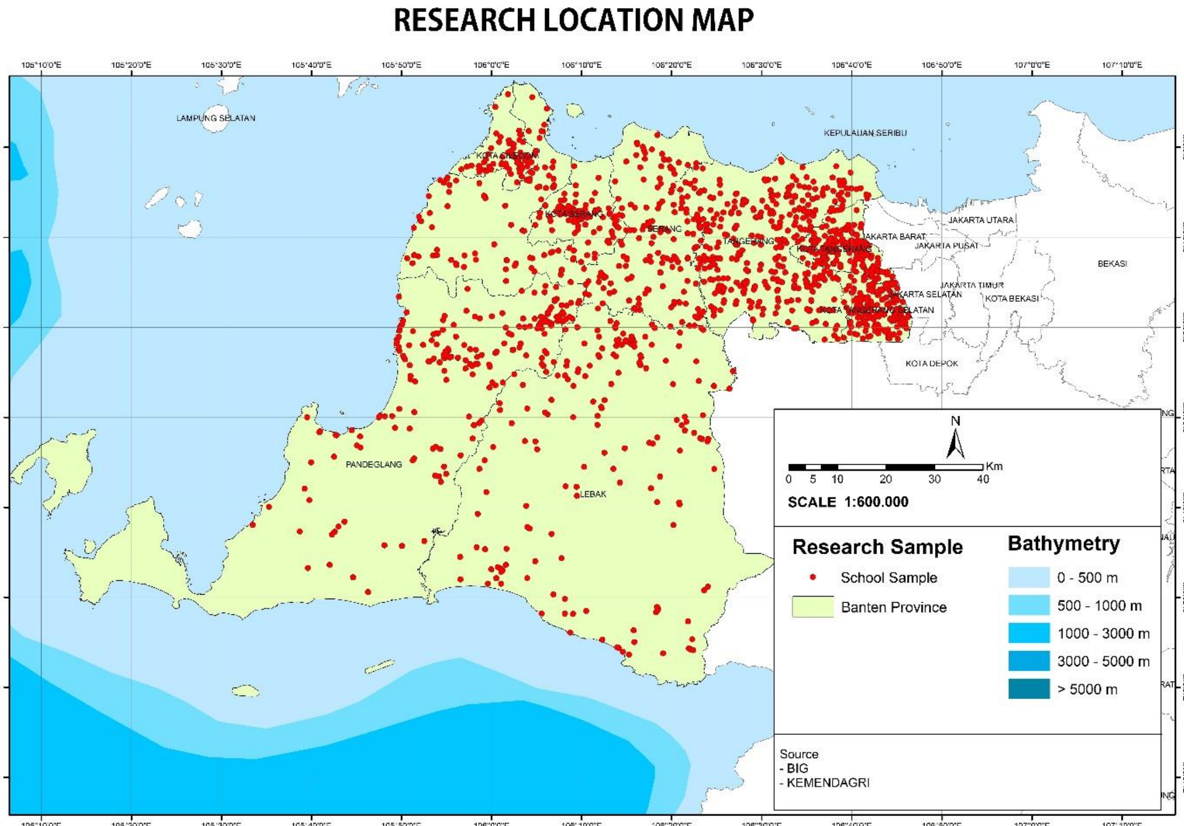

Figure 1. Research Location Map (Geospatial Information Agency, 2023)

Land Surface Temperature

Landsat 8 OLI/TIRS image analysis to obtain LST values is carried out in several stages, starting with converting Digital Numbers to Radiance values, calculating NDVI, adjusting Brightness temperature (BT), calculating the proportion of vegetation, calculating land surface emissivity, obtaining LST based on the equation previously adjusted. According to (Karyati et al, 2022; Aldiansyah & Wardani, 2023), the following are the equations used in image processing.

Conversion of Digital Numbers to Radians:

$$L\lambda = ML \times Qcal + AL - Oi \qquad (1)$$

where $L\lambda$ adalah Top of Atmosphere spectral radiance; ML is a special multiplicative scaling factor of the metadata; AL is the metadata band-specific additive scaling factor; $Qcal$ is the calibrated pixel value; dan Oi is Correction for band 10.

