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Analysis of Air Quality Index Distribution of PM_{10} and O_3 Concentrations in Ambient Air of Medan City, Indonesia

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ABSTRACT: *Development of industries and increase in transportation usage directly affect air quality. Some pollutants have negative impacts on human health and the environment, such as particulate matter 10 microns (PM_{10}) and ozone (O_3). Distribution of PM_{10} and O_3 concentrations from various emission sources in urban areas provide basic information to facilitate development of policies, programs and regulations related to air pollution control. This study aims to map and analyse the air quality index distribution of PM_{10} and O_3 in the city of Medan, Indonesia. This research was conducted by sampling PM_{10} and O_3 at 12 sampling points throughout the city. The concentration of PM_{10} was measured using laser dust monitor model LD 1, while the concentration of O_3 was measured using impinger and chemiluminescent analysis. The results showed that the air quality index obtained was from 23 (good) to 155 (unhealthy) for PM_{10}, and from 8 (good) to 87 (medium) for the O_3 parameter. The mapping of air quality index distribution for PM_{10} and O_3 was done by using Surfer 10 to illustrate the distribution of areas with the unhealthy category for PM_{10} and the medium category for O_3 located in Medan Belawan sub-district. Air pollution control can be done by applying clean technology for the industry sector and mass transportation for transportation sector.*

Keywords: Air quality index, distribution, mapping, O_3, PM_{10}

1. INTRODUCTION

Air pollution occurs when the presence of pollutant parameters changes the function of air, thus disrupting the activity of living things. The most dominant

pollutants affecting human health are particulate matter 10 micron (PM_{10}), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO) and ozone (O_3). The pollutants are increasing in line with the industry development and the population growth.

PM_{10} is one of the causes of pneumonia or asthma on children and cardiovascular disorders on the elders.[1] A research conducted in the United States showed that high PM_{10} concentrations in ambient air produce significant and negative impacts on adults.[2] In addition, particulate diameter also affects the respiratory tract function. The smaller the particulate diameter, the greater the risk exposed to the receptors.[1,3–5]

O_3 is a secondary pollutant formed due to precursors such as NOx, volatile organic compounds (VOC) and sunlight aid. The presence of O_3 in the ambient air may cause a negative impact on human health and damage to ecosystems and agricultural land.[6–8] Excessive ozone in the air can cause respiratory problems, trigger asthma, reduce lung function and cause lung disease. Several studies have reported that the daily mortality rate increase by 0.3% and 0.4% for heart disease, per 10 $\mu g\ m^{-3}$ of increased ozone exposure.[9]

The condition of ambient air quality in the city of Medan, Indonesia has also decreased due to the increasing of vehicle mobilisation and is directly proportional to the increase in population. The increasing number of vehicles in Medan affects mainly the public health. Based on the data, one of the 10 most suffered diseases by the residents of Medan in the last five years is respiratory infection, i.e., acute respiratory infection (ARI). The number of ARI patients in 2014 was 221,635 people or approximately 10% of the total population of Medan.[10]

This study aims to map the concentration distribution and index of ambient air quality of Medan. Therefore, the analysis covered the most dominant areas polluted by PM_{10} and O_3 pollutants. The mapping of the index distribution of ambient air quality can be used as consideration basis for the government in implementing the control and management planning of urban air.

The study involves 12 sampling points throughout the city representing transportation, industry, trade, urban and residential sources. The parameters studied in this research were PM_{10} and O_3. The selection of PM_{10} and O_3 parameters was due to their chemical and physical characteristics.[1]

Medan has four air pollution monitoring stations which have been in inactive status since 2012. Previous studies explained that the spatial modeling distribution

of pollutants can help to estimate the concentration of pollutants in areas that do not have air pollution monitoring stations. In addition, the studies can identify areas that exceed air pollution standards. Furthermore, spatial modeling of pollutant distribution can be utilised for exposure assessment and epidemiological studies.[11–13]

2. EXPERIMENTAL

2.1 Determination of Number of Samples and Sampling Locations

Determination of the number of sampling points was done using an approximation curve.[14] The population of Medan is 2,210,624 people with low pollution levels. Based on the relationship between population size and pollution level seen on the approximation curve, it was determined that the number of representative ambient air quality monitoring points was 12 sampling points.[10,15]

2.2 Sampling Method and Tools

PM_{10} samples were taken by using laser dust monitors with laser light sensor method from photodiodes. Meanwhile, O_3 samples were taken with impinger and analysed in the lab with chemiluminescent method. The chemiluminescent method involves the ozone gas reacting with acetylene to form the aldehyde and releasing light, while the intensity of the light is measured with a photomultiplier proportional to O_3 concentration. Sampling was done at 12 different points by recording the coordinates and counting the type and number of vehicles by using a counter. The sampling result in the form of the concentration of each point was plotted in the Surfer 10 program to obtain the distribution picture of PM_{10} and O_3 air ambient concentration in Medan.

