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SPATIAL-TEMPORAL ANALYSIS BETWEEN LANDCOVER CHANGE AND URBAN SURFACE TEMPERATURE OF BEKASI CITY, INDONESIA

Irland Fardani[1], Fadhlul Razak[2], Saraswati[3]

[1,2,3]Department of Urban and Regional Planning,
BANDUNG ISLAMIC UNIVERSITY INDONESIA

Abstract

Unregulated urban growth can result in a rise in urban population density, leading to the expansion of developed land into suburban regions. The urbanization of Bekasi City inevitably results in the conversion of vegetated land and green open spaces into built-up areas. In addition, there has been a notable rise in the exceptionally high average surface temperature of 12.66 °C during the past 25 years. It is vital to investigate the correlation between landcover change factors and surface temperature, considering these two significant occurrences. This study conducted a spatial-temporal analysis of the relationship between landcover and urban surface temperature in the years 1993, 1998, 2004, 2009, 2018, and 2023. The Random Forest classification approach was employed to acquire comprehensive landcover information, while the remote sensing/image satellite approach was utilized to obtain surface temperature data. The temperature is determined using the thermal channel of satellite photography. The research findings indicate a robust correlation between alterations in land cover, specifically high-density buildings, medium/low-density buildings, and high-density vegetation, and variations in the surface temperature of an urban area. Hence, it is imperative to closely monitor the expansion of land cover to uphold the stability of surface temperature in urban areas.

***Keywords**:* Landcover Change, Local Climate Zone, Urban, Surface Temperature.

[1] Lecturer at Urban and Regional Planning Bandung Islamic University, Email : irland.fardani@unisba.ac.id

INTRODUCTION

Currently, the inevitable phenomena of urbanization is responsible for the ongoing developments in cities and urban areas in Indonesia. Uncontrolled urbanization can result in a rapid growth of population and a rise in urban density, leading to the expansion of developed land into suburban regions (Engelke & Biehl, 2010; Essex, 2016). This is due to the correlation between the rise in population growth and the corresponding surge in demand for land required to construct essential infrastructure, including residential buildings, educational institutions, medical facilities, and other supporting facilities (Darsono, 2022; Singh, 2019). The need for land for the procurement of these supporting facilities will result in land conversion from non-built-up land to built-up land.

The rapid population growth in Bekasi City has resulted in the procurement of built-up land in Bekasi City also growing rapidly as well. The transformation of land use in Bekasi City is evident through the comparison of data from 1989 and 2015. In 1989, the city had developed land covering 26.43% of the whole area, equivalent to around 5,661.31 hectares. By 2015, this figure had increased significantly to 72.64% of the total area, or approximately 15,576.48 hectares. The expansion of urban areas always comes at the cost of natural vegetation and green open spaces. During this period, the City of Bekasi has experienced a loss of 74% of its accessible green open space (Danniswari et al., 2020).

The City of Bekasi has experienced a massive change in the area of land use from open space to built-up land, and this development does not take into consideration environmental factors such as air temperature. The significant rise in average surface temperature in Bekasi City is evident, with a notable increase of 12.66 °C during the past 25 years (Danniswari et al., 2020). The aforementioned variables demonstrate the occurrence of urbanization and significant fluctuations in air temperature. Hence, it is imperative to investigate the correlation between alterations in land cover extent and fluctuations in surface temperature within Bekasi City.

LITERATUR REVIEW

Landcover Change

Changes in land cover that occur in Bekasi City are mostly the conversion of vegetated land into built-up land (Marko et al., 2016; Rachma et al., 2022). One of the factor of change in cities is sprawl of the development and the increase in built-up areas (Agustina et al., 2022; Noor et al., 2013). Land cover change refers to the process of land being converted from one form of use to another, resulting in a decline in other types of land use over time. This might also involve a change in the function of the land at a later period. Alterations in land cover typically lead to corresponding advancements in the quantity of amenities and infrastructure that facilitate community activities (Singh, 2019).

