Analysis of Variations in the Relationship of Human Activities to Land Surface Temperature During the Covid-19 Pandemic in Yogyakarta City

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Abstract. On March 11, 2020, the World Health Organization (WHO) declared *coronavirus disease* 2019 (Covid-19) a global pandemic. The uncontrolled spread of Covid-19 has caused world governments to impose restrictions on activities in public spaces to reduce positive Covid-19 counts. Similarly, Yogyakarta City also implemented this policy, which caused a temporary drop in land surface temperature (LST) as a result of lessened human activity. Human activities have an impact on various problems, such as the amount of energy consumption, vehicle pollution, and land use changes. This study used Landsat 8 and Landsat 9, for which the recording time was adjusted to the policy of the Government of Yogyakarta Special Region. *Normalized Difference Vegetation Index* (NDVI) and *Normalized Difference Built-up Index* (NDBI) are variables used as proxies for vegetation and building density, respectively. The objectives of this study were (1) to analyze the spatial distribution of LST due to reduced human activity before, during, and in the transition period of the Covid-19 in Yogyakarta City; and (2) to analyze the variation of distance relationships from road networks, vegetation density, and building density to LST before, during, and in the transition period of the Covid-19 in Yogyakarta City. The results showed that Yogyakarta City dominated the temperature range of 29.1–33 °C, which changed to 24.1–26 °C as an effect of reduced human activity during lockdown. In the meantime, the relationship between NDVI and road network variables is more significant than that between NDBI variables. However, the three variables do not have a very significant influence when viewed based on the coefficient of determination of multiple linear regression.

Keywords: *Coronavirus Disease* 2019 (Covid-19) · human activity · land surface temperature · road network · vegetation density · building density

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1 Introduction

In 2021, the number of tourist visits in Yogyakarta decreased dramatically from 4,378,609 tourists in 2019 to 1,276,468 tourists in 2021 (Dinas Lingkungan Hidup Kota Yogyakarta, 2022). This was also followed by a decrease in the average air temperature recorded in 2020, reaching 28.34 °C before decreasing to 28.15 °C in 2021. Yogyakarta City is a city with dense community activity and potentially continues to experience a rise in land surface temperature from year to year due to the intensity of high population growth, the increase in the number of migrations, the increase in motor vehicles, and the transfer of land functions to meet the needs of space intended to support the increasing community activities (Atianta, 2020). This anomalous event was on account of the influence of the Covid-19 pandemic that hit the world at the end of 2019.

As of March 11, 2020, the World Health Organization (WHO) declared the Covid-19 virus outbreak a global pandemic. This is because the Covid-19 outbreak has widely spread to more than 110 countries, with the number of cases reaching 118,000 in 2020 (Maya & Kusnoputranto, 2021). Covid-19 is an infectious disease caused by *Severe Acute Respiratory Syndrome Coronavirus 2* (SARS-COV2), with various effects for infected victims, such as fever, cough, or shortness of breath (Kementerian Kesehatan Republik Indonesia, 2020). The virus, which was first discovered in Wuhan, China, at the end of 2019, was transmitted through saliva that comes out of the nose or mouth of someone who has been positively infected (Aditia, 2021).

The spread of Covid-19, which was increasingly out of control, caused the world government to impose several policies in order to reduce the death rate and positive cases of Covid-19, which are referred to as "lockdown". Similarly, the Indonesian government also enforced a series of policies, starting from large-scale social restrictions (PSBB) to the implementation of community activity restrictions (PPKM). Yogyakarta Special region itself set various policies starting from the instruction of the governor of Yogyakarta Special Region Number 2/INSTR/2020 regarding increasing awareness of the risk of infection transmission of *Corona Virus Disease* (Covid-19) as of March 3, 2020. The lockdown activity that was implemented proved to be quite effective in reducing the increase in Covid-19 cases. In addition, policies that cause a reduction in human activity in public spaces also have a positive impact on the environment in the form of temporarily decreasing land surface temperature and air pollution (Ju et al., 2021).

This situation was also investigated by Hadibasyir et al., (2020) which explains that the implementation of restrictions on people's mobility in public spaces has a positive impact on urban air temperature trends. This is evidenced by comparing the surface temperature of the land in Wuhan City in the past 3 years with the air temperature during lockdown due to the Covid-19 pandemic with the same image recording data. The results of the study found a decrease in land surface temperature since the implementation of the lockdown policy in late January to early March 2020. Based on the results of the research, it can be concluded that one of the factors contributing to decreasing land surface temperature is the contribution of anthropogenic activities in built-up areas that continue to have a negative value.

One of the human activities contributing to a decrease in land surface temperature is a reduction in the use of motor vehicles. Exhaust substances produced from each motor vehicle will continue to congregate and accumulate in the atmosphere, causing an increase in land surface temperature (Ismail, 2020). On a daily basis, the existence of human activities is represented by the mobility of motor vehicles occupying each road section of the road, causing higher temperatures around the road (Liu et al., 2020). The implementation of restrictions on human activities during the Covid-19 pandemic has caused a decrease in the volume of vehicles on the road. This is evidenced by the comparison of vehicle volume with road capacity on several Yogyakarta City roads in 2019 and 2020, as shown in Table 1. In comparison to the average in 2019, the total number of vehicles and the capacity of the roads both decreased significantly in 2020 (Perhubungan DIY, 2021).

According to Subarna (2017) the existence of changes in vegetated land due to human activities into asphalt or concrete on road networks, buildings, or other structures that cause the soil surface to be replaced and cause more to absorb solar heat and reflect it is one of the factors for changes in land surface temperature. In addition to assessing changes in land surface temperature from human activities in the form of reduced use of motor vehicles on roads and in public spaces, This is due to differences in the characteristics of land cover materials and albedo values of each object surface resulting in different land surface temperature values (Rushayati et al., 2018). Viewed based on the factors of change in the characteristics of land cover material, this condition demands a study of changes in land surface temperature based on the distance from the road network, vegetation index, and built-up land index as independent variables. The variation of the selected variables aims to portray the empirical evidence of the relationship between the distance variable from the road network, vegetation density, or building density to changes in land surface temperature.

Based on the aforementioned background, the objectives of the study were (1) to analyze the spatial distribution of land surface temperature due to reduced human activity before, during, and in the Covid-19 pandemic transition period in Yogyakarta City; (2)

Table 1. Comparison of vehicle Volume with the capacity of Yogyakarta City roads (Perhubungan DIY, 2021).