2.3 Data Sampling Analysis

PM_{10} and O_3 concentrations in the ambient air in μg m^{-3} were converted into the air quality index values that correspond to the Decree of the Head of the Environmental Impact Management Agency no. Kep-107/Kabapedal/11/1997 on Technical Guidelines Calculation and Reporting Information, as well as the Air Pollution Index (API) standards. Calculating the API (I) can be done using Equation 1:

$$I = \frac{Ia - Ib}{Xa - Xb}(Xx - Xb) + Ib \quad (1)$$

where *Ia* and *Ib* are API upper limit and lower limit, respectively. The parameters *Xa*, *Xb* and *Xx* represent ambient upper limit, ambient lower limit and concentration of measured gas. The air quality index value obtained from the calculation was determined according to its category, as shown in Table 1.

Table 1: Numbers and air pollutant index categories.

No.	Index	Category
1	1–50	Good
2	51–100	Moderate
3	101–199	Unhealthy
4	200–300	Very unhealthy
5	>300	Dangerous

Source: Bapedal[16]

Calculations of air quality index were then plotted to Surfer 10 and overlaid with the administrative map of Medan to generate the air quality index map of each region in the city. The distribution map of the ambient air quality index can be used to determine critical areas related to ambient air quality.

In addition, factors resulting high concentrations of PM_{10} and O_3 in the ambient air should also be assessed. Therefore, it is necessary to test the correlation between the number of sources of emissions with ambient air concentration and the influence of meteorological factors such as temperature and humidity to ambient air concentration by using equation that tests the correlation, as shown in Equation 2:

$$R = \frac{n.\sum xy - (\sum x).(\sum y)}{\sqrt{\left(n.\sum x^2 - (\sum x)^2 (n.\sum y^2 - (\sum y)^2)\right)}} \quad (2)$$

where R = correlation, x = dependent variable and y = independent variable.

If the value of R is close to or equal to +1 then the correlation is strongly positive. If the value of R is close to or equal to –1 then the correlation is strongly negative, and if $R = 0$, there is no correlation.

3. RESULTS AND DISCUSSION

3.1 Analysis of Ambient PM_{10} and O_3 Distribution Concentrations

The distribution map of PM_{10} and O_3 ambient concentrations in Medan was completed using the Surfer 10 program. The inputs for this program are the coordinates (longitude and latitude) and concentration values at each sampling point. The map of ambient PM_{10} concentration distribution in Medan can be seen in Figures 1 and 2.

In the figures, the highest ambient PM_{10} concentration value reaches 224 μg m^{-3} and O_3 reaches 206 μg m^{-3} recorded in Medan Belawan sub-district. Comparing this result with the national ambient air quality standard (PP No. 41 of 1999), the PM_{10} concentration has exceeded the quality standard of 150 μg m^{-3}. The concentration of O_3 in the ambient air of Medan still meets the national ambient quality standard of 235 μg m^{-3}. However, comparing with the World Health Organization (WHO) standard, the limit of PM_{10} is 50 μg m^{-3} and O_3 100 μg m^{-3}, some sub-districts such as Medan Amplas and Medan Sunggal exceeded the WHO standards.

High concentrations of PM_{10} and O_3 in Medan Belawan sub-district not only come from motor vehicles but also from the industries. One of the largest industrial areas in Medan is the Medan Industrial Estate (KIM), located in Belawan sub-district. KIM has an area of ± 525 ha with about 335 companies operating. The industries in KIM vary from the palm oil processing, food processing, fertiliser, iron and steel, warehouse leasing and others.

