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Distribution Patterns of Ambient Air Quality Pre- and During Pandemic in the Urban Area of Yogyakarta, Indonesia

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ABSTRACT

This study identified the spatial distribution pattern of the ambient air quality in the Yogyakarta Urban Area. It was performed to determine the distribution pattern of SO_2, CO, and NO_2 concentrations for 2016–2019 (pre-pandemic) and 2020 (during pandemic). Furthermore, the spatial analysis was performed using the Inverse Distance Weighting interpolation method. This study proved that spatial modeling using this method has good accuracy, and it is easier to map the distribution pattern of ambient air quality. In 2020, most of the locations met the quality standard (62.64%). As a result, the SO_2 and CO parameters immediately showed that most conditions are satisfactory. In 2016, the SO_2 parameters met the quality standards at 74.24% of locations. In 2020, the number increased to 85.71%. In addition, the CO parameter reached the quality standard at 81.82% of locations in 2016 and a perfect level of 100% in 2020. This occurred due to the effects of the COVID-19 pandemic because most human and business activities decreased drastically. Therefore, all studies can be used as the basis for air quality modeling and post-COVID-19 predictions. This study is also important as a policy material in the monitoring and management system of ambient air quality in urban areas.

Keywords: ambient air quality, spatiotemporal distribution, inverse distance weight, urban.

INTRODUCTION

In 2020, due to the global pandemic triggered by the novel SARS-CoV-2 (COVID-19), there was an ecological deviation, which initially occurred in Wuhan, China, towards the end of 2019, but quickly subsided and spread worldwide. The World Health Organization (WHO) officially declared the COVID-19 a pandemic on March 9th, 2020, and stated that it could become endemic like the Human Immunodeficiency Virus (HIV). The prediction is that this virus will never disappear, even if an antivirus is found. Hence, the world must be prepared for an era in which new habits will be adopted. This era needs to balance between daily life and health protocols. Besides, health protocols affects tourists' intention to visit, especially in Indonesia (Pahrudin, et al., 2021).

Due to the pandemic, most human activities, including outdoor activities, have been suspended, and lockdown conditions have been imposed. These activities can automatically reduce the emissions from fossil fuel vehicles by mobilization people, because people no longer have outdoor activity and choose to stay at home during the pandemic, which have not been replaced by renewable energies (Brontowiyono, 2020). However, most of the environmental impact of the pandemic has been positive, as it has become more natural and healthier (Brontowiyono, 2021). Performing activities such as working from home reduced air pollution due to the decline in industrial activity and transportation systems. Energy consumption has also decreased significantly. As a result, the air quality pollution has decreased, and urban heat islands are under control.

The 2020 World Air Quality Report also highlights the impact of lockdowns imposed on the global concentration of particulate matter

($PM_{2.5}$) in several countries due to the COVID-19 pandemic and changes in human behavior (IQAir, 2020)

Furthermore, a temporal analysis is needed to show the patterns of the spatial distribution of air quality before the pandemic or when conditions were still normal. Therefore, this study aimed to identify the spatial distribution pattern of ambient air quality in urban areas in the Yogyakarta Urban Area, Indonesia.

The factors affecting urban air quality are human activities that affect all components. It can cause air pollution, especially in the Yogyakarta Urban Area. Air pollution is caused by the increase in active industries and transportation, such as SO_2, CO, and NO_2 can quickly spread through the air (Cooper and Alley, 2011). This study used descriptive analysis methods that are based on the result of the spatial analysis. First, base maps and spatial data were created with Google earth pro and Digital Elevation Model (DEM). The air quality interpolation method was then counted with ISPU units using the Inverse Distance Weighting (IDW) method that presented the mapping results through the ArcGIS software. In general, the spatial analysis with digital mapping modeling aims to discover the distribution pattern of ambient air quality between 2016 and 2020 before comparing air quality depending on various concentrations of SO_2, CO, and NO_2 prior to and during the COVID-19 pandemic in the Yogyakarta Urban Area. Simultaneously, the specific objective is to determine the distribution pattern of ambient air quality based on the quality standards and the category of Air Pollution Standard Index (ISPU) in the Yogyakarta Urban Area in 2016–2020. This study should be used as a material for policymaking in post-pandemic air quality control management systems.

DATA AND METHOD

Data collection

This study was conducted in the Urban Area of Yogyakarta, Indonesia. This area consists of 3 regencies, including the entire City of Yogyakarta, part of Sleman Regency, and Bantul Regency. The data used for the analysis are based on the ambient air quality monitoring points set by the Department of Environment and Forestry or called Dinas Lingkungan Hidup dan Kehutanan DI Yogyakarta (DLHK DIY), and the administrative map of the Yogyakarta Urban Area was obtained from the Indonesian Geospatial Information Agency. In total, 379 points were taken from the 2016–2020 monitoring data. The pollutants such as SO_2, CO, and NO_2 were taken from the analysis report on air quality monitoring that uses UV-Vis and NDIR Spectrophotometric methods based on regulation Decree of the Governor of Yogyakarta number 153 of 2002.

Data analysis method

Spatial processing was used to perform data analysis to obtain more definitive conclusions about the ambient air quality in the Yogyakarta Urban Area. The base map and spatial data were created with Google earth pro and Digital Elevation Model (DEM). The interpolation method on air quality was counted with ISPU units using the Inverse Distance Weighting (IDW) method that presented the mapping results through the ArcGIS software. Finally, data processing was carried out based on testing with the specified test data parameters using K-Fold Cross Validation (Rohani, et al., 2017).

