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Assimilative Capacity of Air Pollutants Using Emission Inventory and Dispersion Model

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Abstract

Air pollution in urban areas will increase along with increasing population activity. This study, with the location of Magelang Regency, examines the assimilative capacity of air pollution. The study began with the identification of emission inventories for transportation, household, waste burning and industrial activities. The results of the inventory were used to examine the distribution of air pollutants. The results of the emission inventory in Magelang Regency showed that the transportation sector was the dominant contributor of emissions compared to the waste, household and industrial sectors with an emission load of 2-3.5 times higher. The transportation sector contributes dominantly to the NO_2 parameter (94%) and PM parameter (72%), with a relatively similar contribution to the industrial sector in the SO_2 parameter (40%). Dispersion modeling showed that the distribution of emissions was even throughout Magelang Regency and showed an accumulation of emissions, especially for the NO_2 parameter which was centered on the arterial and collector road networks. When compared to the Ambient Air Quality Standard in Indonesia, the maximum concentration values for SO_2, NO_2 and PM parameters meet the quality standard. However, the NO_2 parameter needs to be considered because its concentration value has reached 75% of AAQS. Based on environmental assimilative capacity of air pollutants, Tegalrejo, Mungkid and Mertoyudan sub-districts are still in good condition. Based on this study, to improve the estimation of assimilative capacity air pollutants, the government needs to increase reliable ambient air measurements and robust emission inventory to determine air pollution status and to support air class determination.

Keywords: Ambient air, dispersion model, inventory, mitigation, pollution

1. Introduction

Air pollution is caused by complex interactions between dispersion and emission of toxic pollutants from factories. Air pollution caused by the entry of dust particles, gases, and smoke into the atmosphere exceeds the air quality level. Air pollutants are precursors of photochemical smog and acid rain that cause asthma problems leading to serious lung cancer, deplete stratospheric ozone, and contribute to global warming. There are many sources of air pollution, namely industry, fossil fuels, agricultural waste, and vehicle emissions.

The development of urbanization with the presence of real estate can affect ambient particulate levels (Ma et al., 2025). Improvement of industrial processes, energy efficiency, control of agricultural waste combustion, and fuel conversion are important aspects to reduce pollutants that cause industrial air pollution. Mitigation is needed to reduce the threat of air pollution by using various technologies that can be applied such as CO_2 absorption, industrial energy efficiency, improvement of vehicle engine combustion processes, and reduction of gas production from agricultural cultivation.

Air pollution causes mortality and morbidity impacts (Bayram et al., 2025). Globally, emissions from motor vehicles and industry (Wallace et al., 2018) as well as emissions from biogenic sources and biomass burning are thought to impact air quality ((Butt *et al.*, 2016; Bond et al., 2013). Evidence of the

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impacts of pollutants on health and the environment in many parts of the world is well documented. Although all regions of the world are affected, more than 85% of air pollution-related deaths occur in developing countries (Awe et al., 2015). This pollution is exacerbated by the reliance on biomass fuels for cooking and older, inefficient vehicles for transportation (Yan et al., 2011). For example, metal pollution in ambient air varies considerably by location (Huboyo et al., 2024). Therefore, efforts to improve air quality management are essential to keep the achievement of the sustainable development goals (SDGs) on track.

Effective air quality management will mitigate air pollution (Amegah and Jaakkola, 2016), as well as its associated environmental and ecosystem impacts (Johansson et al., 2017). It needs technological innovation, industrial restructuring, and public transportation improvements (Cai et al., 2024).However, this requires air quality data which should shift from static data to streaming data model (Li et al., 2020). Availability of real time air quality data is an important factor in air quality management (Liu et al., 2025). The lack of air quality data indicates poor profiling of air pollution concentration levels, sources, and drivers, which can lead to lack critical information for air pollution control and no effective assessment of pollution mitigation strategies. Emission control strategies with a bottom-up system can effectively prevent worsening air pollution (Sharma and Jain, 2024). Intensified provisions are also needed for areas that need to improve air quality in a short time (Bera et al., 2024). Assimilative capacity of air pollutant studies for industrial areas need to be conducted to prevent the impact of air pollution particularly in industrial areas (Panda and Nagendra, 2017) or in city area (Dung and Khue, 2021).

