Distribution analysis of nitrogen dioxide (NO_2) and ozone (O_3) in Medan city with Geographic Information System (GIS)

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Abstract. The development of industry and the increase of transportation mode are directly proportional to the decrease in air quality. Some important pollutants have a negative impact on human health and the environment such as nitrogen dioxide (NO_2) and ozone (O_3). Distribution of NO_2 and O_3 concentrations from various sources of emissions in urban areas will provide basic information in the determination of policies, programs and regulations related to air pollution control. This study aims to map and analyze the concentration distribution of NO_2 and O_3 pollutants in Medan City. This research was conducted by a manual sampling of NO_2 and O_3 at 12 (twelve) points in Medan City. The sampling of NO_2 and O_3 concentrations is using impinger and then analyzed in a laboratory. The results showed that NO_2 pollutant concentration in Medan City ranged from 21.33-306.19 μg/m^3. Meanwhile, for O_3 concentrations ranged from 19.7-205.8 μg/m^3. Mapping of NO_2 and O_3 concentration using Geographic Information System obtained area that has the highest concentration of both NO_2 and O_3 is in Sub District of Medan Belawan. Furthermore, efforts to control air pollution can be done by applying clean technology to industry and encouraging the use of mass transportation.

1 Introduction

Increased development in urban, industrial and transportation uses leads to an increase in the concentration of air pollutants in ambient air. Contaminants that become air pollutants include carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), and particulates matter 10 microns (PM10), sulfur dioxide (SO_2). The effects of these pollutants may irritate the respiratory tract.

Nitrogen dioxide (NO_2) is an essential trace of atmospheric gas, not only because of its health effects but also because the NO_2: a) absorbs visible light radiation and contributes to atmospheric visibility disturbances; b) as visible radiation absorber it can have a potential direct role in global climate change if its concentration high enough; c) together with nitric oxide (NO) control of the free-headed troposphere oxidation capacity by controlling the accumulation and fate of radical species, including hydroxyl radicals; and d) play an essential role in determining the concentration of ozone (O_3) in the troposphere because

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nitrogen dioxide photolysis is the sole primary initiator of ozone photochemical formation, both in polluted or polluted atmospheres [1].

Ozone (O_3) is a secondary pollutant formed due to precursors such as NOx, VOC and sunlight aid. The presence of O_3 in ambient air can have a negative impact on human health and damage to ecosystems and agricultural land [2-4]. Excessive ozone in the atmosphere can cause respiratory problems, trigger asthma, reduce lung function and cause lung disease. Several European studies have reported that the daily mortality rate increased by 0.3% and for heart disease 0.4%, per 10 μg/m^3 increase in ozone exposure [5].

Medan has 4 (four) air pollution monitoring stations with inactive status since 2012. Previous research [6-8] explains that modeling the spatial distribution of pollutants can help to estimate the concentration of pollutants in areas with no air pollution monitoring stations. Also, it can determine areas that exceed air pollution standards. Furthermore, spatial modeling of pollutant distribution can be utilized for exposure assessment and epidemiological studies.

This study aims to map the concentration distribution of pollutant parameters in the ambient air of Medan City so that the analysis covers the most dominant areas polluted by NO_2 and O_3 pollutants. The mapping of the air ambient air quality index distribution can be used as the basis for consideration for the government in planning the control and management of urban air.

The scope of this research is 12 (two) sampling points representing transportation, industry, trade, urban and residential sources. Parameters studied in this research are NO_2 and O_3. The selection of parameters of NO_2 and O_3 for determining the level of photochemical oxidant (dominant ozone gas) is influenced by the presence of NO_2 (nitrogen dioxide), VOC (Volatile Organic Compounds), light intensity, temperature, wind speed, and air inversion level [9,10].

2 Methodology

Determination of the number of sampling points using the approximation curve [11]. The population of Medan City is 2,210,624 people [12] with low pollution levels [13]. Based on the relationship between population size and pollution level seen on the approximation curve, the number of representative ambient air quality monitoring points is 12 (twelve) sampling points.

The sampling of NO_2 and O_3 is taken with the impinger tool. NO_2 samples were tested in the laboratory by Griess Saltzman method. NO_2 gas is absorbed in the Griess Saltzman solution to form a stable pink azo dye after 15 minutes. The concentration of the solution was determined by spectrophotometry at a wavelength of 550 nm [14].

