The Study of Land Surface Temperature Changes in Urbanized Areas of Boyolali from 2009 to 2020

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Abstract. The Land Surface Temperature (LST) phenomenon is closely related to changes in land cover affect ecosystem function and climate and increase or decrease the surrounding LST. Boyolali Regency is one of the rapidly growing regencies in Central Java Province. The population has increased yearly, impacting the development of non-built-up land into built-up land. This research, therefore, aims to analyze land surface temperature changes with land cover and population density in 2009–2020, analyze temperature changes in Boyolali Regency in 2009 and 2020, and analyze changes in land cover in Boyolali Regency in 2009–2020. The research method was descriptive qualitative, with the determinations using secondary data from Statistics Indonesia, Landsat-5 TM image data for 2009 and Landsat-8 OLI/TIRS for 2020 employed the LST method. The changes were then compared by overlaying the two images and subtracting them. The Maximum Likelihood Classification method was used for land cover processing, and the results tested for accuracy were obtained from the Kappa method. The findings uncovered that built-up land and woody vegetation affected LST in Boyolali Regency in 2009–2020, with an increase in built-up land and decreased woody vegetation and rice fields. It also happened in Boyolali Sub-district, which is an urban area. Besides, the LST of Boyolali Regency was dominated by class three, with a temperature range of 27.08°C – 29.14°C. In addition, the relationship between land cover types greatly affects LST, where if there is dense vegetation, the temperature will be lower, and vice versa.

Keywords: Urbanization · land cover · land surface temperature

1 Introduction

Due to the concentration of population and activities, the phenomena of land surface temperature, which is directly tied to changes in land use or land cover, frequently happen in urban areas. Different anthropogenic activities also affect land surface temperatures (Hadibasyir et al., Hadibasyir et al., 2020). Cities have always been the target of urbanization, so they can cause changes in the physical conditions of the environment or land

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cover, affecting climate change. Along with population growth, changes in land use can occur (Iyengar, 2003). The land originally used for agriculture was transferred to non-agricultural use (Bakker et al., 2015). Changes in land use are also always caused by an increase in population in urban areas, both natural population growth in urban areas and population migration to areas around urban areas. This increase in population causes the need for land to increase for housing or fulfill economic needs (Rahman & Triyatno, 2021).

Land cover changes affect ecosystems, biodiversity, and climate, increasing or decreasing the surface temperature of the surrounding land due to differences in the response of each object or material in receiving, absorbing, and re-emitting sunlight. The soil surface temperature of the material in the built-up area differs from that in the undeveloped area. There is also a relationship between land cover and land surface temperature. The built-up surface area has a positive exponential relationship with land surface temperature rather than a simple linear relationship. Thus, an ecological evaluation index can be calculated to reveal the impact of overgrown land surface and built-up surface area on urban heat islands (Balçik, Bektaş Balçik, 2014; Connors et al., 2013; Sahana et al., 2016; Southworth, 2004).

The type of land cover can also influence the land surface temperature. Vegetation land cover can neutralize the increase in land surface temperature because vegetation performs evaporation and transpiration, releasing water into the air and thereby reducing the surrounding air temperature. Then, vegetation can provide microclimate control and thermal comfort since trees help create more thermally comfortable environmental conditions or reduce air temperature (Adyatma et al., 2019). Additionally, the vegetation cover reduces the duration of thermal discomfort by more than half and limits excess heat from solar radiation. Vegetation can also reduce the urban heat island effect and improve air quality and quality of life (Armson et al., 2012; Irmak et al., 2013; Shashua-Bar et al., 2011).

The study on temperature change does not only focus on big cities but also needs to be carried out in regencies with visible physical and social changes and are close to big cities that are influencing changes for the regency. Monitoring temperature changes can also see the comfortable temperature where people live so that areas with hot temperatures can increase the use of air conditioners, which impacts the greenhouse effect, thus contributing to global warming. In fact, air temperature and air humidity will determine comfort (Rushayati et al., Rushayati et al., 2011).

