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Analysis of the Distribution of Carbon Monoxide Gas and Nitrogen Dioxide Gas and *Urban Heat Island* (UHI) Based on Multi-Temporal Satellite Data During the Implementation of the Covid-19

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Abstract: The research aims to determine the distribution and concentration levels of CO and NO_2 gases based on Sentinel-5P Satellite Image processing and UHI levels based on Landsat 8 Image processing during the implementation of Covid-19 Large-Scale Social Restrictions (PSBB) in Pekanbaru City. Data processing begins by extracting CO and NO_2 gas data as well as Landsat 8 imagery via cloud computing on Google Earth Engine (GEE). The PSBB policy in Pekanbaru City came into effect in 2020. The PSBB policy will limit community activities, which will affect the concentration of CO and NO_2 gases as well as UHI. The research results show that before the 2019 Covid-19 PSBB the respective concentrations of CO and NO_2 gases were (CO: 4.16 x 10^{-3} mol/m^2 – 4.70 x 10^{-3} mol/m^2) and (NO_2: 4, 16 x 10^{-5} mol/m^2 – 5.68 x 10^{-5} mol/m^2) with a UHI temperature of 34.23 ^{0}C. Then, when the PSBB was implemented in 2020, there was a decrease in the concentration of CO and NO_2 gases to (CO: 2.87 x 10^{-3} mol/m^2 – 3.20 x 10^{-3} mol/m^2) and (NO_2: 2.98 x 10^{-5} mol/m^2 – 5.28 x 10^{-5} mol/m^2) with the UHI temperature decreasing to 30.24 0C. However, CO and NO_2 gas concentrations increased again after PSBB in 2021 to (CO: 2.90 x 10^{-3} mol/m^2 – 3.31 x 10^{-3} mol/m^2) and (NO_2: 2.87 x 10^{-5} mol/m^2 – 5.76 x 10^{-5} mol/m^2) which was followed by an increase in the UHI temperature to 32.62 ^{0}C. Therefore, it is known that the concentration of CO and NO_2 gases will affect UHI. If the concentration of CO and NO_2 gas increases, the UHI temperature will also increase.

Keywords: Carbon monoxide gas; Covid-19; Nitrogen dioxide gas; Satellite data

Introduction

Indonesia is a country on the Asian continent with the 4th (fourth) most populous population in the world. Its status as the country with the most populous population can be seen from the many activities carried out by residents in Indonesia. In order to support the smooth running of these activities, adequate transportation facilities are needed. There are various types of transportation facilities in Indonesia, one of which is motorized vehicles. Every motorized vehicle and industrial plant that operates will emit residual combustion products in the form of exhaust emissions (Saidal Siburian, 2020; Santos et al., 2021). This emission is one of the causes of air pollution (Gusnita, 2016). According to Ismiyati et al. (2014) there are various types of pollutants originating from industrial gas emissions and residual motor vehicle exhaust. These pollutants are carbon monoxide gas (CO) and nitrogen dioxide gas (NO_2) (Suhardono et al., 2023). Carbon monoxide (CO)

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gas which comes from motor vehicle emissions and nitrogen dioxide (NO_2) which comes from industry are the biggest pollutants that cause air pollution (Hazarin et al., 2019; Sinolungan, 2009).

In 2020 the world was hit globally by the Covid-19 virus pandemic (Corona Virus Disease-19). The spread of the Covid-19 virus is happening very quickly. One of the cities affected is Pekanbaru City. To break the chain of spread of the Covid-19 virus, a policy was created to implement Large-Scale Social Restrictions (PSBB) (Darmawan et al., 2020). Through this policy, it will limit people's driving and industrial activities. In this way, it can affect the levels of CO and NO_2 gas in the environment (Fauzi & Sriyanto, 2024).