Meanwhile, an analysis was performed for the O_3 parameter in a laboratory with the chemiluminescent method. The chemiluminescent method is ozone gas reacts with acetylene to form an aldehyde and releases light, the intensity of light is measured with a photomultiplier that is directly proportional to the concentration of O_3 [15].

Sampling is done at 12 (twelve) sampling points by recording the coordinates and counting the type and number of vehicles using counter. The sampling result of NO_2 and O_3 concentration compared with the national ambient air quality standard is Indonesia Government Regulation Number 41 of 1999 and WHO standard air pollution control as in Table 1.

Mapping of NO_2 and O_3 concentration distribution is done by using Arc View GIS. The sampling result is the concentration of each point plotted to the official map of Medan City with GIS program to obtain the description of the distribution of NO_2 and O_3 level of ambient air in Medan City. Based on the isopleth map of NO_2 and O_3 concentration, the highest concentration areas were obtained. The results of this mapping can be used as

baseline data in determining plans, policies, and programs related to ambient air pollution control in Medan City.

Table 1. Air quality standard for NO_2 and O_3 [6,16]

Parameter	Sampling Duration	Government Regulation No 41/1999 (µg/m^3)	WHO (µg/m^3)
Nitrogen Dioxide (NO_2)	1 hour	400	200
	24 hour	150	-
	1 year/annual	100	40
Ozone/Oxidane (O_3)	1 hour	235	-
	8 hour	160	100
	1 year/annual	50	-

Beside the isopleth mapping of NO_2 and O_3 concentrations, the analysis in this study also includes the effect of the relationship between the number of vehicles and meteorological factors (temperature and humidity) to NO_2 and O_3 concentrations. The most influential factor was determined by a correlation test between the number of emission sources with ambient air concentration, and the influence of meteorological factors such as temperature and humidity on the ambient air concentration by Eq. 1.

$$R = \frac{n.\sum xy - (\sum x).(\sum y)}{\sqrt{(n.\sum x^2 - (\sum x)^2 (n.\sum y^2 - (\sum y)^2))}} \quad (1)$$

with R = correlation, X = dependent variable (NO_2 dan O_3 concentration), Y = independent variable (meteorology factor; temperature and humidity). If the value of R is close to +1 or equal to +1 then the correlation is strongly positive. If the value of R is close to -1 or equal to -1 then the correlation is strongly negative and if R = 0 means there is no correlation.

3 Results and discussions

3.1 Analysis of NO_2 and O_3 concentration in Medan city

The research was conducted in Medan City with 12 sample points that representing public community activities such as industry, transportation, trade, office, city center, etc. The name of the sampling location and the location description can be seen in Table 2.

The sampling result of ambient air concentration for NO_2 parameter can be seen in Fig. 1. Based on Fig. 1, it can be seen that the concentration of NO_2 in Medan City is still below the ambient air quality standard, namely Government Regulation Number 41/1999. However, when it compared to the WHO standard for NO_2 concentrations in 1-hour measurement which is 200 µg/m^3, then there are 2 (two) locations that exceed the quality standards of UA-1 and UA-3. The highest value of NO_2 concentration exists at the point of UA-1. UA-1 point is the representative of the industrial area in Medan City located in Medan Belawan Sub-district, while UA-3 comes from transportation activity located at SM Raja Street, Medan Amplas Sub-district. The main sources of both locations are industry

and transportation. The higher the amount of production and high traffic volume the higher the NO_2 concentration contained in the ambient air.

Table 2. Name of ambient air quality sampling location in Medan city.

Symbol of sampling location	Sampling location	Coordinate		Type
		North	East	
UA-1	Industrial Area of Medan	03°46′41.8″	98°41′56.5″	Industry
UA-2	Sicanang Village	03°45′37.9″	98°39′45.5″	Mangrove area
UA-3	SM Raja Street	03°32′21.0″	98°42′05.0″	Transportation
UA-4	Mangaan VIII	03°39′59.3″	98°40′56.9″	Industry
UA-5	Pinang Baris Street	03°35′52.1″	98°36′32.1″	Transportation
UA-6	Bromo	03°34′34.2″	98°42′32.0″	Settlement
UA-7	Simalingkar	03°30′48.8″	98°37′49.7″	Settlement
UA-8	University of Sumatera Utara	03°33′57.1″	98°39′24.5″	Education
UA-9	Tasbih	03°34′05.8″	98°38′19.6″	Settlement
UA-10	Medan Mall	03°35′15.4″	98°41′11.5″	Trading
UA-11	Merdeka Walk	03°35′28.8″	98°40′38.6″	City center
UA-12	JIP	03°31′34.3″	98°39′31.3″	Settlement

