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Thermal Comfort Level Based on the Temperature Humidity Index Value in Bandung City

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Abstract: The city of Bandung is one part of the Greater Bandung Area which has been designated as a National Activity Center (PKN) which has a role as a collection and distribution center on international, national, and several provincial scales. This has resulted in a high level of development driven by the pace of the economy and population growth which continues to increase in the city of Bandung, resulting in an increase in the need for built-up land which is accompanied by a decrease in non-built land, especially green open space, so that it can affect the temperature and humidity of the air as well as the thermal comfort of the microclimate or temperature. This research aims to identify the distribution of THI as a measure of the level of thermal comfort in Bandung City. The approach is remote sensing, specifically utilizing Landsat 8 OLI/TIRS image processing for 2013 and 2023 on Google Earth Engine Software. The data processing process goes through several stages, including NDVI processing, land cover classification, surface temperature, and THI. After going through these stages, it was found that the distribution of temperature humidity index values in 2023 in Bandung City was dominated by the uncomfortable class (>26°C).

Keywords: NDVI; Land-Cover; Surface-Temperature; THI.

INTRODUCTION

Temperature Humidity Index (THI) is a method used to assess or measure the level of comfort in an area by determining the effect of hot conditions on human comfort which combines the elements of temperature and humidity (Isnoor, Putra, & Firmantari, 2021). THI can also indicate whether or not the temperature and humidity conditions at a location are ideal for humans. The comfort limit for areas that have a tropical climate, especially Indonesia, ranges from 21–26°C (Emmanuel, 2005).

The city of Bandung is located in West Java Province. It is the capital of West Java Province and is included in one of the metropolitan cities in Indonesia which is the center of government, economic center, and education center (Mulyana, 2021). Based on the West Java Province Spatial Planning Plan 2022–2042, Bandung City is one part of the Greater Bandung Area which is designated as a National Activity Center (PKN) which has a role as a collection and distribution center on an international, national and several provincial scales. This has resulted in a high level of development driven by the pace of the economy and population growth which continues to increase in Bandung city.

In 2020, the city of Bandung experienced a significant increase in temperature to 28.54°C. Where time changes in the broad distribution of the highest temperatures are in the Central Bandung City Area (Rachmania & Urufi, 2022). In 2021, the minimum temperature in Bandung City will be 18.5°C with a maximum temperature of 29.7°C and has a humidity range of 48 – 98% (Badan Pusat Statistik Kota Bandung, 2022) . When compared with the theory from Niewolt (1976) in tropical areas, especially in the city of Bandung, it shows that THI values vary, namely comfortable and uncomfortable, which are spread across the city of Bandung. This research aims to identify the distribution of THI as a measure of the level of thermal comfort in Bandung City.

METHODOLOGY

Research variable

Research variables are variables that have parameters based on theory and previous studies used for research purposes. Research variables are important to ensure researchers are focused and directed. Table 1 shows the variables used in the research.

Table 1. Research Variable

No	Purpose	Variable	Sub Variables
1	Identifying the distribution and condition of the Temperature Humidity Index in Bandung City	. Temperature . Relative Humidity	Temperature Humidity Index (THI)

Source: Ismayanti et al **(2020)**

Normalize Different Vegetation Index (NDVI)

Normalized Difference Vegetation Index (NDVI) is an index used to measure the amount and density of vegetation in an area using image data that utilizes radiation absorption in the near-infrared (NIR) and red spectral ranges on satellites. NDVI is based on the reflection or reflection of various types of light waves on different surfaces (Marisa, Sugiarto, & Sarno, 2018). The following is the NDVI calculation formula.

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \quad (1)$$

Explanation

NDVI : Normalized Difference Vegetation Index

NIR : Band Near Infrared (Band 4)

RED : Band Red (Band 3)

NDVI values range from -1 to +1, consisting of positive values (close to +1) indicating the presence of lush vegetation, negative values (close to -1) indicating the absence or very little vegetation, and values close to zero indicating areas that are consisting of a hard surface, such as rock, sand, or snow. Based on Peraturan Menteri Kehutanan No. P.12/Menhut-II/2012, vegetation density in NDVI is classified in table 2.