To monitor the effect of air pollution on UHI, data from the Sentinel-5P and Landsat 8 satellites are used (Arıkan & Yıldız, 2023; Purwanto et al., 2022). There are several studies related to air pollution such as those carried out by Indriyaningtyas et al. (2021); Parhusip et al. (2022); Priyambodo et al. (2022); Putri (2021) to see the effect of gas emissions on temperature. However, research on the influence of air pollution on changes in urban heat temperatures or Urban Heat Island (UHI) has not been studied comprehensively and thoroughly. Therefore, in this research we will look at the influence of air pollution (CO and NO_2 gas emissions) on urban heat temperatures (UHI) before the implementation of the PSBB, during the PSBB and after the PSBB in Pekanbaru City.

Method

The research method was carried out using remote sensing techniques. Remote sensing is used to obtain information related to objects, areas or symptoms by analyzing data obtained using tools without direct contact with the object, area or symptom being studied (Lillesand & Kiefer, 1994). The basic principle of remote sensing methods is that each object will emit or reflect certain electromagnetic waves which aim to provide information.

This research was conducted in the Pekanbaru City area which is administratively located in Riau Province, Indonesia. Geographically, Pekanbaru City is at coordinates 0˚25' - 0˚45' N and 101˚14' - 101˚34' E with a height above sea level ranging from 50-150 meters. The research location is as seen in Figure 1.

This research, data from the Sentinel-5P and Landsat 8 satellites were used. The Sentinel-5P satellite was used to obtain CO and NO_2 gas data. Meanwhile, the Landsat 8 Satellite is used to obtain UHI temperatures (Alhawiti & Mitsova, 2016; Barbieri et al., 2018; Tsou et al., 2017). Both data are downloaded via Google Earth Engine (GEE). The downloaded data is data recorded in full in 2019, 2020 and 2021. To support the processing of these two image data, ArcGIS and Microsoft Excel software were used.

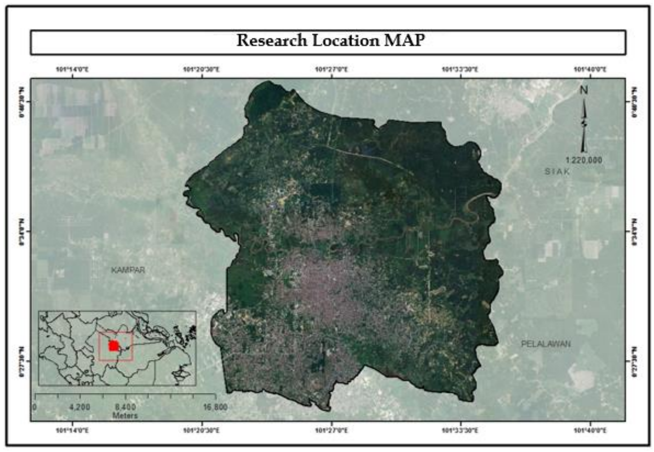

Figure 1. Research location area

Calculation of CO and NO_2 gas levels and UHI

The first stage in processing this data is to input the syntax/script into Google Earth Engine via the page*code.earthengine.com*uto obtain Sentinel-5P image data. GEE (Google Earth Engine) is a cloud-based platform designed to store and process data with very large data collections (Thottolil & Kumar, 2018). In this programming, data filtering is carried out where what is taken is the emission gas elements in the form of carbon monoxide (CO) and Nitrogen Dioxide (NO_2) in a certain time period (Kazemi Garajeh et al., 2023). In the script prepared, processing is immediately carried out to obtain the concentration values for Carbon Monoxide (CO) and Nitrogen Dioxide (NO_2) gases. After the image containing the gas concentration is obtained, it is then processed using ArcGIS software.

In line with the initial process of collecting data on Sentinel-5P imagery, Landsat 8 satellite data collection was also carried out using the same script in Google Earth Engine (Gholamrezaie et al., 2022). After the Landsat 8 satellite data is obtained, it is then processed using ArcviewGIS software. The initial step in this processing is to make corrections to the images recorded by the Landsat 8 satellite. The corrections made are in the form of radiometric and geometric corrections. Radiometric correction aims to eliminate the effects of changes in values due to the influence of the sun's elevation angle and the influence of atmospheric layers. Meanwhile, geometric correction aims to adjust coordinates in the form of the WGS 1984 or UTM datum. To obtain urban heat temperature (UHI) values, there are 2 (two) data sub-processing carried out, namely determining vegetation density (NDVI) and determination of surface temperature (LST).