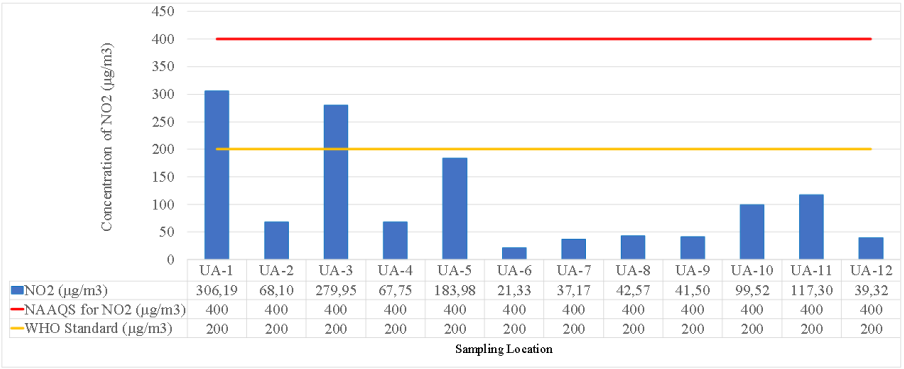

Fig. 1. Concentration NO_2 in Medan.

When the NO_2 concentration of 20 ppm is inhaled, it will cause death to the human. N NO_2 with a concentration of 5 ppm will cause an acute effect when exposed for more than 15 minutes. The 3 ppm concentration can be tolerated by the body in a short time. Severe health effects from continuous exposure to NO_2, include eye irritation, throat, respiratory

irritation, and trigger asthma for people living with asthma. The most potent acute effects are pulmonary edema (pulmonary damage) and heart disease [1, 17-22].

The range of NO_2 concentration from several sampling sites in this research that was 21.33 µg/m^3 (0.012 ppm) to 306.19 µg/m^3 (0.17 ppm). This shows that the one hour exposure had not given significant impact against human health. Nevertheless, from the results it can be stated that the existence of NO_2 in the ambient air of Medan City has decreased urban air quality. Fig. 2 shows results of ambient air concentration for the O_3 parameter samples.

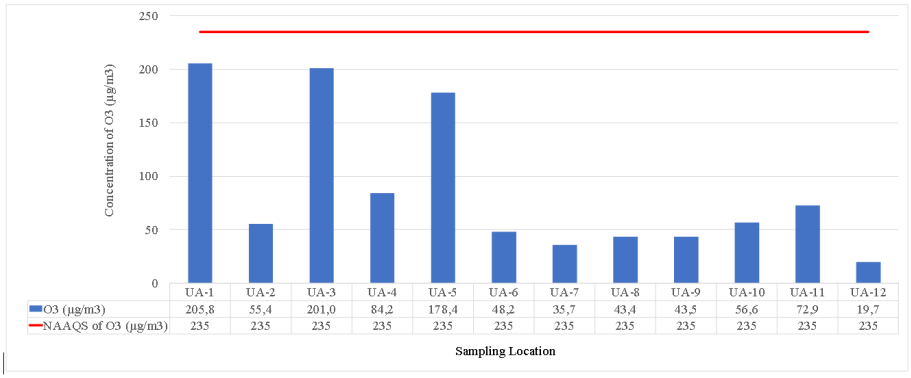

Fig. 2. Concentration of O_3 in Medan city.

The national ambient air quality standard for O_3 concentration in PP 41/1999 for 1-hour measurement is 235 µg/m^3. Fig. 2 shows that the concentration of O_3 in Medan City is still below the ambient air quality standard. The highest O_3 concentration was at UA-1 of 205.8 µg/m^3. The high concentration of O_3 in UA-1 because the source of O_3 comes from industrial activities and vehicle traffic carrying raw materials for the industrial production process. Also, around the UA-1 location which is one of the industrial areas in Medan City, there are also ports and power plants.