Specifically, Boyolali Regency is one of the regencies in Central Java Province. Geographically, it is located at 110° 22' – 110° 50' East Longitude and 7° 7' – 7° 36' South Latitude, with an altitude between 75 – 1500 m above sea level. The eastern part of Boyolali Regency is bounded by Surakarta City, Karanganyar Regency, Sukoharjo Regency, and Sragen Regency, the western part is limited by Semarang Regency and Magelang Regency, the northern part is bordered by Semarang Regency, Salatiga City, and Grobogan Regency, the southern part is bounded by the Special Region Yogyakarta and Klaten Regency. Because of its strategic location, Boyolali Regency has various heterogeneous economic sectors. It is supported by the surrounding area, which influences the hinterland for Boyolali Regency. In addition, Surakarta City has the strongest interaction with Boyolali Regency (Rosita et al., 2019).

Moreover, the phenomenon of microclimate change in Boyolali Regency can be affected by population growth. According to the Boyolali Regency Central Statistics Agency, in 2009, there was a population of 951,717 people, with a population density of 938 people/km^2, while in 2020, there was a population of 1,062,713 people with a population density of 1,047 people/km^2. Thus, in the past 11 years, there has been an increase in the population of 110,996 people. Consequently, population growth will affect land use for survival. Changing non-built-up land or open land into built-up causes changes in the microclimate and affects the land surface temperature. Built-up land continues to increase due to higher population growth. As a result, the vegetation cover has decreased significantly (Adyatma et al., 2019; Muhaimin et al., 2021; Muhaimin et al., 2022). These changes can increase land surface temperatures. For this reason, it is necessary to monitor the dynamic characteristics of the built-up land surface temperature in spatial and temporal measurements (Fikriyah et al., Fikriyah et al., 2022). Therefore, this study aims to analyze land surface temperature changes with land cover and population density in 2009–2020, analyze temperature changes in Boyolali Regency in 2009 and 2020, and analyze land cover changes in Boyolali Regency in 2009–2020. This study used remote sensing techniques and geographic information systems since they can identify changes in land cover and land surface temperature with satellite imagery. It is one of the most effective and efficient analytical techniques, as it can save time, and the results are quite accurate.

2 Research Method

The research was conducted in Boyolali Regency, illustrated in Fig. 1.

