Analysis of the Population Density Correlation with the Temperature Changes in the Semarang Area from 1999 to 2019

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Abstract. The Semarang area is one of the metropolitan areas in Indonesia. It has an impact on high population growth, both from natural growth and urbanization, which results in an increase in population density. In 2019, the population in the Semarang area was recorded at 3,062,936 people and will continue to grow yearly. It can lead to an escalation in the built-up land area to meet the needs of life, which will affect the temperature changes. This study aims to (a) analyze population density in the Semarang area in 1999, 2009, and 2019; (b) examine the temperature distribution in the Semarang area in 1999, 2009, and 2019; and (c) identify the correlation between population density and surface temperature in the Semarang area in 1999, 2009, and 2019. The data used in this study were Landsat 5 TM imagery and Landsat 8 OLI/TIRS imagery for temperature data extraction in the Semarang area. The secondary data were population and area per sub-district from Statistics Indonesia. Google Earth Engine for processing temperature and ArcMap for processing population density were employed in this study. The analysis utilized in this research was a quantitative study. The results revealed a drastic change in area in the temperature class of 31.01 °C–41 °C. Additionally, there is a relatively strong impact between changes in population density and changes in temperature, with a coefficient of determination of 18.3%. It can have an impact on diminishing green space.

Keywords: Population Density · Population · Semarang · Temperature

1 Introduction

Indonesia is one of the countries with a population of more than 269 million people in 2019 and ranks fourth in the world (Muzaky & Jaelani, 2019). This number has increased by more than 10 million, which amounted to 259 million in 2015. According to Statistics Indonesia (BPS), 53.3% of Indonesia's population lives in urban areas, which is predicted to increase by 66.6% in 2035 (Rizaty, 2021). In addition to rapid population growth, the increase in urban population is also caused by urbanization. Urbanization is a phenomenon of population concentration and its activities in a particular area, resulting in a higher population density than the surrounding area (Niandyti et al., 2019). Urban areas

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have developed more promptly compared to other areas since they consist of government centers, economic activity centers, and centers of all activities. These activities will affect the demand for residential areas. As the population increases, the need for housing also increases (Haryana et al., 2013), while land in urban areas is progressively limited. Hence, it will cause changes in land use in various aspects. High population growth can unintentionally cause changes in urban planning, especially the expansion of urban areas that cross the city's administrative boundaries, or urban sprawl (Musiyam, 2016). Urban sprawl causes several adverse effects, including energy consumption and air pollution (Chen et al., 2021; Siles et al., 2018) economic inefficiency, and the decline of agriculture (Wolf et al., 2018; Dadi et al., 2016).

The Semarang area is one of the areas that cannot be alienated from the urban sprawl phenomenon. Semarang is part of the Kedungsepur area (Kendal, Ungaran, Semarang, and Purwodadi), a metropolitan area in the ex- Residency of Semarang. As a metropolitan area, the growth in regional development due to an increase in population, urbanization, and economic improvement is not a new issue. Based on the Statistics Indonesia data, there was an increase in the population of 777,251 people from 2,285,685 in 1999 to 3,062,936 in 2019. This drastic population growth has affected the area of land needed to support daily activities, such as housing, offices, road construction, and industry. The increase in population is not proportional to the reduction in the area of rice fields converted to built-up land.

The conversion of agricultural land into built-up land has an impact on several aspects, including changes in the employment structure, ownership and control of land, the economic structure toward industry, population mobility, and impacts on the environment (Hariyanto, 2010). One of the impacts of converting agricultural land in Semarang Regency is the continued increase in the number of industries. The industrial area is one of the most significant contributors to the Gross Regional Domestic Product (GRDP) in Semarang Regency and absorbs 22.5% of the workforce. The relatively high industrial development has an impact on the high demand for land, both related to industrial activities and other supporting activities (Insan & Prasetya, 2021). The existence of an industrial area in the Semarang area can have an impact on several aspects, one of which is temperature changes. Based on data from the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG), the temperature in Semarang City reached 39.4 °C in October 2019, which was the highest temperature exceeding the temperature of October 18, 2002, reached 38.5 °C.