The result of O_3 concentration sampling in the research location as a whole still meets the ambient air quality standard. However, the presence of O_3 with an ozone concentration of 0.3 ppm can irritate the nose and throat. Contact with ozone at a concentration of 1.0 to 3.0 ppm for 2 hours resulted in severe dizziness and coordination in some people who are sensitive. Whereas contact with a concentration of 9.0 ppm for some time may cause pulmonary edema [23, 24]. The O_3 concentration range of research results was obtained 19.7 µg/m^3 (0.01 ppm) - 205.8 µg/m^3 (0.1 ppm). This figure has not caused a direct impact on public health, but the presence of O_3 pollutants in the ambient air for people with asthma will trigger shortness of breath [23, 24]. In some countries, the European Union concentration exceeding 70 µg/m^3 (8-hour measurements) is estimated to cause premature death of ± 21,000 persons/year [25].

3.2 Distribution analysis of NO_2 and O_3 concentration in Medan city with GIS

Initially, distribution analysis of NO_2 and O_3 concentration was conducted by putting coordinate data of twelve sampling location and their NO_2 and O_3 concentration into Arc GIS software to obtain isopleth map of NO_2 and O_3 concentration. The concentration isopleth map is a map that presents the same concentration at points of observation. Based on the isophletic map, areas that have the highest concentration can be determined an air pollution control can be designed in the region.

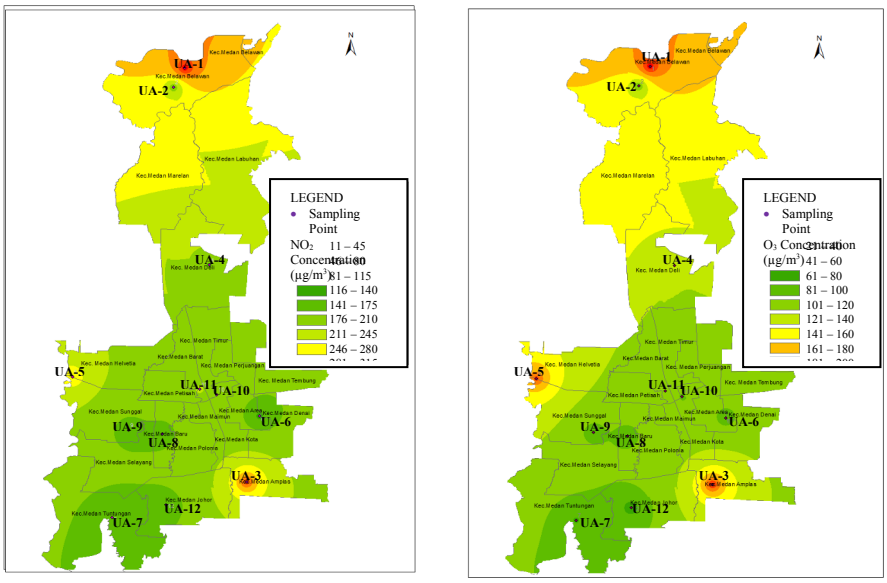

Figure 3. Map of isopleth concentration of NO_2 (right) and O_3 (left) in Medan city.

Fig. 3 shows the isophleth map consists of NO_2 and O_3 concentrations distribution in Medan City. On the isophletic map, the highest concentration is indicated by orange and red color for both pollutant parameters in Medan Belawan, Medan Amplas, and Medan Helvetia subdistricts. The high concentrations of NO_2 and O_3 in these areas are influenced by various emission sources. One of the sources of NO_2 and O_3 emissions in Medan Belawan Sub-district came from industry. The largest industrial area in Medan City is located in Belawan District, Medan Industrial Estate (KIM). Medan Industrial Estate (KIM) has an area of ± 525 Ha with ± 335 companies. The types of industries that exist in KIM vary like the palm oil processing industry, food processing industry, fertilizer industry, iron and steel industry, warehouse leasing and other industries.

Apart from the industrial activities of Belawan Sub-district, the high concentration of NO_2 and O_3 in the middle of Medan City sourced from emissions in urban dominant comes from transportation activities. Type of modes of land transportation in the city of Medan is quite heterogeneous, such as motorcycles, motor tricycles, cars, urban transit, buses, trucks, and trains. An increase in the number of vehicles in Medan City averaged ±10% per year. The dominant vehicle type is the motor that is ±50-60%. However, the distribution of pollutant concentrations is also influenced by other factors such as meteorology, land use and receptors [10, 26].

The source of pollutant in Medan Belawan sub-district is not only derived from the activities of KIM (Medan Industrial Estate) and transportation but also from the operations of power plants and ports around Belawan area. The existing power plant in Belawan is the largest power plant in North Sumatra with a power plant capacity of 260 MW and PLTGU of 817.9 MW [27]. Belawan port is the main port that serves as a cargo terminal, passenger terminal with loading and unloading of goods reaches 2 million TEUs per year. This condition causes more emission sources, the higher the emission load generated and the higher the pollutant in the ambient air.