Plan the stage of determining vegetation density (NDVI), the first step is to enter the Landsat 8 satellite data that has been downloaded. This data is then cut using the extract by mask command according to the research area. Processing using the NDVI technique is carried out by utilizing NIR waves (band 5) and red waves (band 4) on Landsat 8. However, the value of each of these bands is still in the form of a digital number (DN) so calibration needs to be done first. to make it a TOA (Top of Atmospheric) reflectance value (Equation 1). It is known that Pλ' is the TOA reflectance value that has not undergone correction for the sun's elevation angle, Qcal is the digital number value, Mp is the reflectance multiplying factor, and Ap is the reflectance increasing factor. The Mp and Ap values can be seen in the image metadata where each of these variables is the mult band reflectance and add band reflectance values. So that the resulting image is better, it is necessary to correct the sun's elevation angle using Equation 2. Where Pλ is the TOA reflectance value that has been corrected for the sun's elevation angle, θ SE is the value of the sun's elevation angle obtained from satellite image metadata. Because the satellite image has been corrected and calibrated, the next stage is to calculate the vegetation index using the NDVI (Normalized Difference Vegetation Index) technique using Equation 3.

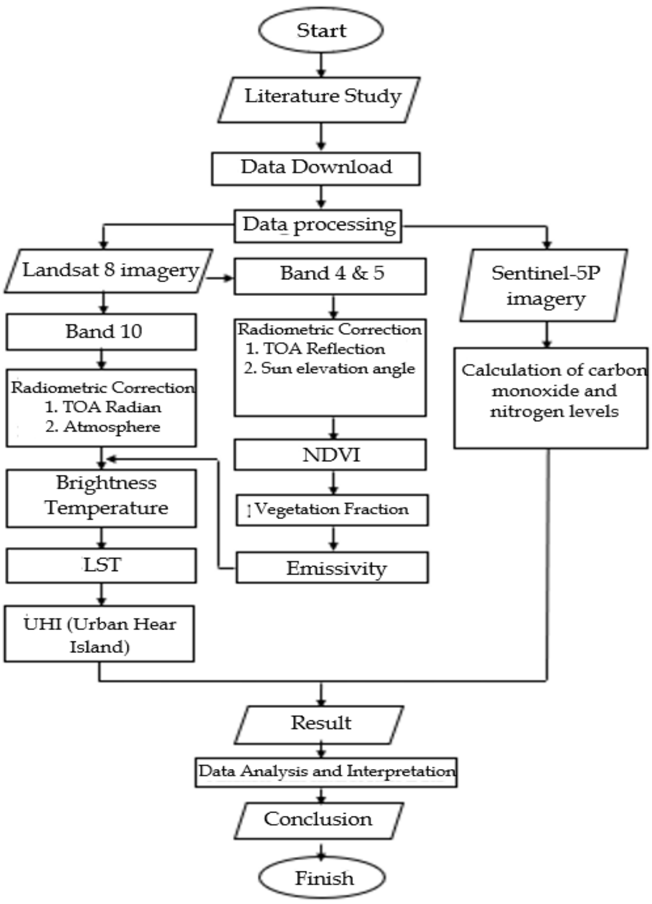

Figure 2. Diagram of the stages of CO and NO_2 gas analysis and UHI

After obtaining the index value/vegetation density, the next stage of data processing is calculating the surface temperature distribution (LST). Determining the surface temperature distribution is the final step in data processing in this research to obtain the UHI value. This processing is carried out using band 10 images on Landsat 8. Similar to NDVI processing, in determining surface temperature distribution it is necessary to correct and calibrate on band 10 on Landsat 8. This calibration aims to convert the digital number value into TOA (Top of Atmospheric) form. radians. This calibration is carried out using Equation 4. Where Lλ' is the TOA radian value that has not undergone atmospheric correction, Qcal is the digital number value, ML is the radian multiplying factor, and AL is the radian increasing factor. The Mp and Ap values can be seen in the image metadata where each of these variables is the mult band radiance and add band radiance values. Because the satellite image has been corrected and calibrated, the next stage is to determine the BT (Brightness Temperature) value using Equation 5. Where BT is the temperature value obtained from the sensor, the K1 and K2 values are thermal conversion constants contained in the metadata. The final stage is the LST calculation using Equation 6 (Yu et al., 2014), where after obtaining the LST value the UHI is then calculated based on Equation 7 (Oke, 1997).