Table 2. NDVI Value Range

No	NDVI Range	NDVI Class	Land Use	Indication
1	-1 s/d -0,03	Non-Vegetation	Water	Not Vegetation
2	-0,03 s/d 0,15	Undense Vegetation	Built-up land, Roads, and/or Open Land	Not Vegetation and/or Unhealthy Vegetation
3	0,15 s/d 0,25	Fairly Dense Vegetation	Moor, Field	Healthy Vegetation
4	0,26 s/d 0,35	Dense Vegetation	Farm, Rice Fields, Bush	
5	0,36 s/d 1,00	Very Dense Vegetation	Dense Forest	Very Healthy Vegetation

Source: Peraturan Menteri Kehutanan No. P.12/Menhut-II/2012

In this study, the classification used is very dense vegetation (0,36 s/d 1,00). This classification will have a significant impact on reducing urban temperatures in Bandung City. Apart from that, it can also make a significant contribution to the thermal comfort of Bandung City.

Land-Cover Classification

Image classification is the process of grouping images based on characteristics or patterns contained in the image to identify and distinguish objects, features, or classes using appropriate algorithms or methods. According to Muttaqin (2016), image classification is divided into two, namely supervised classification and multispectral classification (image classification). In this research, supervised classification is used, where there will be a division of object classes based on the pixel value of each class. In this research, land cover data is the result of supervised classification which is processed using Google Earth Engine according to the administrative boundaries of Bandung City. Based on SNI 7645-2010 in Darlina's research (2018), to simplify the analysis, land cover can be classified as water bodies, built-up land, open land, sparse vegetation, and dense vegetation.

Land Surface Temperature

Surface temperature can be measured using Landsat-8 OLI/TIRS imagery of Bandung City. In Landsat-8 imagery, the thermal sensor used in temperature extraction is band 10: Thermal Infrared (TIRS) 1 by USGS recommendations, because in band 11: Thermal Infrared (TIRS) 2 there has been uncertainty in sensor calibration since 2016 (Fawzi & Husna, 2021). According to Fawzi & Husna (2021), the following are the steps and formulas used to obtain surface temperature values.

1. Convert Digital Number (DN) to Sprectral Radiance ($\mathbf{L_\lambda}$)

$$L_\lambda = \frac{(L_{max\lambda} - L_{min\lambda})}{(Qcal_{max} - Qcal_{min})} \times (Qcal - Qcal_{min}) + L_{min\lambda} \quad (2)$$

Explanation

L_λ	:	Sprectral radiance
$L_{max\lambda}$	:	Sprectral radiance maksimum
$L_{min\lambda}$	:	Sprectral radiance minimum
$Qcal$	:	Total calibration pixel value
$Qcal_{max}$	:	Maximum total calibration pixel value
$Qcal_{min}$	:	Minimum total calibration pixel value

2. Convert Sprectral Radiance value to Brightness Temperature (T_b)

$$T_b = \frac{K2}{ln\left(\frac{K1}{L_\lambda}\right)} - 273 \quad (3)$$

Explanation

T_b	:	Brightness temperature
K1	:	Calibration constant 1 (band 10: 774,8853)
K2	:	Calibration constant 1 (band 10: 1321,0789)
L_λ	:	Sprectral radiance
273	:	Conversion value from Kelvin to Celsius

3. Determine the Proportion of Vegetation (P_v) value

$$P_v = \left[\frac{(NDVI - NDVI_s)}{(NDVI_v - NDVI_s)}\right]^2 \quad (4)$$

Explanation

P_v	:	proportion of vegetation
NDVI	:	NDVI Result
$NDVI_v$	:	NDVI value (bare soil)
$NDVI_s$	:	NDVI value (vegetation fraction)

4. Determine the Emissivity value (e)

$$e = \varepsilon_v . P_v + \varepsilon_\delta (1 - P_v) + 4 < d_\varepsilon > . P_v . (1 - P_v) \quad (5)$$

Explanation

e	:	Emissivity
ε_v	:	Vegetation Emissivity (0,985)
ε_δ	:	Land Emissivity (0,960)
$4 < d_\varepsilon >$	:	Average Value (0,06)

5. Convert Brightness Temperature (T_b) value to Surface Temperature (T_s)

$$T_s = \frac{T_b}{1 + \left(\frac{\lambda T}{\partial} ln\varepsilon\right)} \quad (6)$$