No.	Street Name	V/C Ratio	
		2019	2020
1	Am Sangaji Street front of Gurame Bangjo	0.94	0.43
2.	Mataram Street	0.90	0.86
3.	Malioboro Street	0.87	0.41
4.	Prof. John Herman Street	0.81	0.30
5.	Pasar Kembang Street	0.76	0.68
6.	Diponegoro Street in front of Kranggan Market	0.75	0.31
7.	C. Simanjutak Street	0.66	0.44
8.	Bhayangkara Street	0.43	0.47
Average		0.765	0.488

to analyze the variation in the relationship between the three variables used, namely the distance from the road network, the vegetation density index using the NDVI method, and the building density index using the NDBI method to land surface temperature.

2 Research Methodology

2.1 Research Locations

The location of the study was in the Yogyakarta City which is an administrative part of —the Special Region of Yogyakarta. It is astronomically located between 110°24′19″ 110°28′53″ East Longitude and 07°15′24″–07°49′26″ the South Longitude which can be seen in Fig. 1. Compared with the total area of the Special Region of Yogyakarta, the area of Yogyakarta City reaches 32.5 km^2 or only covers 1.02% (Badan Pusat Statistik Kota Yogyakarta, 2021). Administratively, Yogyakarta City has a total of 14 sub-districts and 45 villages.

Based on Population Census data in 2020 in BPS Kota Yogyakarta (2021) the population of the Yogyakarta City reache 373,589 people with a male population of 182,019 people and a female population of 191,570 people. Ngampilan Sub-district in 2020 is the district with the highest population density, reaching 18,729/km^2 with a total area of less than 1 km^2. In contrast to Ngampilan Sub-district, Umbulharjo Sub-district has a total area of 8.12 km^2 making it as the most extensive district with the rarest population density. However, according to Statistics Indonesia for Yogyakarta City (Badan Pusat Statistik Kota Yogyakarta, 2021), despite its least population density, Umbulharjo Sub-district is the district with the most populous in Yogyakarta City. According to data, the total number of residents in Umbulharjo Sub-district in 2020 reached 68,170 people.

2.2 Tools and Materials

In this study, the primary data used are Landsat 8 and Landsat 9 OLI/TIRS images path/row 120/65 Level-1 or referred to as product Level 1 Precision Terrain (Corrected) (L1TP) with geometrically corrected output using ground control points and also Digital Elevation Model (DEM) used for the calibration process. These data were found in the metadata (USGS, 2019). The data taken were a recording image data before, during, and in the Covid-19 pandemic transition period obtained through the page earthexplorer.usgs.gov shown in Table 2. The software used in image data processing is QGIS Desktop 3.12.1 and ArcMap 10.3, while performing correlation and regression operations used SPSS 16.0.

2.3 Data Processing and Analysis Techniques

The flow of research is presented in Fig. 2. Based on the diagram, the main steps are: 1) radiometric and atmospheric correction process, 2) extraction of vegetation density index (NDVI), 3) extraction of built-up land density index (NDBI), 4) extraction of BT, surface emissivity, and land surface temperature, 5) Euclidean Distance on the road network, 6) Multiple Linear correlation and regression process before, during, and in the Covid-19 pandemic transition in Yogyakarta City.

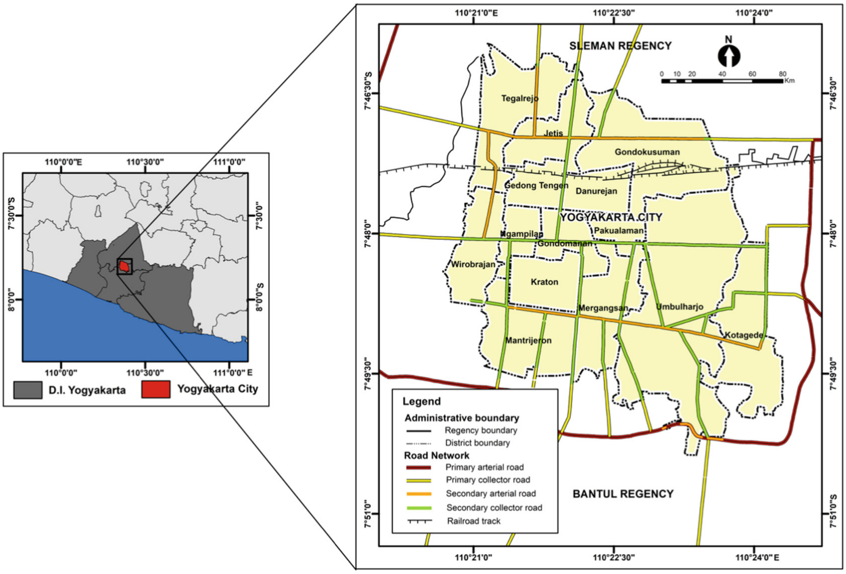

Fig. 1. Map of Yogyakarta City Study Area.

Radiometric and Atmospheric Correction Process

This process utilized Plugins Semi-Automatic Classification Plugin (SCP) owned by QGIS. This process generated images that have been corrected atmospherically through algorithms Dark Object Substraction (DOS).

Extraction Vegetation Density Index (NDVI)

Equation (1) is an NDVI algorithm proposed by Sobrino et al. (2004) to produce a vegetation density index. The classification of vegetation density index is presented in Table 3.

$$NDVI = \frac{(Near\ infrared - red)}{(Near\ infrared + red)} \tag{1}$$

Description:
NDVI: Vegetation Density Index
Near-infrared: Near-infrared channel (on Landsat 8 it’s on channel 5)
Red: Red channel (on Landsat 8 it’s on channel 4)

Extraction Built-Up Land Density Index (NDBI)

Equation (2) is an equation for the NDBI algorithm (Aditia, 2021)

$$NDBI = \frac{(Short\ wave\ infrared - near\ infrared)}{(Short\ wave\ infrared + near\ infrared)} \tag{2}$$

Description:
NDBI: Building density index

Table 2. Landsat image recording and Timeline of DIY Covid-19 countermeasures policy (Pemerintah Daerah Istimewa Yogyakarta, 2022)