Increasing temperature is one of the impacts of climate change, especially extreme weather due to ecosystem imbalances. Reduced wetlands also contribute to changes in temperature each year. Wetlands in the Semarang area in 1999 were recorded at 29,189.272 ha, decreased by 2,379.627 ha over the last 20 years, and remained at 26,819.1 ha in 2019.

Since population density contributes to temperature changes in the Semarang area, this study aims to (a) analyze population density in the Semarang area in 1999, 2009, and 2019; (b) examine the temperature distribution in the Semarang area in 1999, 2009, and 2019; and (c) identify the correlation between population density and temperature changes in the Semarang area in 1999, 2009, and 2019 so that it can be utilized as a guideline for future regional development.

2 Methods

2.1 Study Area and Data

The Semarang area is located between 6° 55′ 00″–7° 30′ 00" South Latitude and 110° 16′ 00″–110° 30′ 00″ East Longitude, with an altitude between 0.75 masl–2000 masl. Administratively, the Semarang area is directly adjacent to Kendal and Temanggung Regencies to the west; Demak, Grobogan, and Boyolali Regencies to the east; Boyolali Regency in the south, and the Java Sea in the north. The research location consists of three regions, namely Semarang City, Semarang Regency, and Salatiga City, which are divided into 39 sub-districts with an area of 1,138,076 ha. The research location can be seen in Fig. 1. The Semarang region had a population of more than three million people in 2019. The climate of the Semarang region is a wet tropical climate with a humidity of more than 80%. The Semarang area experiences high temperatures in August–November with an average temperature of 25–33 °C, while it experiences the lowest temperatures in December–March with an average temperature of 20–27 °C (BMKG, 2022).

Temperature data extraction was completed using Landsat 5 TM and Landsat 8 OLI/TIRS imagery obtained from the Google Earth Engine data catalog. Landsat 5 was utilized for the 1999 and 2009 periods, while Landsat 8 was used for the 2019 period. Temperature processing used thermal bands for each image. For Landsat 5 TM, the thermal band used was band 6, while for Landsat 8 OLI/TIRS, the thermal band used was band 10. The research data can be observed in Table 1.

This study used primary and secondary data. The primary data used in this study was temperature data for the Semarang area, using Landsat OLI/TIRS and Landsat 5 TM imagery. The secondary data utilized in this study were data on the total population