Explanation

T_s	:	Surface temperature (°C)
T	:	brightness temperature
λ	:	The middle wavelength of the thermal band (10.8 µm)
ε	:	Emissivity Value
∂	:	Constant (1,438 x 10^{-2} mK)

Temperature Humidity Index (THI)

Temperature humidity index (THI) can measure the comfort level of the human population in urban areas in degrees Celsius (Ismayanti, Sasmito, & Bashit, 2020). According to Nieuwolt (1976), the temperature humidity index (THI) can be calculated based on the air temperature and relative humidity of Bandung City. The formula and thermal comfort limits according to Nieuwolt in Emmanuel (2005) research are as follows.

$$THI = 0,8T_a + \frac{RH \times T_a}{500} \quad (7)$$

Explanation

THI	:	Temperature Humidity Index
T_a	:	Temperature (°C)
RH	:	Relative Humidity (%)

Table 3. Classification THI Value

No	THI Range Value	Explanation
1	< 24	Comfortable
2	25 – 26	Quite Comfortable
3	>26	Uncomfortable (Too Hot)

Source: Emmanuel (2005)

RESULT AND DISCUSSION

Unit of Analysis

This research uses a square grid system analysis unit. The grid analysis unit is used to simplify sampling, especially in land cover classification and multiple linear regression. The grid analysis unit has a size of 1500 x 1500 m, totaling 103 grids divided throughout the Bandung City area. This size and quantity already meet the minimum number of samples required (90 samples) based on Green's research (1991) and can identify the city of Bandung in detail.

Moreover, each grid will be evaluated to determine its area based on the type of land cover, as well as to calculate the percentage of area for each type of land cover. Next, the average THI data per grid was compiled based on the THI distribution analysis that had been carried out previously. In this research, the grid analysis unit map for Bandung City is shown in Figure 1.

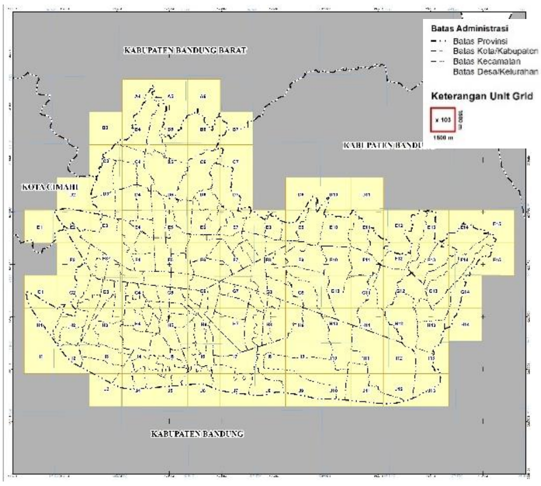
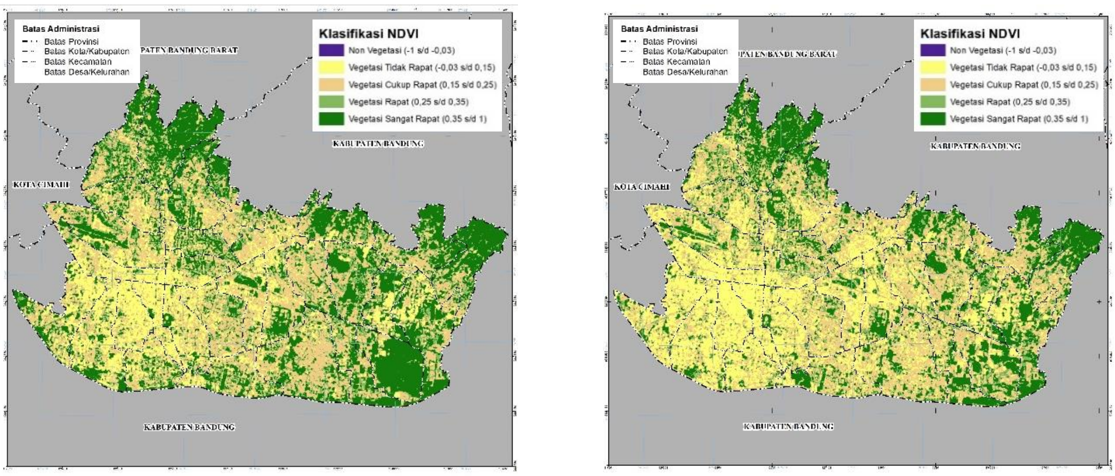


Figure 1. Grid Analysis Unit Map

Normalize Different Vegetation Index (NDVI)

The distribution of vegetation density can be seen from the NDVI value. NDVI analysis is used to measure the value of the vegetation index, where the vegetation index can describe the level of greenness of a plant in a certain area. The following are the results of the NDVI analysis for Bandung City (Figure 2).