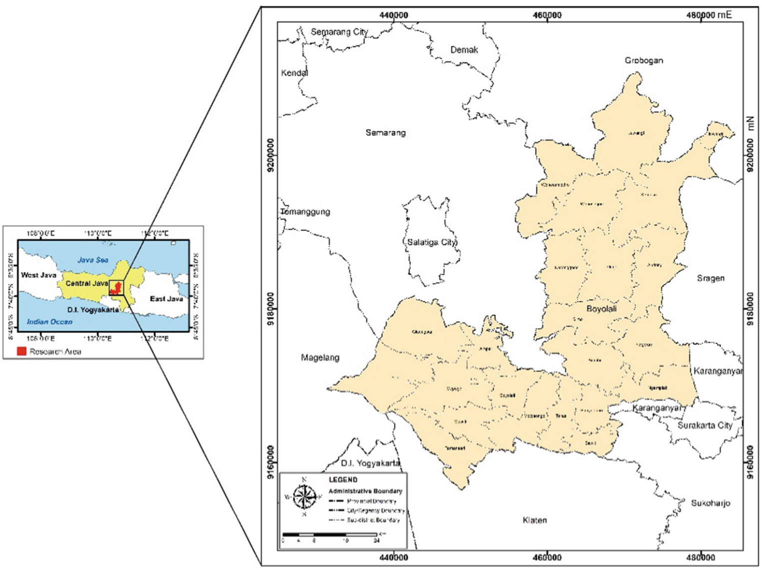

Fig. 1. Administrative Map of Boyolali Regency

The qualitative descriptive method was applied in this research. Population density data were obtained from Statistics Indonesia. To determine the land surface temperature phenomenon in Boyolali Regency, secondary data were used with Landsat-5 TM imagery in 2009 and Landsat-8 OLI/TIRS in 2020, obtained from the United States Geological Survey (USGS) with path 120 and row 65. The data were then processed utilizing the Land Surface Temperature (LST) method through ENVI 5.3 and ArcGIS 10.8 software, which can analyze areas included in the intensity of hot and cold temperatures. In processing image data for LST, a comparison of changes was also carried out by overlaying Landsat-5 TM 2009 and Landsat-8 OLI/TIRS 2020 images, reduced in the raster calculator to get the changed values.

LST analysis was associated with land cover maps processed using the Supervised Classification method on the Maximum Likelihood Classification as a land cover classification, the samples of which were carried out through ROI tools in ENVI 5.3 by classifying them into five classes: vacant land, built-up land, rice fields, water bodies, and vegetation woody. This classification was a guided classification, in which the class for land use was determined by the researchers (Nugraha & Atmaja, 2020). In the classification results, a curation test was performed by taking samples tested through Google Earth Pro and then calculated using the Kappa method (Jensen, 2005) with the formula:

$$KappaAccuracy = \frac{\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} (x_i \times x_{+i})}{N^2 - \sum_{i=1}^{r} (x_i \times x_{+i})} \times 100\% \qquad (1)$$

Description:

r: Row numbers in the matrix

x_{ii} : Sum of the correct cell numbers in the class

x_{i+} : Total for row i

x_{+i} : Total for column i

N: Total cell number in the error matrix

This accuracy test is an important stage in remote sensing data processing classification. The accuracy test is also useful for determining the feasibility of the classification results obtained from research (Asma, 2018). The research flow can also be observed in Fig. 2.

3 Results and Discussion

Population growth in Boyolali Regency in 2009–2020, sourced from Statistics Indonesia (BPS), can be seen in Table 1.

Table 1 presents that data for the Tamansari Sub-district, Gladagsari Sub-district, and Wonosamodro Sub-district in 2009 could not be found because these sub-districts were the result of a division that was recently legalized in 2019. In addition, while the highest population density in 2009 was in Boyolali Sub-district, the lowest population density was in Juwangi Sub-district. In 2020, the highest population density was in Boyolali Sub-district, and the lowest population density was in Kesumu Sub-district. Moreover, Boyolali Sub-district has a strategic area, which is the capital of the Boyolali Regency. According to the Boyolali Regency Regional Regulation Number 9 of 2011 concerning the Boyolali Regency Regional Spatial Plan for 2011–2031 article 7 paragraph 2, for