The air quality measurements in the Yogyakarta Urban Area were conducted in a time frame spanning from 2016 to 2020. Furthermore, descriptive analysis was used to determine the distribution of ambient air quality in the Yogyakarta Urban Area by comparing each parameter tested with the Decree of the Governor of DIY No. 153 concerning Ambient Air Quality Standards. The comparison of each parameter is visualized through trend graphs every year from the three pollutant parameters. The impact of each parameter is correlated with the ISPU issued by the Minister of Environment and Forestry Regulation No. 14 of 2020 concerning the Air Pollutant Standard Index. The following is the ISPU calculation formula based on these regulations.

a) ISPU formula :

$$I = \frac{I_a - I_b}{X_a - X_b} (X_t - X_b) + I_b \tag{1}$$

where: I – $ISPU$ calculated;
She – $ISPU$ upper limit;
I_b – ISPU lower limit;
X_a – ambient upper limit;
X_b – lower limit ambient;
X_x – real ambient level measurement results.

Formula 1 is used to determine the ISPU category, the ISPU value calculation process is carried out with the help of the database. The effect is then measured based on the level of air quality on the calculated ISPU value. Therefore, the ISPU value can be used to reference the community in viewing the ambient air quality around the location.

RESULT AND DISCUSSION

Air quality distribution

Sulfur dioxide (SO_2)

The average yield of the SO_2 concentration (Fig. 1) increased in 2017 with an average value of 63.77. However, until 2020, there was a decrease in the average concentration of SO_2 with a concentration of 23.01 µg/m^3. According to air quality monitoring, the wind velocity in Yogyakarta urban area on 2017 is 1.1 m/s, which is the lowest value before pandemic. Therefore, the concentration of SO_2 at the moment reach the highest value (IKPLHD DIY, 2017)

The result of monitoring SO_2 has a minimum value of 14.5 µg/m^3, and the maximum value is 66.64 µg/m^3 in the mapping (Fig. 2). The results of monitoring SO_2 in 2017 have a minimum value of 24.1 µg/m^3 and therefore, it is denoted with green, while the maximum value is 357.1 µg/m^3. The results of the SO_2 monitoring in 2018 have a minimum value of 14.2 µg/m^3, with 275.7 µg/m^3 as a maximum value. The SO_2 monitoring in 2019 has a minimum value of 0.1 µg/m^3 and a maximum value of 93.3 µg/m^3. The SO_2 monitoring in 2020 has a minimum value of 0.1 µg/m^3 and a maximum value of 105.5 µg/m^3. According to Figure 2a, 2b, 2c, the SO_2 concentration in the atmosphere before pandemic (2016–2019) is shown in the yellow and orange color that is in the middle range of concentration level. Besides the values above the quality standards, it also reaches high concentration comparing to 5 years measurements, including the stable and low concentration during the pandemic.

The locations with the values above the quality standard are on average located in industrial areas. SO_2 is one of the gases produced from a fossil combustion process in power plants and other industrial facilities and fuel combustion in mobile sources such as locomotives, ships, and other equipment. In addition, SO_2 is a pollutant from industrial sources, which has properties as a precursor of sulfuric acid (H_2SO_4), a component of the aerosol particles that can change the content of acid deposition, leading to global climate. The dominant sources of SO_2 are coal-fired power plants, burning fossil fuels, and volcanoes (Jacobson, 2002).

Carbon monoxide (CO)

The average yield of the CO concentration (Fig. 2) in 2016 has an average value of 3224.16 µg/m^3, while until 2020 the data was fluctuating. However, in 2020 the average yield decreased to 733.19 µg/m^3 (Fig. 3)

According to Fig. 4, the results of the CO monitoring in 2016 indicated an air quality value of 24358.5 µg/m^3 or almost close to the quality standard value of 30,000 µg/m^3, symbolized with red. Similarly, in 2018, a maximum value of 11600 µg/m^3 was classified as orange or close to red. Meanwhile, in 2017, the results of the CO monitoring in 2019 had a minimum value of 0.3 µg/m^3 in such a way that it was green, while the maximum value was 5545.7 µg/m^3 in red in the mapping. In addition, CO monitoring in 2020 had a minimum value of 0.3 µg/m^3, and therefore, it was denoted with green, while the maximum value