Therefore, assimilative capacity of air pollutant studies are absolutely necessary to prevent air pollution especially for countries whose economic sectors are developing, such as Indonesia. In Indonesia, according to Government Regulation No. 22/2021, the ambient air quality standards are used a basis for formulating and determining the highest ambient air concentration value in the Air Quality Protection and Management Area (WPPMU) class. WPPMU consists of national WPPMU, cross-provincial WPPMU, provincial WPPMU, cross-sub-district/city WPPMU, and sub-district/city WPPMU.
Considering the importance of controlling air pollution for the sustainability of healthy community life, it is necessary to estimate the assimilative capacity of air pollutants by involving various emission contributing factors such as from industry, household, waste and transportation through combination emission inventory and dispersion modeling approach. So far, the Ministry of Environment has not had a guide in calculating assimilative capacity of air pollutant for determining WPPMU**.** For this reason, in this study, an assimilative capacity of air pollutants calculation method will be carried out using the emission inventory approach and combined with dispersion modeling.

2. Methodology

2.1. Characteristics of Study Location

The study was conducted in Magelang Regency which hasan area of 1,129,983 km^2. Magelang Regency is situated geographically between 7°19'13 "- 7°42'16" S; 110°01'51 "- 110°26'58" E. The Yogyakarta Province, Temanggung Regency, Semarang Regency, Boyolali Regency, Magelang City, Purworejo Regency, and Wonosobo Regency are all administratively adjacent to Magelang Regency. Magelang Regency has 21 sub-districts. The altitude of Magelang Regency is between 202 - 1378 m above sea level (see Figure 1).

In Magelang Regency, plantation fields and food crops account for 68% of land use, with settlements making up the remaining 10%. About 30 industries make up the industrial area in the Tempuran sub-district, which makes about 0.4% of the Magelang Regency's total land area. The amount of rainfall in this area varies greatly; in 2023, March was the most rainfall (386 mm), while September was none at all.

2.2. Estimating Emission Loads for Air Quality Control

Emission inventorying air pollution sources to calculate emission load and it can be used to determine policies in a region through efficient and targeted emission load reduction. A comprehensive record is conducted of the amount of air pollutant in area within a certain time period regarding the source of pollution.
To guide this process, a research flow diagram is provided in Figure 1, showing the steps taken—from identifying pollution sources and collecting data, to calculating emissions and checking whether the air can still absorb them safely. This helps researchers and governments develop better strategies for controlling air pollution and protecting public health.