Surface Temperature

Land Surface Temperature is the average temperature of the type of surface in each pixel which is calculated by covering the weight (Tomlinson et al., 2011). The surface temperature has an important effect on global climate, one of which is rising surface temperature can cause polar ice to melt and cause sea level rise to increase (Rajeshwari & Mani, 2014). The primary climatological parameter is surface temperature. The surface temperature regulates the long wave flux that is emitted back into the atmosphere. Nevertheless, the surface temperature is influenced by other surface factors, including albedo, surface humidity, and vegetation cover. At first, the determination of surface temperature was conducted manually by placing a thermometer on the ground. The data obtained is localized and has a restricted geographical coverage. Thus, in order to get temperature data that has a greater geographical scope, it is necessary to gather temperature data from multiple weather satellites (Yulianto et al., 2016).

RESEARCH METHODOLOGY

Bekasi city is located in the northen part of in West Java, Indonesia. Wiath a geographicl location of 106.99° East Longitude and 6.27° South Lattitutde (see Figure 1). This study utilized Landsat satellite imaging data from three sources: Landsat 5, Landsat 7, and Landsat 8. This research utilizes time series satellite imaging data spanning the years 1993, 1998, 2003, 2013, 2018, and 2023. Each year, satellite imagery data is transformed into surface temperature and landcover information. The variables are subjected to regression analysis to determine the association between them, as depicted in Figure 2.

