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Research Article
Estimated Contaminated Area of Air Pollutant from Industrial In Cilegon

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Abstract
Background and Objective: Cilegon has three industrial zones with different types and capacities of fuel as well as the height of different stack. The amount of fuel capacity and the height of the stack used, it is estimated that air pollutants emitted to outside the industrial area. The aim of research was to estimate polluted air polluted area in Cilegon. **Materials and Methods:** Researchers used the analysis of climate data, emission debit, concentrations and dispersion distance of pollutants in the industrial area, while to know the dispersion is measured in several villages in Cilegon. Concentration analysis and spreading distance of air pollutants were used Screen3 software produced by US-EPA, while the estimation of the distribution used continuity equation. **Results:** The result of climate data analysis shows that Cilegon atmosphere stability between extremely unstable until slightly stable. Furthermore, the results of the Screen3 analysis show that at extremely unstable stability the spreading distance of air pollutants is still in the vicinity of the industrial area, whereas the moderately unstable stability until slightly stable spread out to the industrial area. **Conclusion:** Meanwhile, the result of equation continuity analysis within four periods in 3 month shows the different dispersion pattern. From the six emitted air pollutants, the concentration of air pollutants continues to increase i.e., sulphur dioxide (SO_2). In four analysis periods, SO_2 concentrations got increased from 5.41-19.59 µg m^{-3}. Tamansari Village, Kubangsari and Kepuh are polluted villages of air pollution.

Key words: Pollutant emissions, air pollutant distribution, air pollutant concentrations, fuel, pollution

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Industrial area in Cilegon consists of Krakatau Steel, Pulomerak and Ciwandan zones. The industrial zone was used an area of 2,846.89 ha dispersion in Citangkil subdistrict, Pulomerak and Ciwandan. Each zone has different industry types. This difference is visible from the type of fuel used.

Fuel used by different industries is stated as follows: High speed diesel, marine fuel oil, pyrolysis fuel oil, diesel, residues, fuel gas and coal. The large amount of fuel used, it has implications for the variety of air pollutants emitted. Types of air pollutants that spread in Cilegon: Nitrogen dioxide (NO_2), dust, sulfur dioxide (SO_2), carbon monoxide (CO), hydrocarbons (HC) and lead (Pb). The pollutants were assumed to be emitted from the industrial estate. The amount of concentration of each contaminant depends on the capacity of the fuel used.

The fuel capacity used varies from 1-255 t h^{-1}. Diesel fuel was used by PT Chandra Asri with a capacity of 1 t h^{-1}. The largest fuel capacity used is coal. Coal used PT Indonesia Power as a fuel with a capacity of 170-255 t h^{-1}. The larger the fuel capacity used, the greater the concentration of pollutants emitted[1]. The amount of fuel capacity usually directly proportional to the height of the stack used. The greater the capacity of fuel consumption, the higher the stack used[2].

The use of high stack in Cilegon Industrial Estate varied between 10-275 m. Industries using high stacks are in the Pulomerak zone. PT Indonesia Power has seven stacks with a height of 200-275 m. The differences in height use of stacks were implicated in dispersion distance of polluters[3]. The higher the stack used, the more distant the spread of contaminant emitted[4]. The height of the stack used, it is assumed emitted air pollutants spread outside the industrial area.

The spread of air pollutants is related to the state of the atmosphere[5]. The spread of pollutants in the atmosphere involves three major mechanisms of global air movement, turbulence speed fluctuations and mass diffusion due to concentration differences[6]. In this research, pollutant emission analysis uses Gaussian model with area source, while dispersion of air pollutant uses equation of continuity and equation of motion. The equation, developed by the finite volume method for two-dimensional case. Both models are applied to estimate polluted air pollutants in Cilegon.

This research is currently developed from Ruhiat[4] and Ruhiat *et al*.[1]. Both studies have not been discussed about the type of pollutants and polluted areas. In this study, it discussed about the type of air pollutant that tends to be increased and its contamination in a region.