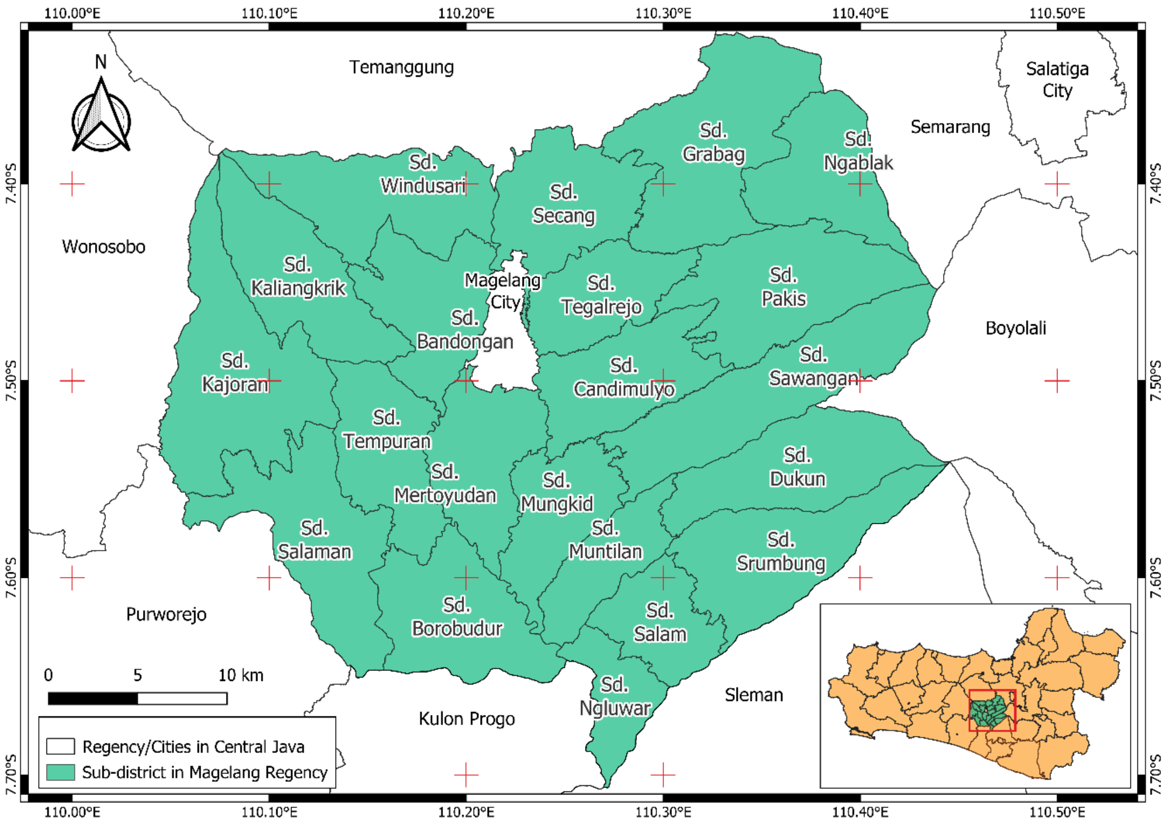

Figure 2. Study location (Magelang regency)

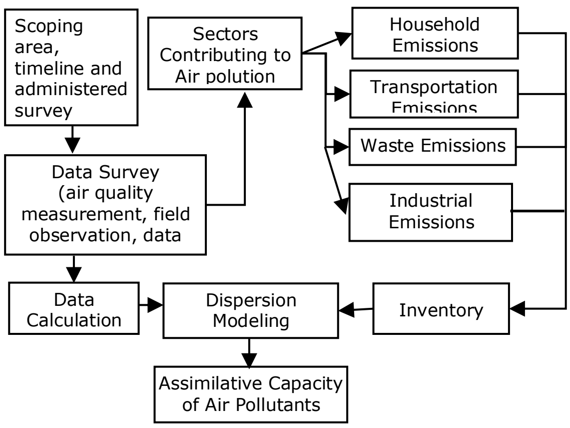

Figure 1. The framework of the study

2.3. Emission Inventory

In the Magelang Regency, the main sources of emissions—transportation, industry, waste, and households—were identified and quantified using SO_2, NO_2, and PM parameter criteria. Both semi-top-down and semi-bottom-up approaches were used in this study's emission inventory. Large point sources (industrial chimneys) are inventoried using the bottom-up method, whereas area sources are inventoried using the top-down method. In this survey (especially for the municipal solid waste and household sectors survey), the Slovin formula was used with a margin of error of 10% to calculate the number of samples needed.