(**a**) (**b**)

Figure 2. NDVI Analysis Map: (**a**) 2013; (**b**) 2023

Figure 2 shows the distribution of five NDVI classes in Bandung City. The distribution of the five NDVI classes includes non-vegetation, not dense vegetation, moderately dense vegetation, dense vegetation, and very dense vegetation. Within a period of 10 years, namely in 2023–2013, there will be changes in the area of each class as shown in Figure 3.

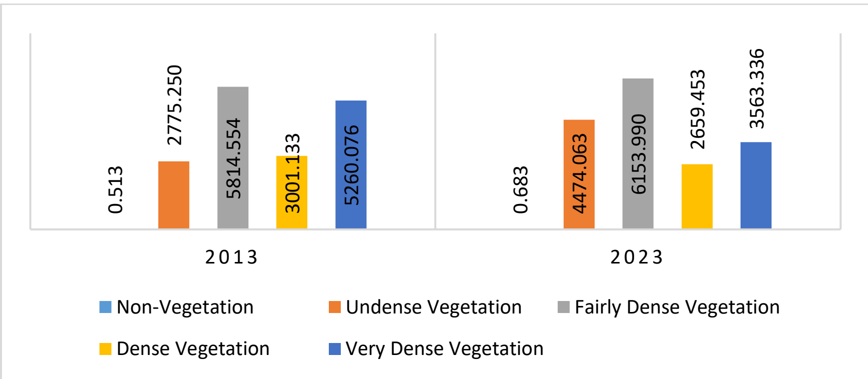
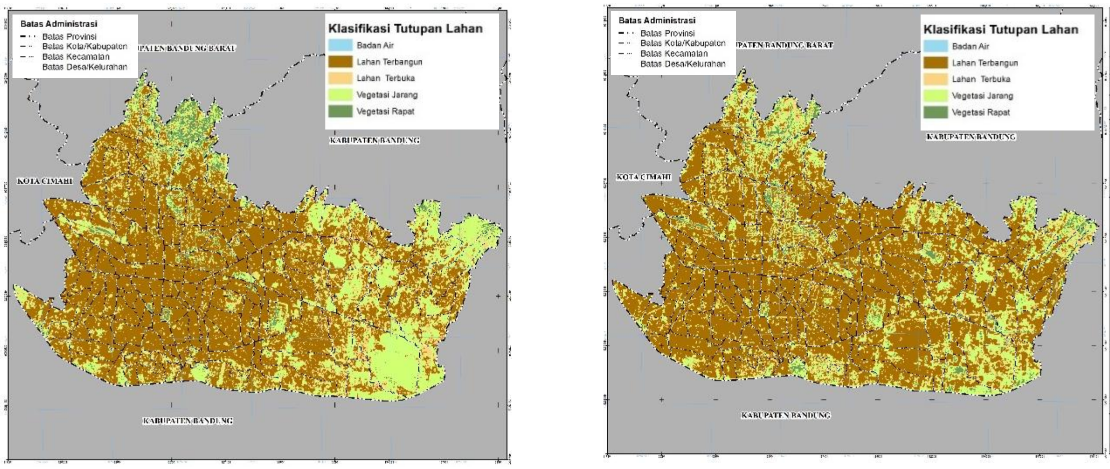


Figure 3. Comparison Chart of NDVI Class Areas for 2013 and 2023

Based on Figure 3, there was an increase in the area of the non-vegetation class by 0.170 Ha, the non-dense vegetation class by 1698,813 Ha, and the moderately dense vegetation class by 339,436 Ha. On the other hand, class reduction occurred in the dense vegetation class of 341,689 Ha and the very dense vegetation class of 1696,740 Ha. The increase and decrease in the area of the NDVI class is indicated by experts in the function of undeveloped land, especially vegetation becoming built-up land. Land function experts that occur can be a problem that results in a reduction in the percentage of existing green open space in the city of Bandung.