Date	Information	DIY Covid-19 Response Policy Timeline
Landsat 8 Imagery 20190422 Recording	Before the Covid-19 Pandemic	–
Landsat 8 Imagery 20190828 Recording		
Landsat 8 Imagery 20200510 Recording	Covid-19 Lockdown Implementation	Decree of the Governor of the Special Region of Yogyakarta Number 65/KEP/2020 concerning the Covid-19 Disaster Emergency Response
Landsat 8 Imagery 20200830 Recording		Decree of the Governor of the Special Region of Yogyakarta Number 227/KEP/2020 concerning the Determination of the third Extension of the third Covid-19 Disaster Emergency Response Status
Landsat 8 Imagery 20210513 Recoding		Instruction of the Governor of the Special Region of Yogyakarta Number 12/INSTR/2021 concerning the Extension of Micro-Based PPKM in DIY
Landsat 8 Imagery 20210817 Recording		Instruction of the Governor of the Special Region of Yogyakarta Number 13/INSTR/2021 concerning the Implementation of PPKM Level 4 Covid-19 in DIY
Landsat 9 Imagery 20220524 Recoding	After the Covid-19 Pandemic/Transition Period	Instruction of the Governor of the Special Region of Yogyakarta Number 15/INSTR/2022 concerning PPKM Level 2 in DIY
Landsat 8 Imagery 20220820 Recoding		Instruction of the Mayor of Yogyakarta City Number 19 of 2022 concerning PPKM Level 1 in the Yogyakarta City Area

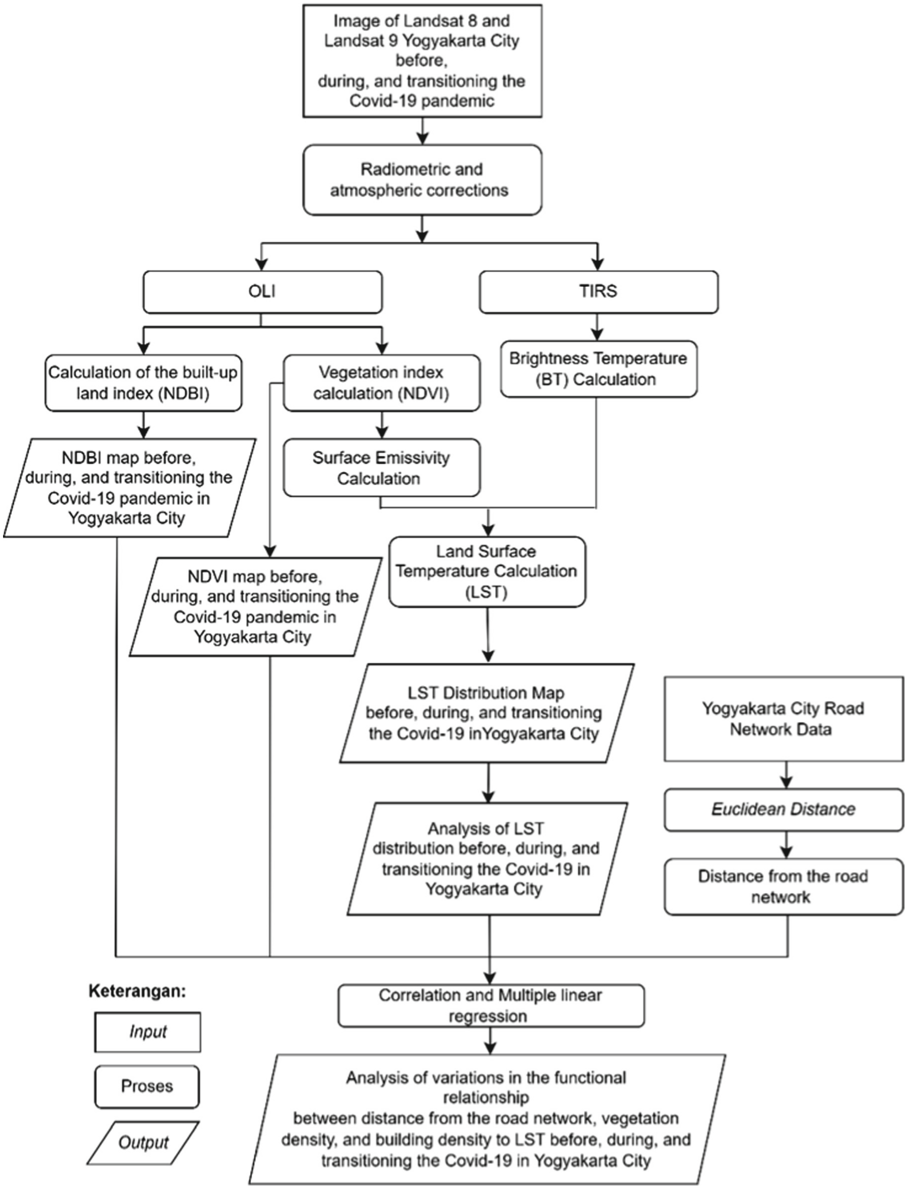

Fig. 2. Research Flow Chart

Short wave infrared: Short wave infrared channel (on Landsat 8 it's on channel 6)
Near-infrared: Near-infrared channel (on Landsat 8 it's on channel 5)

BT Extraction, Surface Emissivity, and LST

Value of Brightness Temperature (BT) is generated from channel 10 without channel 11. This is based on research conducted by NASA because it considers channel 11 on

Table 3. Classification of Vegetation Density Index (NSL et al., 2018).

Density Classification	NDVI value
Not vegetated	−1 to 0.25
Infrequently	0.25 to 0.35
Quite tight	0.35 to 0.45
Tight	0.45 to 0.50
Very Tight	0.50 to 1

Landsat images less ideal for a process producing quantitative analysis data (USGS, 2014). Equation (3) (Deilami et al., 2016).

$$BT = \frac{K_2}{ln(\left(\frac{K_1}{L_\lambda}\right) + 1)} \tag{3}$$

Description:
BT: Rated brightness temperature (in K)
Lλ: Radiance ToA value (Watss/(m^{2*}srad*μm))
K_1: K1_CONSTANT_BAND_X, where X is the channel used
K_2: K2_CONSTANT_BAND_X, where X is the channel used

The surface emissivity value is obtained from the results of Eq. (1) which is then followed by applying the calculation Proportion of Vegetation (PV) with Eq. (4) (Sobrino et al., 2004).

$$Pv = (\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}})^2 \tag{4}$$

Description:
Pv: Proportion of Vegetation
NDVI: Vegetation density index values
$NDVI_{min}$: Minimum vegetation density index values of 0.2 (Sobrino et al., 2004)
$NDVI_{max}$: Minimum vegetation density index values of 0.5 (Sobrino et al., 2004)