Apart from the industrial activities of Belawan sub-district, high concentrations of PM_{10} and O_3 were also found in downtown Medan. This situation is due to the source of emissions in the area which dominantly comes from transportation. Modes of land transportation in the city of Medan is quite heterogeneous that include motorcycles, motor tricycles, cars, urban transportation, buses, trucks and trains. The increase rate in the number of vehicles in Medan is about 10% per year. Based on traffic analysis, motorcycles are the dominant vehicle type comprising about 50%–60%. However, it should be noted that the distribution of pollutant concentrations is also influenced by other factors such as meteorology, land use and receptors.[17–19]

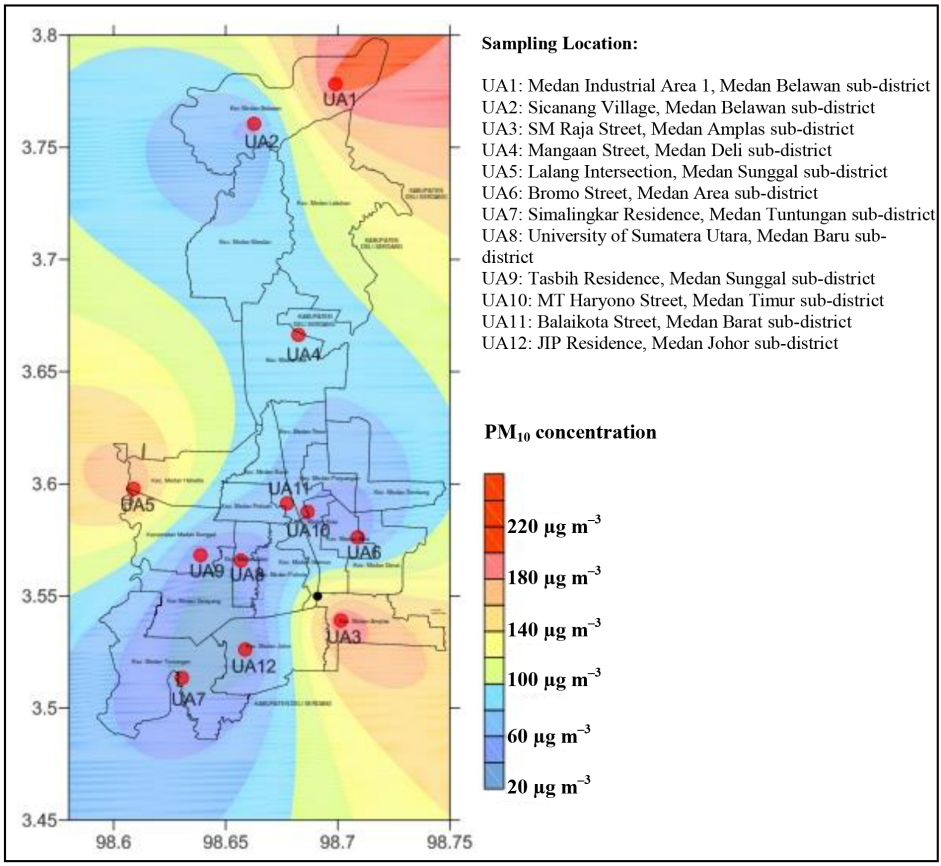

Figure 1: Map of concentration distributions PM_{10} in Medan.