Land-Cover Classification

The land cover classification was obtained from the results of processing Landsat 8 OLI/TIRS images for Bandung City in 2013 and 2023. The results of this processing produced five classes, namely water bodies, built-up land, open land, sparse vegetation, and dense vegetation. The following are the results of the land cover classification for Bandung City (Figure 4).



(**a**) (**b**)

Figure 4. Land-Cover Classification Map: (**a**) 2013; (**b**) 2023

Figure 4 shows the distribution of five land cover classes in Bandung City. The distribution of the five cover classes includes water bodies, built-up land, open land, sparse vegetation, and dense vegetation. Over 10 years, namely 2023–2013, changes in the area of each class can be seen in Figure 5.

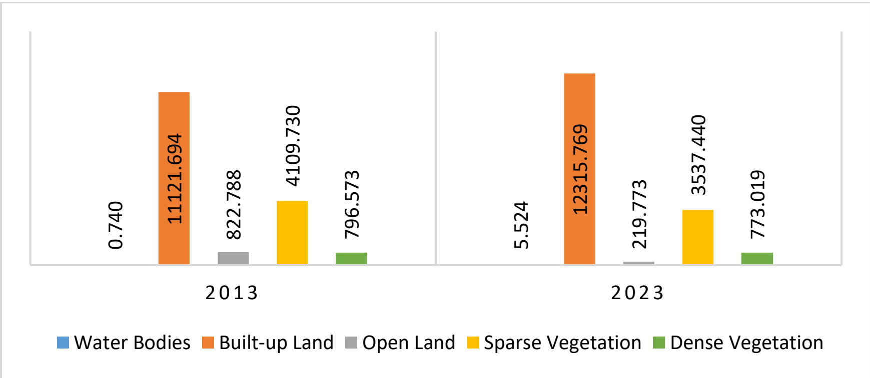


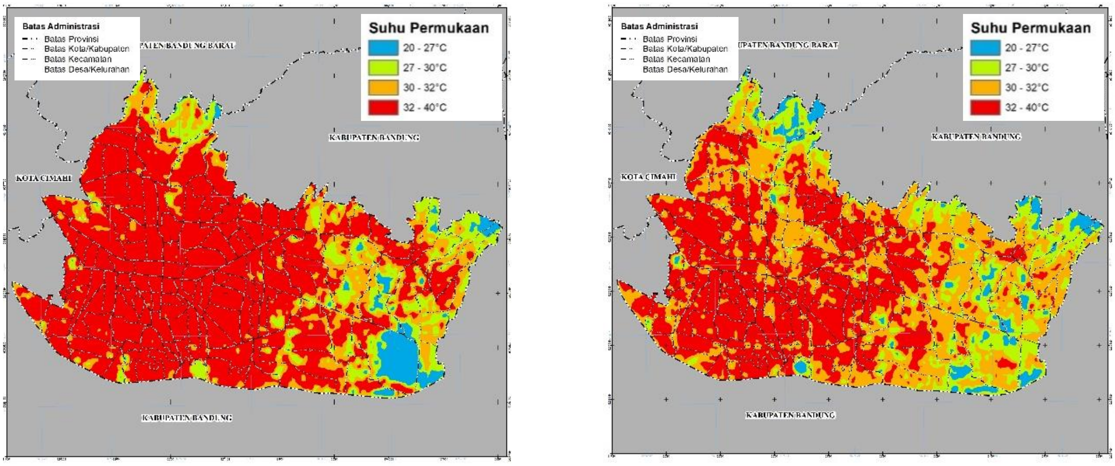
Figure 5. Comparison Chart of Land-Cover Class Areas for 2013 and 2023

Based on Figure 5, there was an increase in the area of the water body class by 4,784 Ha and the built land class by 1194,074 Ha. On the other hand, the class decrease occurred in the open land class of 603,015 Ha, the sparse vegetation class of 472,290 Ha, and the dense vegetation class of 23,554 Ha. This identifies that during this period there was development and development of the city which resulted in experts in the function of vegetation land becoming built-up land.