Calculation of reflectance TOA

$$P\lambda' = MP \text{ X } Qcal + AP \quad (1)$$

Sun elevation angle correction

$$P\lambda' = \frac{P\lambda'}{\text{Sin}(\theta SE)} \quad (2)$$

NDVI

$$NDVI = \frac{(Band\ 5 - Band\ 4)}{(Band\ 5 + Band\ 4} \quad (3)$$

TOA radiant calculation

$$L\lambda' = ML \text{ X } Qcal + AL \quad (4)$$

Calculate Brightness Temperature

$$BT = \left(\frac{K_2}{\left(\frac{K_1}{L\lambda} + 1 \right)} \right) - 273 \quad (5)$$

ESG

$$LST = \frac{BT}{1 + \left(\frac{\lambda \text{X} BT}{P} \right) \ln(e)} \quad (6)$$

UHI

$$UHI = \frac{\text{LST} - \text{LSTm}}{\text{Std}} \quad (7)$$

Results and Discussion

Analysis of CO and NO_2 Gas Levels

Figure 3 shows that in 2019 before the Covid-19 PSBB, the concentration of carbon monoxide gas in Pekanbaru City from January to March continued to increase. In January it was discovered that the value of carbon monoxide gas levels was 3.65 x 10^{-3} mol/m² which had increased to 4.32 x 10^{-3} mol/m². Furthermore, from April to August it was discovered that carbon monoxide gas levels had decreased by 1.13 x 10^{-3} mol/m² so that in July carbon monoxide gas levels were only 3.19 x 10^{-3} mol/m². Changes in the amount of carbon monoxide gas levels in Pekanbaru City experienced a significant spike in September. It is known that in September and October carbon monoxide gas levels reached 9.48 x 10^{-3} mol/m². The amount of this gas has increased by 5 x 10^{-3} mol/m². This large increase in numbers was also influenced by forest and land fires (Karhutla) which occurred at several points in Riau Province (Mulia et al., 2021). So the consequences of this incident significantly affected the amount of carbon monoxide gas levels. However, after this incident, carbon monoxide gas levels decreased again. This is evidenced by the decrease in CO gas levels in November and December, which respectively became 4.33 x 10^{-3} mol/m² and 3.44 x 10^{-3} mol/m². Through the analysis carried out, it is known that the highest average level of carbon monoxide gas in 2019 was 4.70 x 10^{-3} mol/m² and the lowest average was 4.16 x 10^{-3} mol/m².

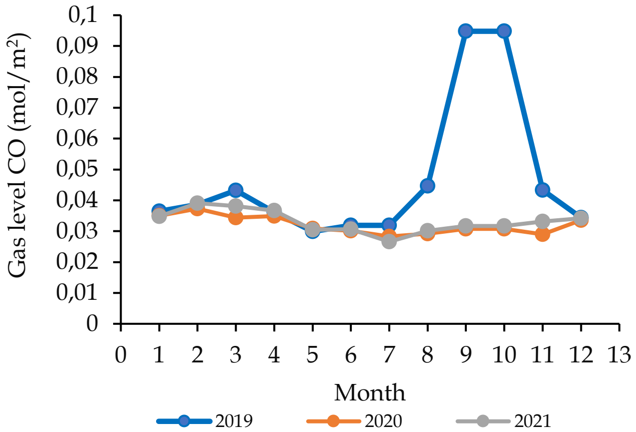

Figure 3. Graph of Changes in CO Gas Levels Before PSBB (2019), During PSBB (2020), and Post PSBB (2021) in Pekanbaru City

