PENGARUH VEGETASI DAN KEPADATAN BANGUNAN TERHADAP KENYAMANAN TERMAL PERKOTAAN (STUDI KASUS KOTA DENPASAR)

EFFECT OF VEGETATION AND BUILDING DENSITIES TO URBAN THERMAL COMFORT (CASE STUDY OF DENPASAR CITY)

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Abstrak

Denpasar adalah Ibukota Provinsi Bali, merupakan salah satu tujuan wisata paling popular di Indonesia. Kegiatan antropogenik telah mengubah penggunaan lahan dan tutupan lahan yang mempengaruhi suhu permukaan tanah dan kenyamanan termal. Kualitas kenyamanan termal yang baik dapat meningkatkan kesejahteraan masyarakat dan wisatawan. Penelitian ini bertujuan a) menganalisis distribusi kerapatan vegetasi dan bangunan, b) memetakan distribusi suhu permukaan tanah dan kenyamanan termal, dan c) menganalisis pengaruh kerapatan vegetasi dan bangunan terhadap kenyamanan termal di Kota Denpasar. LST dan kenyamanan termal diekstraksi menggunakan Landsat 9. Kenyamanan termal dinilai menggunakan *urban thermal field variance index* (UTFVI). Kemudian, korelasi Pearson dan regresi sederhana diterapkan untuk menyelidiki hubungan dan pengaruh vegetasi dan kepadatan bangunan terhadap kenyamanan termal perkotaan. Secara umum, kepadatan vegetasi yang tinggi terletak dibagian utara Kecamatan Denpasar Utara, utara dan timur Kecamatan Denpasar Timur, dan selatan Kecamatan Denpasar Selatan. Kepadatan bangunan yang tinggi tersebar di Kecamatan Denpasar Selatan bagian utara dan sebagian Kecamatan Denpasar Barat. Nilai UTFVI yang rendah menunjukkan kenyamanan termal yang baik. Vegetasi yang lebih besar dan kepadatan bangunan yang lebih rendah, kemungkinan besar akan berdampak pada peningkatan tingkat kenyamanan termal di suatu lokasi. Penelitian ini dapat dijadikan panduan dalam mitigasi pulau panas perkotaan serta perencanaan restorasi ekologi.

Kata kunci: kerapatan bangunan, kerapatan vegetasi, Kota Denpasar, Landsat 9, *urban thermal field variance index* (UTFVI)

Abstract

Denpasar is the capital of Bali Province, which is one of the most popular tourist destination in Indonesia. Anthropogenic activities have changed the land use and land cover (LULC) that affect the land surface temperature (LST) and thermal comfort. Good quality of thermal comfort can improve the livelihood of its citizen as well as the tourists. This research aims a) to analyses the density distribution of vegetation and buildings, b) to map the distribution of LST and thermal comfort, and c) to analyses the effect of vegetation and building density on thermal comfort in Denpasar City. LST and thermal comfort were extracted using Landsat 9. Thermal comfort was assessed using urban thermal field variance index (UTFVI). Then, Pearson correlation and simple regression were applied to investigate the relationship and effect of Effect of vegetation and building densities to urban thermal comfort. In general, high density *of vegetation is located in the northern part of North Denpasar District, north and east of East Denpasar District, and south of South Denpasar District. High density buildings are scattered in the southern Denpasar District, the western eastern Denpasar District, the northern South Denpasar District, and parts of the West Denpasar District. Low UTFVI values indicate good thermal comfort. Greater vegetation and lower building densities are likely to have an impact by improving thermal comfort levels in a location. This research can be served as a guidance in urban heat island mitigation as well as ecological restoration planning.*

Keywords: *urban thermal field variance index (UTFVI), Landsat 9, Vegetation Density, Building Density, Denpasar City*

1. INTRODUCTION

The increase in the number and density of population has resulted in more land conversion from non-built-up land such as vegetation to built-up land. This is a fairly common thing because humans need space to move around and meet various needs of life. Anthropogenic activities have changed the land use and land cover (LULC) in the developed and developing countries in the centuries (Liu & Tian, 2010). The land cover and its pattern changes are major cause of environmental degradation and changes in urban hydrology, rising urban heat Islands, climate change from local to regional scales (Deng & Srinivasan, 2016; Kikon, Singh, Singh, & Vyas, 2016; Zhou et al., 2016). The decrease of vegetation coverage and expansion of impervious surfaces lead to elevated temperatures in developed urban areas. Substantial studies documented that the declining of vegetation coverage and increasing of impervious surfaces are the drivers of environmental problems like land surface temperature (LST) in many cities (Ayanlade, Aigbiremolen, & Oladosu, 2021; Nwakaire, Onn, Yap, Yuen, & Onodagu, 2020).