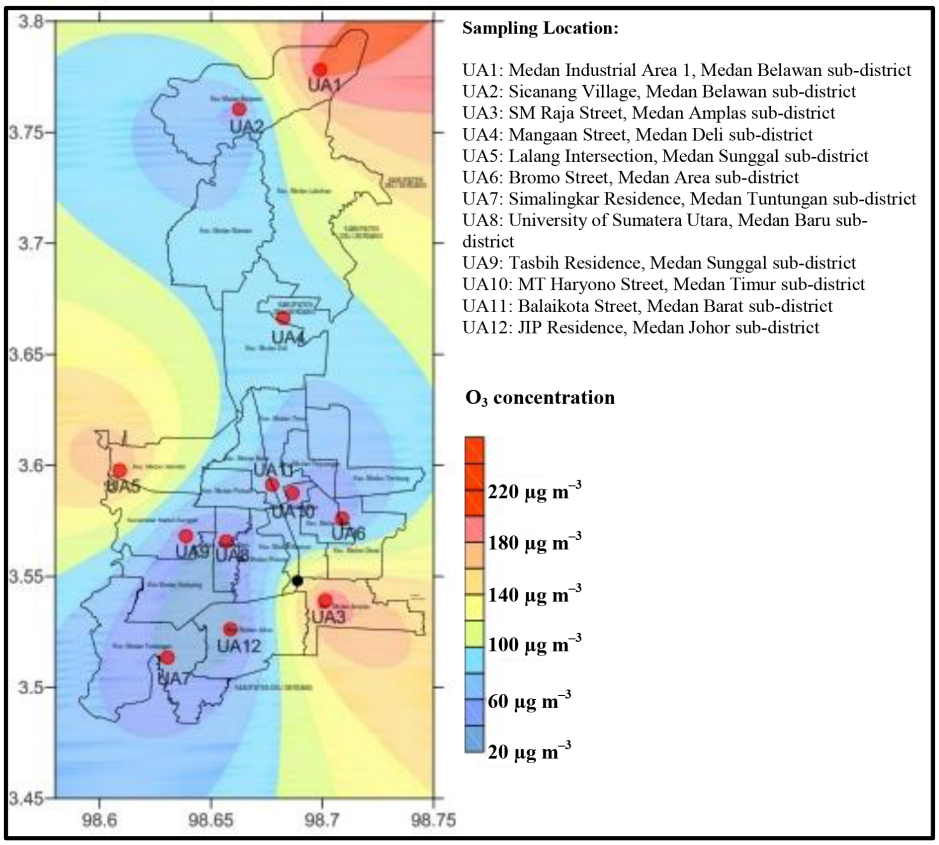

Figure 2: Map of concentration distributions of O_3 in Medan.

3.2 Analysis of Distribution of Air Quality Index for PM_{10} and O_3

An air quality index is a non-unit number. It indicates the air quality condition at a particular place and time. The air quality index is used to provide urban air quality information for the community and local government to create a planning program to control the air quality.

Based on Equation 1, the index of ambient air quality for P_{10} ranges from 27 (good) to 130 (unhealthy), and O_3 ranges from 8 (good) to 87 (moderate). The distribution map of ambient air quality index of PM_{10} and O_3 in Medan is presented in Figure 3. The figure shows that unhealthy indexes were found in some areas such as Medan Belawan, Medan Amplas and Medan Sunggal sub-districts.

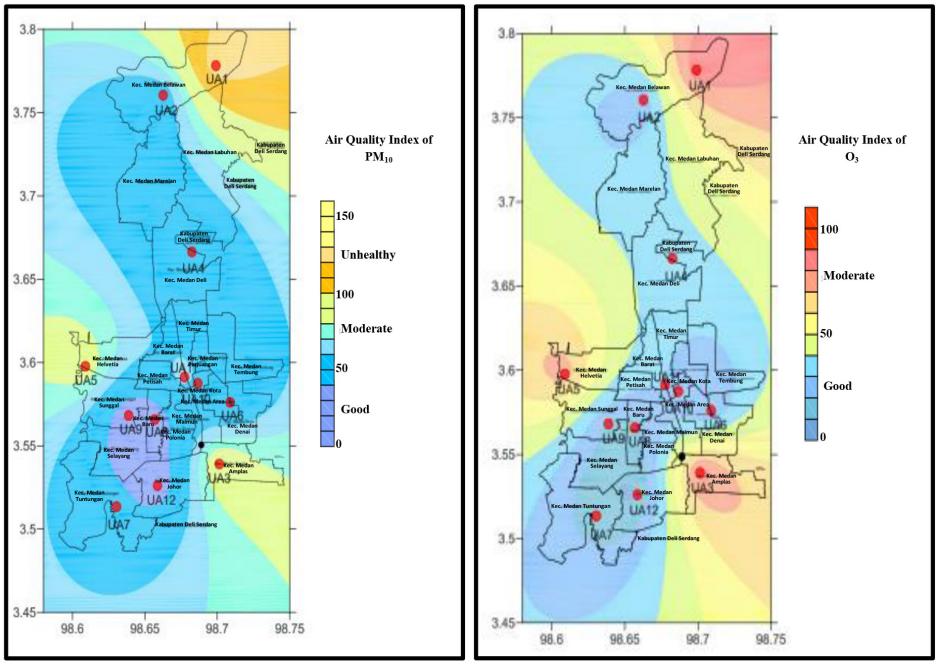

Figure 3: Map of air quality index distribution of concentrations for PM_{10} (left) and O_3 (right).