Changes in the area of each land cover can affect the sustainability of the city, especially in the areas of sparse or dense vegetation classes. Thus, the role of green open space as controlling or stabilizing the microclimate, such as reducing the temperature of urban areas, increasing air humidity, and reducing wind speed will be affected and it will be difficult to implement a public green open space allocation of 20%.

Surface Temperature

Surface temperature values were obtained from the results of Landsat 8 OLI/TIRS image processing for Bandung City in 2013 and 2023 by managing band 10. Based on the analysis results, the distribution of surface temperatures in Bandung City in 2013 ranged from 20 to 39 °C. Meanwhile, in 2023, the distribution of surface temperatures in Bandung City will range from 21 to 39 °C. therefore, to simplify calculations in research, the range of surface temperature values can be classified into 4 classes: low (20–27 °C), medium (27.1–30 °C), high (30.1–32 °C), and very high (>32 °C).



(**a**) (**b**)

Figure 6. Surface Temperature Map: (**a**) 2013; (**b**) 2023

Figure 6 shows the distribution of four surface temperature classes in Bandung. The distribution of the five cover classes includes four classes: low, medium, high, and very high. Over 10 years, namely 2023–2013, changes in the area of each class can be seen in Figure 10.

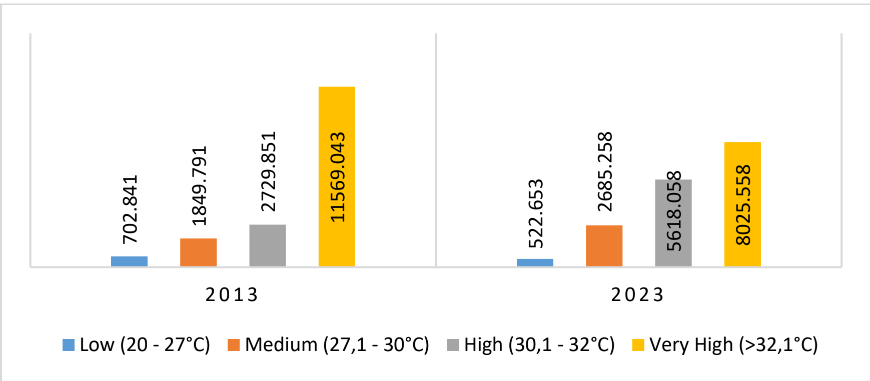
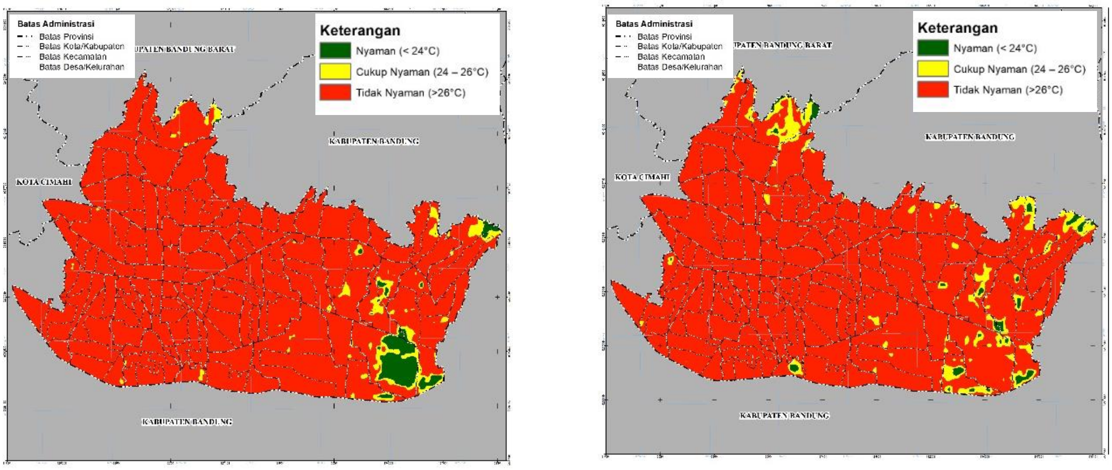


Figure 7. Comparison Chart of Surface Temperature Class Areas for 2013 and 2023

Based on Figure 7, there was an increase in area in the medium class (27–30 °C) by 835,467 ha and in the high class (30–32 °C) by 2891,207 ha. On the other hand, the class reduction occurred in the low class (20–27 °C), amounting to 179,485 ha, and in the very high class (>32 °C), amounting to 3543,485 ha. The extensive decrease in the low (20–27°C) and very high (>32°C) classes was followed by an extensive decrease in land cover in the open land, sparse vegetation, and dense vegetation classes. The reduction in vegetation can influence increasing surface temperatures in the city of Bandung. Meanwhile, the increase in area in the medium (27–30°C) and high (30–32°C) classes was followed by an increase in the area of land cover in the built-up land class. This shows that the increase in built-up land followed by land function experts on vegetated land has an impact on increasing surface temperatures in the city of Bandung.