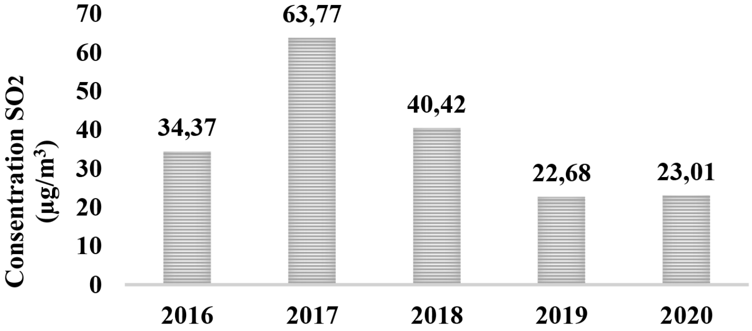
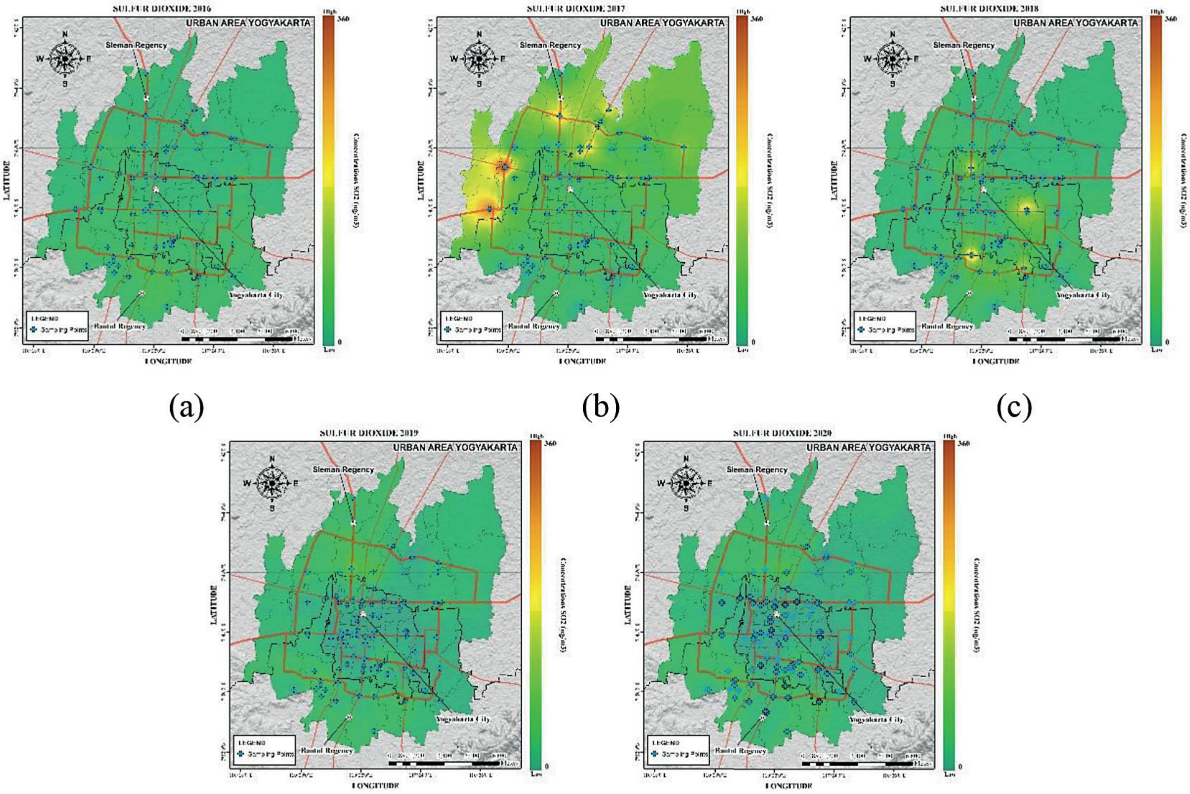


Figure 1. SO_2 concentration in ambient air quality around 2016–2020



(a) (b) (c)

(d) (e)

Figure 2. Distribution pattern of SO_2 in years; (a) 2016; (b) 2017; (c) 2018); (d) 2019 and (e) 2020

was 3010.8 μg/m³. This condition indicates that the air quality is below the quality standard and denoted with green in the mapping. These results showed that air quality during the pandemic is relatively good and stable. The ambient air quality value is almost close to the quality standard, coincides with a terminal and is close to the flyover. In terms of CO quality, this study shows that the highest CO levels in the morning are on the way in and out of the terminal due to the large number of vehicles crossing the road. The results of the measurement show that the highest value was measured during the holidays where vehicles were crowded. In addition, the factors affecting the level of CO in the ambient air are humidity, temperature, wind speed, and the location of this study. This causes the CO gas to disappear very quickly from the location, with large trees inside the Karombasan Terminal making the CO gas prone to dilution. Atmospheric dispersion in open areas is outstanding, because polluting gases such as CO do not last long in one particular location. The following Figure 4 is a form of CO concentration distribution pattern.

Nitrogen dioxide (NO_2)

There was an increase in the average yield of NO_2 concentration (Fig. 5) in 2016 with an average value of 30.93 μg/m³, while until 2020, the data was fluctuating. However, in 2017, the average yield of NO_2 concentration decreased to 25.63 μg/m³, and in 2018, 2019, and 2020, the NO_2 concentration increased from 28.70 μg/m³ to 25.76 μg/m³.

The results of the NO_2 monitoring in 2016 had a minimum value of 16.6 μg/m³, while the maximum value was 66.6 μg/m³. In the monitoring conditions of NO_2 in 2016, the results of the NO_2 monitoring in 2017 had a minimum value of 24.1 μg/m³, while the maximum value was 47.9 μg/m³. The results of the NO_2 monitoring in 2018 had a minimum value of 13.2 μg/m³, while the maximum value was 72.43 μg/m³. The results of the NO_2 monitoring in 2019 had a minimum value of 0.2 μg/m³ denoted with green, while the maximum value was 87.9 μg/m³ denoted with red in the mapping. The results of the NO_2 monitoring in 2020 had a minimum value of 0.2 μg/m³, while the maximum value was 90.7 μg/m³. The high level of NO_2 is due to the location of this study point coinciding with the trading centers