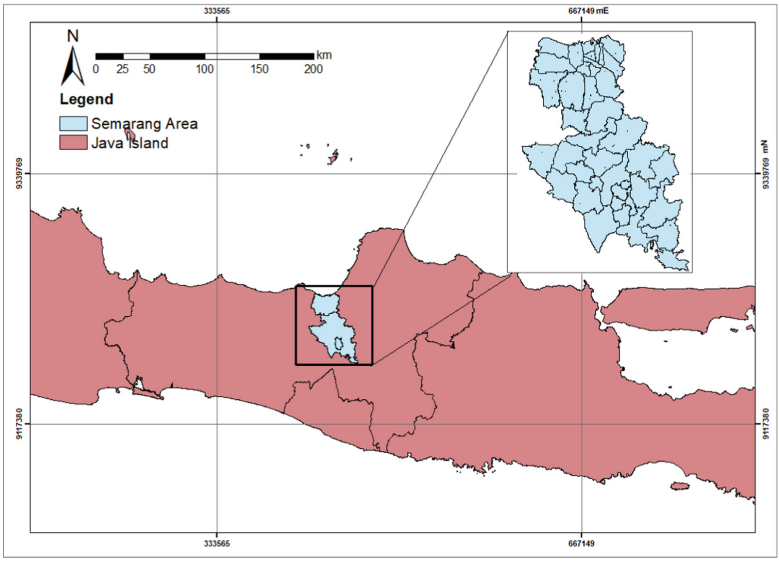


Fig. 1. Regional Study Map

Table 1. Research Data Sources

Data	Source
The temperature of the Semarang Area	Landsat 8 OLI/TIRS, Landsat 5 TM
Total population of Semarang Area	Statistics Indonesia of Semarang City, Statistics Indonesia of Semarang Regency, and Statistics Indonesia of Salatiga City
Total area of Semarang Area	Statistics Indonesia of Semarang City, Statistics Indonesia of Semarang Regency, and Statistics Indonesia of Salatiga City

and area of each district/city obtained from the Statistics of Semarang City, Semarang Regency, and Salatiga City.

2.2 Data Processing Technique

Temperature Data Processing

The data processing in this study was divided into temperature data processing and population density data processing. Data processing for temperature used Landsat 8 OLI/TIRS imagery with temperature correction. The calculation process of a spectral radian (radiance) was completed by Eq. 1.

$$L\lambda = MLxQcal + AL \tag{1}$$

In which:
$L\lambda$: spectral radians
ML: multiplication scale factor
Qcal: quantized and calibrated standard product pixel (DN) values
AL: incremental scale factor.

The conversion of spectral radian values to ground surface temperature was done by Eq. 2.

$$T = \frac{K2}{lnln(\frac{K1}{L\lambda})} \tag{2}$$

In which:
T: temperature (Kelvin)
$L\lambda$: spectral radians
K1: band-specific thermal conversion constants from the metadata
K2: band-specific thermal conversion constant from the metadata

In obtaining the temperature value in Celsius units, the conversion process can be conducted using Eq. 3.

$$\mathrm{T2} = \mathrm{T} - 273.15 \tag{3}$$

In which:
T: temperature (Kelvin)
T2: temperature (Celsius).

Processing using Landsat 5 TM was done with the same process but using different equations, calculation of spectral radians with the Eq. 4.

$$L\lambda = \left(\frac{LMAX_\lambda - LMIN_\lambda}{QCALMAX - QCALMIN}\right) \times (QCAL - QCALMIN) + LMIN_\lambda \quad (4)$$

In which:
$L\lambda$: spectral radians
QCAL: calibrated pixel values in DN
$LMIN_\lambda$ and $LMAX_\lambda$: spectral radians scaled to QCALMIN and QCALMAX
QCALMIN and QCALMAX: minimum and maximum quantized calibrated pixel values (corresponding to $LMIN_\lambda$) on DN

After calculating the spectral radian, calculate the temperature value using Eq. (5).

$$T = \frac{K2}{lnln\left(\frac{K1}{L\lambda} + 1\right)} \quad (5)$$

In obtaining the temperature value in Celsius units, the conversion process can be completed using Eq. 3 (Roy & Bari, 2022).

$$\mathrm{T2} = \mathrm{T} - 273.15 \quad (6)$$

In which:
T: temperature (Kelvin)
T2: temperature (Celsius)

After that, transform the radian temperature from Kelvin units to Celsius units using the Google Earth Engine platform, which is transformed using a programming language. The transformations performed on the Google Earth Engine platform are as follows:

return img.expression (‘((1321.08/(log(774.89/((TIR*0.0003342) + 0.1) + 1)))-273.15)’,{‘TIR’:img})

Population Density

The classification of population density in this study is in line with the Regulation of the Head of Statistics Indonesia Number 32 of 2010 concerning the Classification of Cities and Rural Areas in Indonesia, as seen in Table 2.