Directly proportional to the concentration distribution map in Figures 1 and 2, Medan Belawan was found to be in unhealthy category. The unhealthy category indicates that the air quality level is detrimental to humans or living organisms, and can decrease aesthetic value of an environment. The existence of industrial area and the economic activities mainly from transportations contributed to the polluted air of Medan Belawan.

The distribution of air quality index for O_3 parameter is in the medium category level for Medan Belawan, Medan Amplas and Medan Sunggal sub-districts. Ozone is one of the main constituents of photochemical mist. Ozone comes from the vehicles and industrial emissions and VOCs emitted by vehicles, solvents and industries. The ozone concentration profile in a region has a distinct pattern with other locations. This can be caused by the effect of radiation intensity received by the area. The greater the radiation intensity received, the more ozone the area generates.[9] The intensity of solar radiation during sampling at the study site at 11 AM ranged from 400 W m^{-2} to 420 W m^{-2}. This solar radiation intensity rate is the highest in one day of sampling so that the highest concentration of ozone occurs during the day.

The source of pollutant emissions in Medan Belawan sub-district is not only derived from the activities in KIM industrial area and transportation, but also coming from the power plants and ports around Belawan. The existing power plant in Belawan is the largest power plant in North Sumatra, Indonesia with a capacity of 1,077.9 MW.[20] Belawan port is the main port that serves as a cargo terminal and passenger terminal. The activity of loading and unloading of goods reaches 2 million twenty-foot equivalent units (TEUs) per year. This condition causes more emission which in turn releases more pollutants into the ambient air.

If the air quality index is associated with the incidence rate of the disease, data from Medan City Health Office in 2015 found that pneumonia case in the Belawan Health Center has the highest rate of 98.2%, followed by Teladan Health Center (10.2%), Titi Papan Health Center (6.2%), Medan Denai Health Center (5.6%) and Medan Deli Community Health Center (4.9%). The research on the relationship between air quality parameters NO_2, SO_2, PM_{10} with ARI in Medan for 2013–2016 indicated that PM_{10} has a positive correlation with the incidence of ARI.[21] In some European Union countries, the concentration of PM_{10} exceeding 70 $\mu g\ m^{-3}$ (8-h measurements) could cause premature death of about 21,000 persons/year.[22]

3.3 Attempts to Control Urban Air Pollution

The decline of an urban air quality comes from various sources, such as industrial activities, transportation, settlement development, power generation, waste management and others. The initial stage for pollution control is to determine the distribution of pollutants in an urban area. The map of the pollutant concentration distribution and air quality index are preliminary data, in which information on dominant pollutant sources according to location and time can be obtained. Air pollution control can be planned based on the data.

Unhealthy index was found in Medan Belawan, which is home to an industrial area, a port and a power plant requires contamination control. Pollution from industrial activities can be mitigated by applying clean technology, use of environmentally friendly fuel for the production process, and equipping the chimney with air pollution control device.[23,24] Emissions from the transportation sources, on the other hand, can be reduced by implementing mass transportation, testing of vehicle emissions, applying age restrictions for vehicles, usage of low-emission vehicles, and adding green open spaces.[9]

The implementation of mass transportation for several road segments in Medan can reduce CO by ±29.44% and CO_2 by 42.75%.[25,26] In addition to mass transportation, the addition of green open space in Medan needs to be implemented in accordance

to the mandated in Law No. 26 of 2007 on Spatial Planning. The municipality needs to provide as much as 30% of its area as green open space. Existing conditions of green open space of Medan is 1,403,84 ha.[27] Based on the total area of Medan, the city still needs additional green open space around 7,953 ha.[28]

4. CONCLUSION

The results of research and analysis identified a number of locations that are not meeting the ambient air quality standards. Although ambient O_3 concentration still meets the quality standard, the map of PM_{10} and O_3 concentration distribution of ambient air showed that the highest PM_{10} and O_3 ambient concentration is located in Medan Belawan, Medan Amplas, West Medan and Medan Helvetia sub-districts. The indexes of ambient air quality related parameters PM_{10} and O_3 are classified into a range of categories from good to unhealthy levels, where the unhealthy category occurred in the Medan Belawan. Pollutants in Medan Belawan came from various sources such as the KIM industrial aread, a power plant, a port and land transportations. The controls to reduce pollution include application of clean technology, use of control devices, and air pollution monitoring for the industry. Meanwhile, controlling transportation emission can be achieved with mass transportation, use of low-emission vehicles and by adding more green open spaces.

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