The result of the calculation Proportion of Vegetation (PV) is then followed by Eq. (5) (Sobrino et al., 2004) to produce the surface emissivity.

$$\varepsilon = 0.004\ Pv + 0.986 \tag{5}$$

where Pv is the result of Eq. (4). The result from Eq. (3) to (5) is used to generate the LST value with Eq. (6) (Deilami et al., 2016).

$$LST = \frac{BT}{1 + \left[\left(\lambda x \frac{BT}{\alpha}\right) ln\varepsilon\right]} - 273,15 \tag{6}$$

Description:
LST: Land Surface Temperature values (in °C)

BT: Brightness Temperature values (in K)
λ: The wavelength of emitted radiance equal to 11.5 μm
α: hc/b (1.438 x 10^{-2} mk = 14388 μmk)
ε: Surface emissivity

Euclidean Distance Process on a Road Network

Euclidean distance is one of the processes of calculating the distance from two points contained in Euclidean space to study the relationship between angle and distance (Miftahuddin et al., 2020). The ArcGIS, Euclidean Distance tools is categorized into spatial analyst tools. The type of road network used in the study consisted of secondary arterial roads and secondary collector roads. Results from Euclidean Distance are shown in Fig. 3.

Multiple Linear Correlation and Regression Process

Correlation analysis shows the relationship of each variable (Gogtay & Thatte, 2017), while regression is an analysis used to measure how much influence there is between the independent variable and the dependent variable (Sujarweni, 2014). The model of multiple linear regression is described as Eq. (7) with the interpretation of the level of

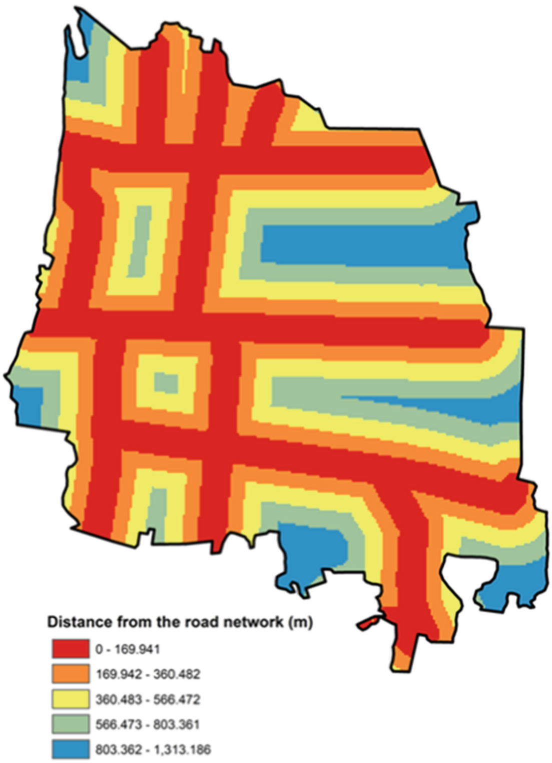

Fig. 3. *Euclidean Distance* of Yogyakarta City Road Network

Table 4. Classification of correlations and coefficients of determination (Sugiyono, 2009).

Coefficient Interval	Relationship level
0.00–0.199	Very weak
0.20–0.399	Weak
0.40–0.599	Quite strong
0.60–0.799	Strong
0.80–1.000	Very strong

correlation coefficient and coefficient of determination shown in Table 4.

$$Y = \alpha + b_1x_1 + b_2x_2 + b_3x_3 \quad (7)$$

Description:
Y: Land Surface Temperature
α: Regression constant
b_1, b_2, b_3: Regression coefficient
X_1: Vegetation density index
X_2: Built-up density index
X_3: Distance from the road network.

3 Results and Discussion

3.1 Vegetation Density and Building Density

Figure 4 shows the distribution of vegetation density in the Yogyakarta City, which is divided into three time periods. In the picture, point (a) and point (b) are NDVI conditions before the Covid-19 pandemic, while Point (c), (d), (e), and (f) is a condition of NDVI when the enactment of lockdown/The implementation of community activity restrictions (PPKM), and point (g) and (h) are parts of the transition period of the Covid-19 pandemic. Over the three time periods mentioned earlier, there was essentially no change from the eight distribution conditions of vegetation density. However, in the lockdown period as of May 10, 2020, there have been considerable changes. This can also be observed through Fig. 5 where the proportion of the area of the very dense vegetation density class increases in breadth, while the area of sparse vegetation density becomes narrower in May 2020 which is part of the lockdown period/Imposition of Restrictions on Community Activities.

The southeast side of the Yogyakarta City tends to have a very tight and quite tight proportion of the distribution of the level of vegetation density, which is the most extensive compared to other parts of the Yogyakarta City. This is in line with the condition in Umbulharjo Sub-district which is the district with the largest area but has a lower population density (Badan Pusat Statistik Kota Yogyakarta, 2021). In the center of Yogyakarta City, the districts of Gondomanan, Pakualaman, Danurejan, and Kraton are those dominated by the density level of vegeration that is quite tightly, rarely, until not vegetated.

Based on Fig. 5, it can be concluded that the Yogyakarta City was in three periods (before the Covid-19 pandemic, lockdown/PPKM, and the Covid-19 pandemic transition period) and was dominated by sparse and fairly dense vegetation density.

Based on the multitemporal distribution of building density shown in Fig. 6, there is no significant change from time to time. The proportion of the area based on the level of building density is dominated by tight building. The tight building class is mostly found in the center of Yogyakarta City, namely Kraton, Gondomanan, Pakualaman, and Ngampilan Sub-districts. Meanwhile, the level of density of rare buildings is rarely found in Umbulharjo Sub-district. Similarly, as described earlier, there is a change in the proportion of the area in May 10, 2020 which is part of the lockdown period/PPKM in Yogyakarta City, which is presented in Fig. 7. In that period, the surface area of dense settlement was reduced, while the surface area of the settlement rarely increased.

3.2 Analysis of Land Surface Temperature Distribution Before, During, and in the Covid-19 Pandemic Transition Period in Yogyakarta City

In general, the average LST in August during lockdown was higher than that in April and May. The maximum LST occurred in August 2020 which reached 35.28 °C. The period of May 2020 was the period with the lowest average land surface temperature when compared to other average periods, starting from April 2019 to August 2022, which can be shown in Table 5. Likewise, the standard deviation value in May 2020 became the lowest standard deviation value compared to that of other periods. The lower the value of the standard deviation, the more homogenous the distribution of LST in the study area.