Municipal Solid Waste Sector

To calculate the domestic waste emission load, the UNEP emission calculation method is used as a reference (Shrestha et al., 2013). Emission inventory of municipal solid waste is calculated based on the amount of waste that openly burned at source.

$$Ms = Pc \times P\,(frac) \times MSWGR \times \delta \times \mu \times 365 \quad (1)$$

Remark:

Ms = burned waste (kg annually)
Pc = population (capita)
$P\,(frac)$ = percentage of people who burn garbage
$MSWGR$ = per capita waste generation factor (kg.waste/day/capita)
δ = combustible waste fraction
μ = efficiency of combustion and oxidation (fraction)

The waste generation factor per capita (MSWGR) is 1.0 kg/capita-day. The Pfrac value for developing countries can be estimated based on the number of people whose waste is not collected in open dumps and then burned. The fraction of incomplete waste combustion, η is 1 for the incinerator process, while for open burning the waste fraction is 0.58. The waste combustion emission factor uses the database from the United Nations Environment Programme (Shrestha et al., 2013).

Household Sector

The calculation of household sector emissions is estimated based on LPG fuel consumption from household activities. Other fuel users (kerosene and firewood) are excluded with an average about 12% users. Data on population distribution, total LPG fuel usage, and emission variables are needed for the household sector emissions inventory.

The formula to estimate the emission is :

$$E_i = \sum_{c=1}^{n}(A \times EF_{ci}) \quad (2)$$

Remark:

E_i = Emissions of pollutants I from houses (in kilograms per year)

A = Household sector fuel usage (tons/year for LPG)

EF_{ci} = Fuel C's pollutant emission factor I (kg/ton for LPG)

Industry Sector

For industrial emission estimation, two approaches were used, namely direct measurements from 10 relatively large industries, the results of which are in the previous study (Huboyo et al., 2025) and for other industries using the IPPS approach.

The Industrial Pollution Projection System (IPPS) method is used to calculate the emission load of the industrial sector by taking into account the number of workers and the industry type (Hettige et al., 1994). The industrial sector emission load calculation is represented mathematically as

$$PL = \frac{PI \times TEM}{1000 \times 2.204{,}6 \times Ratio} \quad (3)$$

Remark:

PL = load of emissions (tons/year)

PI = pollution intensity (lb/1000 workers/year)

TEM = workers number (people)

2.204,6 = lb to ton conversion

Ratio = Indonesian and American industrial IPPS conversion values

Transportation Sector

To calculate the transportation emission load, the emission calculation method from the Ministry of Environment is used as a reference (Suhadi and Febrina, 2013).

The emission factors were derived from PermenLH No.12/2010 for SO_2 and PM parameters (Kementerian Negara Lingkungan Hidup, 2010). We also use this emission factors for NOx parameter (specifically for motorcycle emission). While the non-motorcycle NOx parameter uses the emission factor from the EMEP/EEA 2023 – Update 2024 (Mellios and Ntziachristos, 2024) air pollutant emission inventory guidebook.

The vehicle fuel consumption and vehicle kilometers traveled (VKT) approach, which was acquired through odometer surveys at authorized workshops and transportation agencies, was used to undertake the transportation sector emission inventory. Three methods were used to estimate the emission load: total emission load, area emission load for minor roads, and line emission load for arterial and collector highways.

Line source guidelines are used to calculate vehicle emissions on the major road network, assuming that cars on this road segment have fixed traffic characteristics. The following is the calculation of line source VKT:

$$VKT_{j,line} = \sum_{i=1}^{n} Q_{ji} \times I_i$$
$$E_{ij} = VKT_{ji} \times EF_{cj} \times \frac{100 - C}{100} \quad (4)$$

Remark:

$VKT_{j,line}$ = VKT of vehicle category j on route I calculated as line source (km/year)

Q_{ji} = road section I vehicle volume in category J (vehicles/year)

I_i = road section I's length (km)

E_{ij} = pollutant c emissions for vehicle category j on segment I of the road

C = equipment efficiency for emission control (%), C = 0 in the absence of established control equipment

Area source emissions were used to estimate emissions on local roads. This is because traffic volume and road data for local roads are not available.

