INTERNATIONAL JOURNAL OF CONSERVATION SCIENCE
ISSN: 2067-533X Volume 15, Issue 2, 2024: 1021-1032 www. ijcs. ro
DOI: 10. 36868/IJCS.2024.02.18

THE INFLUENCE OF LAND COVER ON SPATIO-TEMPORAL VARIATION OF AIR TEMPERATURE IN GROGOL DISTRICT, CENTRAL JAVA-INDONESIA

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Abstract

As an urban fringe of Surakarta City-Indonesia, Grogol District is experienced by increasing temperature. The purpose of this study is: 1) to determine the spatial and temporal variations of air temperature in the Grogol District and 2) to determine the difference in air temperature between built-up land cover and non-built-up land cover, particularly rice fields. Air temperature data was obtained by temperature data logger from four sample points on October 27th to December 13th, 2021. Air temperature and land cover data were analyzed by descriptive and inferential statistics as well as spatial interpolation on air temperature data. The result indicates that higher air temperatures are spread over the northern part which is dominated by settlements. Lower air temperatures are found in the southern part which is dominated by rice fields. The temporal variation of air temperature at the four sample points shows almost the same pattern. However, the air temperature was higher in the built-up land cover than in the rice fields. The statistical difference test also showed that there were differences between the two land covers. In conclusion, Grogol District is affected by the urban heat island phenomenon from Surakarta City. This is particularly related to land cover change and increasing population. Therefore, to prevent the increasing temperature, the protection of the open greenspace area should be implemented.

***Keywords**: Air temperature; Land cover; Spatial-temporal variations*

Introduction

Cities are growing rapidly along with the increasing rate of urbanization [1, 2]. The increase in the rate of urbanization causes large and increasing demand for settlements and their related facilities. The need for built-up land, particularly in developing countries often associated with land cover changes from vegetated land to built-up land. This conversion has an impact on the energy exchange, atmospheric processes (evaporation, transpiration, and precipitation), and wind circulation systems in urban areas [1]. The resulting impact is the differences in atmospheric conditions between urban areas and their surrounding areas [3]. One of the phenomena that are related to the atmospheric condition in the urban area is Urban Heat Island (UHI) [4]. This phenomenon is characterized by higher air temperatures in urban areas compared to the surrounding rural areas [5, 6].

The UHI phenomenon in Indonesia has been identified in several cities such as Surakarta [7], Jakarta [8] and Bandung [9]. The formation of UHI in Surakarta is characterized by the difference in temperature between the city and its surroundings [7]. High surface temperatures are generally found in the center of Surakarta City to the southern part of the city while low

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surface temperatures are recorded around Surakarta City. The minimum temperature recorded was 20.1°C while the maximum temperature recorded was 34.7°C.

The higher air temperature in the central part of Surakarta City, especially in the Pasar Kliwon Sub-district, is associated with rapid development in this area [7]. This development is indicated by the high population activity and conversion of vegetated land into built-up land. The increase in population activity and land conversion also occurred on the urban fringe outside Surakarta City. Grogol District is located adjacent to Surakarta City and is affected by the development of the city. This is indicated by the construction of new buildings for business centers, hotels, apartments, and hospitals. The residential area also increases in line with the increase in population.

Land cover influences the air temperature. Built-up land cover absorbs most of the solar radiation and only a small portion of solar radiation is reflected upwards. The amount of reflected solar radiation could be represented as an albedo value. A small albedo value indicates that incoming shortwave radiation will be absorbed more than reflected [1]. Buildings with dark roofs or walls have an albedo value of 0.28 and buildings with glass have an albedo value of 0.09 [10]. The absorbed solar radiation will be emitted back as longwave radiation with a higher intensity [11]. This causes a warmer surface over the urban area as well as the urban air temperature [1, 12].

Compared to the built-up area, the vegetated land cover has varying albedo values. Grasslands have albedo values ranging from 0.10 to 0.30 [11]. Low-altitude green vegetation has albedo values of 0.10 to 0.20; while dry vegetation is 0.20 to 0.30 [13]. Although small albedo values contribute to warmer air temperatures, plants play an important role in lowering air temperatures. This is related to the evapotranspiration process, particularly in terms of latent heat [6]. When the evaporation process occurs, energy is taken from the environment to convert water into water vapor so that there is a cooling process or a decrease in temperature in the environment [11].