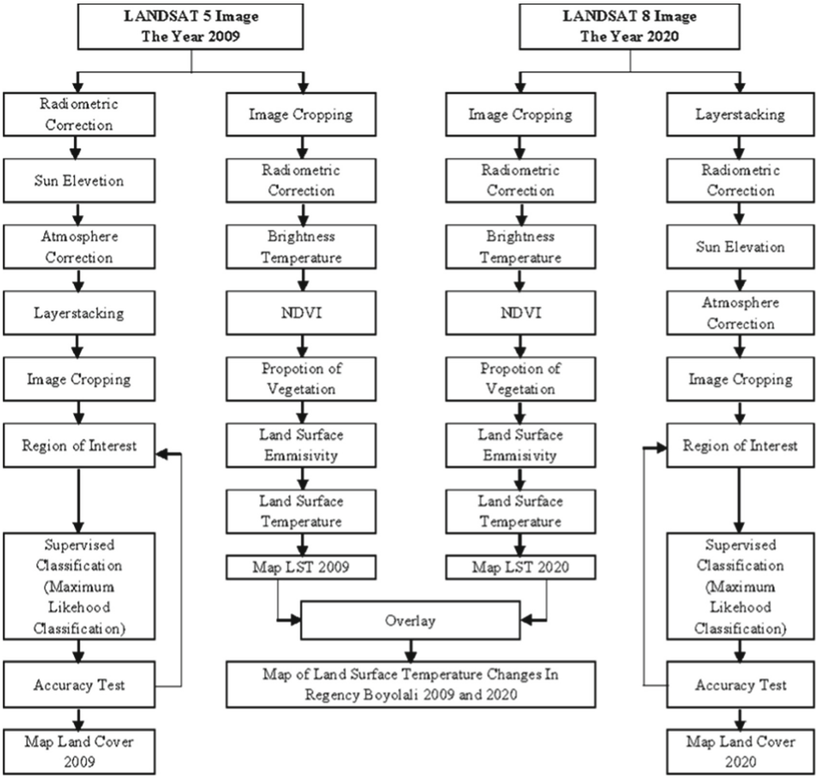

Fig. 2. Research Flowchart

the planned activity center system as referred to in paragraph (1), letter a, Boyolali Sub-district is a Regional Activity Center (PKW). PKW is an urban area that serves the activities of several regencies or provincial scales, whose function is as the center of the area of government, trade and services, education, health, and worship. A study (Iskandar, 2014) explained that Boyolali Sub-district is included in the PKW area and has the highest hierarchy in scalogram analysis compared to other sub-districts in Boyolali Regency.

The results of processing satellite imagery for land cover in Boyolali Regency in 2009 and 2020 with the classification of land cover changes from the Maximum Likelihood Classification results were divided into five classifications: vacant land, built-up land, rice fields, water bodies, and woody vegetation. The classified rice fields were those during the rice planting period, while empty rice fields were classified as vacant land. Also, it was revealed that the changes occurring over 11 years were very significant. It can be seen in Fig. 3.

In Fig. 3, an accuracy test of the classification results of each land cover was carried out by taking 50 samples each. Then, an accuracy test was performed with Google Earth to know whether the land cover processing results were correct or incorrect. The correct accuracy test results were added and divided by the total correct number in Google Earth.

Table 1. Number and Population Density of Boyolali Regency in 2009 and 2020 (BPS Boyolali Regency, 2009; BPS Boyolali Regency, 2021)

Sub-districts	2009		2020	
	Total	Population Density (person/km^2)	Total	Population Density (person/km^2)
Selo	26,845	479	30,052	527
Ampel	68,781	761	40,796	1,337
Cepogo	53,101	1,002	60,083	1,127
Musuk	60,328	928	32,039	1,055
Boyolali	59,411	2,263	72,948	2,748
Mojosongo	51,330	1,182	59,356	1,339
Teras	45,628	1,524	51,486	1,652
Sawit	32,996	1,915	32,280	1,913
Banyudono	45,194	1,781	53,088	2,074
Tamansari	0	0	28,923	847
Gladagsari	0	0	42,634	697
Wonosamodro	0	0	30,606	514
Sambi	48,583	1,045	47,311	1,030
Ngemplak	70,861	1,839	96,254	2,297
Nogosari	60,524	1,099	72,409	1,315
Simo	43,633	908	49,740	1,045
Karanggede	40,570	972	45,870	1,112
Klego	45,907	885	47,773	946
Andong	61,924	1,136	61,023	1,133
Kemusu	46,310	467	34,456	425
Wonosegoro	54,734	589	38,274	755
Juwangi	35,057	438	35,312	444
Boyolali Regency	951,717	938	1,062,713	1,039

To find out the percentage value, the result was multiplied by 100. From the calculation output, the 2009 Kappa coefficient value was 87%, and the 2020 Kappa coefficient value was 85%.

Further, the description of the map image explains that the coloring of land cover classes is as follows: brown for vacant land, red for built-up land, light green for rice fields, blue for water bodies, and dark green for woody vegetation. Very significant color changes can be observed from 2009 to 2020, where the red color or built-up land dominated the change. From the changes in land cover, area calculations were carried out in each land cover classification. The area results are presented in Table 2.