Total VKT of area sources = Total VKT of moving sources – VKT of line sources

The VKT area obtained is proportioned to each sub-district by taking into account the weighting of the number of residents and the length of roads in each sub-district.

The equation for estimating total VKT is:

$$VKT_{b,c} = \overline{VKT}_{b,c_{odo}} \times N_{b,c} \quad (5)$$

Remark:

$VKT_{b,c\ odo}$= VKT based on odometer survey for category B vehicles using C fuel (km/year)
$VKT_{b,c}$ = VKT of all category B automobiles using c gasoline (kilometers per year)
$N_{b,c}$ = The quantity of fuel-using category B motor vehicles

2.4. Dispersion Modeling

Emission dispersion modeling is used to estimate the distribution of pollutants in the atmosphere and is used to estimate the assimilative capacity of air pollutants within a region. By modeling the distribution of emissions, it is possible to know where pollutants accumulate at a certain time. Modeling was conducted with AERMOD v.9.6.0, a Gaussian-based pollutant dispersion model. Rectangle area with 42 × 42 km covering Magelang Regency with a 2.1 km grid spacing was used for the modeling scenario. The meteorological data was collected from openweathermap.org. for modeling was run only in during the dry season so it is possible that the pollutant levels are high.

3. Results and Discussion

3.1. Emission Inventory - Municipal Solid Waste

The calculation of emissions from waste burning is based on the amount of waste burned at the source. Waste burning is expected to occur in areas that are not served by waste collection services. In this study, it is estimated that the number of people who are not served by waste processing facilities is 563,667 people.

Based on the results of surveys and interviews with 100 respondents, it was found that about 90% of areas not served by waste collection facilities burn their waste on open land. The waste generation factor in 2023 is 0.527 kg/person/day. In this study, a combustion efficiency approach of 0.58 (Shrestha et al., 2013) and a combustible waste fraction of 0.6 (Wahyudi et al., 2019) were used to obtain waste generation (Ms) in Magelang sub-district of 33,958.45 tons/year as shown in Table 1.

Table 1. Emission load resulting from waste combustion

Pollutant	Ms (ton/year)	Emission Factor (kg/ton)	Emission Load (ton/year)
SO_2	33,958.45	0.50	16.98
NO_2		3.00	101.88
PM		6.43	218.18

3.2. Emission Inventory – Household Sector

Emissions generated in the household sector were estimated by multiplying the amount of LPG consumption by the emission factor for each parameter. Survey results on 100 respondents in Magelang Regency showed an average LPG consumption (Ac) of 52,439.64 tons/year as shown in Table 2.

Table 2. Household sector emission load

Pollutant	Ac (ton/year)	Emission Factor (kg/ton)	Emission Load (ton/year)
SO_2	52,439.64	0.01419	0.74
NO_2		2.69610	141.39
PM		0.10406	5.46

3.3. Emission Inventory – Industrial Sector

The calculation of emissions in the industrial sector is carried out by combination of emission measurement and estimation the number of workers with pollution intensity by IPPS approach. There are 37 industrial facilities in Magelang Regency, grouped into 17 industry categories (Table 3).

Table 3.Industry sector emission load

Industry	Employees	Pollutant Load (ton/year)		
		SO_2	NO_2	PM
MUT	1,657	0.25	0.13	0.93
SWM	4,329	37.19	71.93	304.27
MTV	1,439	3.33	1.44	4.35
PLC	328	0.15	0.03	0.12
SFT	665	13.36	15.77	6.21
FMP	321	0.43	0.82	0.89
TXT	2,439	15.13	5.35	23.41
FDP	189	0.68	0.59	0.80
PAF	132	0.81	0.19	3.81
PPP	73	15.46	6.90	7.91
CFT	66	0.05	0.01	0.01
MFI	78	0.02	0.01	0.01
TLF	57	0.61	0.14	0.19
DMC	66	1.00	0.36	0.49
SCP	95	2.39	19.76	47.16
NMP	40	1.07	0.41	4.70
PCE	35	0.09	0.04	0.27
Total	12,009	92.01	123.87	405.54