Correlation Between Population Density and Temperature

Calculation of the correlation between population densities can be calculated using the Eq. 7.

$$\mathrm{r} = \frac{n\sum XY - (\sum X)(\sum Y)}{\sqrt{(n\sum X^2 - (\sum X)^2)(n\sum Y^2 - (\sum Y)^2)}} \quad (7)$$

In which:

Table 2. Population Density Classification

Population Density	Score
<500	1
500–1249	2
1250–2499	3
2500–3999	4
4000–5999	5
6000–7499	6
7500–8499	7
>8500	8

r: Pearson correlation coefficient
n: number of samples
$\sum XY$: the sum of the product of the variables X and Y
$\sum X$: the sum of the X values
$\sum Y$: sum of Y values
$\sum X^2$: the sum of the squared X values
$\sum Y^2$: the sum of the squared Y values

3 Result and Discussion

3.1 Population Density

Based on the classification of population density that has been determined by the Head of Statistics Indonesia, the results are displayed in Table 3.

Table 3 shows changes in population density classes in the Semarang area from 1999 to 2019. Several sub-districts have experienced changes in population density classes, such as Mijen, Gunungpati, Banyumanik, Gajahmungkur, Tembalang, Pedurungan, Genuk, Ngaliyan, Getasan, Tengaran, Ambarawa, Bawen, Bergas, and Sidorejo. This change was dominated by class 2 population density, with a population density of between 500–1249 people/km^2, and this class change typically occurs at one level. Population density values are presented with red gradations on the map. A high population density is indicated by a dark color gradation, while a low population density is denoted by a lighter color gradation. The population density in the Semarang area can be observed in Fig. 2.

Based on Fig. 2, the areas with the highest population density from 1999 to 2019 are several sub-districts in Semarang City, including West Semarang, North Semarang, Central Semarang, East Semarang, Gayamsari, South Semarang, Candisari, Gajahmungkur, and Pedurungan. The population distribution in the Semarang area in 2009 was more even than in 1999. It was influenced by several factors, one of which was the creation of several new regions. The regions that became new sub-districts were Ungaran Sub-District (becoming West Ungaran and East Ungaran Sub-Districts) which was regulated

Table 3. Population Density Class in the Semarang Region

No	Subdistrict	Class of Population Density		
		1999	2009	2019
1	Mijen	2	2	3
2	Gunungpati	2	3	3
3	Banyumanik	4	5	6
4	Gajahmungkur	5	6	6
5	South Semarang	8	8	8
6	Candisari	8	8	8
7	Tembalang	3	4	5
8	Pedurungan	6	7	8
9	Genuk	3	4	5
10	Gayamsari	8	8	8
11	East Semarang	8	8	8
12	North Semarang	8	8	8
13	Central Semarang	8	8	8
14	West Semarang	6	6	6
15	Tugu	2	2	2
16	Ngaliyan	3	4	5
17	Getasan	2	2	2
18	Tengaran	2	3	3
19	Susukan	2	2	2
20	Suruh	2	2	2
21	Pabelan	2	2	2
22	Tuntang	2	2	2
23	Banyubiru	2	2	2
24	Jambu	2	2	2
25	Sumowono	2	2	2
26	Ambarawa	3	2	3
27	Bawen	2	2	3
28	Bringin	2	2	2
29	Pringapus	2	2	2
30	Bergas	2	2	3
31	Ungaran	3	3	3

(*continued*)

Table 3. (*continued*)

No	Subdistrict	Class of Population Density		
		1999	2009	2019
32	Argomulyo	3	3	3
33	Sidorejo	4	4	5
34	Sidomukti	4	4	4
35	Tingkir	4	4	4