Spatial variation of air temperature in the Grogol District is important to understand the influence of Surakarta City, especially in the northern part which is directly adjacent to the city. The difference in air temperature between the built and non-built land cover can provide an overview of the process related to the energy balance. Therefore, the purpose of this study is 1) to determine the spatial and temporal variations of air temperature in the Grogol District based on the type of land cover and 2) to determine the difference in air temperature between built-up land cover and rice fields.

Experimental part

This research is conducted in the Grogol District which is one of the sub-districts in Sukoharjo Regency, Central Java-Indonesia. Grogol District is located directly adjacent to the south of Surakarta City (Fig. 1). The Grogol sub-district is dominated by various land covers, including settlements, rice fields, and industrial buildings.

The data collected in this study are air temperature data and land cover data. Land cover data were obtained by the interpretation of Sentinel 2A imagery dated July 7th, 2021. The land cover data was then used to determine sample points. Determination of sample points is done by *purposive sampling method* based on the variation of land cover in the study area (Fig. 2).

Air temperature data is obtained by field measurements using four temperature data loggers. Installation of the air temperature logger is carried out in a place that is not exposed to direct sunlight, not exposed to rain, and at an altitude of 1.5 to 2.3 meters above ground level. Air temperature measurements were carried out for approximately 1.5 months from October 27th, 2021, to December 13th, 2021. The spatial variation of air temperature is done by making a contour map of air temperature using several interpolation methods. The interpolation method used is the Inverse Distance Weighting (IDW), spline, and kriging using the gaussian and spherical semi-variogram method. The results of interpolation processing between methods can be compared with the level of accuracy by calculating the *Root-mean-square-error* (RMSE) value [14].

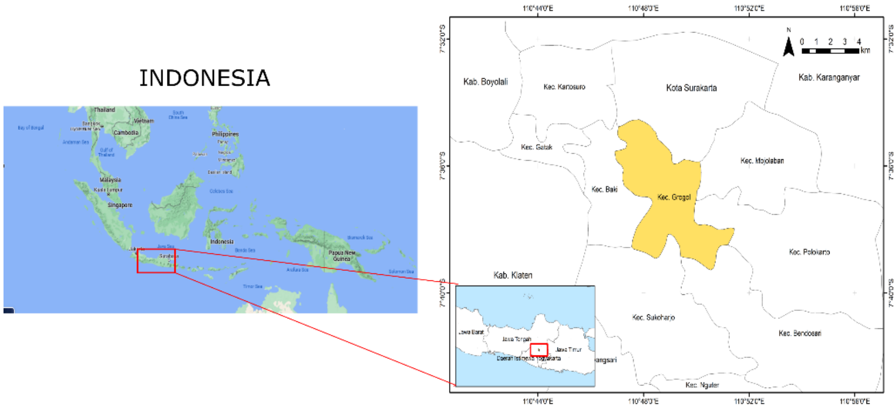


Fig. 1. Map of the study area (basemap from google map and the Indonesian Geospatial Agency)

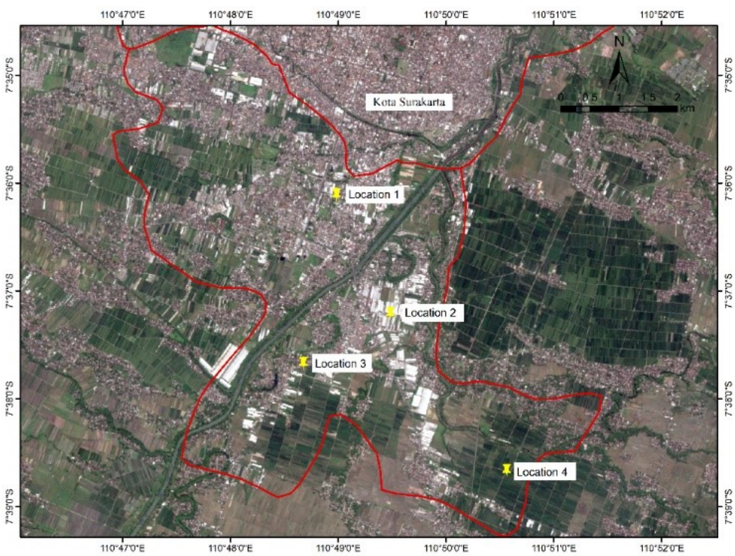


Fig. 2. Map of the sample location for temperature data logger recording (basemap from sentinel imagery July 7th, 2021)