NDVI (Normalize Difference Vegetation Index):

$$NDVI = \frac{NIR\ (Band\ 5) - Red\ (Band\ 4)}{NIR\ (Band\ 5) + Red\ (Band\ 4)} \qquad (2)$$

where NIR is near-infrared radiation; and Red is red light radiation.

Brightness Temperature:

$$BT = \frac{K2}{ln(\frac{K1}{L\lambda} + 1)} - 273.15 \qquad (3)$$

where BT is ToA Brightness Temperature; K1 adalah Konstanta konversi termal 1; dan K2 is the thermal conversion constant 2.

Proportion of vegetation:

$$Pv = (\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}) \qquad (4)$$

where Pv is the proportion of vegetation, $NDVI_{min}$ shows the minimum NDVI value, dan $NDVI_{max}$ shows the maximum NDVI value NDVI.

Land Surface Emissivity:

$$\varepsilon\lambda = \epsilon v\lambda Pv + \epsilon s\lambda (1 - Pv) + C\lambda \qquad (5)$$

where $\varepsilon\lambda$ is the emissivity value; Pv is the proportion of vegetation; $\epsilon v\lambda Pv$ is the thermal conversion constant 1; $\epsilon s\lambda$ is the thermal conversion constant 2; dan $C\lambda$ is NDVI value.

Land Surface Temperature:

$$LST = \frac{BT}{\left[1 + \left(\frac{\lambda\ x\ BT}{C2}\right) ln\ (\varepsilon)\right]} \qquad (6)$$

where LST is land surface temperature; BT is ToA Brightness Temperature; λ is the wavelength; $C2$ value is 14388μmK; dan ε is emissivity value.

Indicator of Learning Comfort Level

After the LST value is obtained, the next step is to classify the LST value based on comfort level indicators based on SNI 03-6572-2001 (Table 1). The LST results are classified based on thermal comfort indicators, then identified based on the distribution of schools, and the distribution in each class is calculated using standard statistics.

RESULT AND DISCUSSION

Extracted NDVI values are analyzed for the last 5 years every July. The results of data processing show the spatial distribution of NDVI with values varying from -0.01-0.48 (Table 1). The highest NDVI distribution will be in 2022. The distribution of very sparse vegetation density is spread across the north to the northeast of the region. This region borders Jakarta where geographically and governmentally Banten acts as a buffer zone, so changes are quite significant in this region. A very dense distribution of vegetation density still dominates most areas, especially in mountainous areas.

Table 1. Comfort Level Indicator based on SNI 03-6572-200

No.	Condition	Effective Temperature
1	Cool comfortable	20.5ºC – 22.8ºC
2	Threshold	24.0ºC
3	Optimal comfort	22.8ºC – 25.8ºC
4	Threshold	28.0ºC
5	Warm cozy	25.8ºC – 27.1ºC
6	Threshold	31.0ºC

The spatial pattern of NDVI variation is not only influenced by the amount of vegetation but also by topography, slope slope, availability of solar radiation, and other factors (Singh et al., 2015). However, NDVI is also limited in several aspects. NDVI is sensitive to variations in atmospheric conditions, such as clouds, haze, and aerosols, which can affect light reflectance at visible and near-infrared (NIR) wavelengths. This can cause errors in NDVI values and make it difficult to interpret NDVI images accurately. Another limitation of NDVI is that it cannot differentiate between different types of vegetation or different vegetation health conditions. NDVI values can be similar for different vegetation types, such as trees and shrubs, and NDVI values can also be similar for healthy and stressed vegetation. NDVI can also be influenced by sensor characteristics, such as spatial resolution, spectral resolution, and radiometric resolution, which can affect NDVI values.

NDVI values from different sensors or different bands may not be directly comparable, and NDVI values may be affected by sensor characteristics. NDVI can also be affected by the angle of the sun, NDVI values can be affected by the angle of the sun, and NDVI values can change depending on the time of day or year when the image was obtained. This can make it difficult to compare NDVI values from different images or detect changes in vegetation cover over time.