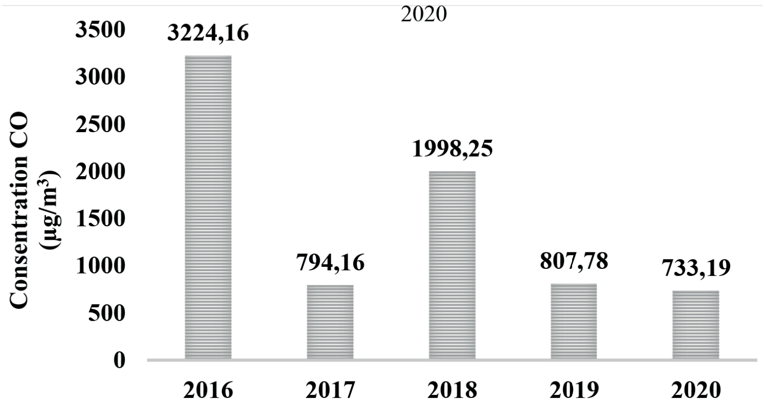


Figure 3. The concentration of CO in ambient air quality around 2016–2020

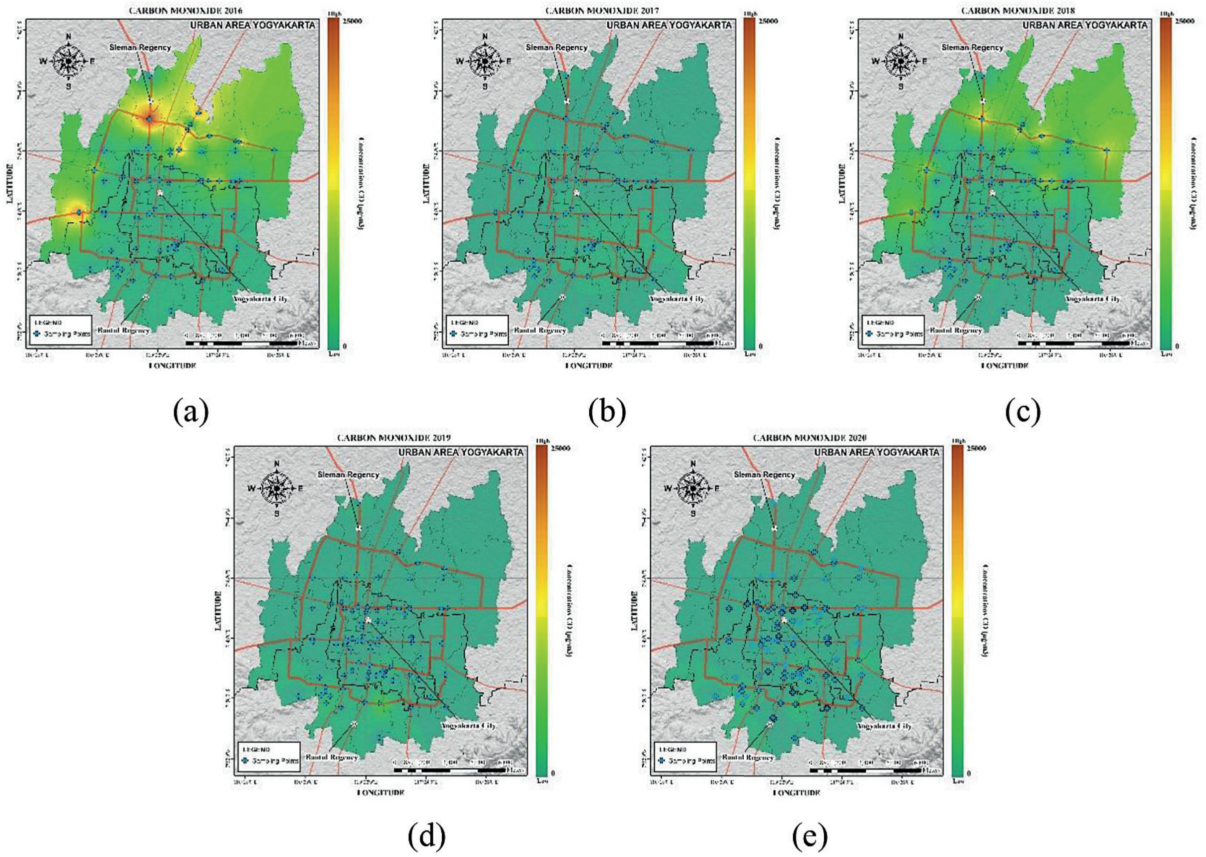


Figure 4. Distribution pattern of CO in years; (a) 2016; (b) 2017; (c) 2018); (d) 2019 and (e) 2020