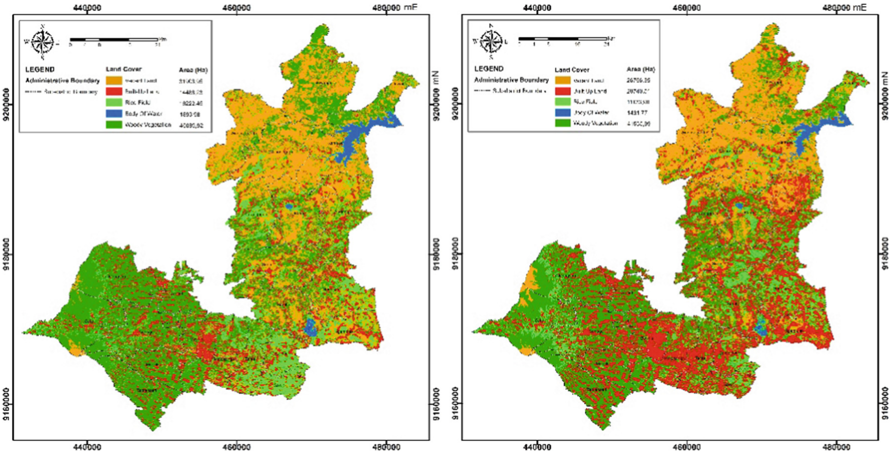

Fig. 3. Land Cover Map in Boyolali Regency in 2009 and 2020

Table 2. Land Cover Area of Boyolali Regency in 2009 and 2020

No.	Land Cover	Value (ha)	
		2009	2020
1.	Vacant Land	31,903.95	26,756.35
2.	Built-Up Land	14,488.23	28,740.51
3.	Rice Field	16,222.45	11,133.90
4.	Body of Water	1,893.98	1,413.77
5.	Woody Vegetation	45,089.92	41,535.99

From Table 2, each land cover decreased, except for built-up land in 2009, which had an area of 14,488.23 ha with a percentage of 13.2, which experienced a change in increase in 2020 of 28,740.51 ha with a percentage of 26.2. Every year, vacant land, rice fields, and woody vegetation decreased due to an increase in built-up land. Vacant land, which initially had an area of 31,903.95 ha with a percentage of 29.1 in 2009, changed to 26,756.35 ha in 2020 with a percentage of 24.2. In 2009, the rice field area was 16,222.45 ha with a percentage of 14.8, which also changed to 11,133.90 ha in 2020 with a percentage of 10.2. In woody vegetation, the area was 45,089.92 ha with a percentage of 41.1 in 2009, which also experienced a change in 2020 of 41,535.99 with a percentage of 37.9. In addition, water bodies also experienced a decrease in the area due to sedimentation, especially in the Kedungombo Reservoir, where the capacity decreases yearly (Nasution & Wulandari, 2021). The area of the body of water in 2009 was 1,893.98 ha with a percentage of 1.7, which changed in2020 to 1,413.77 ha with a percentage of 1.3. This land change influenced the value of land surface temperature in Boyolali Regency. Figure 4 presents the percentage change in land cover.