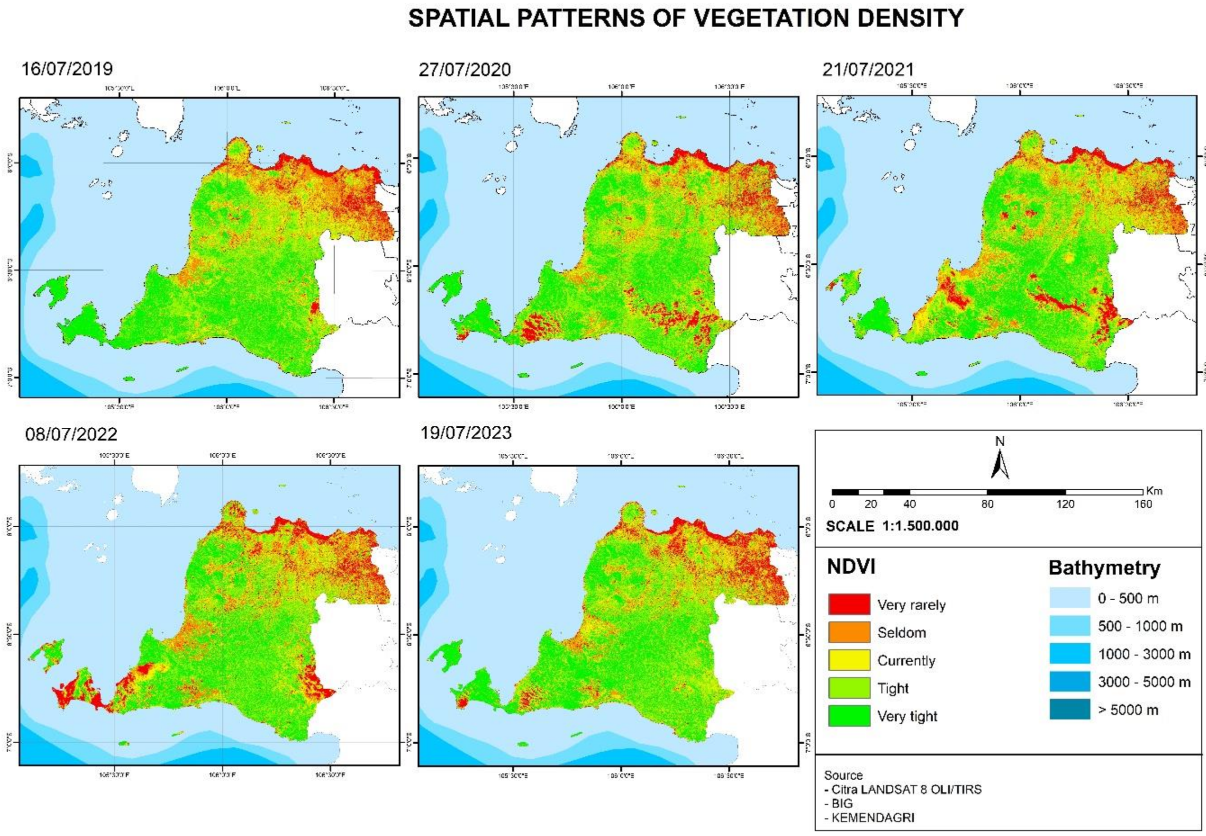

Figure 1. Spatial Pattern of Vegetation Density

Table 2. Vegetation density value.

Acquisition Date	Min	Max	Mean	Std Deviation
16/07/2019	-0.01	0.5	0.1818	0.08288
27/07/2020	0.02	0.45	0.1922	0.08133
21/07/2021	0.01	0.46	0.1965	0.07946
08/07/2022	0.01	0.48	0.1801	0.08866
19/07/2023	0.01	0.47	0.1864	0.08173

The results of NDVI are further analyzed to obtain multi-temporal LST variations. LST data shows a range of values varying from 18.69˚C-39.54˚C. The condition of land cover as a certain emissivity determines the surface temperature value of each object recorded by the image (Nugraha et al 2019). LST data compared with NDVI shows that high LST values are consistent with low NDVI values as evidenced by the spatial pattern of surface temperatures with high values in the urban-dominated northern part. Low temperatures consistent with high NDVI values can be seen in the central part with topography dominated by mountains. The highest temperature will be in 2023 with a value of 39.54˚C. The LST spatial pattern is shown in Figure 2.