The temporal variation of air temperature is done by calculating the average, maximum, and minimum values. In addition, the air temperature data was also carried out inferential statistical tests using different tests to determine differences between types of land cover. The different tests used are the *independent sample T-test* or the Mann-Whitney test if the data are not normally distributed [15].

The land cover map of the Grogol District is shown in Figure 3.

Residential land cover dominates Grogol District, especially in the north and northwest parts. The area of residential land cover is 15.02km^2 (44.64% of the total area). The rice field cover is the second largest with an area of 12.42km^2 (36.9% of the total area). The paddy field cover appears to be clustered, especially in the southern and western parts of the Grogol District.

The land cover for industrial buildings has an area of 2.32km^2 or 6.90% of the total area. Industrial building land cover ranks third in the largest land cover in Grogol District. The land cover for industrial buildings is quite clustered in the central part of the Grogol District. Land cover in the form of rivers, mixed crops, grasslands, open land, shrubs, and swamps has a small proportion, namely 0.95, 1.95, 0.70, 0.20, 0.05 and 0.04km^2 respectively.

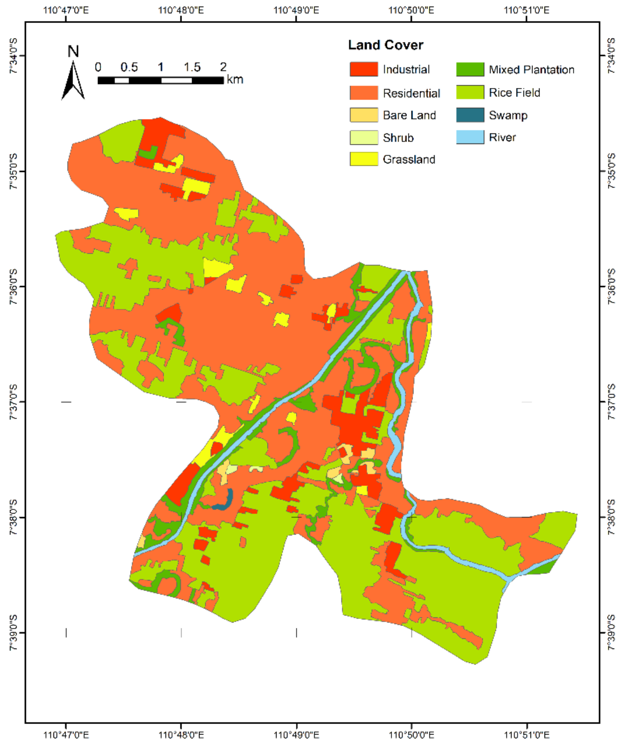


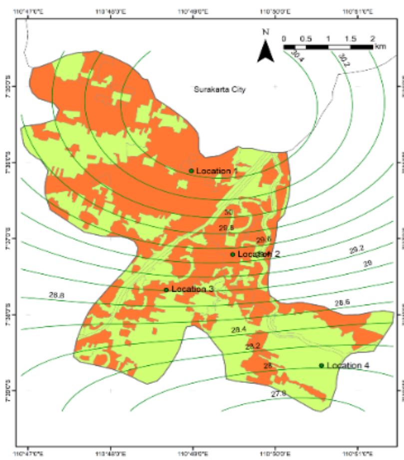
Fig. 3. The land cover map of the Grogol District (source: interpetation of sentinel data)

Results and Discussion

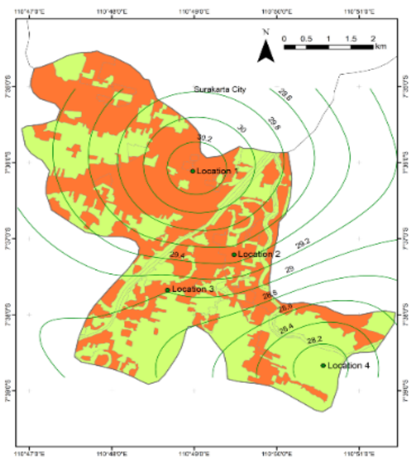
Spatial Variation of Air Temperature in the Grogol District

Spatial variations in air temperature are represented as contour (isotherm) maps as shown in figure 4a–d.