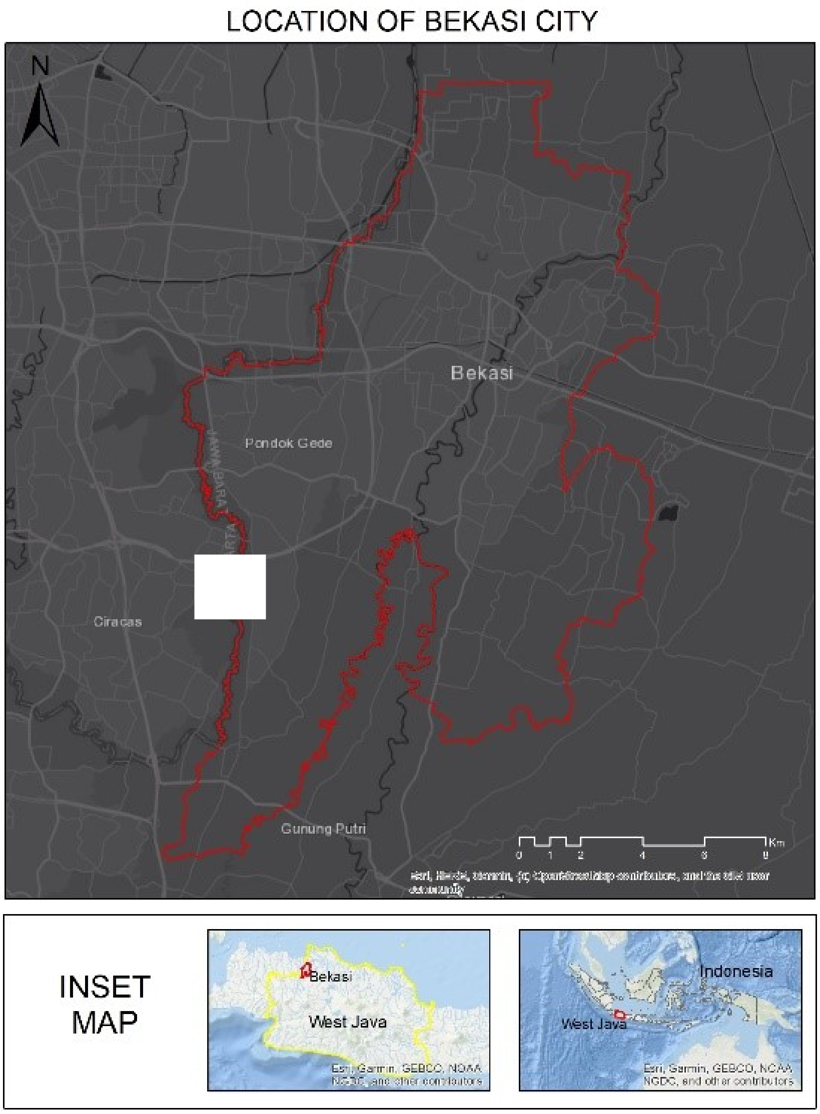

Figure 1: The position and Location of Research Area

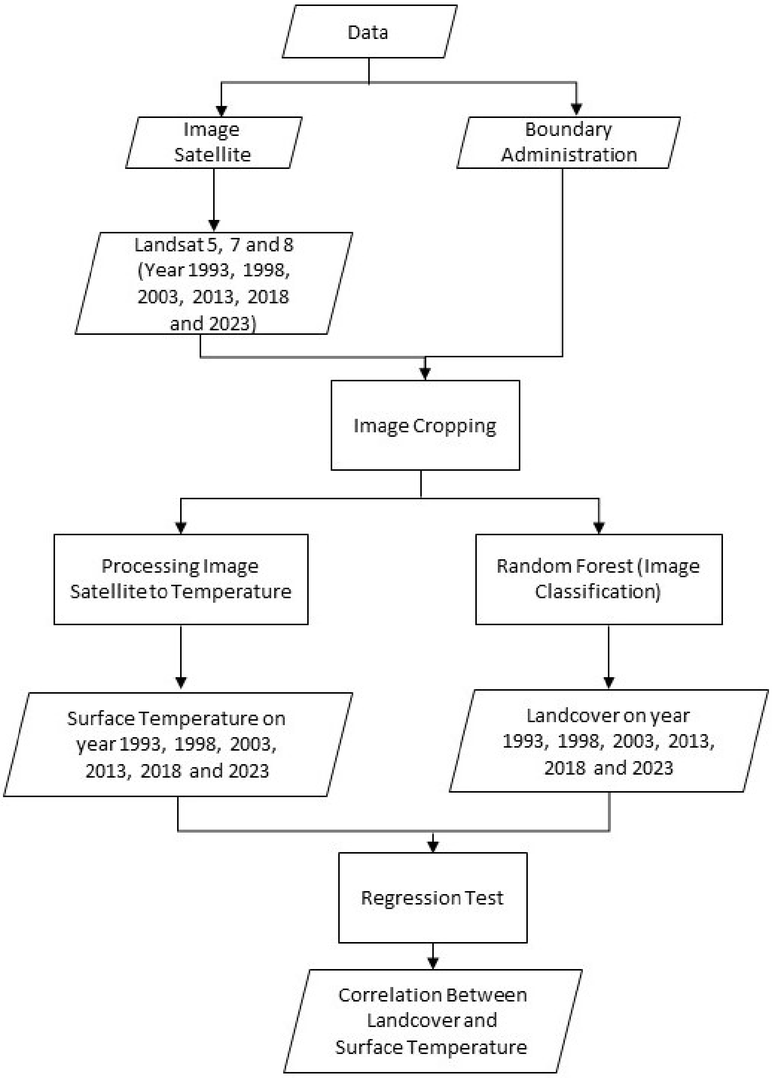

Figure 2: Flowchart Diagram of Research

Random Forest Classification

Random forest classification is an algorithm that is often used for land cover classification using remote sensing (Rodriguez-Galiano et al., 2012). Prior to doing the random forest classification, training points were generated for each category of land cover. Training points are representative sample locations that demonstrate the specific land cover type. The digitization of this training location is conducted utilizing the Google Earth Engine platform. Training points are used to ascertain the statistical attributes of pixel values representing land cover in the accessible multi-spectral photos. This information is subsequently employed to construct a model that classifies all images into distinct land cover categories. Training point digitization is required only for each category, as the random forest classifier method classifies the entire area based on the given training area. Increasing the number of training regions leads to improved accuracy in the classification results (Pradhesta et al., 2019). The land cover classification applied in this study refers to the Local Climate Zone, which includes (Stewart & Oke, 2012):