MATERIALS AND METHODS

This study was carried on April, 2016 until May, 2017. The emission measurement was done at industrial area and at the 24 samples point in all area of Cilegon. To analyze the magnitude and distance of air pollutant concentration emitted from industry, the researchers used Screen3 software. The software is made by US-EPA that serves to analyze air pollutant emissions from point or area sources. Furthermore, to know the distribution of air pollutant in a region used continuity equation for unsteady flow. Analysis of air pollutant distribution pattern using Matlab software, while to know its distribution in a region using ArcView software.

The concentrations of air pollutants emitted from each industry were analyzed using Screen3. The software serves to be estimated concentrations and maximum distances from the various atmospheric stability of point sources and source areas[7]. As inputs, data related to emissions sources and meteorological data are required. The data relating to emission sources were stated as follows: Emissions discharge, stack height , diameter, speed and temperature of exit gas and ambient air temperature. Meanwhile, relating to meteorological data, namely: Atmospheric stability and wind speed 10 m above the surface.

To know the stability of the atmosphere, it was used Pasqual-Gifford-Turner (PGT) model. The PGT category includes:

A = Extremely unstable
B = Moderately unstable
C = Slightly unstable
D = Neutral
E = Slightly stable
F = Moderately stable

Furthermore, to calculate the emission debit required data of emission factor and fuel catalyst. The industrial pollutant emission debit is calculated using[8] equation as follows:

$$E = \sum \left(EF_{abd} \times A_{abc} \right) \quad (1)$$

Where:
E = Emission
EF = Emission factor
A = Energy consumption
a, b, c = The type of fuel used

The sector or type of activity and the pollution control technology. The output of Screen3 obtained the concentration and the emission distances emitted from the industry. The data were examined its distribution through the continuity equation.

The continuity equation is formed from the flow pattern by considering the formula of conservation[9]. The continuity equation used is derived from the formula of conservation of the general equation of transport for unsteady flow[10], as follows:

$$\frac{d}{dt}(\rho\phi) + \text{div}(\rho\phi u) = \text{div}(\Gamma \text{grad}\phi) + S_\phi \quad (2)$$

Where:

- ρ = Air density (kg m^{-3})
- Γ = Diffusivity of pollutant (kg $msec^{-1}$)
- u = Wind speed (m sec^{-1})
- S = Source
- ϕ = Air pollutant property (µg m^{-3})

To solve Eq. 2 integrate on the control volume with the time interval from t to t+Δt. The stream fulfills the continuity rules:

$$\frac{d(\rho\phi u)}{dx} = 0$$

Thus, the equation becomes:

$$\rho\left(\frac{\phi_p - \phi_p^o}{\Delta t}\right)\Delta x = \theta\left[\frac{\Gamma_e(\phi_E - \phi_P)}{\delta x_{PE}} - \frac{\Gamma_w(\phi_P - \phi_W)}{\delta x_{WP}}\right] \quad (3)$$

where, θ is the parameter used to evaluate the integralas ϕ_P, ϕ_E and furthermore, Eq. 3 discretization was obtained:

$$\begin{aligned} a_P\phi_P &= a_W\left[\theta\phi_W + (1-\theta)\phi_W^o\right] + a_E\left[\theta\phi_E + (1-\theta)\phi_E^o\right] \\ &+ \left[a_P^o + (1-\theta)a_W - (1-\theta)a_E\right]\phi_P^o + b \end{aligned} \quad (4)$$

where, $a_P = \theta(a_W + a_E) + a_P^o$ and:

$$a_P^o = \rho\frac{\Delta x}{\Delta t}$$

In analyzing the equations, the researchers used implicit scheme with parameter θ = 1 in the case of two dimensions. Discretize the flow of pollutant dispersion into Versteeg and Malalasekela[10]:

$$a_P\phi_P = a_W\phi_W + a_E\phi_E + a_S\phi_S + a_N\phi_N + a_P^o\phi_P^o + S_u \quad (5)$$

where, $a_P = a_W + a_E + a_S + a_N + a_P^0 + \Delta F - S_P$ and:

$$a_P^o = \frac{\rho_P^o \Delta x \Delta y}{\Delta t}$$

After forming the equation on the control volume, the result of Eq. 5 analysis is arranged into a matrix.