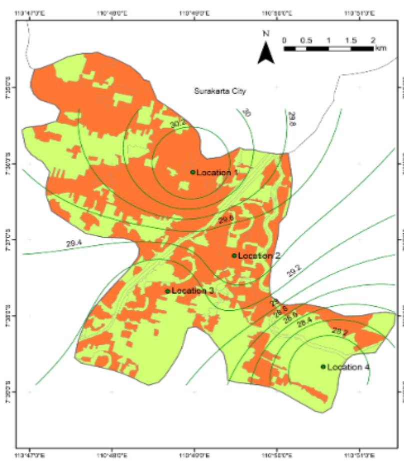
The figure shows four interpolation methods to represent the spatial variation of the air temperature, The interpolation methods used are (a) Kriging with gaussian type semi-variogram, (b) Kriging with spherical type semi-variogram, (c) Inverse Distance Weighting (IDW) and (d) Spline. Each interpolation method shows different spatial patterns of air temperature. The kriging method (gaussian type semi-variogram) has an air temperature range of 27.8 to 30.6°C. The highest air temperature value is concentrated in Surakarta City, while the lowest air temperature is in the southeastern part of the Grogol District. The kriging method (spherical semi-variogram type) has an air temperature range of 28.2 to 30.4°C. The spherical type shows that the highest air temperature is concentrated at settlement 1 in the northern part of the Grogol District. Meanwhile, the lowest air temperature is concentrated in the rice field sample point in the southeastern part of the Grogol District. The IDW method shows air temperature patterns that are similar to the kriging method (spherical semi-variogram type), where the highest air temperature is concentrated in the sample point of settlement 1. The air temperature range is between 28.2 to 30.4°C. The spline method shows that the range of air temperature ranges from 27.8° to 31.0°C. There is no significant difference between the interpolated air temperature contour although the validation indicates that spline and kriging with gaussian type semi-variogram perform better than the rest (Table 1).



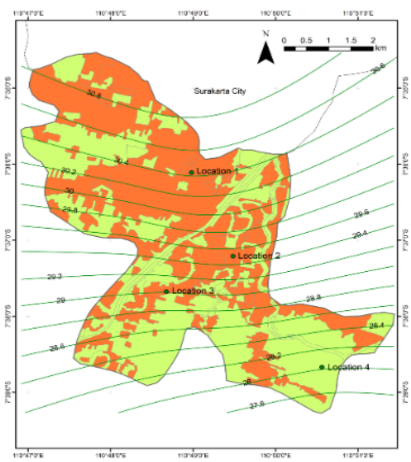
a) Kriging with gaussian type semi-variogram



b) Kriging with spherical type semi-variogram



c) Inverse distance weighting (IDW)



d) Spline interpolation

Fig. 4. Map of the air temperature in the Grogol District using different interpolation methods: (a) Kriging with gaussian type semi-variogram, (b) Kriging with spherical type semi-variogram, (c) IDW and (d) Spline

Table 1. RMSE value of air temperature map using the IDW, spline, kriging with gaussian type semi-variogram, and kriging with spherical type semi-variogram interpolation (source: data processing)

No.	Methods	RMSE
1.	Inverse Distance Weighting (IDW)	1,00
2.	Spline	0,36
3.	Kriging (spherical semi-variogram)	0,85
4.	Kriging (gaussian semi-variogram)	0,37

In general, the northern part of Grogol District, which is directly adjacent to Surakarta City, has a higher air temperature than the southern part of Grogol District. This is particularly observed from the sample point of settlement 1. The northern part is also dominated by built-up land, both residential and industrial buildings. The southern part of the Grogol District, which has lower temperatures, is associated with the paddy field land cover. The southern part of the Grogol District is also dominated by non-built-up land cover. In the southern part of the Grogol District, there is also a settlement sample point 2. However, the air temperature at the settlement in the 2nd sample point is not as high as the settlement in the 1st sample point.