1. High-density built-up land (covering LCZ 1, 2 and 3)
2. Low and medium-density built-up land (covering LCZ 4, 5 and 6)
3. Lush trees (LCZ A)
4. Scattered trees (LCZ B)
5. Shrubs (LCZ C)
6. Vacant Land (LCZ F)
7. Waters (LCZ G)

Surface Temperature
Band 6 in Landsat 5 photography can be utilized to acquire surface temperature data, whereas band 10 is the thermal band employed for Landsat 8 and Landsat 9 photos. It is recommended to use band 10 with an accuracy of ~±1 K for simple estimation. The spectral radian is obtained from the conversion of pixel values in the image by performing the following equation:

$L\lambda = MLQcal + AL$ ………………….…………(1)
which:
$L\lambda$ = spectral radian on the sensor (W/(m2 .sr.µm)
Qcal = pixel value / digital number (DN),
ML = rescaling constant, obtained from image metadata
AL = incremental constants, obtained from image metadata

The spectral radian value above is then converted to the top of atmosphere (TOA) brightness temperature, which is denoted TB. Brightness temperature itself is the effective temperature on the satellite, assuming a uniform emissivity level. The conversion of the spectral radian value to the top of atmosphere (TOA) is by using the following equation :

$TBK = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda}\right)+1}$ ....(2)

which:
TBk = Brightness temperature (Kelvin)
K1 = Spectral radian calibration constant (W/(m2.sr.µm), obtained in band 10 metadata
K2 = Spectral radian calibration constant (W/(m2.sr.µm), obtained at band 10 or 11 metadata
Lλ= emissivity corrected spectral radian values

Converting from Kelvin to Celsius, it is necessary to reduce it by an absolute value of zero (273.15 °C), as presented in the equation below.
TBC = TBK - 273,15....................................(3)

ANALYSIS AND DISCUSSION

Surface Temperature

Based on the results of the analysis, the surface temperature of Bekasi City was obtained from 1993, 1998, 2004, 2009, 2013, 2018 and 2023. The surface temperature of Bekasi City based on the results of more detailed analysis can be seen in Table 1, Surface Temperature of Bekasi City in 1993 – 2023 as well as in Figure 3.

Table 1: Bekasi City Surface Temperature 1993 – 2022 (°C)

Year	Surface Temperature	
1993	Maximum	29,15
	Mean	23,76
	Minimum	20,2
1998	Maximum	27,91
	Mean	23,48
	Minimum	20,2
2004	Maximum	31,19
	Mean	26,48
	Minimum	21,08
2009	Maximum	38,29
	Mean	30,86
	Minimum	23,26
2013	Maximum	40,67
	Mean	32,33
	Minimum	21,38
2018	Maximum	43,2

Year	Surface Temperature	
	Mean	32,98
	Minimum	23,5
2023	Maximum	39,71
	Mean	32,37
	Minimum	24,73

(Source: Analysis Results, 2023)

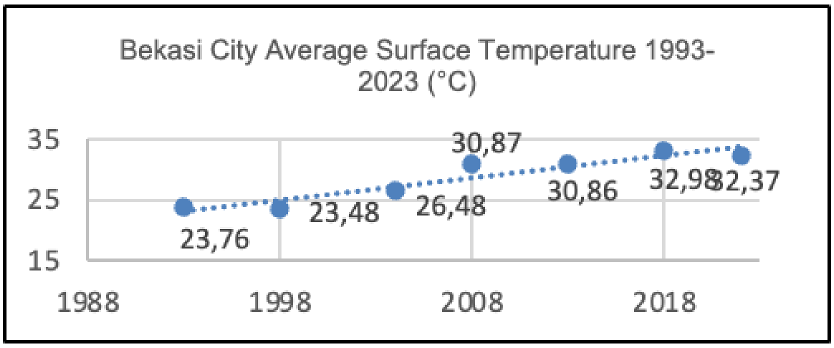

Figure 3: Bekasi City Average Surface Temperature 1993-2022 (°C)
Analysis Results, 2023

Table 1 and Figure 3 show that Bekasi's surface temperature has risen significantly during the past 30 years. The average surface temperature of Bekasi city was 23.76 °C in 1993 and 32.37 °C in 2023. This means Bekasi's average surface temperature rose 8.61 °C during the period. Bekasi's highest temperature rose 10.56 °C between 1993 and 2023. The highest maximum temperature was 43.2 °C in 2018. Figure 4 shows that western Bekasi City, notably Medan Satria District, West Bekasi District, Pondok Gede District, and Pondok Melati District, has the highest temperatures. All of these sub-districts are in West Bekasi, which borders DKI Jakarta Province.