When the Covid-19 pandemic occurred in 2020, the Pekanbaru City Government implemented the PSBB policy. The enactment of the PSBB policy affects the amount of gas levels in the air (Nasution, 2023; Prasetyo et al., 2023). It is known that in January the carbon monoxide gas level was 3.50 x 10^{-3} mol/m² which increased to 3.73 x 10^{-3} mol/m² in February. Furthermore, in March and April carbon monoxide gas levels fell to 3.44 x 10^{-3} mol/m² and 3.44 x 10^{-3} mol/m². Changes in the amount of carbon monoxide gas levels in Pekanbaru City occurred in May, where the gas levels continued to decline until December, where the carbon monoxide gas levels were only 2.90 x 10^{-3} mol/m². Through the analysis carried out, it is known that the highest average level of carbon monoxide gas in 2020 was 3.20 x 10^{-3} mol/m² and the lowest average was 2.87 x 10^{-3} mol/m².

Furthermore, after the implementation of the PSBB, in 2021 the amount of gas levels increased compared to 2020. This can be seen that in January the carbon monoxide gas levels were 3.48 x 10^{-3} mol/m² which increased to 3.91 x 10^{-3} mol/m² in February. Furthermore, in March and April carbon monoxide gas levels fell to 3.81 x 10^{-3} mol/m² and 3.67 x 10^{-3} mol/m². The change in the amount of carbon monoxide gas levels in Pekanbaru City in 2021 occurred in May when the amount of gas levels fell to 3.05 x 10^{-3} mol/m². However, in September gas levels rose again to 3.17 x 10^{-3} mol/m². The amount of carbon monoxide gas levels continued to increase until December, when carbon monoxide gas levels reached 3.42 x 10^{-3} mol/m². Through the analysis carried out, it is known that the highest average level of carbon monoxide gas in 2021 is 3.31 x 10^{-3} mol/m² and the lowest average is 2.90 x 10^{-3} mol/m².

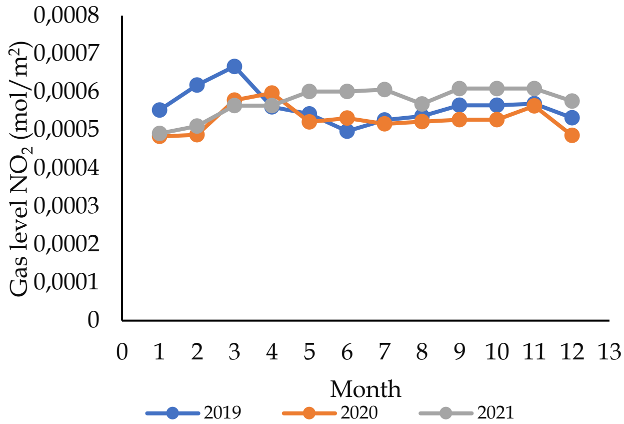

Figure 4. Graph of Changes in NO_2 Gas Levels Before PSBB (2019), During PSBB (2020), and Post PSBB (2021) in Pekanbaru City

Figure 4 shows that in 2019 before the Covid-19 PSBB, the concentration of nitrogen dioxide gas in Pekanbaru City from January to March continued to increase. In January it was discovered that the value of nitrogen dioxide gas levels was 5.52 x 10^{-5} mol/m² which had increased to 6.67 x 10^{-5} mol/m². Furthermore, from April to August it was discovered that nitrogen dioxide levels had decreased by 1.41 x 10^{-5} mol/m² so that in July nitrogen dioxide gas levels were only 5.26 x 10^{-5} mol/m^2. Changes in the amount of nitrogen dioxide gas levels in Pekanbaru City increased again in September. It is known that in September and October nitrogen dioxide gas levels reached 5.65 x 10^{-5} mol/m^2. The amount of this gas continued to increase to 5.69 x 10^{-5} mol/m^2 in November but decreased slightly in December to 5.32 x 10^{-5} mol/m^2. Through the analysis carried out, it is known that the highest average level of nitrogen dioxide gas in 2019 was 5.68 x 10^{-5} mol/m^2 and the lowest average was 4.16 x 10^{-5} mol/m^2.