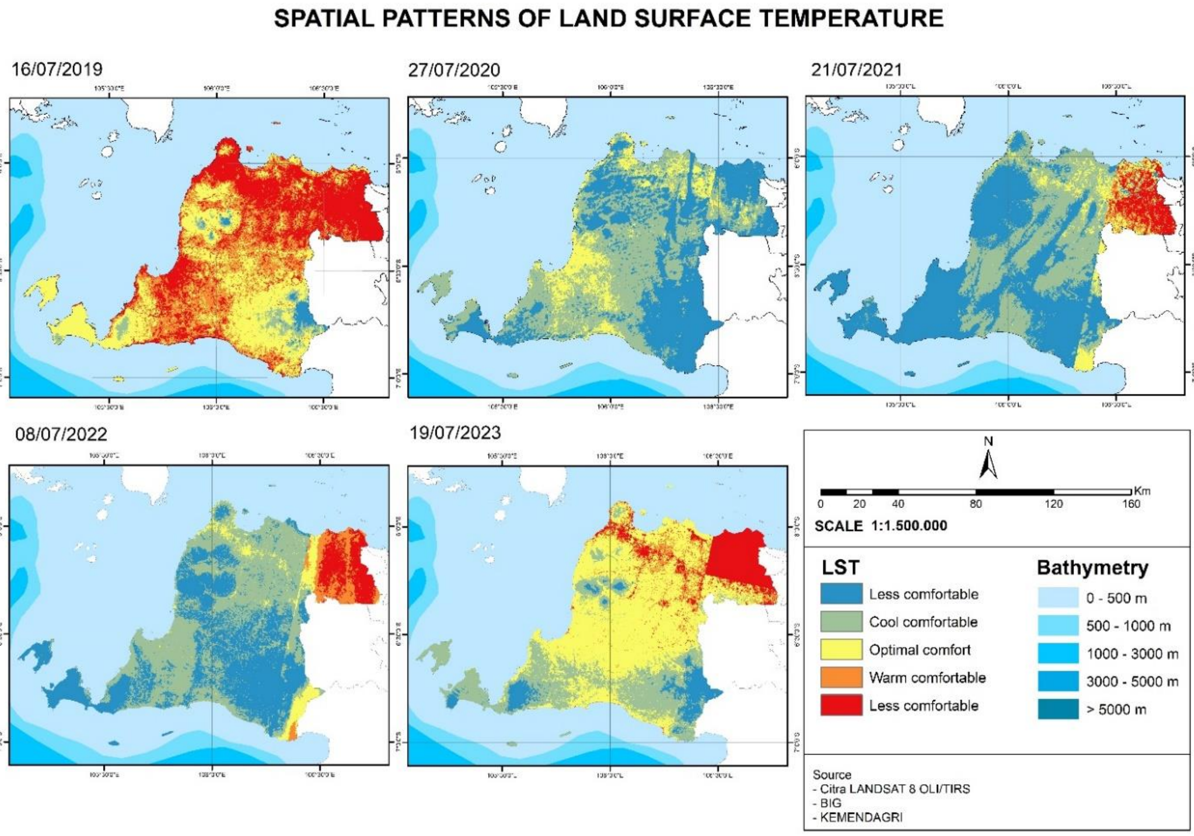

Figure 2. Spatial Patterns of Land Surface Temperature

Table 3. Land Surface Temperature value

Acquisition Date	Min	Max	Mean	Std Deviation
16/07/2019	19.88	34.28	29.4577	1.95165
27/07/2020	12.58	26.90	20.5629	3.05163
21/07/2021	18.69	31.22	24.2449	4.15598
08/07/2022	20.00	39.49	26.1155	7.70104
19/07/2023	22.52	39.54	29.3333	4.96040

Table 4. Distribution of schools based on thermal comfort indicators

Class	Effective Temp (˚C)	2019	2020	2021	2022	2023
Less comfortable	< 20.5 dan >27.1	1418	679	727	1316	835
Cool comfortable	20.5−22.8	0	560	474	210	31
Optimal comfort	22.8−25.8	65	351	275	50	374
Warm comfortable	25.8−27.1	109	2	116	16	352
Total		**1592**	**1592**	**1592**	**1592**	**1592**

The results of the LST were then analyzed further using the distribution of schools in Banten Province. The thermal comfort threshold is set so that it is not too cold (<20.5ºC) and not too hot (>27.1ºC). Comfort indicators based on SNI 03-6572-2001 show that several schools have thermal comfort conditions as shown in Table 4 above.