Surface temperature in Bekasi increased significantly from 1998 to 2003 and 2008 to 2013. Between 1998 and 2003, temperatures rose from below 25 degrees to 25–27 degrees Celsius, showing a change from low to moderate temperatures. Between 2008 and 2013, temperatures rose from 30–34 degrees Celsius to over 34 degrees Celsius. Red maps, which indicate high surface temperatures, are becoming more common.

Land Cover Analysis

Currently, land cover is categorized into seven distinct classifications: high density built-up land, medium and low-density built-up land, high density vegetation, low density vegetation shrubs, unoccupied land, and waters. The initial phase in this research involves identifying the training points for each of the 56 classifications (El-Hattab, 2016). Subsequently, the random forest algorithm is executed using the Google Earth Engine software by inputting the outcomes of the created training points into the script, resulting in the generation of a land cover categorization. By doing a random forest classification study, it is feasible to ascertain the extent of the seven distinct categories of land cover that have been identified. The table 3 displays the respective areas of each land cover category.

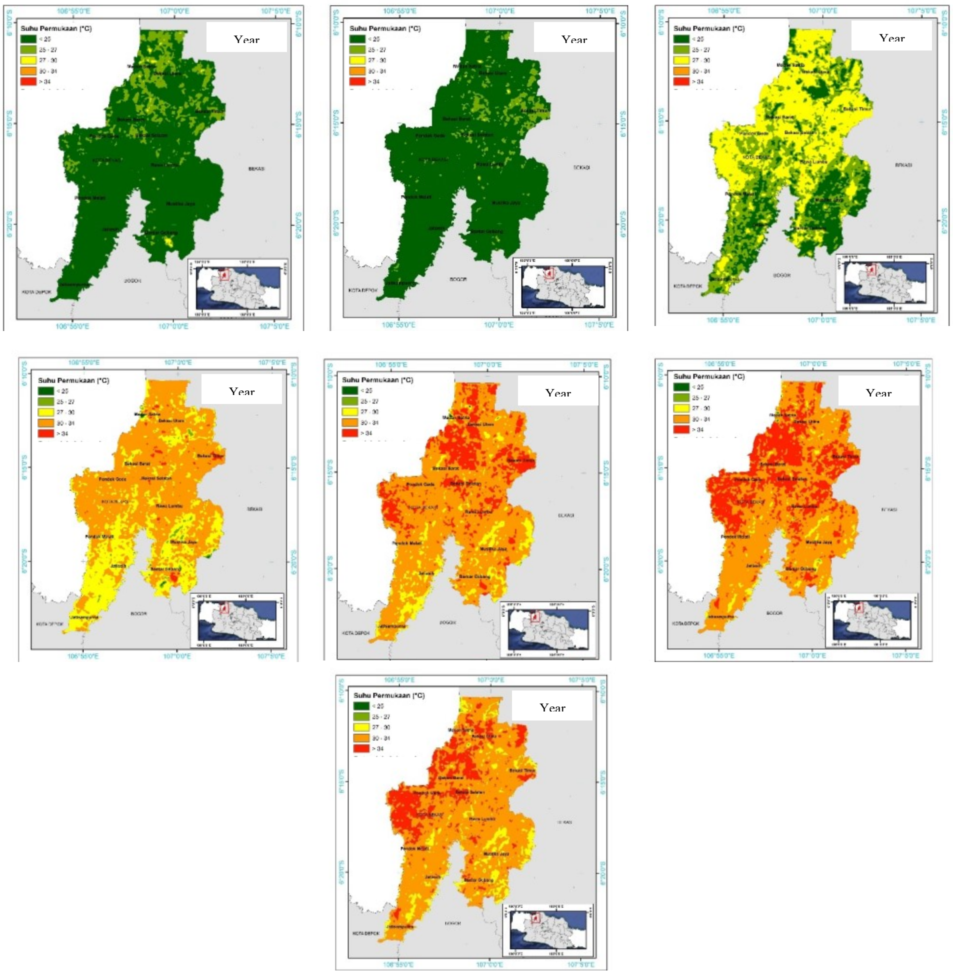

Figure 4: Bekasi City Surface Temperature Conditions in Years 1993, 1998, 2003, 2008, 2013, 2018 and 2023.

Table 3: Area of Each Type of Land Cover in Bekasi City 1993-2023 (Km²)

Tahun	High-Density Built-up Area	Medium and Low-Density Built-up Areas	Total Built-up Area	High-Density Vegetation	Medium and Low-Density Vegetation	Total Vegetation	Shrubs	Empty land	Waters	Total
1993	1,22	40,32	41,54	80,55	10,43	90,98	78,21	1,32	2,04	214,09
1998	4,59	58,77	63,36	76,39	0,85	77,24	63,20	8,09	2,19	214,09
2004	14,64	89,25	103,90	47,53	0,30	47,84	57,52	3,17	1,67	214,09
2009	17,23	107,26	124,49	34,40	1,13	35,53	50,75	1,31	2,01	214,09
2013	21,37	126,81	148,18	28,61	2,41	31,02	28,34	3,77	2,78	214,09
2018	33,19	118,57	151,76	29,32	1,96	31,28	23,74	4,90	2,42	214,09
2023	40,63	115,22	155,85	20,41	6,10	26,51	27,98	1,41	2,33	214,09

(Source: Analysis Results, 2023)

Table 3 shows a notable rise in the land area occupied by built-up areas between 1993 and 2023. Table 3 reveals a rise of approximately 114.31 km² in the built-up area land cover, resulting in built-up areas accounting for nearly 53% of Bekasi city. Conversely, the vegetation land cover has experienced a substantial decline from 1993 to 2023, namely by 64.47 units, resulting in around 51% of the vegetation remaining compared to the initial year.

Figure 5 illustrates the notable alterations in land cover within the city of Bekasi between 1993 and 2023. The most prominent transformations occurred in the northern and western regions, where there was a transition from vegetative land cover to built-up areas. In 1993, the city of Bekasi was primarily covered by vegetation, however in 2023, nearly all parts of the city had been developed into built-up regions.