Bali Island is a very popular tourist destination in Indonesia. Look Asmiwyati (2016). In the face of climate change, the most commercially successful islands, such as Bali, Java, and Sumatra, are most susceptible (World Bank, 2009). The provincial capital of Bali is Denpasar City. Diverse human activities that directly impact LULC changes have been moving toward the southern coastline fringe area of Bali and have been growing in both quantity and spatial distribution. As a result, there has been long-term, negative environmental deterioration in certain places in particular. This results from LULC conversions, which frequently do not follow the principles of sustainable development (Asmiwyati, 2016). Look Moisa (2022). Rapid urbanization transforms natural surfaces into built-up areas, which has a significant impact on the thermal conditions of cities (Qu et al., 2020; Sadiq Khan, Ullah, Sun, Rehman, & Chen, 2020). The urban thermal field variance index (UTFVI) can be used to gauge the degree of urban thermal comfort.

UTFVI is calculated based on land surface temperature data. Conducting field survey for measuring temperature and thermal comfort is costly, time and energy consuming. Hence, remote sensing data can be used as a tool for earth observation purposes with less time and energy consuming. Remote sensing imagery can be used to map land surface temperature in various scale (Fikriyah et al., 2022; Hadibasyir, Rijal, & Sari, 2020; Saputra et al., 2022). One of the commonly used imagery for mapping LST in moderate resolution is Landsat imagery.

The creation of more sustainable urban environmental management strategies may be influenced by an understanding of the link between urbanization and these patterns (Chen, Zhao, Li, & Yin, 2006; Earl & Simmonds, 2018). The great majority of people who move to new cities and their activities place a significant burden on housing, infrastructure, food security, and ecosystem services (Li, Zhang, Zheng, & Chen, 2020; Tariq et al., 2019). Moreover, Bali is the popular tourist destination. Hence, good quality of thermal comfort can improve the livelihood of its citizen as well as the tourists. This research aims a) to analyses the density distribution of vegetation and buildings, b) to map the distribution of LST and thermal comfort, and c) to analyses the effect of vegetation and building density on thermal comfort.

2. METHODS

2.1 Research Area

The research location is Denpasar City (Figure 1). The geographical location of Denpasar City is between 115.173698 East Longitude to 115.274271 East Longitude and 8.591728 South Latitude to 8.752372 South Latitude. To the north, the city of Denpasar is bordered by Gianyar Regency and Badung Regency. To the east, the city of Denpasar is bordered by the Bali Sea. To the south, Denpasar City is bordered by the Bali Sea and Badung Regency. To the west, Denpasar City is bordered by Badung Regency. Denpasar City is the capital of the Province of Bali which consists of four sub-districts, namely North Denpasar, East Denpasar, South Denpasar and West Denpasar.

2.2. Materials and Data

The data used is Landsat 9 path/row 116/66 imagery with a recording time of March 25, 2022. The choice of recording time was based on the latest imagery of Denpasar City (at the time this research was conducted) with minimum cloud cover. The software used were ArcMap 10.8, ENVI 5.3, and QGIS 3.18 for satellite image processing and data visualization. In addition, SPSS software is used for statistical tests in the form of Pearson correlation and simple linear regression.