From Fig. 8, the Yogyakarta City is dominated by LST with temperatures between 29.1–33 °C, spreading almost throughout the Yogyakarta City. There was a significant change in temperature in May 2020, during which period it was part of the implementation of lockdown/PPKM due to the Covid-19 pandemic. In May 2020, the entire Yogyakarta City was dominated by temperatures between 24.1–26 °C, even in this period there was no temperature class found more than 26.1 °C. This condition was temporary because in August 2020 Yogyakarta City was again dominated by temperatures between 29.1–33 °C and even became the period with the highest temperature compared to other LST periods. In August 2020 and 2021, which were the lockdown period, LST tended to be higher, the temperature was between 33.1–36 °C, which could be found in urban centers such as Gondomanan, Kraton, Pakualaman, Danurejan, and Ngampilan Sub-districts.

3.3 Analysis of the Variation of the Relationship Between the Distance from the Road Network, Vegetation Density, and Building Density to Land Surface Temperature in the Yogyakarta City Before, During, and in the Covid-19 Pandemic Transition

Table 6 shows the correlation between distance variables from the road network, NDVI, and NDBI to LST. Variable distance from the road network becomes variables with no correlation relationship to the changes in LST. This can be seen from the level of correlation coefficient relationship, which is very weak. Meanwhile, NDVI variables as a whole

Fig. 4. Multitemporal distribution of vegetation density in Yogyakarta City (a) April 22, 2019, (b) August 28, 2019, (c) May 10, 2020, (d) August 30, 2020, (e) May 13, 2021, (f) August 17, 2021, (g) May 24, 2022, and (h) August 20, 2022.

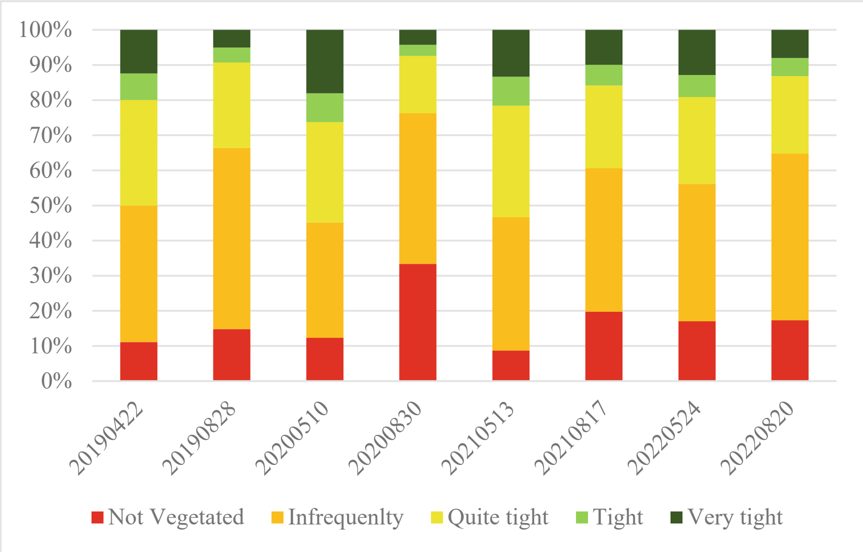

Fig. 5. The proportion of Area based on the Multitemporal Levels of Vegetation Density in Yogyakarta City.

have a negative correlation or inversely proportional to the changes in LST. This shows that the higher the value of vegetation density, the lower the value of LST in a particular region. Unlike the NDBI variable which has a positive correlation relationship, the value of building density in a region is higher, and the LST value will be directly proportional to the value of building density. In the lockdown period/PPKM, the relationship between NDVI variables with LST is stronger than the correlation in other periods.

Based on Table 7, value of the determination coefficient is (RSquar*e*/R^2) before the Covid-19 pandemic increased. In the period of April 2019, RSquare between the variable distance from the road network and NDVI is 16.5%, while in the period of August 2019 a large RSquare is 23.3%. It also supports the results of the determination coefficient of the calculation between the variable distance of the road network and NDBI. The value of the determination coefficient indicates that the influence of each independent variable (distance from the road network, NDVI, and NDBI) to the dependent variable LST is 16.5%, while the rest (100% − 16,5% = 83,5%) is influenced by other variables not selected in this study.

The value of t_{count} and t_{table} is (a/2; n-k-1), where a = 5% (0.05) resulting in t_{table} = t (0.025;234) = 1.970, which is viewed by the influence of partial variables. Because a value of $t_{count} < t_{table}$ (0.386 < 1.970), the hypothesis is rejected. It can be concluded that the variable distance from the road network does not affect the change in LST. The value of t_{count} NDVI variable is -6.773, where the result is greater than the value of t_{table}. Thus, the NDVI variable affects the change of LST with the inverse/negative relationship, while NDBI partially affects the LST with the positive relationship. In contrast to the results of the t test in April 2019, the processing in the August 2019 period between the distance variable from the road network and NDVI produced two independent variables