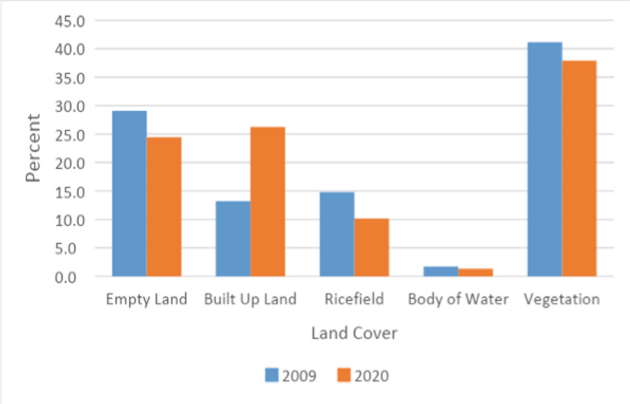

Fig. 4. Graph of Comparison of Land Cover Changes in 2009 and 2020

Significant land cover changes in Boyolali Regency also occurred in Boyolali Sub-district, an urban center. Looking at the land cover calculated from the 2009 sub-district administrative boundary shapefile, there was 1,109.20 ha of built-up land, 1,284.80 ha of woody vegetation, 0.01 ha of water bodies, 403.21 ha of rice fields, and 131.21 ha of vacant land. In 2020, the built-up area was 1,676.74 ha, woody vegetation was 1,093.87 ha, water bodies were 0.10 ha, rice fields were 131.49 ha, and vacant land was 26.22 ha. The comparison is very visible between 2009 and 2020, with an increase in the built-up land area followed by bodies of water, while the area of woody vegetation, rice fields, and vacant land has decreased in the area.

Furthermore, the land surface temperature results were obtained from the extraction process of the thermal channel radian spectral values from Landsat 5 TM in 2009 and Landsat 8 OLI/TIRS in 2020, resulting in a map of Land Surface Temperature in Boyolali Regency in 2009 and 2020, depicted in Fig. 5.

Based on the results of the Land Surface Temperature (LST) map in Boyolali Regency, it was found that the lowest temperature was 12.02°C and the highest was 40.97°C in 2009, while in 2020, the lowest temperature was 10.71°C and the highest was 38.65°C. Class division at each temperature into five is shown in Table 3.

In Table 3, it can be seen that there was a decrease in the lowest and highest temperatures between 2009 and 2020. However, the area was different, as in 2009, the distribution area of class 1 was 3,298.28 ha, class 2 was 27,059.74 ha, class 3 was 40,313.06 ha, class 4 was 26,869.56 ha, and class 5 was 12,057.89 ha. In 2020, the area of class 1 temperature was 4,142.40 ha, class 2 temperature was 28,522.57 ha, class 3 temperature was 33,435.99 ha, class 4 temperature was 21,942.98 ha, and class 5 temperature was 21,554.61 ha.

In addition, the highest temperature area percentage in 2009 was in class 3 with a temperature of 27.08°C – 29.14°C with a percentage of 36.8, and the lowest was in class 1 with a temperature of 12.02°C – 22.77°C with a percentage of 3.0. In 2020, the highest temperature area was in class 3 with a temperature of 27.08°C – 29.14°C with