Temporal Variation of Air Temperature in the Grogol District

The graph of the daily average air temperature is shown in figure 5. The daily average air temperature during the measurement shows a variation from the beginning to the end of the period. This variation is related to the beginning of the rainy season. The air temperature tends to be lower on rainy days than the non-rainy days. This is in line with the rainfall analysis report by the Indonesian Bureau of Meteorology, Climatology, and Geophysics (BMKG) which shows a high amount of rainfall in November 2021 in the study area [16]. Meanwhile, in August 2021, the rainfall is less than 100mm/month [16]. While in September 2021 and October 2021, there is an increasing amount of rainfall to 100-150mm/month [16]. The figure also shows that there is a similar pattern of daily temperature over the study area. However, there is a difference in each location regarding the highest and lowest temperature. Location 1 which represents settlement in the north part has the highest temperature over the entire period. In contrast, location 4 which represented rice fields in the south part has a lower temperature.

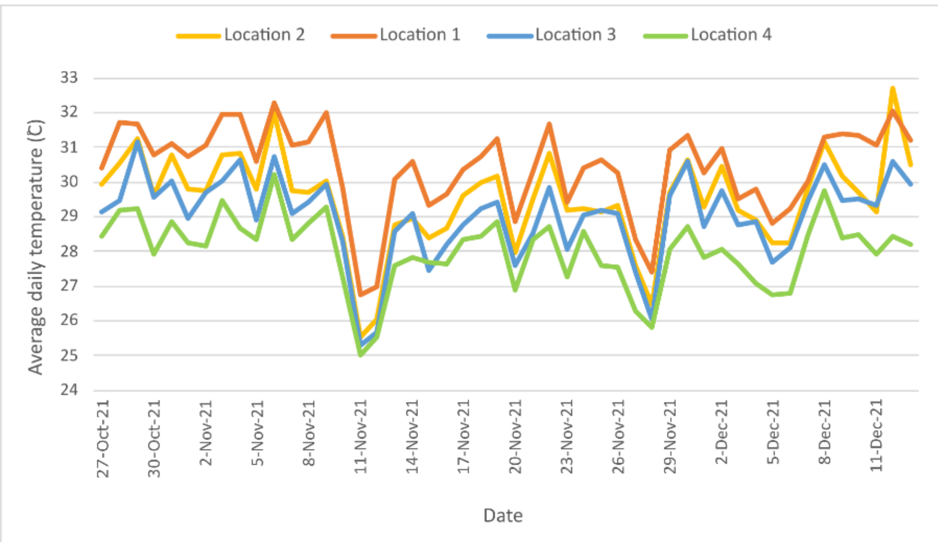


Fig. 5. Graph of the daily average air temperature of the four sample points from 27 October to 13 December 2021

Daily air temperature variations based on hours are shown in Figure 6.

The four graphs use measurement data from December 13, 2021. The weather conditions on that day were sunny and not cloudy and not raining. It can be seen from the four graphs, that the daily temperature indicates a similar pattern. The temperature is decreasing from midnight (00.00 local times) to reaching the minimum value just before sunrise, then rises until it reaches the maximum value 2-4 hours after noon and then decreases steadily until midnight. The maximum peak of daily air temperature is related to weather conditions. In sunny and cloud-free conditions, the maximum air temperature generally occurs at two to five in the afternoon.

The graph of the *diurnal ranges of temperature* (DTR) is shown in figure 7. The DTR graph uses measurement data from November 23rd to 25th, 2021, and December 11th to 13th, 2021. Weather conditions from November 23rd to 25th, 2021 represent the rainy day. While on December 11th to 13th, 2021, represents non-rain days with no or small amount of cloud cover and rainfall.