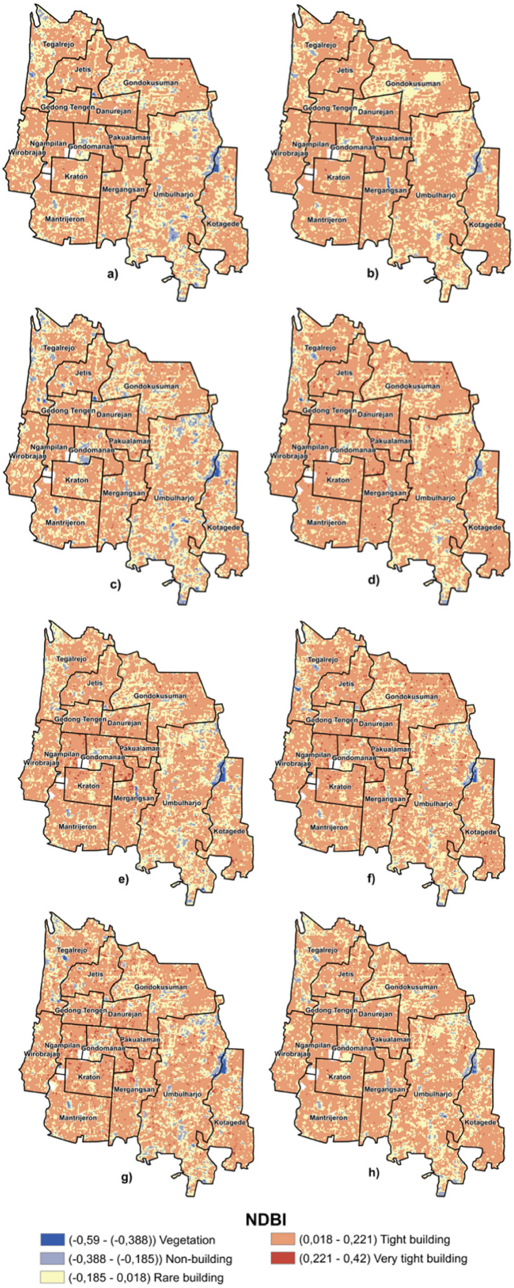

Fig. 6. Multitemporal Distribution of Vegetation Density in Yogyakarta City (a) April 22, 2019, (b) August 28, 2019, (c) May 10, 2020, (d) August 30, 2020, (e) May 13, 2021, (f) August 17, 2021, (g) May 24, 2022, and (h) August 20, 2022.

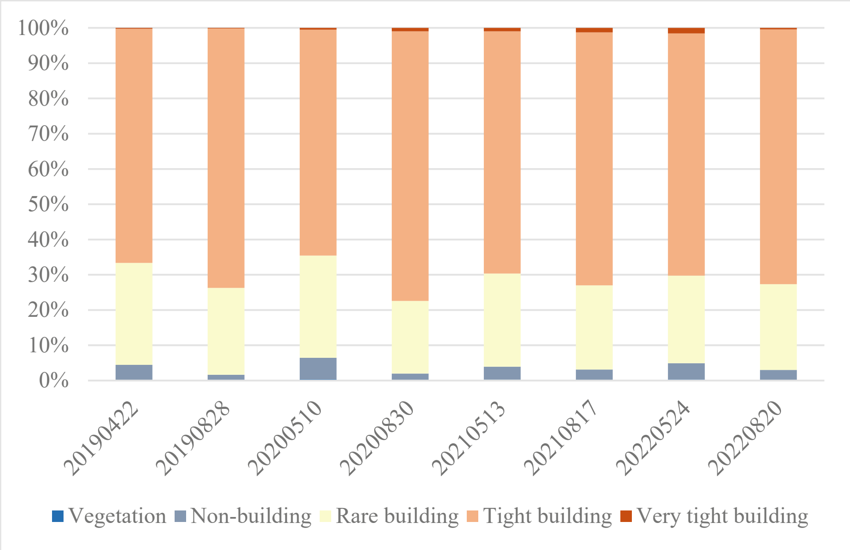

Fig. 7. The Proportion of Area based on the Multitemporal Levels of Building Density in the Yogyakarta City.

affecting LST with positive relationship directions for the distance variable from the road network, and negative relationship directions for NDVI. The equation of multiple linear regression in the period before the Covid-19 pandemic is presented in Table 8.

In the early period of lockdown implementation with the Covid-19 Disaster Emergency Response status in May 2020, the value of the determination coefficient of the distance variable from the road network and NDVI reached 34.7%, while the distance from the road network with NDBI reached 21.8%. However, in the subsequent periods: August 2020, May 2021, and August 2021, the contribution of the distance variable from the road network and NDBI was greater than the contribution of the distance variable from the road network with NDVI, which is shown in Table 9. Some periods produced the distance variable from the road network with a partial effect on LST if regressed with the NDVI variable. For instance, it occurred in August 2020 and August 2021 with a positive relationship direction towards LST. In the period of May 2020, the distance variable from the road network had a negative relationship when it was negotiated with NDBI. The equation of multiple linear regression during Covid-19 pandemic is presented in Table 10.

There is not much difference between the results of multiple linear regression before and during the Covid-19 pandemic transition period which presented in Table 11. Partially, the distance variable from the road network when it was negotiated with NDVI in August 2022 had an influence on the direct proportional relationship to the LST. Meanwhile, the distance variable from the road network partially also has an influence on LST with the inversely proportional relationship when it is regressed with the NDBI variable in May 2022. The equation of multiple linear regression in the Covid-19 pandemic transition period is shown in Table 12.

Table 5. Descriptive statistics of Multitemporal LST in Yogyakarta City.

Date	Information	Policy Timeline	Minimum	Maximum	Average	Std.Dev
20190422	Before the Covid-19 Pandemic	–	25.11	32.55	30.2	1.1
20190828			26.04	32.92	29.77	0.9
20200510	Covid-19 Lockdown Implementation	Covid-19 Disaster Emergency Response	22.99	26.31	24.77	0.6
20200830		Extension of the third Covid-19 Disaster Emergency Response Status	28.36	35.28	32.25	0.8
20210513		Extension of Micro-Based PPKM in DIY	26.16	31.2	29.59	0.8
20210817		Implementation of PPKM Level 4 Covid-19 in DIY	28.21	34.86	32.01	0.9
20220524	After the Covid-19 Pandemic/Transition Period	PPKM Level 2 in DIY	26.35	31.62	29.97	0.7
20220820		PPKM Level 1 in Yogyakarta City	24.47	31.86	27.95	0.9

4 Discussion

The influence of human activity has its own role in the change of LST in a region. As mostly mentioned by the previous research, there is influence of population, land cover changes, and the city that continues to massively grow (Singh et al., 2017) to be the biggest factor in the change of LST. This is also evidenced by the state of LST in the districts of Kraton, Gondomanan, Pakualaman, and Ngampilan which have sparse vegetation density and tight settlement classes which tend have a higher LST state compared to other districts. However, a significant decline in LST in Yogyakarta City occurred because of the lockdown policy, which caused human activity to decline in public spaces. It indicates that human activity factors also play an important role in the change of LST. If viewed from the statement put forward by Singh et al. (2017) regarding the results of the research, the change in land cover is an essential factor in the change of LST is not directly proportional to the state of the building density level (Fig. 7) in Yogyakarta City. In general, there is no significant change in those particular months