To know each coefficient in Eq. 5 used tridiagonal matrix algorithm (TDMA)[11]. Furthermore, an elemination is performed so that the contaminant concentration can be obtained. The resulting pollutant concentration distribution becomes the basis for determining the polluted area[12]. To determine the polluted area the steps are taken: (a) Provision of Cilegon city base map, (b) Digitizing the base map and (c) Overlapping the concentrations of air pollutants on the base map with the ArcView software.

RESULTS AND DISCUSSION

To know the dispersion of air pollutants emitted from the industry, measurements were taken at 24 sample points. This was done to determine the initial condition of pollutant concentration in a region. The pollution concentration monitoring results are shown in Fig. 1.

Based on Fig. 1, the concentration of dust and HC at some sample points, has exceeded the air quality standard. Meanwhile, the concentrations of CO, NO_2, SO_2 and Pb are still below the standard. However, the concentrations of CO and SO_2 at some sample points continue to increase.

The improvement of CO concentration is related to the increasing number of vehicles operating in Cilegon. The result of research is similar with Sood *et al.*[13], that the CO concentration is positively correlated with traffic volume. Meanwhile, the increase of SO_2 concentration as an implication of the large capacity of coal and the high stack used by the industry. To know the amount of SO_2 concentration emitted from the industry, an emission analysis was done using Screen3.

Based on the running Screen3 software program, firstly the researchers analyzed atmospheric stability and emission debit of each pollutant source that exist in industrial area of Cilegon. Then, they put the results of atmospheric stability analysis of Cilegon in the morning, afternoon and evening varies between A-E. This case indicates that the air condition in between the extremely unstable until slightly stable. Meanwhile, the average monthly wind speed ranges from 0.2-4.0 m sec^{-1} with direction from West to East. Furthermore,