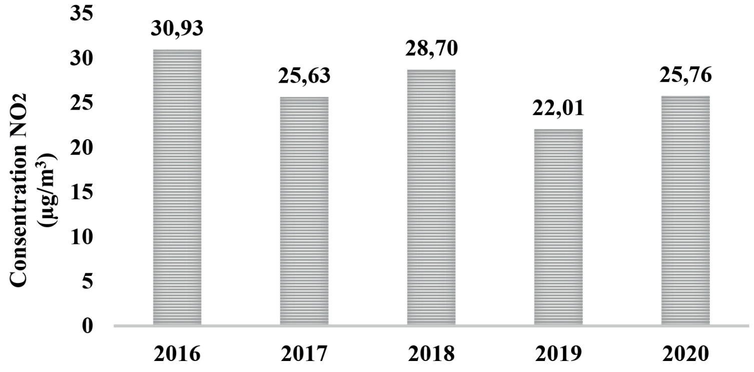


Figure 5. The concentration of NO_2 in ambient air quality around 2016–2020

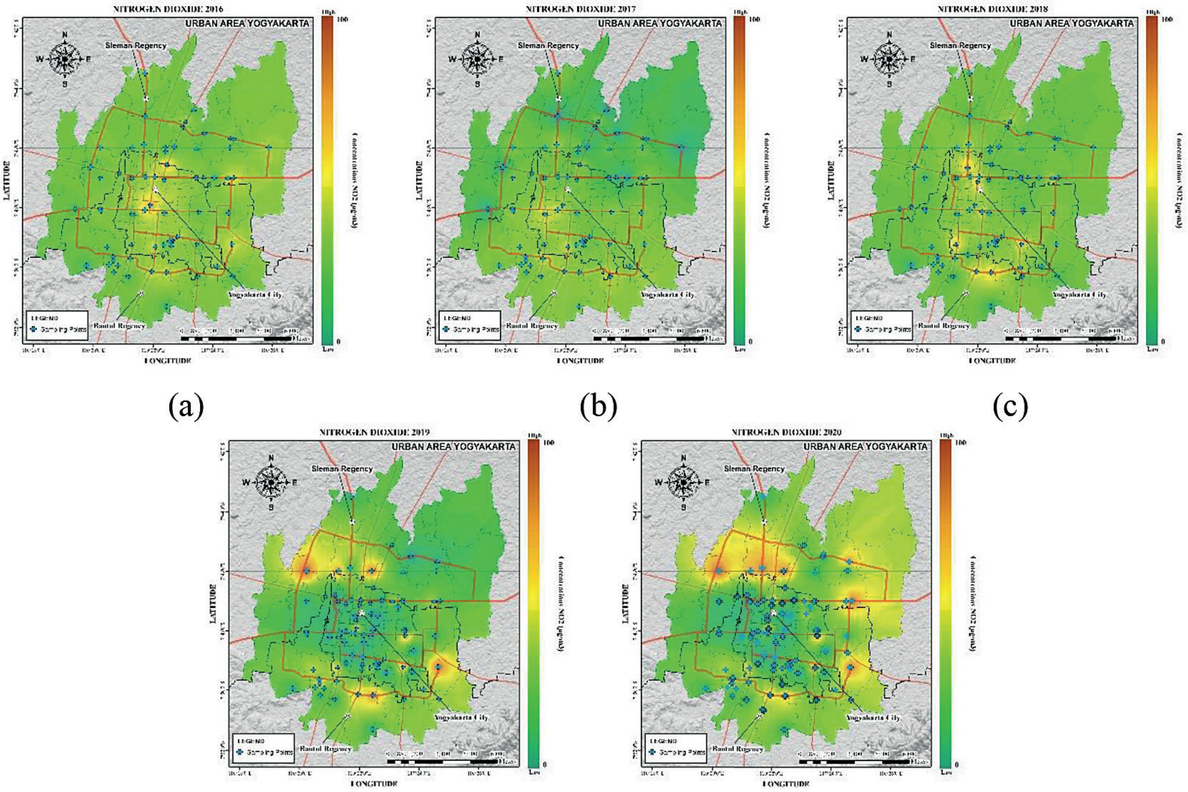
and souvenirs located in front of the Janti Ruko adjacent to the Gedongkuning Flyover Three intersection. Therefore, the number of vehicles at certain times will increase at each measurement point. The more the vehicles, the higher the levels of NO_2 are. For the maximum value exceeding the quality standard or 400 µg/m^3, found in 2018, (Fig. 6) exhibits the NO_2 concentration distribution. According to Figure 6, the concentration of NO_2 before pandemic was relatively in the middle range comparing to the pandemic period. However, the concentrations between pandemic are high in some points and in the green color range in several points. It was shown that some areas decrease the concentration during the pandemic because of decreasing the amount of vehicles.

ISPU distribution

Distribution of SO_2

Determination of the level of climate comfort for humans using the DI method produces varying values. The DI value was obtained from daily data of air temperature (°C) and relative humidity (%). The daily values of each parameter are averaged into monthly values.

The ambient air quality data processing results are processed by looking at the state of the ISPU at the monitoring point. The calculation of the ISPU value for the distribution of SO_2 in 2016 has 5 points that have an ISPU value of medium category or around 7.6%. Meanwhile, 61 points are debited with green, or about 92.4% of ISPU quality is categorized as healthy. Calculating the ISPU value, the SO_2 distribution in 2017 has 7 points, having the ISPU value in the unhealthy category or around 10.6%. In addition, it has 10 points or about 15.2% in the medium category, and there are 49 green dots or about 74.2%. In calculating the ISPU value for the distribution of SO_2 in 2018, 3 points have an ISPU value in the unhealthy category or around 4.1%. Besides, it has 5 points or about 6.8% in the moderate category, and there are 65 green dots or about 89%. There are 6 points or about 7.2% in the medium category, and there are 77 green points or around 92.8% in 2019. The ISPU calculation in 2020 had 6 points or about 6.6% in the medium category, and there are 85 colored dots green or around 93.4% in 2020. Figure 7 outlines a graph of the distribution of the ISPU quality parameter SO_2 in the Yogyakarta urban area.



(a) (b) (c)

(d) (e)

Figure 6. Distribution pattern of NO_2 in years; (a) 2016; (b) 2017; (c) 2018); (d) 2019 and (e) 2020

On the basis of SNI: 03–6572–2001, the ideal air temperature conditions for tropical areas, especially for Indonesians are divided into three categories, namely cool comfortable (20.8°C–22.8°C), optimal comfort (22.8°C–25.8°C), and warm comfortable (25.8°C–27.1°C). According to the DI value, the comfortable category occurs in July and August, while the uncomfortable category occurs in September – June. The average DI value in Yogyakarta is 24.97°C, which is included in the optimal comfort category. However, overall from the results of monthly calculations, it can be concluded that most (more than 50%) of the people of Yogyakarta City feel uncomfortable with the existing thermal conditions. The index values that do not meet or exceed the threshold can cause discomfort and trigger heat stress in the community when outdoors.

The SO_2 exposure by living things, especially humans, will affect the human health. The ISPU index (Fig. 7) with a good category of 0–50 has the potential to be exposed to the SO_2 gas, and there is a mixture with O_3 for 4 hours in a row, which will result in several plant species being harmed. For the moderate category with an index value of 51–100, plants were affected, but the time is less than 4 hours in a row. In the ISPU category 101–200 or unhealthy, there was an effect on increasing the smell that can cause poisoning in living things. The ISPU value in the range of 201–300 will be sensitive to humans, especially for the individuals who already have asthma and bronchitis. In turn, ISPU > 300, categorized as a hazard, will severely affect the entire population (Kurniawan, 2017).