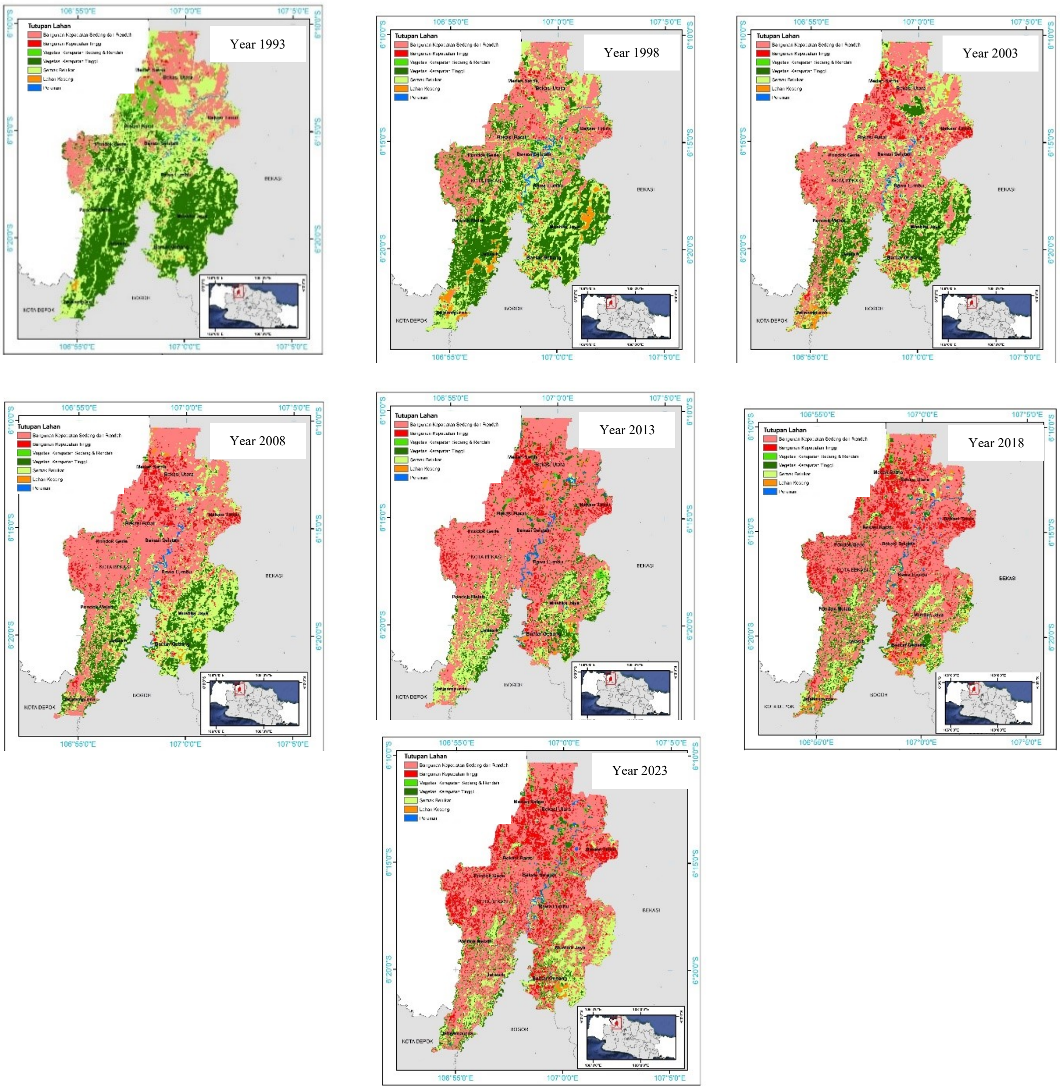

Figure 5: Bekasi City Land Cover in the Years 1993, 1998, 2003, 2008, 2013, 2018 and 2023.

Analysis of the Relationship between Land Cover and Surface Temperature

The comparison of surface temperature and land cover reveals a clear and substantial link between land cover and surface temperature. According to the data, built-up land and vacant land generally have high average surface temperatures, whereas regions with dense flora and water tend to have low average surface temperatures. For the statistics, refer to Table 4.9 which provides specific information on the surface temperature of Bekasi City's land cover from 1993 to 2022.

Table 4: Average Surface Temperature and Land Cover in Bekasi City (°C)

Year	High-Density Built-up Area	Medium and Low-Density Built-up Areas	High-Density Vegetation	Medium and Low-Density Vegetation	Shrubs	Empty land	Waters
1993	24,95	25,18	22,87	24,83	23,87	25,26	23,46
1998	24,83	24,48	22,68	23,84	23,26	24,25	23,24
2004	28,16	27,45	25,03	25,31	25,68	26,46	25,69
2009	32,24	31,62	28,73	29,87	30,21	32,06	28,91
2013	33,75	33,01	30,33	30,88	30,37	32,66	30,12
2018	34,31	33,51	31,38	32,69	31,10	32,31	30,89
2022	33,70	32,76	30,88	31,79	30,04	32,03	29,77

(Source: Analysis Results, 2023)

Analysis of the Relationship between Area Change of Each Land Cover and Surface Temperature

This analysis was carried out using a simple linear regression method by comparing the average surface temperature each year (variable y) with the proportion of each type of land cover each year (variable x) as has been done. This analysis was conducted to find out how significant changes in each type of land cover are to changes in surface temperature in Bekasi City.