These include: Made-Up Textile Apparel (MUT), Sawmill Planning and Other Wood Mills (SWM), Motor Vehicles (MTV), Plastic Products (PLC), Spinning and Finishing Textiles (SFT), Fabricated Metal Products (FMP), Textiles (TXT), Food Products (FDP), Prepared Animal Food (PAF), Pulp, Paper, and Paperboard (PPP), Confectionery Products (CFT), Manufacturing Industries (MFI), Tanneries and

Leather Finishing (TLF), Drugs and Medicines (DMC), Structural Clay Products (SCP), Nonmetallic Mineral Products (NMP), and Pottery, China, and Earthenware (PCE).

3.4. Emission Inventory – Transportation

Line Sources

Emission load is estimated using 3 approaches, namely line emission load for main roads, area source emission load for small roads and total emission load.

The calculation of VKT line source is used to calculate the length of vehicle trips on the main road section by multiplying the vehicle traffic volume by the length of the road. The Annual Average Daily Traffic (AADT) in Magelang Regency was collected from Central Java Province Public Work for 2023.

The line source emission load from the transportation sector is calculated by multiplying the VKT by the emission factor for each parameter in each vehicle type (Table 4).

Table 4. Line source emission load

Nama of Road	Emission Load (ton/year)		
	SO_2	NO_2	PM
Magelang – aliangkrik	14.50	440.88	145.75
Magelang – Ngablak	16.10	431.62	77.09
Salaman - Purworejo	9.64	213.25	30.74
Borobudur – Salaman	9.80	248.12	39.93
Magelang - Salaman	31.66	700.58	108.44
Jl. Panca Arga	4.70	110.99	16.19
Blondo - Mendut	4.58	129.98	28.43
Blabak - Jerakah	24.81	514.93	92.43
Muntilan - Klangon	5.44	143.20	29.04

Area Sources

The calculation of transportation emissions on local roads in Magelang Regency is estimated using the area source approach due to the absence of direct vehicle traffic count data. In this method, it is assumed that buses and trucks do not operate on these local roads, so only smaller vehicle types are included in the Vehicle Kilometers Traveled (VKT) calculation. The number of vehicles is categorized based on each sub-district within Magelang Regency to reflect local conditions more accurately.

To estimate the emission load from the transportation sector as an area source, the VKT values are multiplied by the appropriate emission factors for each vehicle type. These emission factors, which represent the average pollutant emissions per kilometer traveled, are listed in Table 5. This approach allows for an estimation of emissions in the absence of direct measurement data, supporting local air quality assessments and planning. The total sectoral emission load is calculated by summing up the area source emission load and line emission load grouped by sub-district (Table 6).

Table 5. Area source emission load

Sub-district	Emission Load (ton/year)		
	SO_2	NO_2	PM
Bandongan	4.87	205.08	65.89
Borobudur	5.01	210.81	67.73
Candimulyo	5.66	237.99	76.46
Dukun	3.73	157.10	50.47
Grabag	8.18	344.12	110.56
Kajoran	5.42	228.09	73.28
Kaliangkrik	4.35	182.97	58.78
Mertoyudan	7.30	307.33	98.74
Mungkid	4.30	181.11	58.19
Muntilan	6.32	266.02	85.47
Ngablak	4.43	186.26	59.84
Ngluwar	3.34	140.35	45.09
Pakis	6.90	290.36	93.29
Salam	4.82	202.65	65.10
Salaman	5.09	214.01	68.76
Sawangan	5.46	229.83	73.84
Secang	6.07	255.47	82.08
Srumbung	4.16	175.04	56.24
Tegalrejo	4.84	203.47	65.37
Tempuran	3.50	147.12	47.27
Windusari	5.03	211.55	67.97
Total	108.77	4576.73	1470.39