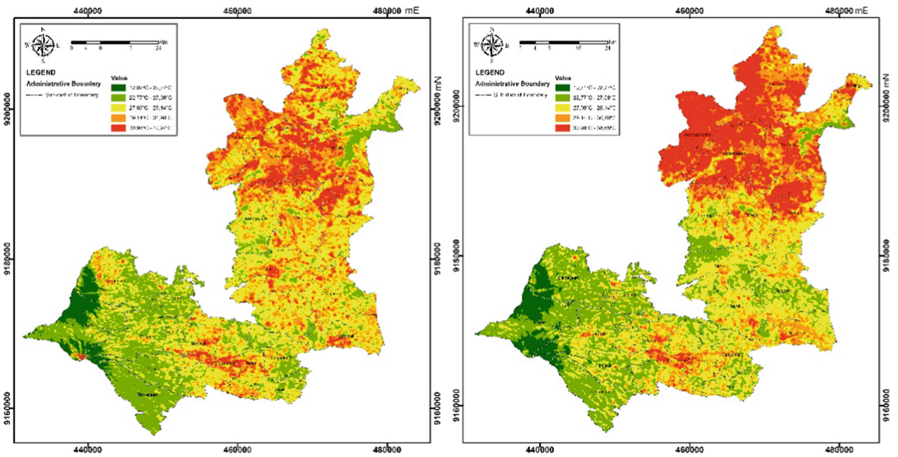

Fig. 5. Map of Land Surface Temperature in Boyolali Regency in 2009 and 2020

Table 3. LST Values for Boyolali Regency in 2009 and 2020

Class	Value			
	2009		2020	
	Temperature (°C)	Area (Ha)	Temperature (°C)	Area (Ha)
1	12.02 – 22.77	3,298.28	10.71 – 22.77	4,142.40
2	22.77 – 27.08	27,059.74	22.77 – 27.08	28,522.57
3	27.08 – 29.14	40,313.06	27.08 – 29.14	33,435.99
4	29.14 – 30.98	26,869.56	29.14 – 30.98	21,942.98
5	30.98 – 40.97	12,057.89	30.98 – 38.65	21,554.61
	Total	109,598.53		109,598.53

a percentage of 30.5, and the lowest was in class 1 with a temperature of 10.71°C – 22.77°C with a percentage of 3.8. A comparison of the area of the percentage change in LST values can be seen in Fig. 6 below.

In Fig. 6, there is a clear comparison of the area of change in LST, dominating in classes 3 and 4, with moderate temperatures between 27.08°C – 30.98°C in 2009, while class 5, with temperatures between 30.98°C – 38.65°C dominated 2020, meaning there was an increase in hot temperatures in that year.

In Fig. 6, there is a clear comparison of the area of change in LST, dominating in classes 3 and 4, with moderate temperatures between 27.08°C – 30.98°C in 2009, while class 5, with temperatures between 30.98°C – 38.65°C dominated 2020, meaning there was an increase in hot temperatures in that year.

Table 4 displays the positive and negative results from comparing LST values for Boyolali Regency in 2009 and 2020. Negative values signify a decrease at -24.46°C

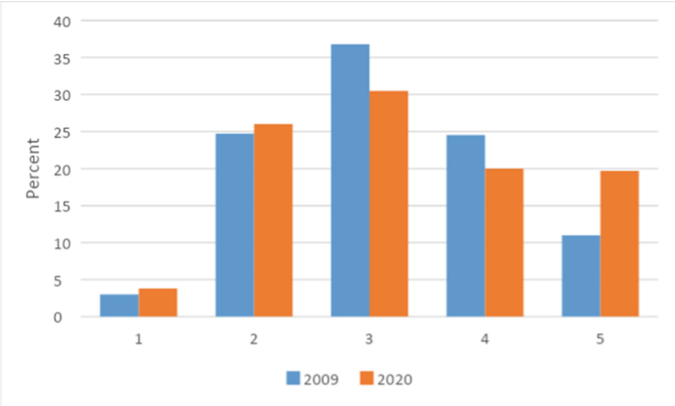

Fig. 6. Graph of Comparison of Areas of LST Change in 2009 and 2020

Table 4. Comparison of Boyolali Regency LST Values in 2009 and 2020

Class	Value (°C)
1	-24.46 to -6.30
2	-6.30 to -1.76
3	-1.76 to 0.11
4	0.11 to 1.81
5	1.81 to 10.75

to -6.30°C with an area of 443.75 ha, at -6.30°C to -6.30°C 1.76°C with an area of 10,315.69 ha, and at -1.76°C to 0.11°C with an area of 35,673.53 ha. On the other hand, the positive results indicate an increase in temperature at a temperature of 0.11°C to 1.81°C with an area of 47,560.29 ha and at a temperature of 1.81°C to 10.75°C with an area of change of 15,589.05 ha. The value of this change index is illustrated in the maps of changes in Land Surface Temperature in Boyolali Regency in 2009 and 2020 below (Fig. 7).

Changes in land surface temperature can also be seen in Boyolali Sub-district, an urban area. In 2009, class 2 temperatures 22.77°C – 27.08°C had an area of 525.56 ha, class 3 temperatures 27.08°C – 29.14°C had an area of 1,326.24 ha, class 4 temperatures 29.14°C – 30.98°C had an area of 828.05 ha, and class 5 temperature 30.98°C – 40.97°C had an area of 288.59 ha. In 2020, class 2, with a temperature of 22.77°C – 27.08°C, had an area of 740.26 ha, class 3, with a temperature of 27.08°C – 29.14°C had an area of 1,104.90 ha, class 4, with a temperature of 29.14°C – 30.98°C had an area of 842.78 ha, and class 5 with a temperature of 30.98°C – 40.97°C had an area of 280.49 ha. The increase in temperature in Boyolali Sub-district in 2020 was in classes 2 and 3. An increase or decrease in temperature also occurred in other sub-districts in Boyolali Regency.