2.3. Data Processing

2.3.1. Image Pre-Processing, Vegetation and Building Density Mapping

Image pre-processing was carried out by performing radiometric and atmospheric corrections as well as brightness temperature extraction from Landsat images using QGIS which has been equipped with the semi-automatic classification (SCP) plugin. SCP was created by Congedo (2021). The SCP's atmospheric correction algorithm was Dark Object Subtraction (DOS). The output of image processing with SCP was brightness temperature data (band 10 processing results) and at-surface reflectance data (band 1-7 atmospheric correction results). After obtaining at-surface reflectance data, the next step was normalized difference vegetation index (NDVI) extraction to obtain vegetation density data and normalized difference built-up index (NDBI) to obtain building density data. The algorithm used for NDVI extraction was the same as that carried out by (Hadibasyir, Rijal, et al., 2020), while the NDBI extraction algorithm was the same as that carried out by Fikriyah et al. (2022).

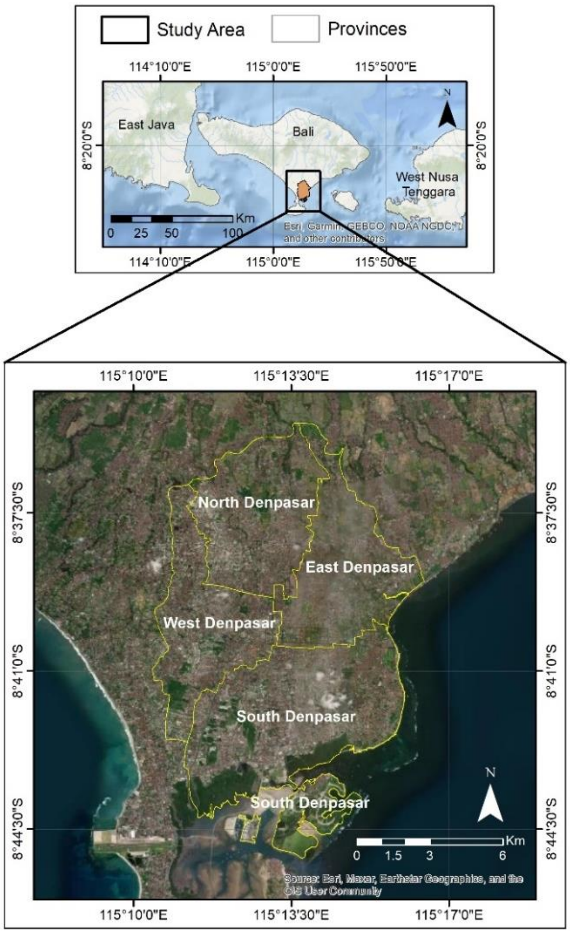

Figure 1. Denpasar City as the research location

2.3.2. Thermal Comfort Extraction

The brightness temperature data needs to be transformed to LST. The transformation process requires emissivity data. The emissivity extraction was carried out using NDVI data. Furthermore, brightness temperature and emissivity are used to obtain LST with an algorithm like that done by (Sobrino, Jiménez-Muñoz, & Paolini, 2004). Thermal comfort can be identified by UTFVI (Moisa & Gemeda, 2022). In order to determine the thermal comfort of an area, UTFVI calculations are performed using Equation 1 (Singh, Kikon, & Verma, 2017).

$$UTFVI = \frac{LST - LST_{mean}}{LST_{mean}} \qquad (1)$$

LST is the LST of a pixel in the study area (K) and LSTmean is the average LST in the study area (K). UTFVI can be classified into five levels of thermal comfort (Table 1). The lower the UTFVI value, the better the thermal comfort, while the higher the UTFVI, the worse the thermal comfort. In addition, UTFVI can also be used as an indicator of urban ecological conditions.

Table 1. UTFVI classification of thermal comfort (Guha, Govil, Dey, & Gill, 2018; Moisa & Gemeda, 2022)

UTFVI	Thermal Comfort	Ecological Condition
< 0	Excellent	Excellent
0 – 0.005	Good	Good
0.005 – 0.010	Normal	Normal
0.010 – 0.015	Bad	Bad
0.015 – 0.020	Worse	Worse
> 0.020	Worst	Worst

2.3.3. Correlation and Regression Between Vegetation and Building Density on Thermal Comfort

NDVI and NDBI are used as proxies for independent variables representing vegetation and building density, respectively. UTFVI is used as a proxy for the dependent variable which represents thermal comfort. NDVI and NDBI were carried out by Pearson correlation with UTFVI to determine the degree of the relationship between vegetation and building density on thermal comfort. Furthermore, a simple linear regression analysis was performed to examine the effect of vegetation and building density on thermal comfort at the study site.