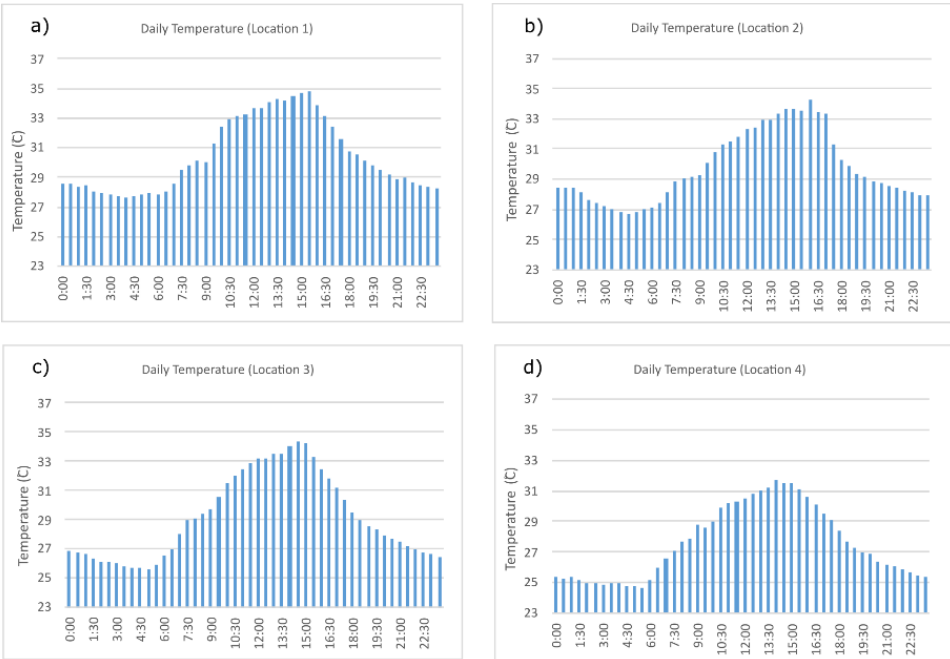


Fig. 6. Graph of a daily air temperature of sample points: (a) settlements 1, (b) industrial buildings, (c) settlements 2, and (d) rice fields on December 13, 2021

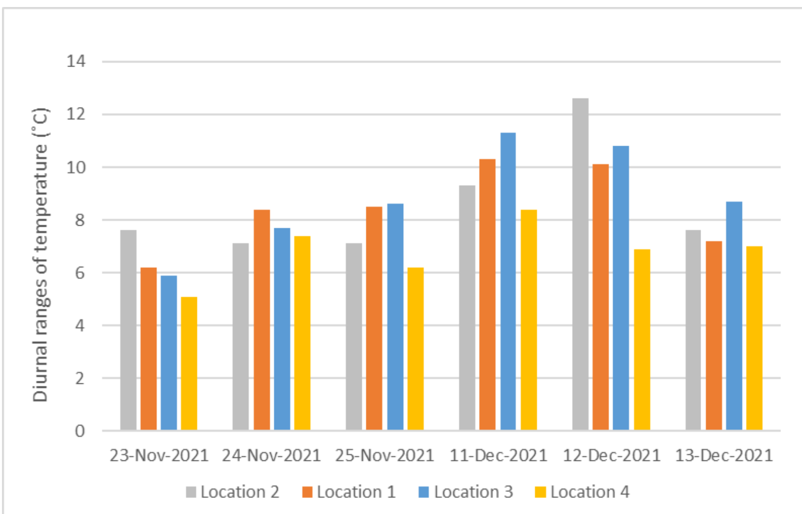


Fig. 7. Graph of Diurnal Ranges of Temperature (source: data processing)

The DTR value on November 23rd to 25th, 2021 tends to be lower than the DTR value from December 11th to 13th, 2021. On non-rain days, solar radiation can directly penetrate the Earth's surface. On a cloudy day, some of the incoming solar radiation will be reflected by the clouds and decrease the air temperature. On the other hand, during cloudy nights, the radiation emitted by the Earth is partially reflected the Earth's surface so that it can heat the air column close to the Earth's surface [11]. Meanwhile, on a clear night, the Earth emits radiation without being reflected on the surface. Therefore, the DTR value from December 11th to 13th is higher because the air temperature during the day is higher (than on a rainy day) while the air temperature at night is lower (than on a cloudy night).