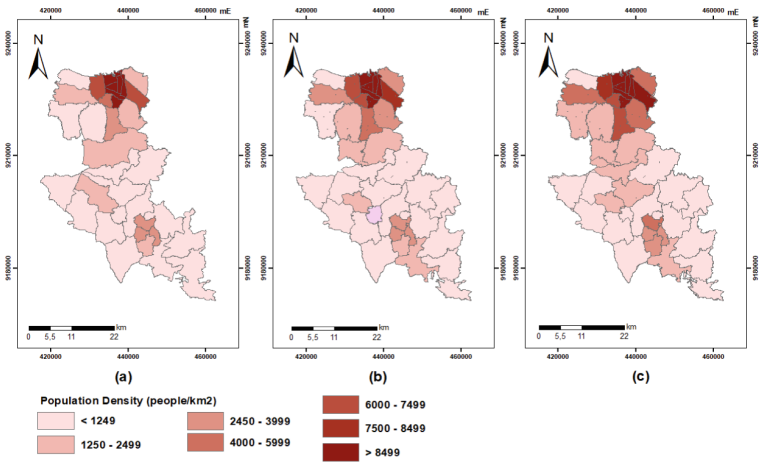


Fig. 2. Population Density Map of Semarang Area in (a) 1999, (b) 2009, and (c) 2019

in Regional Regulation of Semarang Regency number 33 and 34 of 2003, Susukan Sub-District (becoming Susukan Sub-District and Kaliwungu Sub-District) which was regulated in Regional Regulation of Semarang Regency number 34 of 2001, and Bringin Sub-District (becoming Bringin Sub-District and Bancak Sub-District) which was regulated in Regional Regulation of Semarang Regency number 33 of 2001. Creation of new sub-district areas can be done if the area has a large number of villages, a dense population, and an extensive area so that it reduces the effectiveness of the former area. The creation of new sub-districts is expected to trigger more equitable services for the community because the sub-districts are closer (El Fitri et al., 2013).

3.2 Temperature Distribution

The results of processing temperature data using the Google Earth Engine are obtained, as shown in Fig. 3.

Based on Fig. 3, it can be perceived that in 1999 the temperature that dominated the Semarang area was in the temperature range of 23.01–26 °C. In 2009, the temperature was dominated by 26.01–29 °C. Meanwhile, the temperature was dominated by 31.01–41 °C

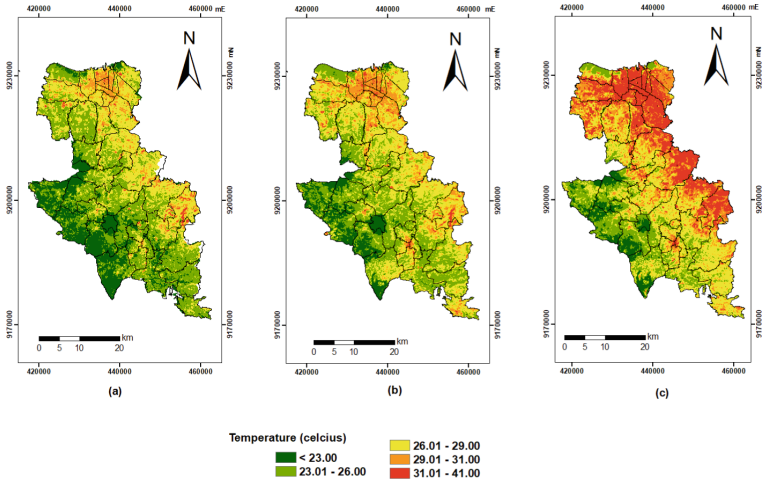


Fig. 3. Map of Semarang Area Temperature Distribution in (a) 1999, (b) 2009, and (c) 2019

in 2019. The figure also shows that high temperatures covered almost the entire eastern part of the Semarang area. The surface temperature in the Semarang area has increased over time. It is in line with research conducted by (Singh et al., 2017) in (Hadibasyir et al., 2020), which states that, in general, surface temperatures have increased over time along with changes in land cover, regional growth, and population growth. Changes in temperature area can be seen in Fig. 4.