The results of data processing show that the land surface temperature at each school location in Banten province shows an unstable condition. The number of schools that were thermally uncomfortable in 2019-2023 was 89.07%, 42.65%, 45.66%, 82.66%, and 52.44%, respectively. This shows that there is a decrease in the number of schools that are thermally uncomfortable, namely 36.63% from 2019-2023. Thermal conditions and air quality in classrooms can influence student concentration and learning performance (Nugroho, 2011). Thermal dissatisfaction, such as a classroom that feels too hot or too cold, is associated with a form of physical stress (thermally) and can cause students to become less concentrated and even sick. Thermal comfort is important to pay attention to considering that high student density in the classroom can have a negative influence on student learning performance (Kwok, 1997). The study reported by Gunawan & Ananda (2017) shows that the majority of general and vocational high school buildings in Mandau District do not meet the thermal comfort requirements (25.90ºC - 27.60ºC) for use in the teaching and learning process.

Mutiara (2023) found that several lecture rooms had thermally uncomfortable room temperatures if the lowest temperature was <27.1ºC and the highest was 30.5ºC. This situation is also supported by air slowness, airspeed, sunlight intensity, inadequate room area, and height. Cahyani et al. (2017) found that sports facilities in West Java gave a warm to hot thermal sensation. This means that the sports facilities do not provide thermal comfort. Helfialna (2023) also reported that there was thermal discomfort in the laboratory room due to the absence of wind blowing because the building structure was too dense. This is a result of changes in land use and development of urban areas (Mallick et al 2008), and building age (Ramawangsa & Prihatiningrum, 2021). Changes in vegetation density can be caused by changes in green land to built-up land as an area develops (Aprilia et al., 2021). This has the impact of certain locations having hotter temperatures than other areas. According to Hadibasyir et al. (2020) the lower the level of vegetation density, the higher the ground surface temperature.

Vegetation such as trees plays a very important role in reducing air temperatures that are too high (Rushayati et al., 2018). Vegetation can change the surrounding environment by influencing air quality, reducing pollutant emissions, reducing the reflected effect of heat radiation from buildings, and reducing noise levels (As-syakur & Rahman, 2005). Therefore, the comfort level of school locations is largely determined by the condition of the vegetation. According to Masitoh & Rusydi (2020), the comfortable or somewhat comfortable environment depends on the density of the vegetation. Comfortable and somewhat comfortable locations are separated into areas with medium and high density, while uncomfortable to very uncomfortable are in areas with sparser vegetation. Areas that become less comfortable can be overcome by increasing vegetation density (Suwasono et al., 2013). Apart from contributing to ecological aspects, vegetation also plays a role in maintaining the beauty and increasing comfort of the environment, so that it can stimulate a person's creativity and productivity (As-syakur & Rahman, 2005).

The rapid increase in urban population and expansion of urban areas has led to an increase in built-up land and a decrease in vegetation cover (Kumari et al., 2018). Urbanization causes the conversion of green land and agricultural land, especially those on the outskirts of cities, into built-up areas (Kumari et al., 2018). The reduction in green land which functions to absorb sunlight causes surface temperatures to increase. Fikriyah et al. (2022) examined the relationship between building density and LST and concluded that an increase in built-up land area causes an increase in surface temperature. This increase in surface temperature causes a decrease in the comfort level of an area.

CONCLUSION

Temporal variations in LST tend to increase, which is followed by the increasing number of schools that feel thermally uncomfortable, namely 36.63%. However, despite this, this research only describes the situation in this area, but its application can be applied to similar areas in studying similar phenomena in the future. Increasing surface temperature as a parameter of suitability for living space will greatly influence aspects of life, both social, economic, and environmental control over space changes in use need to be enforced to guarantee future life.

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