Table 5: Relationship of the Proportion of Land Cover Area with Surface Temperature in Bekasi City, 1993 - 2022

No	Land Cover	R^2 Value	Change in Surface Temperature for Every 1% Increase in Land Cover Area (°C)	Correlation
1	High-Density Buildings	0,83	0,55	Very strong
2	Medium and Low-Density Buildings	0,87	0,25	Very strong
3	High-Density Vegetation	0,92	-0,34	Very strong
4	Medium and Low-Density Vegetation	0,04	-0,47	Very weak
5	Shrubs	0,84	-0,33	Very strong
6	Empty land	0,09	-1,06	Very weak
7	Waters	0,25	12,28	Weak

(Source: Analysis Results, 2023)

According to the analysis, high-density vegetation has the highest R^2 value. The high-density vegetation variable has the greatest impact on the fluctuations in average surface temperature in Bekasi City. The analysis indicates that high-density vegetation has a strong correlation with a R^2 value of 0.92. Furthermore, a 1% increase in the proportion of high-density vegetation will result in a decrease of the average surface temperature by 0.34°C. Furthermore, shrubs have an inverse relationship with average surface temperature, similar to vegetation. Shrubs have a high R^2 value of 0.84, indicating a strong correlation. Increasing the proportion of shrub-covered area by 1% results in a notable decrease of 0.33 °C in average surface temperature.

In addition to high-density vegetation and shrubs, buildings also have a significant effect on surface temperature, and this can be seen in Table 5. 10 The study examines the correlation between land cover area proportion and surface temperature in Bekasi City from 1993 to 2022, using regression analysis. High-density buildings exhibit a R^2 value of 0.82 in relation to surface temperature, whereas medium and low-density buildings demonstrate a R^2 value of 0.87 in relation to surface temperature. These data suggest a highly significant correlation between building factors and surface temperature. Furthermore, the findings of this analysis indicate that a 1% increment in the ratio of high-density built-up land in Bekasi City will result in a surface temperature increase of 0.55°C. Similarly, a 1% increase in the ratio of medium and low-density built-up land in Bekasi City will lead to a surface temperature rise of 0.25°C. There is not a significant correlation between other factors such as low and medium density vegetation, bare land, and waters. The research indicates that the association between these three factors and the average surface temperature falls under the weak and very weak categories. Consequently, the changes in these variables have no impact on the surface temperature.

CONCLUSION

According to the results of the land cover categorization research, Bekasi City has had substantial alterations in the past three decades in terms of the categories of land cover, including construction land cover, vegetation, and shrubs. According to the data, the urbanized area in Bekasi City has expanded from 41.54 km² to 155.85 km², representing a growth of 375.22% during the past three decades. Simultaneously, there was a reduction in the amount of vegetation and shrubs. The vegetation declined by 70.86%, going from 90.98 km² to 26.51 km². Similarly, the shrubs decreased from 78.21 km² to 27.98 km², representing a decrease of 64.22% over the past 30 years. According to the surface temperature analysis, the average surface temperature of Bekasi City has risen by 8.61 °C during the past 30 years. In 1993, the average surface temperature of Bekasi City was 23.76 °C, however in 2022, it increased to 32.37 °C.

Certain land covers exhibit a substantial association with fluctuations in temperature. The relationship between the average surface temperature and each type of land cover can be observed through the R^2 value. Vegetation with a high density has a strong correlation coefficient (R^2) of 0.92. Additionally, a small increase of 1% in the proportion of vegetated area will result in a noticeable decrease of 0.34°C in the average surface temperature. Furthermore, shrubs exhibit a contrasting influence on the average surface temperature. For instance, when compared to vegetation, shrubs demonstrate a R^2 value of 0.84. Additionally, a just 1% increase in the proportion of shrub-covered area results in a notable decrease of 0.33 °C in the average surface temperature. Conversely, high-density built-up land and medium & low-density built-up land have R^2 values of 0.82 and 0.87, correspondingly, in response to a 0.55°C and 0.25°C rise in average surface temperature for every 1% increase in area.

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