Distribution of CO

The CO monitoring at Yogyakarta Urban Area is located at intersections, flyovers, and bus terminals. These locations are places for inter-city or provincial vehicle traffic to go to Jogja or vice versa. The overall distribution of ISPU in 2017 was good, which is around 100%. Furthermore, this can be interpreted that the CO condition in 2016 was healthy. The distribution of ISPU in 2018 was in the unhealthy category, which is 8 points or about 11%. Furthermore, there was medium category or totaling 4 points or about 5.5%. There are 61 green dots, categorized as healthy, with a total of approximately 83.6%. The distribution of ISPU in 2019 has a blue color in such a way that it can be interpreted in the medium category with a total of 4 points or around 1.2%. Additionally, there are 82 green dots, categorized as healthy with a total of about 98.8%. Therefore, the overall ISPU distribution of points is green, about 100%. It can be interpreted that the CO condition in 2020 was healthy, which happens because of the COVID-19 pandemic that occurred in 2020. Therefore, all people must continue to do activities at home. Figure 8 shows the percentage of ISPU by CO parameter in the Yogyakarta Urban Area.

The effect of the CO air quality parameter on the health of humans and living creatures can be seen based on the ISPU value. The concentration of the CO gas in the ISPU Index category 0–50 does not affect living things. The ISPU value in the moderate category or ranges from 51–100 will cause a change in chemical processes in blood but is not detected. The ISPU value of 101–199 is categorized as unhealthy, because there is an increase in the CO gas. As a result, it can cause an

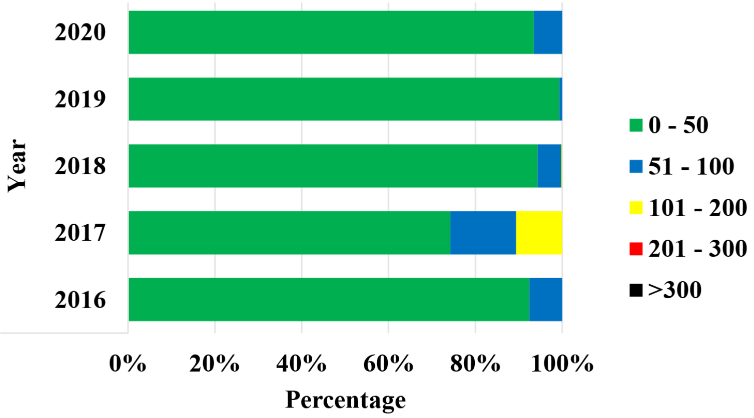


Figure 7. Percentage of Yogyakarta urban area based on ISPU of the SO_2 value

increase in cardiovascular risk by a smoker who has heart disease. The ISPU value in the range of 200–299 is categorized as unhealthy for smokers, will increase cardiovascular risk, and weaken the body significantly. Meanwhile, ISPU values ranging from >300 can have a dangerous impact on all living things (Kurniawan, 2017).

Distribution of NO_2

The overall ISPU distribution of points is green, about 100%. Therefore, it can be interpreted that the conditions of NO_2 in 2016, 2017, and 2018 were categorized as good, and there is no effect on these parameters. The distribution of ISPU in 2019 was all green, i.e., 78 points or around 94%, and there are 5 points or about 6%, which have the ISPU values between 51–100. As such, they are in the medium category. The overall distribution of the ISPU points is green, which is about 98.6%. For the distribution of ISPU in 2020, all of the points are green, which is 83 points or approximately 91.2%. There are 8 points or around 9.3% having an ISPU value between 51 and 100, placing it in the medium category. Figure 9 outlines the percentage of ISPU values from Parameter NO_2

The ISPU index in a good category ranges from 0–50. Under these conditions, the exposure to NO_2 will cause an odor. The ISPU index ranges from 51–100 with a medium category, which will cause a more concentrated odor. The ISPU index from 101–200 is included in the unhealthy category, and thus the odor increases and becomes sharper. This condition can affect humans, namely, asthmatics reactivity in the vessels in the throat, and are categorized as very unhealthy. Between 201 and 300 will have an impact on the sensitivity by the patients who have asthma and bronchitis. Meanwhile, the ISPU value is categorized as dangerous with a value >300.

International standard analysis

The World Research Institute (WRI) noted that until early 2018, Indonesia was included in the list of the ten countries with the most significant greenhouse gas emissions in the world. The