Based on Fig. 4, it can be seen that the temperature area in the Semarang area has changed over the past 20 years. The light green graph indicates the temperature <23 °C, the light blue graph shows the temperature in the range of 23.01–26 °C, the

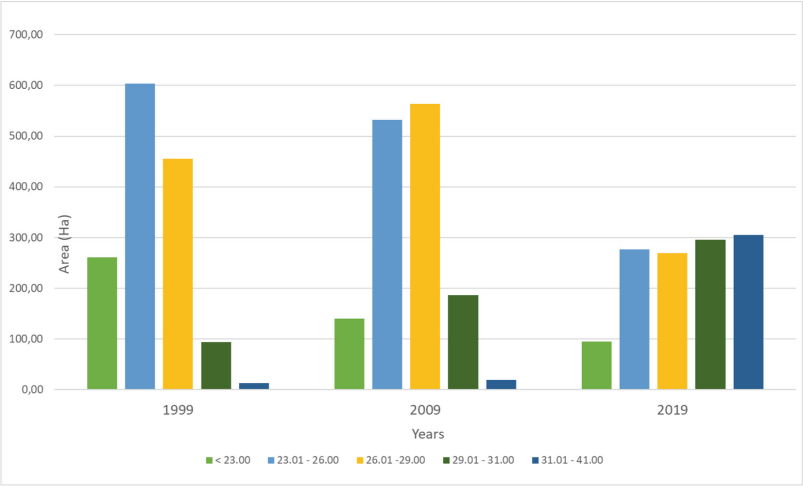


Fig. 4. Graph of Temperature Changes in the Semarang Area from 1999–2019

yellow graph displays the temperature in the range of 26.01–29 °C, the dark green graph demonstrates the temperature in the range 29.01–31 °C, and the dark blue graph denotes the temperature in a range of 31.01–41 °C. The area of surface temperature that had changed drastically is the area of temperature with the range of 31.01–41 °C from initially only 12.90 hectares in 1999 to 305.01 hectares in 2019. The temperature in 2019 was more unfluctuating compared to previous years. It is indicated by the difference in the area that is not too far apart, except at temperatures <23 °C. Several issues, including the emergence of industrial areas in Semarang City or Semarang Regency, instigated the increase in temperature in the Semarang area. These industrial areas include the Bukit Semarang Baru industrial, the Guna Mekar Indonesia industrial, the Candi industrial, the Terboyo, the Pringapus industrial, the Bawen industrial, the Tengaran industrial area, the Susukan industrial area, and the Kaliwungu industrial area. The higher the percentage of built-up land in an area, the higher the temperature in that area. Conversely, the higher the percentage of green open space, the lower the temperature in that area (Rushayati et al., 2011).

3.3 Correlation Between Population Density and Temperature

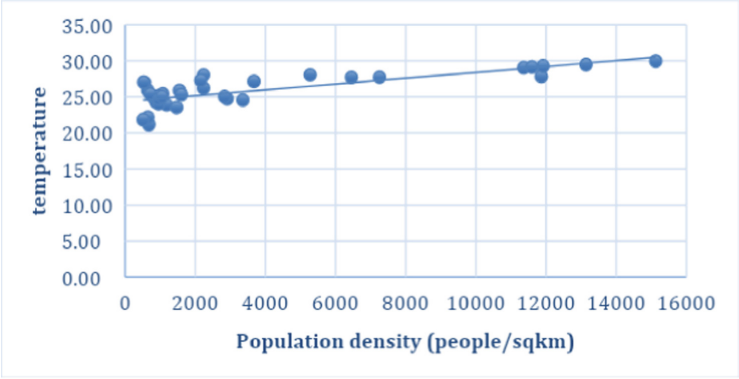
Population density can have an influence on climate, especially on temperature changes. The relationship between population density and temperature changes in this study was completed using the Pearson correlation test between the two variables. The results of the correlation test can be observed in Table 4.

Based on Table 4, the correlation value between population density and temperature is 0.672–0.765, which is included in a strong and positive relationship. It means that the greater the population density value, the higher the temperature value. The coefficient of determination illustrates how much influence population density has on temperature rise, namely 57.7% in 1999; 58.5% in 2009; and 45.1% in 2019. The correlation between population density and temperature can also be done using simple linear regression, which can be perceived in Fig. 5.