3. RESULTS AND DISCUSSION

3.1. Analysis of The Density Distribution of Vegetation and Building Densities

There are variations in the density of vegetation and buildings in Denpasar City. Figure 2 illustrates the condition of the distribution of vegetation density in Denpasar City with the help of the NDVI value. A negative NDVI indicates a body of water (Hadibasyir, Fikriyah, Sunariya, & Danardono, 2020). An NDVI that is close to zero is open land or built-up land, while an NDVI that is close to one is high-density vegetation.

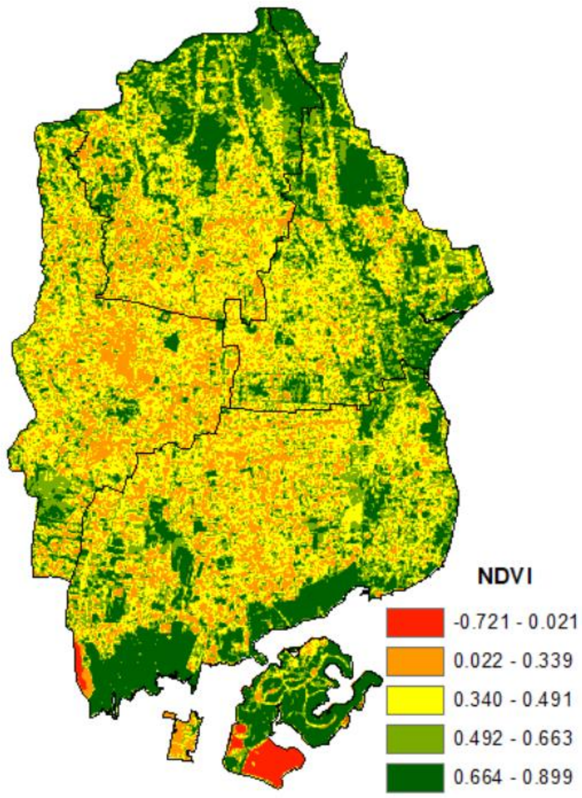

Figure 2. NDVI as a proxy for vegetation density. Higher NDVI indicates land with denser vegetation density

In general, high density vegetation (0.491 < NDVI < 0.663) and very high (NDVI > 0.663) are located in the northern part of North Denpasar District, north and east of East Denpasar District, and south of South Denpasar District. West Denpasar District has relatively the lowest vegetation density compared to the other three districts in Denpasar City. The vegetation density is low, very low, and is being spread over the southern part of the North Denpasar District, the western part of the East Denpasar District, the northern part of the South Denpasar District, and most of the West Denpasar District.

Building density was identified with the help of the NDBI. A negative NDBI tends to indicate the condition of a water body. An NDBI with a value close to zero indicates vegetation, while an NDBI whose value is closer to one indicates land with high density buildings. Based on the NDBI value, land with high density buildings are scattered in the southern Denpasar District, the western eastern Denpasar District, the northern South Denpasar District, and parts of the West Denpasar District. The vegetation and bodies of water are scattered in the northern part of North Denpasar District, north and east of East Denpasar District, and south of South Denpasar District.