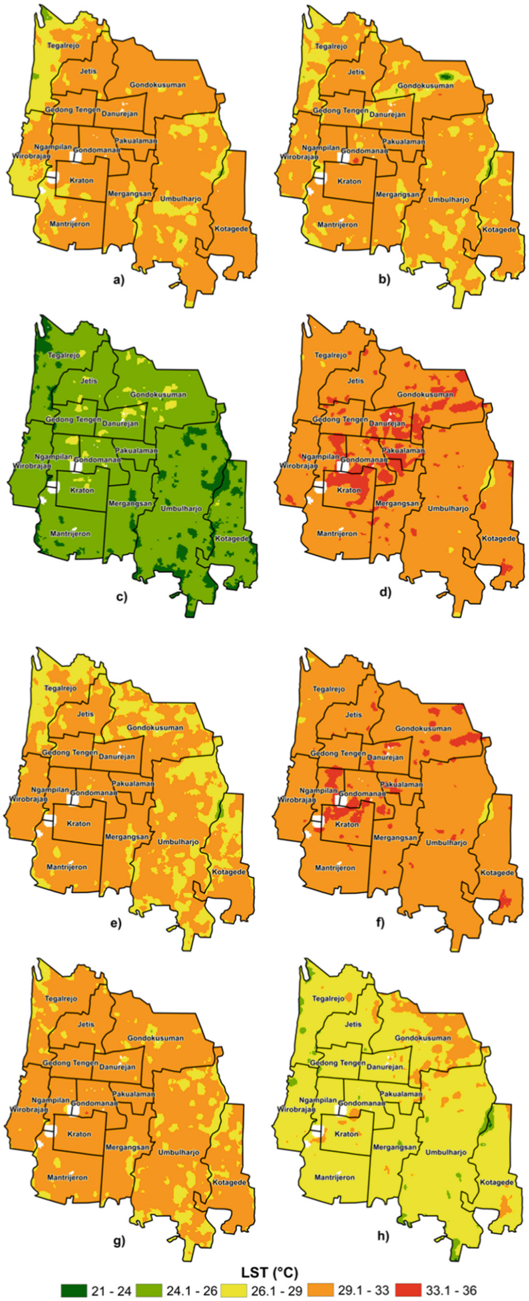

Fig. 8. Multitemporal Distributions of Vegetation Density in Yogyakarta City are (a) April 22, 2019, (b) August 28, 2019, (c) May 10, 2020, (d) August 30, 2020, (e) May 13, 2021, (f) August 17, 2021, (g) May 24, 2022, and (h) August 20, 2022.

Table 6. Correlation of LST with Distance Variable from Road Network, NDVI, and NDBI.

Date	Information	DIY Covid-19 Response Policy Timeline	Correlation of Distance from Road Network with LST	Correlation of NDVI with LST	Correlation of NDBI with LST
20190422	Before the Covid-19 Pandemic	–	−0.043	−0.406	0.442
20190828			0.061	−0.517	0.559
20200510	Covid-19 Lockdown Implementation	Covid-19 Disaster Emergency Response	−0.235	−0.579	0.43
20200830		Extension of the third Covid-19 Disaster Emergency Response Status	0.023	−0.452	0.473
20210513		Extension of Micro-Based PPKM in DIY	−0.085	−0.455	0.536
20210817		Implementation of PPKM Level 4 Covid-19 in DIY	0.057	−0.51	0.53
20220524	After the Covid-19 Pandemic/Transition Period	PPKM Level 2 in DIY	−0.172	−0.441	0.52
20220820		PPKM Level 1 in Yogyakarta City	0.041	−0.411	0.423

of the period. Factors of reduced human activity in public spaces show considerable effectiveness despite the short period of time. This is evidenced by the results (Fig. 8 Point c), which show the majority of the distribution of LST Yogyakarta City was between 24.1 and 26 °C, while the temperature in general was between 29.1 and 33 °C due to reduced human activity.

Although there was a drastic decrease in LST in May 2020, the next period (Fig. 8 points d, e, and f) showed that the distribution of LST in Yogyakarta City was again dominated by temperatures between 29.1–33 °C, and even the temperature distribution of 33.1–36 °C was also found in August 2020 and 2021. In spite of the status of Yogyakarta City policy in the third extension period of the Covid-19 emergency response status, referred to the decree of the governor of Yogyakarta Special Region number 227/KEP/2020, the number of tourists who began to enter to Yogyakarta in August 2020 continued to increase. Based on data in May 2020, there were only 86 tourists, and

Table 7. Multiple Linear Regression of the Period before the Covid-19 Pandemic.

Date	Information	DIY Covid-19 Response Policy Timeline	Variable	R_{square}	Constant	Unstandardized Coefficients (B)	t
20190422	Before the Covid-19 Pandemic	–	Distance from the road network	0.165	31.420	0.09565	0.386
			NDVI			−3.931	−6.773
			Distance from the road network	0.199	29.949	0.000	−1.020
			NDBI			4.490	7.598
20190828			Distance from the road network	0.233	30.864	0.000	2.161
			NDVI			−4.029	−8.303
			Distance from the road network	0.238	29.347	0.000	0.660
			NDBI			4.805	8.419

Table 8. Multiple Linear Regression Equation of the Period before the Covid-19 Pandemic in Yogyakarta City.

20190422
$Y = 31{,}420 + 0{,}09565X_1 - 3{,}931X_2$ (i)
$Y = 29{,}949 + 0{,}000X_1 + 4{,}490X_2$ (ii)
20190828
$Y = 30{,}864 + 0{,}000X_1 - 4{,}029X_2$ (i)
$Y = 29{,}347 + 0{,}000X_1 + 4{,}805X_2$ (ii)

(i) Distance from Road Network and NDVI to LST.
(ii) Distance from Road Network and NDBI to LST.

that number increased to 51,855 tourists in August 2020 (Badan Pusat Statistik Kota Yogyakarta, 2021). According to research conducted by Jumadi, et al. (2022), there was

Table 9. Multiple Period Linear Regression during the Covid-19 Pandemic.