Temperature Humidity Index (THI)

THI can measure the level of thermal comfort in urban areas. THI was obtained by considering air humidity and temperature data for Bandung City. The following are the results of the THI distribution for Bandung City (Figure 8).



(**a**) (**b**)

Figure 8. Temperature Humidity Index Map: (**a**) 2013; (**b**) 2023

Figure 8 shows the distribution of the three THI classes in Bandung City. The distribution of THI classes includes comfortable (<24°C), quite comfortable (24–26°C), and uncomfortable (>26°C). Over 10 years, namely 2023 – 2013, changes in the area of each class can be seen in Figure 9.

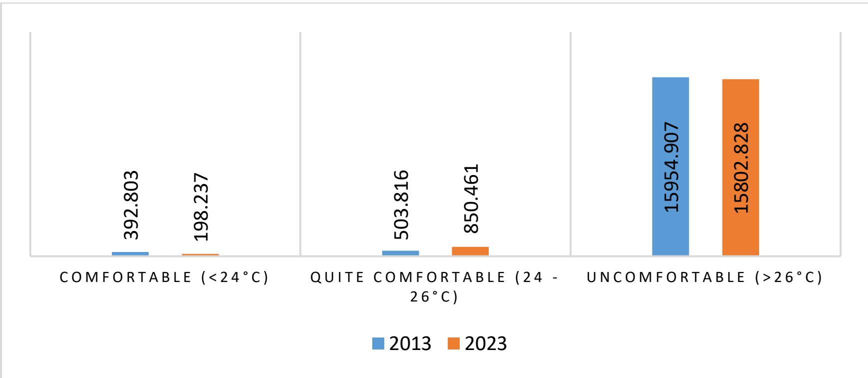


Figure 9. Comparison Chart of THI Class Areas for 2013 and 2023

Based on Figure 9, there was an increase in area in the quite comfortable class (24–26 °C) amounting to 346,645 ha. On the other hand, class reduction occurred in the comfortable class (<24°C) of 194,566 Ha and the uncomfortable class (>26°C) of 152,079 Ha. The decrease in area in the comfort class (<24°C) was followed by a decrease in area in the open land, sparse vegetation, and dense vegetation classes. Meanwhile, the decrease in area in the uncomfortable class (>26 °C) was followed by an increase in area in land cover in the water body class. This shows that the increase in built-up land followed by land function experts on vegetated land has an impact on increasing THI in Bandung City.

CONCLUSIONS

Based on the results and discussions that have been carried out by researchers. It can be concluded several things in achieving the objectives of this research. The conclusions obtained in this research are as follows.

1. In 2013–2023, the distribution of land cover in Bandung City tends to be dominated by the built-up land class and will experience an increase in area of 1194,074 ha. The changes that occurred during this period identified the development and development of the city, which resulted in the

function of non-built land, especially vegetation, becoming built-up land and could affect the sustainability of the city, especially in the sparse and dense vegetation classes.

2. In 2013–2023, the surface temperature distribution of Bandung City tends to be dominated by the very high class (>32 °C). The very high-class dominance is due to the increase in built-up land, followed by land function experts on vegetation land. This has an impact on increasing surface temperatures in the city of Bandung.
3. In 2013–2023, the THI distribution tends to be dominated by the uncomfortable class (>26 °C). The dominance of the uncomfortable class is due to the increase in built-up land, which is followed by land function experts on vegetated land. This had an impact on increasing the distribution of THI, especially in uncomfortable classes in Bandung City during that period.
4. The highly uncomfortable class in the THI distribution can cause thermal discomfort in Bandung City. So efforts are needed to idealize the value of THI, with one effort being to develop green open space in Bandung City.

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