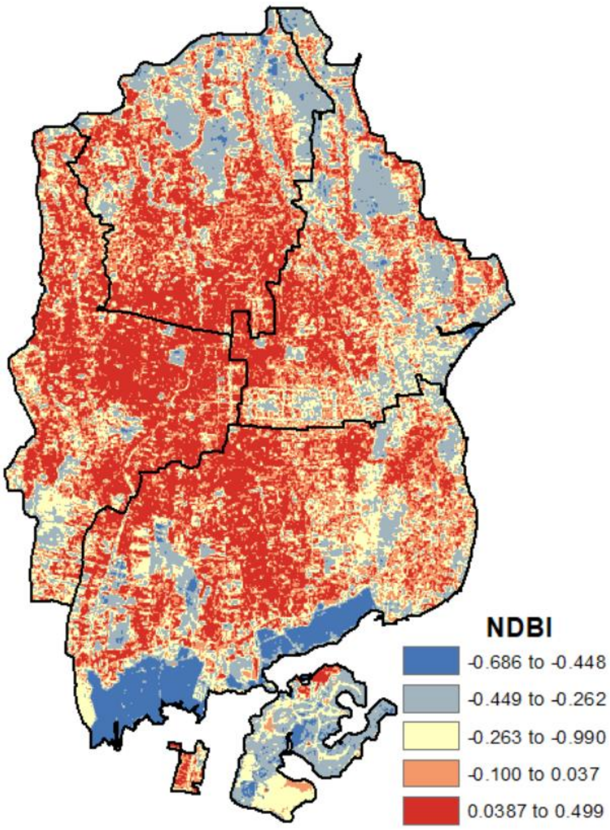

Figure 3. NDBI as a building density proxy. The higher the NDVI, the higher the density of buildings

3.2. Mapping the distribution of LST and thermal comfort

LST is the basis for determining thermal comfort with the UTFVI algorithm (Moisa & Gemeda, 2022). SPL that has been extracted from Landsat 9 imagery is presented in Figure 4. In general, areas with relatively higher temperatures than the average temperature in a city/region will have relatively low thermal comfort. Conversely, areas with relatively lower temperatures than the average temperature in a city/region will have higher thermal comfort.

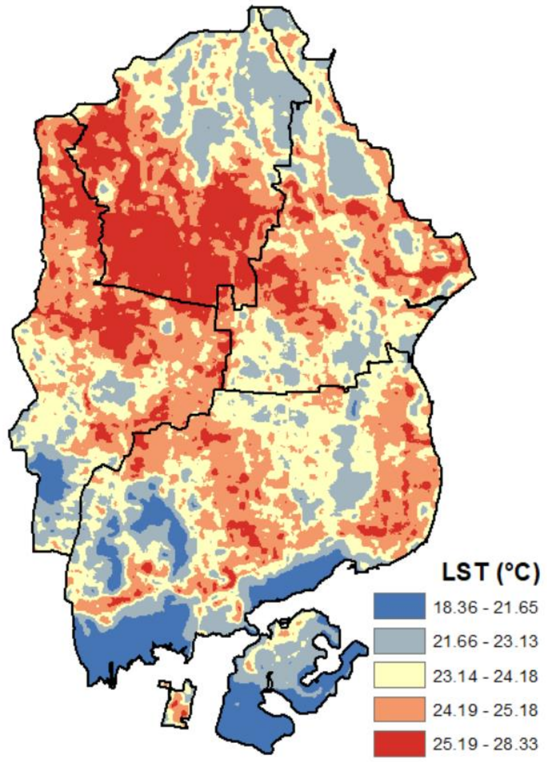

Figure 4. LST in Denpasar City extracted from Landsat 9 imagery.

Based on the results of Landsat 9 imagery data processing, the LST in Denpasar City has a minimum value of 18.37 ºC, a maximum value of 28.33 ºC, an average value of 23.89 ºC, and a standard deviation of 1.38 ºC. The LST in Denpasar City is classified into five classes, namely very low (18.36 – 21.65 ºC), low (21.66 – 23.13 ºC), medium (23.15 – 24.18 ºC), high (24.19 – 25.18 ºC), and very high (25.9 to 28.33 ºC). LST with very low values are scattered in the southern part of South Denpasar District and the southern part of West Denpasar District. SSTs with low scores are found in the northern part of North Denpasar District, north and south east Denpasar District, east and south of South Denpasar District, central and south West Denpasar District. LST with low and very low values are in bodies of water and vegetation. This is in line with research conducted by Hadibasyir, Rijal, et al. (2020).

Most of the LST with medium values were found in the northern part of North Denpasar District, the eastern part of South Denpasar District, the western part of West Denpasar District, and spread evenly in East Denpasar District. High and very high LST are found in the southern part of North Denpasar District, the central part of East Denpasar District, the central and eastern part of South Denpasar District, and the northern part of West Denpasar District. The LST with high and very high values tends to be located on land with a high density of buildings.