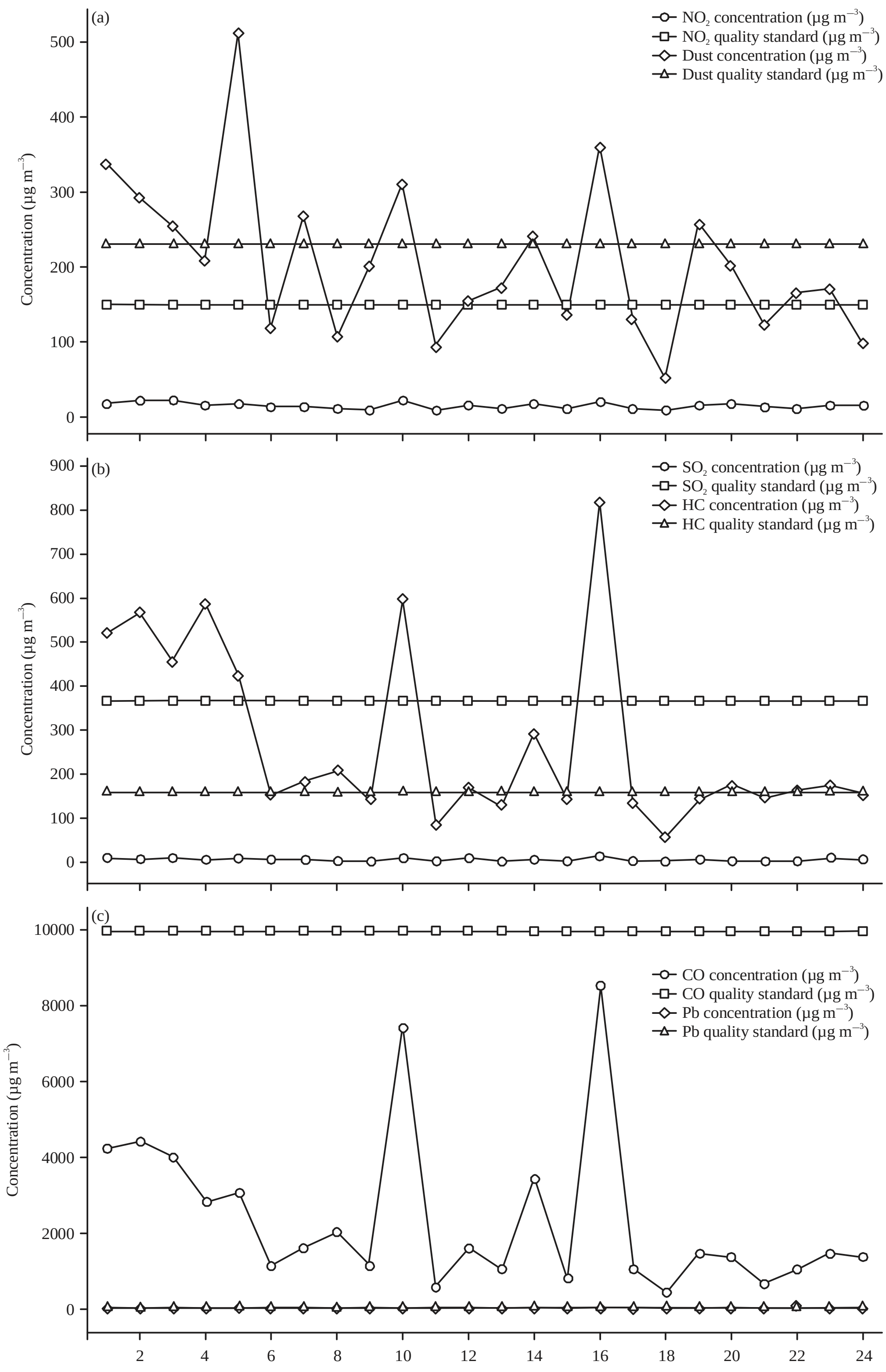

Fig. 1(a-c): Distribution of air pollutants in Cilegon (a) NO_2 and dust pollutants, (b) SO_2 and HC Pollutants and (c) CO and Pb Pollutants

With samples point: (1) Nirmala Optik, (2) Polres, (3) Ramayana, (4) Sumur Wuluh, (5) Bea Cukai Office, (6) Semang Raya, (7) Cikuasa Baru, (8) Cikuasa Lama, (9) Pasar Merak, (10) ASDP Merak, (11) Randakari, (12) Perum KS, (13) Arga Baja Pura, (14) Pabuaran Lor, (15) Kruwuk, (16) PENI, (17) Kelapa Tujuh, (18) Palem Hils, (19) Pelindo, (20) KBS, (21) Pengabuan, (22) Cilodan, (23) Telkom Warnasari and (24) PCI

Table 1: Air pollution emission debits

			Kandungan		Efisiensi		Faktor emisi		Debit emisi	
Nama Perusahaan	Jenis bahan bakar	Jumlah bahan bakar (t/jam)	SO_2 (%)	Carbon (%)	SO_2 (%)	Carbon (%)	SO_2 (kg t^{-1})	Carbon (kg t^{-1})	SO_2 (g dt^{-1})	Carbon (g dt^{-1})
PT Krakatau daya listrik	Residu	80.00	2.75	83.00	0.00	0.00	27.50	830.0	611.11	18,444.44
PT Chandra asri	Solar	1.00	0.45	0.00	0.00	0.00	4.50	0.0	1.25	0.00
	PFO	3.72	0.13	0.00	0.00	0.00	1.25	0.0	1.29	0.00
	MFO	3.76	0.10	86.00	0.00	0.00	1.00	860.0	1.04	898.22
PT Cigading (Pembangkit listrik)	Residu	80.00	2.50	85.00	0.03	0.03	25.00	850.0	555.56	18,888.89
PT Indonesia power										
Unit 1-4	Batu bara	680.00	0.30	49.00	0.00	0.00	6.00	490.0	1,133.33	92,555.56
Unit 5-7	Batu bara	765.00	0.30	49.00	0.00	0.00	6.00	490.0	1,275.00	104,125.00
PT Karkatau steel	HSD	170.70							0.00	0.00
	MFO	444.44	0.10	0.00	0.00	0.00	1.00	0.0	123.46	0.00