Date	Information	DIY Covid-19 Response Policy Timeline	Variable	R square	Constant	Unstandardized Coefficients (B)	t
20200510	Covid-19 Lockdown Implementation	Covid-19 Disaster Emergency Response	Distance from the road network	0.347	25.804	0.000	−1.970
			NDVI			−2.416	−10.130
			Distance from the road network	0.218	24.878	0.000	−3.118
			NDBI			2.010	6.906
20200830		Extension of the third Covid-19 Disaster Emergency Response Status	Distance from the road network	0.220	33.106	0.000	2.185
			NDVI			−3.808	−8.147
			Distance from the road network	0.227	31.784	0.000	1.036
			NDBI			3.901	8.324
20210513		Extension of Micro-Based PPKM in DIY	Distance from the road network	0.208	30.623	−0.04502	−0.257
			NDVI			−2.979	−7.710
			Distance from the road network	0.296	29.367	0.000	−1.629
			NDBI			3.977	9.810
20210817		Implementation of PPKM Level 4 Covid-19 in DIY	Distance from the road network	0.279	32.924	0.000	2.476
			NDVI			−3.570	−9.395
			Distance from the road network	0.282	31.555	0.000	0.582

(*continued*)

Table 9. (*continued*)

Date	Information	DIY Covid-19 Response Policy Timeline	Variable	R square	Constant	Unstandardized Coefficients (B)	t
			NDBI			4.178	9.468

Table 10. Multiple Linear Regression Equation during the Covid-19 pandemic in Yogyakarta City.

20200510	20210513
$Y = 25{,}804 + 0{,}000\ X_1 - 2{,}416\ X_2$ (i)	$Y = 30.623 - 0.04502\ X_1 - 2{,}979\ X_2$ (i)
$Y = 24{,}878 + 0{,}000\ X_1 + 2{,}010\ X_2$ (ii)	$Y = 29{,}367 + 0{,}000\ X_1 + 3{,}977\ X_2$ (ii)
20200830	20210817
$Y = 33{,}106 + 0{,}000\ X_1 - 3{,}808\ X_2$ (i)	$Y = 32{,}924 + 0{,}000\ X_1 - 3{,}570\ X_2$ (i)
$Y = 31{,}784 + 0{,}000\ X_1 + 3{,}901\ X_2$ (ii)	$Y = 31{,}555 + 0{,}000\ X_1 + 4{,}178\ X_2$ (ii)

(i) Distance from Road Network and NDVI to LST.
(ii) Distance from Road Network and NDBI to LST.

a surge in Covid-19 cases in Indonesia in mid-June 2020 that continued to occur until early March 2021. This activity also affects the state of air pollution which continues to increase since the beginning of August 2020 until the end of December 2020 which also coincides with the end of the year, Christmas, and New Year holidays. This statement was also supported by Ju et al. (2021) which mentions that air pollution (PM_{10}, SO_2, O_3, NO_2, and CO), according to the study, also significantly affected the change of LST.

Considering from the correlation and regression when there is a decrease in LST, the resulting NDVI variable relationship is more significant than the relationship to the NDBI variable. In fact, the relationship of NDBI variables is generally more significant than NDVI. As seen in Table 6, the correlation value of NDVI is more significant than the correlation of NDBI variables when there is a decrease in LST. Similarly, during this time period, there is a negative correlation between LST and the variable distance from the road network. This is due to reduced anthropogenic activity, which gives space for vegetation to grow faster. The increased activity in vegetation is one of the effects given by the reduction of anthropogenic activities that have an impact on the decline of LST, and the relationship of NDVI to changes in LST is getting more significant (Guha & Govil, 2021). This is also confirmed by research conducted by Fikriyah et al. (2022) that shows the influence of NDBI decreases on the change of LST. This is due to other upcoming affecting factors: urban conditions, urban morphology, and the height of the building.

Table 11. Multiple Linear Regression in the Covid-19 Pandemic Transition Period.

Date	Information	DIY Covid-19 Response Policy Timeline	Variable	R square	Constant	Unstandardized Coefficients (B)	t
20220524	After the Covid-19 Pandemic/Transition Period	PPKM Level 2 in DIY	Distance from the road network	0.201	30.779	0.000	−1.312
			NDVI			−2.411	−7.059
			Distance from the road network	0.291	29.856	0.000	−2.595
			NDBI			2.992	9.271
20220820		PPKM Level 1 in Yogyakarta City	Distance from the road network	0.186	28.957	0.000	2.167
			NDVI			−3.526	−7.256
			Distance from the road network	0.182	27.671	0.000	1.007
			NDBI			3.564	7.172

Table 12. Multiple Linear regression equation of Covid-19 pandemic transition period in Yogyakarta City.

20220524
$Y = 30{,}779 + 0{,}000X_1 - 2{,}411X_2$ (i)
$Y = 29{,}856 + 0{,}000X_1 + 2{,}992X_2$ (ii)
20220820
$Y = 28{,}957 + 0{,}000X_1 - 3{,}526X_2$ (i)
$Y = 27{,}671 + 0{,}000X_1 + 3{,}564X_2$ (ii)

(i) Distance from Road Network and NDVI to LST.
(ii) Distance from Road Network and NDBI to LST.

5 Conclusion

In general, the spatial distribution of LST Yogyakarta City is dominated by temperatures of 29.1–33 °C and this class of LST spreads almost throughout the Yogyakarta City. During lockdown, Yogyakarta City experienced a very significant temperature decrease;

during that period of LST, Yogyakarta City was dominated by temperatures between 24.1 and 26 °C in May 2020. However, this situation did not last long enough because in the next period (August 2020, May 2021, and August 2021), the Yogyakarta City was again dominated by temperatures between 29.1 and 33 °C and a temperature distribution of 33.1 and 36 °C was also found. This shows that human activities have an important role in changing the existing LST. Even over a short period of time, LST in the area has decreased when there is a decline in human activity in public areas. When there was an increase in LST in the period from August 2020 to August 2021 due to the trend of increasing tourist visits in the Yogyakarta City, human activities returned to normal as before the enactment of lockdown. Consistently, the center of Yogyakarta City, namely Kraton, Gondomanan, Pakualaman, and Danurejan Sub-districts are always included in the LST class with temperatures between 29.1–33 °C, characterized by the sub-districts dominated by sparse vegetation classes and dense settlement classes compared to other sub-districts.

The direction of the relationship of NDVI variables to correlation and regression is negative. The correlation value of NDVI produces a more significant level of relationship than the correlation of NDBI variables when there is a decrease in LST. The distance variable from the road network in general does not have a significant influence on the change in LST; often, the result of the correlation of these variables has a very small value. During lockdown, the value of the coefficient of determination shows that the percentage contribution of the distance variable from the road network, NDVI, and NDBI is greater than the period before and during the Covid-19 pandemic transition period. However, the value of the coefficient of determination of the three variables with three different time periods selected in the study showed an insignificant influence from the results of multiple linear regression processing. This can be seen from the results, which show that the average is only classified into a class of weak relationships.

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