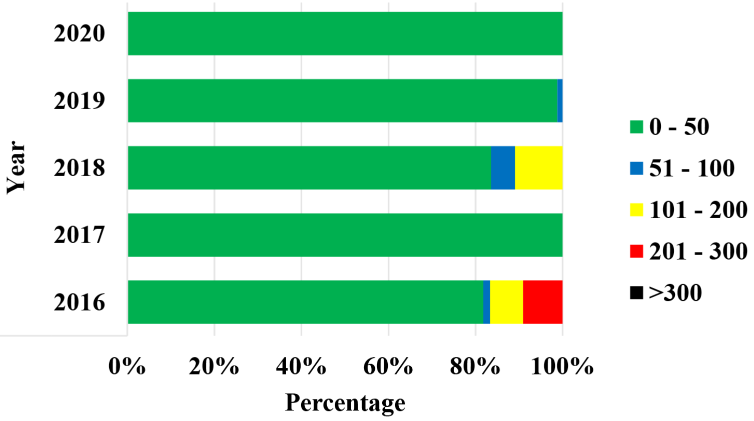


Figure 8. Percentage of Yogyakarta urban area based on ISPU of the CO value

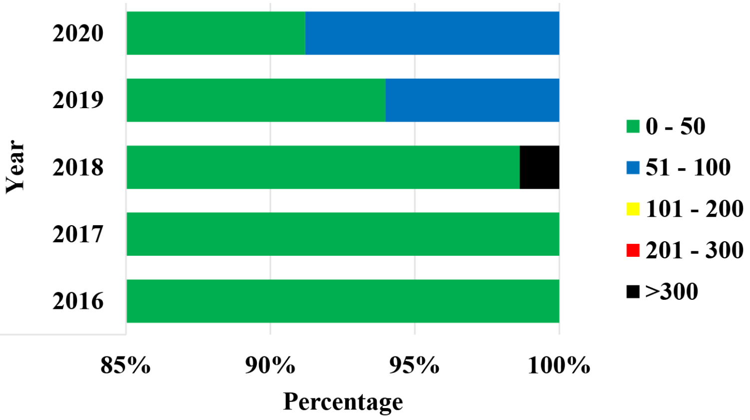


Figure 9. Percentage of Yogyakarta urban area based on ISPU of NO_2 valuee

recorded greenhouse gas emissions produced in the country amounted to 965.3 Mt CO_2, equivalent to 2% of world emissions. The majority of Indonesia's greenhouse gas emissions are from the energy sector, located in urban areas, and have a relationship with ambient air quality conditions in this study.

The relevance of air quality conditions in the study area to international conditions can be analyzed based on international standards. The World Health Organization (WHO) has just issued the Global Air Quality Guidelines replacing the 2005 guidelines. This study concludes that the air quality conditions based on the new WHO standards continue to show positive results, i.e., increasing the coverage of urban areas that meet the quality standards

Table 1 shows that with the NO_2 parameter initially in 2016, most locations did not meet the quality standard (66.67%). Furthermore, there were fluctuations, and finally, in 2020, the situation could be reversed, and therefore most of the locations met the quality standard (62.64%). Meanwhile, for SO_2 and CO, the conditions were mainly fulfilled from the beginning, but the scope expanded in 2020. The SO_2 parameter in 2016 met the quality standard at 74.24% of locations, and in 2020, it increased to 85.71%. The CO parameter in 2016 met the quality standard at 81.82% of locations, and in 2020, it increased to 100%. This condition is predicted to occur due to the effects of the pandemic, where the human and business activities were reduced drastically.

DISCUSSION

Sulfur dioxide or SO_2 is one of the gases produced during a fossil combustion process in power plants and other industrial facilities and when fuels are burned in mobile sources such as locomotives, ships, and other devices. SO_2 is a pollutant from industrial sources; it has the properties of a precursor of H_2SO_4, a component of aerosol particles that can change the level of acid rain deposits, which may affect the climate. The main sources of SO_2 are coal-fired power plants, burning fossil fuels, and volcanoes (Jacobson, 2002).

Sulfur dioxide (SO_2) is a colorless gas, which has a noxious odor and stings. It is also very irritating to the skin, non-flammable and explosive. Therefore, in an activity such as waste treatment, which involves sulfur in copper, zinc, and iron, SO_2 gas is emitted. In other words, when people burn solid waste, this results in the SO_2 emissions (Elmina, 2016). However, the distribution of human-made pollutants, particularly SO_2, is generally uneven (Fitriana, 2019). The main source of the SO_2 pollution is not from transportation but stationary combustion (electric generators and machines), and therefore the second source of SO_2 pollution is industrial processes (Wardhana, 2016).

Carbon monoxide (CO) is an odorless, colorless, or tasteless gas and is produced to about 6% by the exhaust gases of motor vehicles. If the value of the ambient air quality is close to the quality standard, then the location coincides with a terminal and is close to the flyover. The analysis shows that the highest CO levels are on the way

Table 1. Recapitulation of ambient air quality based on WHO quality standards

Parameters and Criteria	Percentage of sample point per year (%)				
	2016	2017	2018	2019	2020
NO_2					
Meet quality standard	33.33	28.79	43.84	69.88	62.64
Does not meet quality standards	66.67	71.21	56.16	30.12	37.36
Total	100	100	100	100	100
SO_2					
Meet quality standard	74.24	57.58	82.19	83.13	85.71
Does not meet quality standards	25.76	42.42	17.81	16.87	14.29
Total	100	100	100	100	100
CO					
Meet quality standard	81.82	100.00	83.56	98.80	100.00
Does not meet quality standards	18.18	0.00	16.44	1.20	0.00
Total	100	100	100	100	100

in and out of the terminal in the morning, as the roads are packed with large numbers of vehicles. This shows that the highest CO value is measured during holidays when there is a tendency for more vehicles to be on the road. The factors that influence the level of CO in the ambient air are humidity, temperature, wind speed, and the study location. In the air pollution system, the intensity of the pollutants emission is released into the atmosphere, the latter being the receiving medium. As a result, the atmosphere can spread (dispersion) and dilute (dilution). The terminal state is open and located in flat lowland, and the wind speed is high enough to cause the CO to disperse (dispersion) and quickly disappear from the location. Furthermore, with the presence of large trees in the terminal, the CO Gas can also be diluted (dilution). Atmospheric dispersion is excellent in open areas, and therefore polluting gases such as CO do not linger in a particular place for long.

The CO levels in urban areas are very different and are influenced by several community activities, especially the use of motorized vehicles. The increase in the number of vehicles leads to an increase in the demand for fuel oil, especially gasoline and diesel. The incomplete combustion process can cause high gas emissions. Therefore, an increase in traffic can reduce the air quality and increase the air pollution in the form of the CO gas (Ratnawati, 2010). Subsequently, the CO monitoring can then be carried out in the Yogyakarta Urban Area at intersections, flyovers, and bus terminals, which serves as transport nodes for inter-city or provincial vehicle traffic on the way to Jogja or vice versa. More CO is produced in large cities, which means that the recorded levels are relatively high (Saputra, 2019).