When the Covid-19 pandemic occurred in 2020, the Pekanbaru City Government implemented the PSBB policy so that nitrogen dioxide gas levels in Pekanbaru City in January to April were lower compared to 2019. As is known, in January it was known that the value of nitrogen gas levels dioxide was 4.83 x 10^{-5} mol/m^2 which increased to 5.97 x 10^{-5} mol/m^2 in April. Furthermore, from May to October it was discovered that nitrogen dioxide levels had decreased by 0.007 x 10^{-5} mol/m^2 so that in November the nitrogen dioxide gas levels were only 5.63 x 10^{-5} mol/m^2. However, gas levels decreased slightly in December to 5.28 x 10^{-5} mol/m^2. Through the analysis carried out, it is known that the highest average level of nitrogen dioxide gas in 2020 was 5.28 x 10^{-5} mol/m^2 and the lowest average was 2.98 x 10^{-5} mol/m^2.

After the PSBB, nitrogen dioxide gas levels in January increased by 4.91 x 10^{-5} mol/m^2 which increased to 6.06 x 10^{-5} mol/m^2 in July. Furthermore, in August it was discovered that nitrogen dioxide gas levels had decreased slightly to 5.68 x 10^{-5} mol/m^2. However, from September to November levels of nitrogen dioxide gas increased again to 6.09 x 10-5 mol/m2. However, nitrogen dioxide gas levels decreased slightly again in December to 5.76 x 10^{-5} mol/m^2. Through the analysis carried out, it is known that the highest average level of nitrogen dioxide gas in 2021 is 5.76 x 10^{-5} mol/m^2 and the lowest average is 2.87 x 10^{-5} mol/m^2.

Analysis of the Spatial Distribution of CO and NO_2 Gases

The levels of carbon monoxide gas and nitrogen dioxide gas are spread over 3 (three) levels. The first is the distribution of gas in high quantities, the second is the distribution of gas in medium quantities, and the third is the distribution of gas in low quantities. Spatially, the area with the highest amount of gas is the area right in the middle of Pekanbaru City, which includes Sukajadi District, Sail District, and Pekanbaru City District. The second area is spread across the northern part of Pekanbaru City which includes Senapelan District and Limapuluh District. Meanwhile, the third area is the area in the eastern part of Pekanbaru City, namely Tenayan Raya District. Areas that have high levels of carbon monoxide gas and nitrogen dioxide gas are areas with dense levels of activity (Yuwono & Alfianita, 2021). These activities can be community activities, motorized activities, or industrial activities such as operating factories in the area (Cahyono et al., 2023).

The area with moderate gas levels is in Payung Sekaki District which is located in the western part of Pekanbaru City. Apart from that, there are also areas located in the southern part of Pekanbaru City including the Tampan District, Marpoyan Damai District, and Bukit Raya District. Apart from that, it is also known that there are areas with low intensity gas levels in the North West and North East parts of Pekanbaru City. In the northwest part of Pekanbaru City, it covers the Rumbai District area. Meanwhile, the northeastern part of Pekanbaru City includes the Rumbai Pesisir District and Tenayan Raya District. This sub-district still has a relatively high level of vegetation density. Apart from the relatively minimal level of community activity, there are also not many industrial facilities in these areas (Ihsan et al., 2023). So, it will affect gas levels in the area (low).