Characteristics of Air Temperature based on Land Cover Types

The Grogol sub-district is dominated by settlements, rice fields, and industrial buildings. Air temperature measurement is focused on these three types of land cover. Some studies have stated that different land cover types have different effects on the energy balance in the atmosphere [17, 18]. This energy balance condition will then affect the air temperature in each type of land cover. The graph of the daily average air temperature on the six measurement days is shown in figure 8. Settlement 1 becomes the land cover with the highest average air temperature on all measurement days except December 12th, 2021. While the rice fields have an average air temperature lowest on all measurement days. The industrial buildings have an average air temperature that is almost the same as settlement 2. However, the industrial buildings have a higher temperature than the settlement 2.

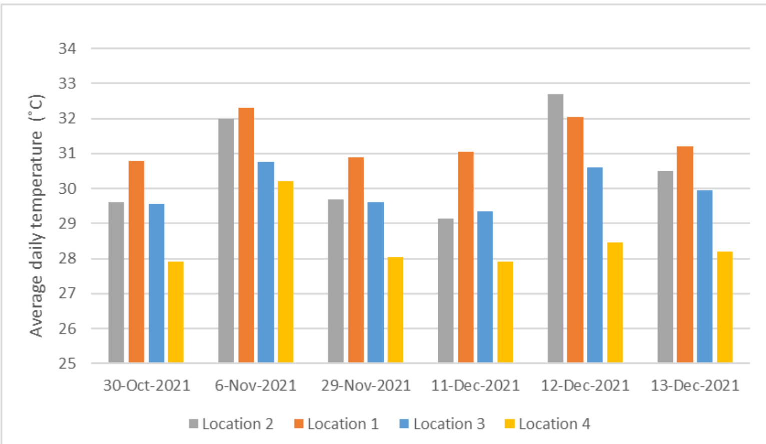


Fig. 8. Graph of daily average air temperature on October 30th, 2021; 6th and 29th November 2021; and 11th, 12th, and 13th December 2021

The difference in air temperature shown in the graph above is related to the characteristics of each land cover that has different energy balance conditions. Residential land cover in general is painted dark and has a small albedo value. This energy balance condition causes the air temperature in the residential land cover to be high. There is a difference in air temperature between the sample points of settlement 1 and settlement 2. In detail, the characteristics of the two settlements are different. Settlement 2 has less urban density and is located close to the paddy fields. In contrast settlement 1 has a higher density and has a less vegetated area. Although residential buildings are often associated with high air temperature, settlement 2 is also influenced by non-built-up areas.

The paddy field sample points have a lower average daily air temperature than the other sample points. This is related to the presence of vegetation and water that affects evapotranspiration. The evaporation process absorbs energy from the surroundings to convert water into vapor and resulted in a decrease in temperature [11]. In some aspects, industrial buildings have the same characteristics as residential. It is dark-painted and is covered with concretes, causing the albedo value to be small. This small albedo value causes the air temperature to be high.

The air temperature difference is validated statistically using the T-test for normally distributed data, or the Mann-Whitney test if the distribution of not-normal. To classify the normality of the data, a normality test using the Shapiro-Wilk method was conducted, and the result is shown in table 2. The air temperature data at the industrial buildings, settlements 1, and settlements 2 are normally distributed. The air temperature data at the rice fields are not normally distributed. The results of the statistical test between two sample points are shown in table 3.

Table 2. The normality test of the air temperature data at each location using the Shapiro-Wilk method

No	Location	Shapiro-Wilk Significance	Distribution
1.	Industrial buildings	0,319	Normal
2.	Settlement 1	0,141	Normal
3.	Settlement 2	0,279	Normal
4.	Rice fields	0,006	Non-normal

Table 3. The results of the statistical validation using the T-test and Mann-Whitney test

No	Land Cover	T-Test		Mann-Whitney Test	
		Sig. (2-tailed)	Conclusion	Sig. (2-tailed)	Conclusion
1.	Settlement 1 vs Rice Fields	-	-	0,004	Different
2.	Settlement 1 vs Settlement 2	0,002	Different	-	-
3.	Settlement 1 vs Industrial buildings	0,254	No differences	-	-
4.	Settlement 2 vs Industrial buildings	0,346	No differences	-	-
5.	Settlement 2 vs Rice Fields	-	-	0,025	Different

The difference test between the sample points of settlement 1 and rice fields shows a value of 0.004. This means that statistically, there is a difference in the average value of air temperature between the two sample points. The T-test conducted at the sample points of settlement 1 and settlement 2 showed a value of 0.002. This means that there is also a difference in the average value of air temperature statistically at the two settlements. The T-test which was carried out at settlement 1 and industrial buildings showed a value of 0.254. This means that statistically, the air temperature at settlement 1 and industrial buildings is similar. The T-test conducted between the sample points of settlement 2 and industrial buildings showed a value of 0.346, which also indicates no difference between the two sample points.