Table 2: SO_2 emission concentration

		Stability of atmosphere				
Number		A	B	C	D	E
Wind velocity 2 (m sec^{-1})						
Zona Ciwandan	Candra asri Ciwandan	300.2580	221.5860	168.4548	64.1192	66.7630
Zona KS	KS (HYL) KDL	515.5800	968.6400	799.9200	394.3800	288.3800
Zona Pulomerak	PLTU (1-4) PLTU (5-7)	5057.8000	2124.2000	1369.3000	75.2120	56.3750
SO_2 (µg m^{-3})		5873.6380	3314.4260	2337.6748	533.7112	411.5180

Table 3: Distance distribution of SO_2 from the Pulomerak zone

Stability of atmosphere	High of stack (m)	Diameter stack (m)	Distance of spreading (m)	High of stack (m)	Diameter stack (m)	Distance of spreading (m)
A	200	5.5	1162	275	6.5	1302
B	200	5.5	4332	275	6.5	5390
C	200	5.5	9733	275	6.5	12592
D	200	5.5	18800	275	6.5	18800
E	200	5.5	18800	275	6.5	18800

to calculate the emission discharge used Eq. 1. The results of the analysis with these equations are shown in Table 1.

Based on atmospheric stability data, wind speed and emission debit, then the concentration and dispersion distance of contaminants can be calculated with Screen3. The Screen3 running result based on various atmospheric stability with a monthly average wind speed of 2 m sec^{-1} is shown in Table 2.

Based on the Table 2, it appears that the largest concentration of SO_2 at various atmospheric stability, emitted from the Pulomerak zone. The spacing distances are shown in Table 3.

Based on Table 3 appears that the powers of the Pulomerak zone have the farthest distance of emissions. At stability A the range of air polluters emitted from each zone is almost the same, i.e., ranged from 1000-1090 m. However, at stability E the pollutant distance emitted from the Krakatau Steel zone is only 23% while the Ciwandan zone is only 75% of the distance emitted from the Pulomerak zone. The maximum distance emitted from the Pulomerak zone reaches 18800 m. This means pollutants emitted to outside the industrial estate. The result of research is similar with Sankaran *et al.*[14], that the atmospheric stability conditions in the atmospheric surface layer can control the distance and direction of transport of air contaminants. The results of the model analysis show that on stability A the distribution of air pollutants occurs around the source. Distribution of pollutants away from sources occurs in moderately unstable to slightly stable stability (B-E). The result of research is similar with Ruhiat[4] that the air pollutant emitted from the industrial area spread to outside the industrial area. To detect polluted air pollutant in Cilegon, Eq. 5 was used. In detecting it, firstly done analysis of air pollutant distribution pattern in Cilegon. The pattern of air pollutant distribution based on Eq. 5 for the two-dimensional case as follows:

- Cilegon industrial area is in the Southwest, then for the western node obtained equation:

$$134\varphi_p = 0.01664(\varphi_E + \varphi_S + \varphi_N) + 129\varphi_P^0$$

where, $a_w = 0$ and $S_P = S_U = 0$ because there is no source

- The node positioned between West and East, the equation is obtained:

$$136\varphi_p = 0.01664(\varphi_W + \varphi_E + \varphi_S + \varphi_N) + 129\varphi_P^0 + S_U$$

- The positioned of eastern node, the equation is obtained:

$$134\varphi_p = 0.01664(\varphi_W + \varphi_S + \varphi_N) + 129\varphi_P^0$$

where, $a_E = 0$ and $S_P = S_U = 0$ because there is no source

- The equations were analyzed using Matlab software. The results of the analysis were arranged in a matrix, so that the concentration of air pollutants in an area at any time is obtained

The result of model analysis shows that on the stability of A the distribution of SO_2 occurs in industrial area. The spread of SO_2 from the industrial area to the entire Cilegon occurs in stability B-E. The result of research is similar with Narayanachari *et al.*[15], that the concentration pollutant is less in magnitude for the neutral atmosphere when compared to the stable condition. In stability B with wind speed of 1 m sec^{-1} high SO_2 concentration, with 13 µg m^{-3} upwards occurred in four sub-districts, namely: Pulomerak District has two locations, Grogol Sub-district has four locations, Purwakarta sub district and Citangkil sub district have one location. Then at the same atmospheric stability with a wind speed of 1.5 m sec^{-1} high concentration occurred in three sub-districts, namely: Pulomerak district has two locations, Grogol district has four locations and Purwakarta district has one location. The analysis result of air pollutant distribution pattern using Matlab software is shown in Fig. 2.