The O_3 formation other than dependent on O_3 stratosphere also influenced the concentration of NOx, VOC, and the ratio of VOC to NOx [28]. When the VOC to NOx ratio is less than 8 to 10, a decrease in NOx tends to increase ozone formation. If the

VOC/NOx ratio is higher than 8 to 10, a reduction in NOx tends to decrease ozone formation. However, NO_2 and O_3 concentrations in ambient air may change due to various factors (e.g., meteorology, precipitation, and particle gas conversion) [29].

3.3 Influence of meteorological factors on distribution of NO_2 and O_3 concentrations

Distribution of pollutants in the ambient air is influenced by meteorological factors. The influential meteorological factors are wind speed and direction, temperature, humidity, pressure, atmospheric stability, solar radiation [30-32].

In this study observed is the effect of temperature and humidity on NO_2 and O_3 concentrations. The result of analysis with statistic obtained R-value for the relation of NO_2 with temperature is 0.605 and R-value for O_3 relation with temperature is 0.716. This figure states that the correlation between the concentration of pollutants and ambient air temperature is a strong positive correlation. This means that the higher the temperature, the higher the concentration in the ambient air. The results of this study are in line with several other studies suggesting that the temperature is directly proportional to the intensity of pollutants [30,31,33].

Meanwhile, the influence of moisture on NO_2 and O_3 concentration obtained R-value respectively that is -0,525 and -0,665. This figure states that the correlation between pollutant concentrations with ambient air moisture is a strong negative correlation. This means that the lower the moisture, the higher the concentration of pollutants in the ambient air. Humidity is inversely proportional to the concentration of contaminants. [30] states that high relative humidity is usually associated with rainfall. Rain can wash the pollutant in the ambient air so that the concentration of the contaminant becomes low.

3.4 Attempts to control urban air pollution in Medan city

The initial stage for pollution control is to determine the distribution of pollutants in an urban area. Map of distribution of pollutant concentration is preliminary data so that can be obtained information of dominant pollutant source according to location and time. If the inventory has been determined, the air pollution control based on the cause can be planned.

The high concentrations of NO_2 and O_3 in Medan Belawan sub-district come from industrial zones, ports and power plants. An effort to control air pollution following emission sources should be made. For industrial activities can be done with the application of clean technology, the use of environmentally friendly fuel for the production process, equip the chimney with air pollution control device [34]. Meanwhile, for transportation sources can be done by implementing mass transportation, test vehicle emissions, age restrictions for vehicles, the use of low-emission vehicles, the addition of green open space.

The presence of green open space with shady trees can help reduce the amount of ambient air O_3 due to gas phase reaction, uptake in stomata leaves and the presence of antioxidants in the form of volatile isoprenoids. Indirectly the existence of vegetation will affect the microclimate such as temperature and humidity. High humidity will cause the water-soluble ambient O_3 precursors such as NO_2 to decrease. If NO_2 decreases, then the concentration of O_3 in ambient air is formed too little [23, 35].

The addition of green open space in Medan City needs to be upgraded as mandated in Law No. 26 of 2007 on Spatial Planning is as much as 20% green open space and 10% private green open space. Existing condition of green open space of Medan City is 1,403,84 Ha [36]. Based on total area of Medan City still needed 7.953 Ha green open space [37].

4 Conclusions

The result of this study indicate the NO_2 and O_3 concentration in Medan City still meet the standard quality. Map distribution of NO_2 and O_3 concentration of ambient air shows that the highest concentration of NO_2 and O_3 is located in Medan Belawan District, Medan Amplas Subdistrict and Medan Helvetia Subdistrict. Pollutants in Medan Belawan sub-district come from various sources such as industrial fields, power plants, ports, and land transportation. The dispersion of NO_2 and O_3 pollutants is influenced by meteorological factors such as temperature and humidity. The temperature is directly proportional to the increase in the concentration of pollutants in the ambient air while the moisture is inversely proportional to the intensity of the contaminant. The control efforts that can be done is the application of clean technology, the use of control devices and air pollution monitors for the industry. Meanwhile, for sources of emissions regarding land transportation is the use of mass transportation, the use of low emission vehicles and the addition of green open spaces.

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