Air quality often decreases and changes due to human activity, which is reflected in physical and chemical properties. Chemical changes can be manifested in a decrease or increase in chemical constituents in the air, commonly referred to as air pollution, one of these chemical components is NO_2. Nitrogen gas is oxidized to the NO_2 gas. The number of vehicles in a certain area influences the concentration of NO_2. This result was later verified by Sihayuardhi et al. (2021), there was a decrease of transportation amount and traffic ratio to road capacity in Yogyakarta urban area between 2019 until 2020. This is because of the pandemic that makes people stay at home while working and schooling. Besides, this study proves that spatial modeling with the Inverse Distance Weight (IDW) method has good accuracy and that the model of the distribution of air quality is easier to map. Furthermore, IDW has the advantage of being able to map a distribution that exceeds the minimum data, which is 14 (Yasrebi, et al., 2009). IDW has a high interpolation value from the Kriging and Spline method and has a good accuracy value (Phachomphon, 2010; Gong, et al., 2014). On the basis of the research using the fuzzy clustering model,) the fuzzy technique showed no superiority over the tested data type (Thomas, et al., 2021).

Spatial variation analysis carried out showed the distribution patterns based on the homogeneity of regional characteristics and are, therefore, a valuable tool for policymakers (Fanelli, et al., 2020). This study also creates spatial distribution patterns related to ambient air quality, which can be used as policy material for monitoring and managing ambient air quality, especially in urban areas.

It is interesting to develop future research by consulting the results of this study with other aspects such as population density, transportation density, industrial location, and human mobility. This occurs, and as a result, more dynamic and comprehensive spatial projections and modeling can be carried out. A multi-approach methodology for research with an intrinsically interdisciplinary character has proven to be an effective way to analyze the complexity of environmental problems (Teodoro, et al., 2021), including ambient air quality.

The presence of vegetation contributes to the quality of the environment in urban areas. However, population growth and urban development have led to land conversion with less vegetated areas. In 1999, most areas belonged to the very dense vegetation class, while in 2019 they belonged to the low vegetation class (Zaitunah, et al., 2021). These findings provide reliable information in selecting the best agricultural management practices, which simultaneously increase agricultural productivity and reduce the GHG emissions, enabling climate-smart agriculture (Macharia, et al., 2021). An integrated regional collaboration is required to meet the challenges of climate change (Beni, et al., 2021).

The COVID-19 lockdown has significantly reduced air pollution. The use of biofuels to generate energy and electricity has also been shown to reduce the release of air pollutant emissions (Rita, et al., 2021). Economic activity will resume shortly after the pandemic, and the situation could change. Therefore, this study also describes the possible ways to achieve long-term environmental benefits. Appropriate implementation of the proposed strategy is expected to support global environmental sustainability (Ruma and Ul, 2020). Meanwhile, high $PM_{2.5}$ concentrations are associated with low relative humidity and strong wind conditions in spring. The results show seasonal variations in the $PM_{2.5}$ concentrations and demonstrate the need for future work to understand the effects of air pollution on human health (Romero, et al., 2020).

The results of this study are in line with the research which concluded that there was a decrease in the NO_2 concentrations in India between 2019 and 2020 (Biswal, et al., 2020) and also in Guangzhou, China that the concentrations of SO_2, NO_2 and CO were noticed at the lowest value in second period of the lockdown (Wen, et al., 2022). Besides that, in Ghaziabad and Patiala, India, NO_2 was observed as the most significant reduction during the pandemic with range 3–79% (Kumari, et al., 2020). This is due to the limited human activity during the pandemic. In the absence of significant activity, contributions from multiple sources were estimated, and emissions from biomass combustion were identified as the main source of tropospheric NO_2 during the lockdown. These findings provide an opportunity to understand the mechanisms of the NO_2 emissions through air quality modeling and management strategies. The SO_2 and CO parameters can be analogous to the results for the NO_2 parameter. In this study, the air quality modeling for NO_2, SO_2, and CO parameters was followed up.

CONCLUSIONS

On the basis of the results of research and discussion, it was found that the model fluctuates when analyzing the distribution of air quality with the SO_2, CO, and NO_2 parameters but tends to remain stable, both before and during the pandemic. The ISPU index can be calculated by measuring the SO_2, CO, and NO_2 parameters in the urban area of Yogyakarta. Additionally, the SO_2 parameters have an ISPU value of 88.92% with a range (0–50), then 8.44% with a range (51–100), and 2.64 % with a range (101–200). The CO parameter with a total number of 379 monitoring points from 2016 to 2020 has an ISPU value of 93.4% with a range (0–50), then 1.6% with a range (51–100), then 3.4% with a range (101–200), and 1.6% with a range (201–300). The NO_2, parameters with a total number of 379 monitoring points from 2016 to 2020, have an ISPU value of 96.6% with a range (0–50) and 3.4% with a range (51–100). On the basis of the latest WHO quality standards, it can be seen that the NO_2 parameter did not meet the quality standards in most of the locations in 2016 (66.67%). There were fluctuations and in 2020 the situation was finally reversed, most locations meet quality standards (62.64%). While the conditions for SO_2 and CO were largely met from the beginning, the scope was expanded in 2020. In 2016, the SO_2 parameter met the quality standard at 74.24% of locations, and in 2020 increased to 85.71%. The CO parameter met the quality standard at 81.82% of locations in 2016, and in 2020 it increased to 100%.

On the basis of the above-mentioned conclusions, recommendations for further studies can be implemented by adding data. The addition of data can be performed by direct testing at several monitoring points, and therefore the results of the analysis will be more comprehensive. In addition, it is necessary to add monitoring times related to the parameters in order to facilitate the calculation of the ISPU index. On the basis of this study, air quality modeling for future predictions can be continued as a further research topic. Therefore, it is necessary to continue the study of air quality management strategies that meet the post-pandemic quality standards.

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