The three built-up land covers (settlement 1, settlement 2, and industrial building) have different characteristics. The strong influence of urban areas affects the higher air temperature at settlement 1. The industrial buildings are often clustered and located close to each other and affected by high air temperature, although lower than settlement 1. The T-test result also shows that there is no difference in the average value of air temperature between the two sample points. However, the air temperature in the industrial buildings is lower than in the settlements 1. The settlement 2 air temperature is lower than industrial buildings. Therefore, the industrial building temperature differences are statistically less significant compared to the two settlements.

The difference test was also carried out between the sample points of settlement 2 and rice fields, with a value of 0.025. This means that there is a difference in air temperature between settlement 2 and rice fields. Settlement 2 which includes built-up land has a higher air temperature, while the rice fields are covered with vegetation which affects the decrease in air temperature. Although settlement 2 is located close to the paddy fields, the effect is less significant.

The characteristics of air temperature on the built-up and vegetated land cover are related to the UHI phenomenon. The UHI phenomenon is characterized by high temperatures in urban areas. Research on the UHI phenomenon has been carried out in several big cities in Indonesia and is also often associated with the trend of changing vegetated areas into built-up land. For example, the UHI phenomenon in Yogyakarta is characterized by a surface temperature difference of 6.93°C with a temperature range of 24.45 to 31.38°C [18]. Another UHI phenomenon was found in Semarang. The UHI phenomenon in Semarang City is characterized by a difference in surface temperature of 18°C with a temperature range of 22 to 40°C [19]. Land cover conversion also contributes to the increase in the intensity of the UHI phenomenon. In 2008 residential land cover had a temperature range of 26 to 30°C, which then increased to 30 to 34°C in 2018 [20]. Residential land cover in this case also dominates the area with the highest surface temperature. In general, the UHI phenomenon in Surakarta City is less significant compared to Semarang and Yogyakarta cities. However, the influence of UHI from Surakarta City still affects the temperature of the Grogol District. Higher air temperatures were found in areas closer to Surakarta City than in areas further away.

Conclusions

The spatial variation of air temperature in the Grogol District shows that the higher air temperature is in the northern part. The northern part of the study area is dominated by built-up land, both residential and industrial buildings. Lower air temperatures are spread in the southern part of the Grogol District. The southern part is dominated by non-built land cover. Temporal variations of air temperature in each land cover showed almost the same temporal pattern, however, the minimum to the maximum range is different. Daily variations in air temperature by hour indicate the time when the minimum peak air temperature occurs just before sunrise and the maximum peak time occurs two to four hours after noon. In addition, the DTR value tends to be higher when the weather is sunny than when it is cloudy and rainy. The results of air temperature measurements on built-up land cover and rice fields show different air temperatures. A statistical difference test with the T-test or the Mann-Whitney test was also carried out to support this where there was a difference in the average value of air temperature between the two land covers. Built-up land covers have a higher air temperature than rice fields. This is due to the contribution of plants in lowering air temperature through the evapotranspiration process.

In the study area, the mitigation of the rising air temperatures due to expansion of built-up land cover can be done particularly by protection and conservation of vegetated land. Open green spaces, especially in the form of vegetated land dominated by large trees play an important role to reduce the rate of increasing air temperature. The above recommendation could significantly affect the air temperature in the study area. This is related to the high demand for settlement areas due to increasing urban activities in Surakarta city [21].

Acknowledgments

This research is supported by grants of "Hibah Penelitian Dasar Perguruan Tinggi (PDUPT)" in 2022 with Dr. Andung Bayu Sekaranom as principal investigator (Contract number 1623/UN1/DITLIT/Dit-Lit/PT.01.03/2022 under the contract 018/E5/PG.02.00.PT/2022).

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Received: Octomber 02, 2023
Accepted: May 24, 2024