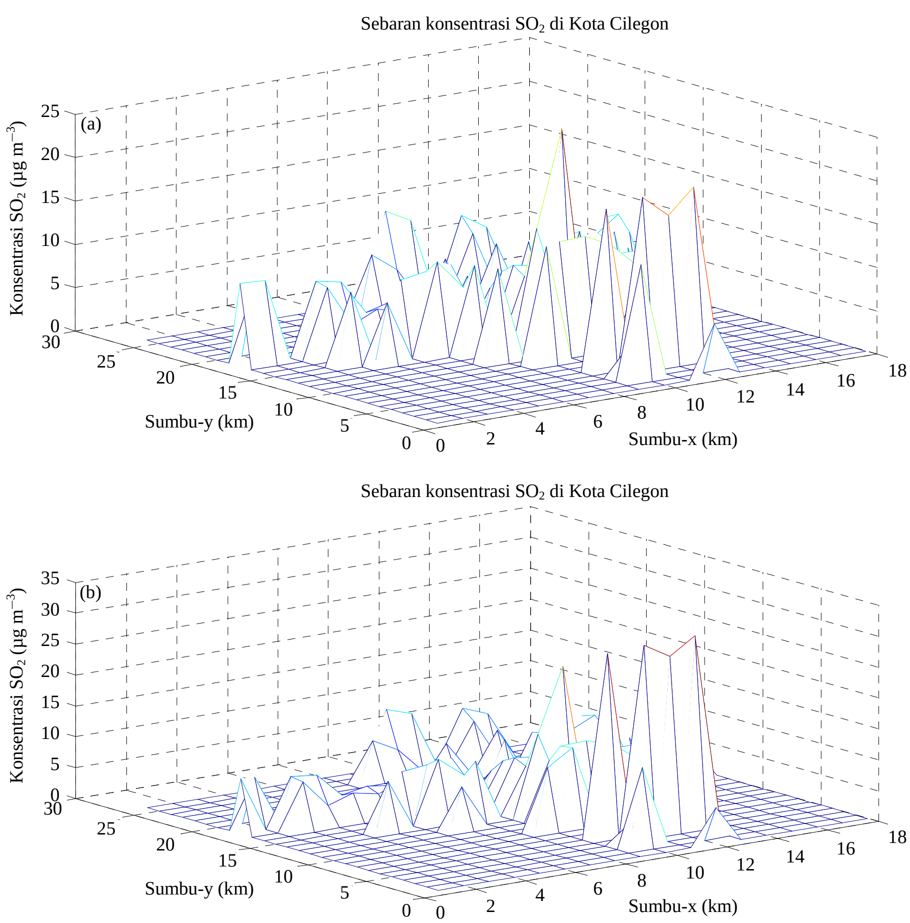

Fig. 2(a-b): Pattern of pollutant distribution, (a) Distribution of pollutants in the first 3 months and (b) Distribution of pollutants in the 3rd month