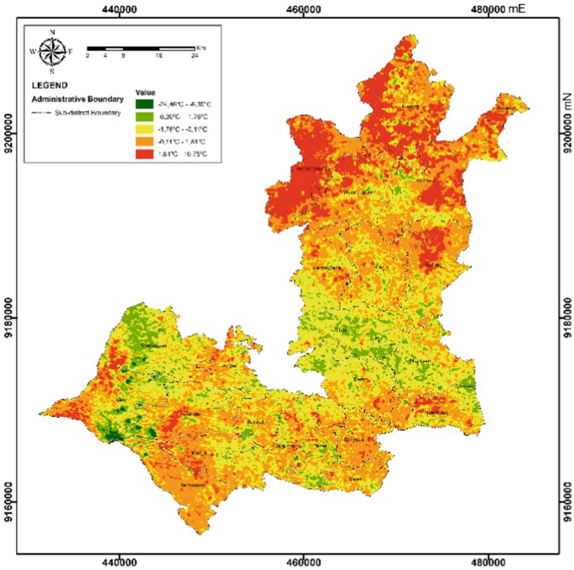

Fig. 7. Map of Changes in Land Surface Temperature in Boyolali Regency in 2009 and 2020

If it is related to the existing land cover in Boyolali Regency, the changes in land surface temperature are very influential, and the type of land cover can be known. The air temperature in built-up areas with tree vegetation will be lower than in built-up areas without tree vegetation (Rushayati et al., 2018). For example, very low temperature with dark green color, when compared with land cover in 2009, indicates that the area was a land cover dominated by dense vegetation, as well as in 2020. At low temperatures with light green color, when compared with land cover land each year, it was a land cover dominated by dense vegetation and bodies of water. Compared with land cover each year, moderate temperatures in yellow were land cover dominated by vegetated rice fields. Furthermore, when compared with land cover, high temperatures with orange color showed land cover dominated by non-vegetated rice fields or empty rice fields. Then, at very high temperatures, compared to the existing land cover each year, it was dominated by built-up land or vacant land.

4 Conclusions

Due to anthropogenic activity in urban areas, land cover significantly affects the land surface temperature in micro terms. The increase in the population of Boyolali Regency occurred in 2009 and 2020, which impacted land cover, where the built-up area index and the woody vegetation index affected land surface temperature with an increase in the built-up area. Meanwhile, woody vegetation and agricultural land or rice fields decreased. Moreover, the Boyolali Sub-district, which is the area with the highest population density and is the center of regional activity, also experienced land cover changes comparison between 2009 and 2020, the area of built-up land increased, followed by bodies of water, while the area of woody vegetation, rice fields, and vacant land decreased. LST also increased in class 2 with a temperature of 22.77°C – 27.08°C and class 3 with a temperature of 27.08°C – 29.14°C. Land surface temperature in Boyolali Regency was dominated by class 3 with a temperature range of 27.08°C – 29.14°C. The comparison results of the LST values between 2009 and 2020 obtained a negative value, indicating a decrease, whereas a positive value result signifies an increase in temperature. In addition, the relationship between land cover types greatly affects land surface temperature, where the temperature is lower if there is dense vegetation, and conversely, the temperature is higher if there is less vegetation density. In other words, there is a relationship between land cover and land surface temperature. For temperature control efforts in Boyolali Regency, this research can be used as evaluation material for both the government and the community in implementing land cover arrangements for development and vegetation land so that the temperature in Boyolali Regency can be maintained properly and become a comfortable place to live for the community.

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