UHI Distribution Analysis

The highest UHI temperature level reached 34.23 ^{o}C. Meanwhile, the lowest temperature was 19.17 ^{o}C. If you look at the distribution, in 2019 it shows that the distribution of temperatures with moderate to high intensity is spread evenly in every area of Pekanbaru City. This is because in 2019 Pekanbaru City experienced a forest and land fire disaster (Karhutla). Apart from the forest and land fires factors, high UHI temperatures are also influenced by surface heat factors triggered by activities carried out by the community and low/reduced levels of vegetation density. These factors will trigger an increase in temperature in urban areas.

When compared with the UHI temperatures that occurred in 2019, the distribution of UHI temperatures in 2020 actually experienced a significant change. This change can be seen from the maximum temperature and distribution of UHI temperatures in the sub-districts in Pekanbaru City. The highest UHI temperature in 2020 was 30.24 ^{o}C and the lowest temperature was 15.85 ^{o}C. If calculated mathematically, from 2019 to 2020 it is known that the UHI temperature in 2020 has decreased by 4 ^{o}C. This decline can be influenced by several factors. The first factor is that in 2020 the forest and land fire disaster has begun to stop and can be resolved well. Apart from these factors, in 2020 Pekanbaru City was one of the areas that was also affected and hit by the Covid-19 pandemic. With this pandemic, the PSBB policy was implemented. Through this policy, community activities are limited.

Table 1. Classification of UHI temperature levels in Pekanbaru City

Year	Max Temp. (°C)	Average Temperature (°C)	Min Temp. (°C)
2019	34.23	26.70	19.17
2020	30.24	23.04	15.85
2021	32.62	24.48	16.33

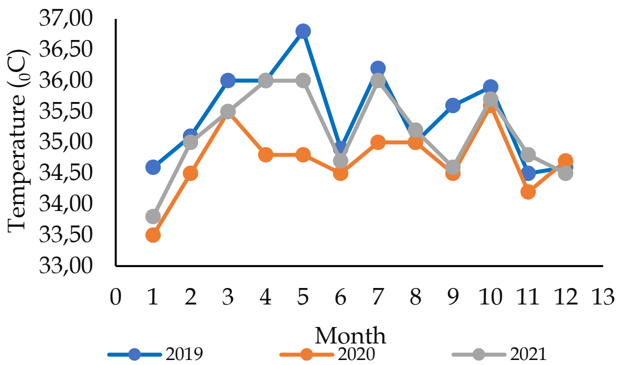

Figure 5. In-situ temperature graph for 2019, 2020 and 2021 in Pekanbaru City (Source: BMKG Pekanbaru City, 2024)

After the Covid-19 pandemic that occurred throughout 2020, it is known that in 2021 there will be an increase in UHI temperatures with a maximum temperature reaching 32.62 °C. If calculated by the maximum UHI temperature that occurred in 2020, it is known that there will be an increase in UHI temperature of 2 °C in 2021. If we look further, the distribution of high-intensity UHI temperatures in 2021 is spread across sub-districts located in the middle of middle of Pekanbaru City. This increase in temperature occurred in connection with the end of the PSBB policy implemented by the Pekanbaru City Government. In detail, the UHI temperature classification can be seen in Table 1. Changes in UHI temperature are also supported by in-situ temperatures as shown in Figure 5.

Conclusion

The distribution of gas levels is directly proportional to changes in UHI temperature. If the levels of carbon monoxide (CO) and nitrogen dioxide (NO_2) gas increase, the UHI temperature also increases. Vice versa, if the levels of carbon monoxide (CO) and nitrogen dioxide gas (NO_2) decrease, the UHI temperature also decreases. During the implementation of the Covid-19 PSBB, the concentration of CO and NO_2 gas levels and UHI temperatures were lower when compared to before PSBB and post PSBB in Pekanbaru City.

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Author Contributions

Conceptualization, Z.; methodology, MI; instrument research, Z.; data retrieval, Z, MI,DS; data curation, Z.; writing—original draft preparation, Z; writing—review and editing, MI, and DS: visualization, MIS and DS:software, Envi5.3 and Excel. MI and DSAll authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper

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