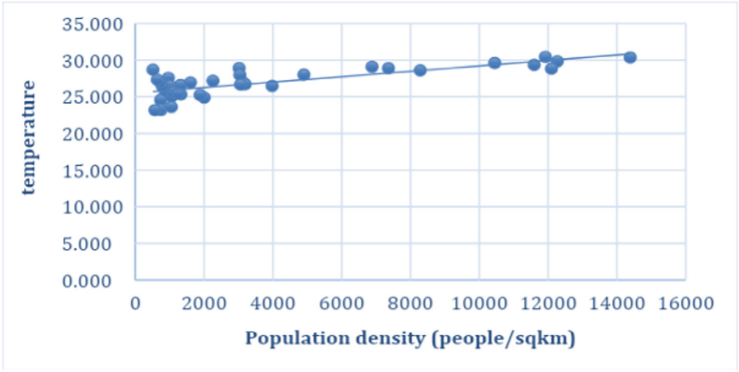
Figure 5 presents the results of the simple linear regression coefficient between population density and temperature changes from 1999–2019. Population density and temperature show an increasing straight-line trend, which indicates a positive relationship between the two variables. The increase in population density is equal to the development of settlements, so it can affect the increase in temperature. It is in line with research conducted by Maishella et al., (2020) that areas with high temperatures came from areas with high building density and were still in the development stage. According to Rushayati et al., (2011), areas with high population density and low green open space

Table 4. Table of Correlation and Regression of Population Density to Temperature

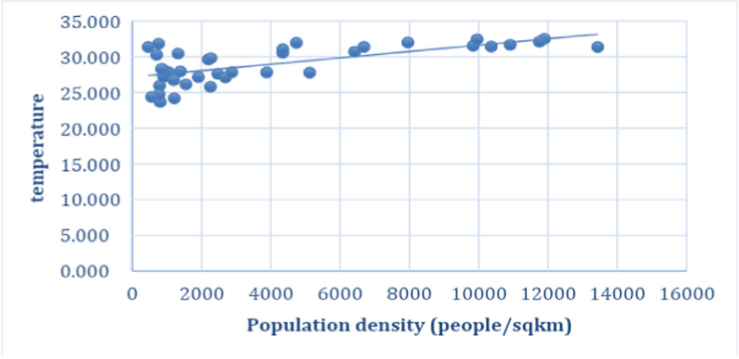
Year	R	R2	Coefficient of Determination	N
1999	0.760	0.577	57.7%	35
2009	0.765	0.585	58.5%	39
2019	0.672	0.451	45.1%	39



(a)



(b)



(c)

Fig. 5. Linear Regression of Population Density and Temperature in the Semarang Area in (a) 1999, (b) 2009, and (c) 2019

Table 5. Correlation Between Changes in Population Density with Changes in Temperature

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.428[a]	0.183	0.161	0.577480

will result in hotter areas than the surrounding areas. The correlation between the difference in population density and the temperature difference in 1999 and 2019 is presented in Table 5.

Table 5 displays the regression results between changes in population density and temperature changes. There is a moderate relationship between changes in population density and temperature changes. It can be seen from the correlation coefficient value of 0.428 and the determination coefficient value of 18.3%, which means that the increase in population density has an effect of 18.3% on temperature changes.

4 Conclusions

The Semarang area is dominated by the class 2 population density that ranges from 500–1,249 people/km^2. The areas with the highest density from 1999 to 2019 were in the middle of Semarang City, such as the Districts of West Semarang, North Semarang, Central Semarang, East Semarang, Gayamsari, South Semarang, Candisari, Gajahmungkur, and Pedurungan. One of the factors that helps population distribution in the Semarang area is the creation of three sub-districts in Semarang City and Semarang Regency into six sub-districts.

The temperature of the Semarang area from 1999–2019 has changed every decade. Areas that experience drastic temperature changes are those with a temperature range of 31.01–41 °C. The difference in surface temperature in 2019 based on area is extremely high in the class, with a range of 23.01–26 °C.

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