The extracted LST was then converted into thermal comfort in the form of UTFVI (Figure 5). The thermal comfort level in Denpasar City consists of the general distribution of thermal comfort levels similar to the LST distribution. The lower the UTFVI value, the higher the level of thermal comfort, conversely, the higher the UTFVI, the lower the thermal comfort (Table 1). In places with low LST are likely to have good thermal comfort. Conversely, places with high LST will tend to have bad thermal comfort. There are four levels of thermal comfort classification in Denpasar City, namely excellent, good, normal, and bad. In general, northern Denpasar is dominated by good and excellent levels of thermal comfort. Thermal comfort with the most dominant normal level is found in North Denpasar District when compared to the other three sub-districts in Denpasar City. West Denpasar District is the second largest normal class thermal comfort area after North Denpasar District. Thermal comfort in East Denpasar District and South Denpasar District is dominated by good and excellent thermal comfort classes.

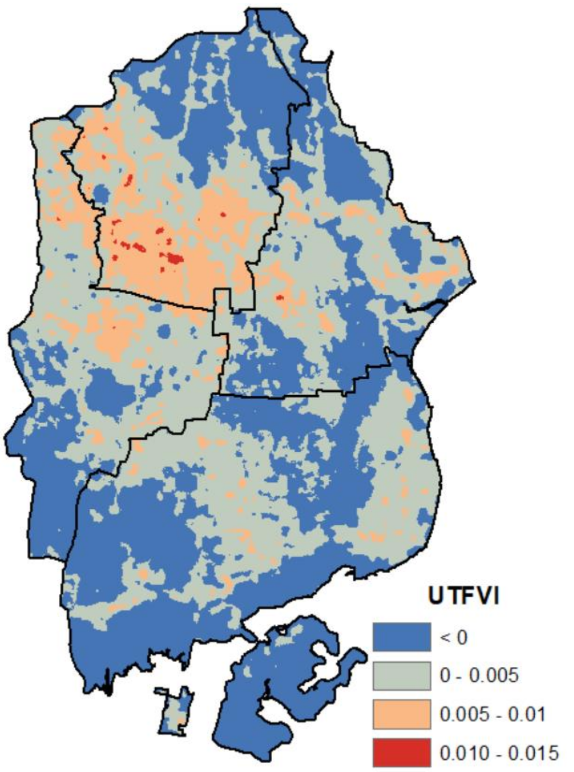

Figure 5. Thermal comfort in Denpasar City with a UTFVI proxy

3.3. Analysis of the effect of vegetation and building density on thermal comfort

Pearson correlation has been carried out to test the degree of closeness of the relationship between NDVI, NDBI, and UTFVI as a proxy for thermal comfort (Table x.). The lower the UTFVI, the better the thermal comfort, and vice versa. NDVI has a strong negative relationship with UTFVI (r = -0.632), the relationship that occurs is also statistically significant at the level of α = 0.01. This shows that the higher the density of vegetation in a place, the higher the level of thermal comfort. Conversely, the lower the level of vegetation density, the lower the level of thermal comfort.

Table 2. Results of Pearson's correlation among NDBI (building density), NDVI (vegetation density), UTFVI (thermal comfort). Low UTFVI values indicate good thermal comfort

		NDBI	NDVI	UTFVI
NDBI	Pearson Correlation	1	-.912**	.680**
	Sig. (2-tailed)		0	0
	N	104	104	104
NDVI	Pearson Correlation	-.912**	1	-.632**
	Sig. (2-tailed)	0		0
	N	104	104	104
UTFVI	Pearson Correlation	.680**	-.632**	1
	Sig. (2-tailed)	0	0	
	N	104	104	104

**. Correlation is significant at the 0.01 level (2-tailed).

NDBI has a strong positive relationship with UTFVI (r = 0.680), the relationship that occurs is also statistically significant at the level of α = 0.01. This shows that the higher the density of buildings in a place, the lower the level of thermal comfort. Conversely, the lower the building density, the higher the thermal comfort level.