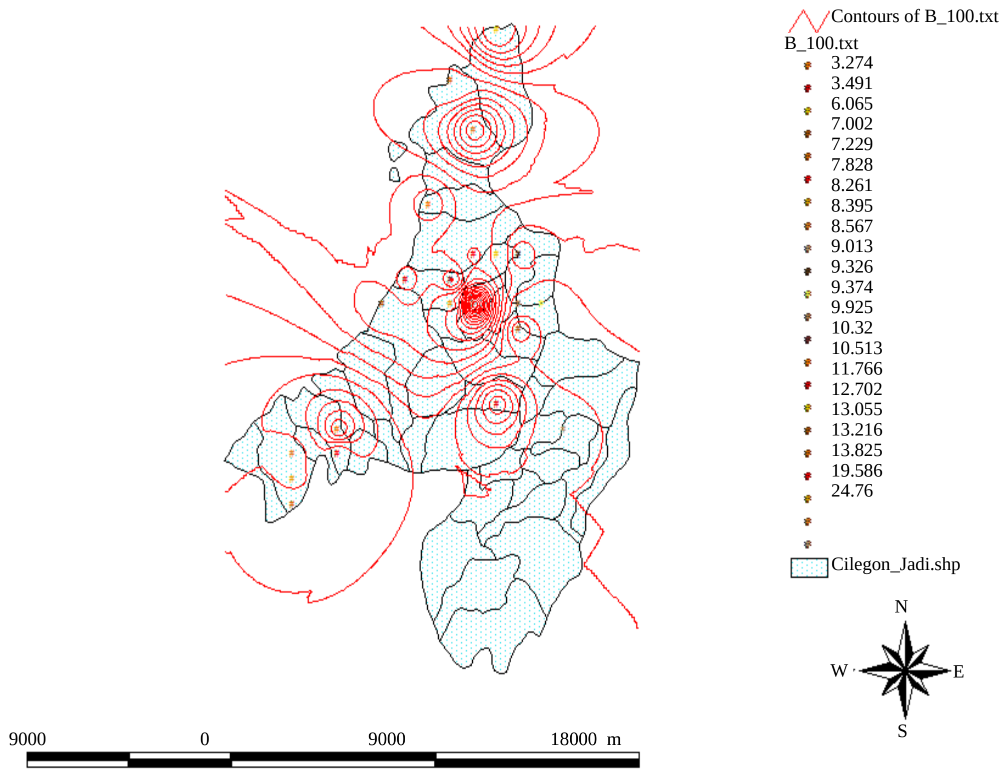

Fig. 3: Contour distribution contour in Cilegon

Based on Fig. 2, in the first 3 months it appears that the concentration of contaminants is still fluctuating, this is due to the concentration value in the initial conditions. In the second 3 months, the concentration of pollutants began to spread, graphically at certain points have decreased. The concentration of pollutants spread from west to east. The findings were similar with Ruhiat *et al.*[1], which explored the spread of air pollutants depends on wind direction and concentration differences. Based on the data of pollutant concentration and the pattern of its distribution, then overlapping is done with the base map. The overlap result with the ArcView program, shown in Fig. 3.

Based on Fig. 3, Tamansari, from three sample point locations, one location shows a change. The concentration of SO_2 increased from 5.41-19.59 µg m^{-3}. However, in Citangkil sub-district in Warnasari Village and in Kubangsari Village and Kepuh SO_2 concentration has increased. In Warnsari Village, Citangkil sub-district from five sample point locations, two locations showed an increase. The concentration of SO_2 increased from the range of 7.93-13.03 µg m^{-3}. In Kubangsari and Kepuh Village Ciwandan sub-districts from 14 sample points, three locations showed increased concentration. The concentration of SO_2 increased from the range of 8.67-12.04 µg m^{-3}.

CONCLUSION

It was concluded that a mathematical application for solving model equations, using partial solutions of partial differential equations, the mathematical model constructed was solved by the finite volume method. For model splitting, an analysis of the air pollution dispersion model as a function of time is used. The scheme used is an implicit scheme with parameter $\theta = 1$ in the case of two dimensions.

The results of model analysis show that on stability A the distribution of air pollutants occurs around the source. Distribution of pollutants away from sources occurs in the stability of B-E. The maximum distance emitted from the industrial estate reaches 18800 m. The concentration of SO_2 increased from 5.41-19.59 µg m^{-3}. Tamansari village, Kubangsari and Kepuh are polluted villages of air pollution.

SIGNIFICANCE STATEMENTS

This study discovers the polluted air pollution area that can be beneficial to protect the society from the air pollutant. This study also help to find the critical areas of air pollutant from the industry that many researchers are not able to explore. Thus, the function of continuity equations theory through Screen3 software to estimate the amount of air pollutant emitted from the industry is significantly important.

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