The density of vegetation and buildings is a predictor of the level of thermal comfort. However, NDVI and NDBI have a strong negative relationship (r = -0.912), which is also statistically significant at the α = 0.01 level. A strong relationship between predictor variables can lead to multicollinearity problems. As a consequence, multiple regression cannot be used to examine the effect of vegetation and building density together on thermal comfort. Therefore, analysis of the influence of vegetation and building density on thermal comfort is analyzed by simple linear regression with two regression implementation processes. Implementation of the first simple linear regression to test the effect of vegetation density (predictor variable) on thermal comfort (dependent variable). Then, simple linear regression was carried out again to examine the effect of building density on thermal comfort.

The results of a simple regression test between vegetation density (NDVI) and thermal comfort (UTFVI) are presented in Table 3. The coefficient of determination (R2) is 0.399, which means that thermal comfort is affected by vegetation density by 39.9%, while the remaining 60.1% is influenced by variables other than vegetation density. The regression equation created is UTFVI = 0.008 – 0.016*NDVI. The regression coefficient of the NDVI variable is negative, which indicates that the effect of NDVI on UTFVI is inversely proportional. In other words, denser vegetation will have an effect in the form of increasing the quality of thermal comfort in a place. Conversely, the lower the level of vegetation density, the lower the quality of thermal comfort in a place will be. In addition, the p-value <0.001 indicates that NDVI has a significant effect on UTFVI at a significance level of 0.01.

Table 3. Simple linier regression test results between vegetation density (NDVI) and thermal comfort (UTFVI)

	Unstandardized Coefficients		Sig.
	B	Std. Error	
(Constant)	0.008	0.001	0
NDVI	-0.016	0.002	0
R Square: 0.399			
Predictor: NDVI, Dependent Variable: UTFVI			

The results of a simple linear regression test between building density (NDBI) and thermal comfort (UTFVI) are presented in Table 4. The coefficient of determination (R^2) is 0.463, which means that thermal comfort is affected by building density by 46.3%, while the remaining 53.7% is influenced by other variables. apart from building density. The regression equation created is UTFVI = 0.001 – 0.015*NDBI. The regression coefficient of the NDBI variable is positive, which indicates that the effect of NDBI on UTFVI is directly proportional. In other words, denser buildings will have an effect in the form of a decrease in the quality of thermal comfort somewhere. Conversely, buildings with lower density levels will have an effect in the form of increasing the quality of thermal comfort in a place. In addition, the p-value <0.001 indicates that NDVI has a significant effect on UTFVI at a significance level of 0.01.

Table 4. Simple linear regression test results between building density (NDBI) and thermal comfort (UTFVI)

	Unstandardized Coefficients		Sig.
	B	Std. Error	
(Constant)	0.001	0	0
NDBI	0.015	0.002	0
R Square: 0.463			
Predictor: NDBI, Dependent Variable: UTFVI			

In general, the higher the density of vegetation and the lower the density of buildings, the higher the quality of thermal comfort. Conversely, the higher the density of vegetation and the lower the density of buildings, the higher the quality of thermal comfort will be. This is in line with the results of previous research (Guha et al., 2018; Hadibasyir, Fikriyah, Sunariya, & Danardono; Sadiq Khan et al., 2020; Singh et al., 2017). Therefore, increasing the quality of thermal comfort can be done by increasing the density of vegetation and minimizing the built-up area. Good thermal comfort can be an indicator of good urban ecological conditions and a sustainable city.

4. CONCLUSION

Diverse human activities that have an immediate influence on LULC alterations have been expanding in both quantity and geographical distribution as they move closer Bali's southern shoreline fringe area. The standard of living for both locals and visitors can be raised by providing high-quality thermal comfort. High density vegetation is often found in North Denpasar District's northern portion, East Denpasar District's north and east, and South Denpasar District's south. The southern Denpasar District, the western Eastern Denpasar District, the northern South Denpasar District, and portions of the West Denpasar District all have land with high density structures. Low UTFVI values indicate good thermal comfort. NDVI has an inversely proportionate impact on UTFVI. In other words, greater vegetation will have an impact by improving thermal comfort levels in a location. UTFVI and NDBI have a direct proportional relationship. In other words, there will be a decline in the level of thermal comfort someplace as a result of denser structures. By reducing the built-up area and increasing plant density, thermal comfort can be improved. This research can be served as a guidance in urban heat island mitigation as well as ecological restoration planning.

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