Table 6. Transportation sector emission load

Sub-district	Emission Load (ton/year)		
	SO_2	NO_2	PM
Bandongan	7.5	256.0	70.3
Borobudur	10.6	317.7	77.2
Candimulyo	5.7	238.0	76.5
Dukun	3.7	157.1	50.5
Grabag	8.2	344.1	110.6
Kajoran	7.2	262.3	76.2
Kaliangkrik	7.1	236.7	63.4
Mertoyudan	20.7	551.4	121.0
Mungkid	9.8	275.5	64.6
Muntilan	7.9	295.2	88.1
Ngablak	6.4	224.8	63.2
Ngluwar	3.9	150.7	46.0
Pakis	12.4	396.8	102.6
Salam	4.8	202.6	65.1
Salaman	21.4	533.8	96.1
Sawangan	23.0	502.9	102.1
Secang	6.1	255.5	82.1
Srumbung	4.2	175.0	56.2
Tegalrejo	8.3	271.5	71.3
Tempuran	15.2	362.3	66.8
Windusari	5.0	211.6	68.0
Total	99.0	6,221.6	1,617.8

3.5. Total Emission Load

Total emission load is the sum of emission load from all inventoried sources including household, waste burning, industry and transportation sectors. The percentage of each emission source is depicted in Fig. 3.

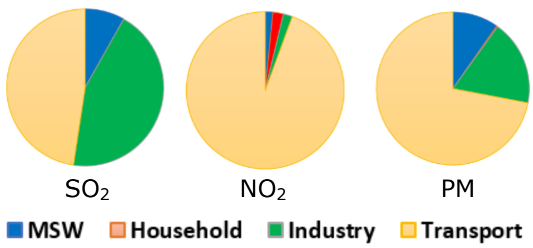

Figure 3. Share of emission sources in 2023

Based on the results of the emission inventory, the dominant parameter contributions are NO_2 then PM and the last is SO_2. The transportation sector is the dominant emission contributor for all parameters with an emission load more than 94% for NO_2 and the second is particulate matter i.e more than 72% than other emission sectors.

The high emission burden from the transportation sector in Magelang Regency may be caused by the large number of vehicles and high transportation activities, especially on arterial and collector roads which are national connecting roads. The industrial sector is the second highest emission contributor after the transportation sector. This is due to the large number of large and medium industries that are centralized in industrial designation areas such as Salam sub-district, Salaman sub-district and Tempuran sub-district.

Based on the pollutant parameters, the dominant pollutant parameters in the household and transportation sectors are NO_2 while in the waste and industrial sectors are SO_2 and PM. In the household and transportation sectors, the high NO_2 parameter is caused by the combustion of gasoline (transportation) and LPG (household) fuels. NO_2 is generated when nitrogen (N_2) in the air reacts with oxygen (O_2) at high temperatures in combustion engines or stoves. Different from the transportation sector, the dominant types of pollutants in the industrial and waste sectors produce PM and SO_2. PM can be sourced from incomplete and low-efficiency combustion of coal fuels and waste so that particles are formed and released into the air. In addition, high PM in the industrial sector can be caused by emission control systems that are not working properly. As for the dominant SO_2 parameter from the industrial sector, it is caused by the large number of industries that use coal as fuel.

3.6. Emission Dispersion Model

Emission dispersion modeling covering the entire Magelang Regency for SO_2, NO_2 and PM parameters. The emission load used is the result of inventory on emission sources in Magelang Regency including waste, household, industrial and transportation sectors. Figure 4 shows the concentration of SO_2 distribution map.

The concentration of SO_2 is not very widespread from the road, especially accumulating in areas where there is industry. The distribution of NO_2 concentration (Figure 5) is wider than the SO_2 parameter because the NO_2 emission load is greater than SO_2.

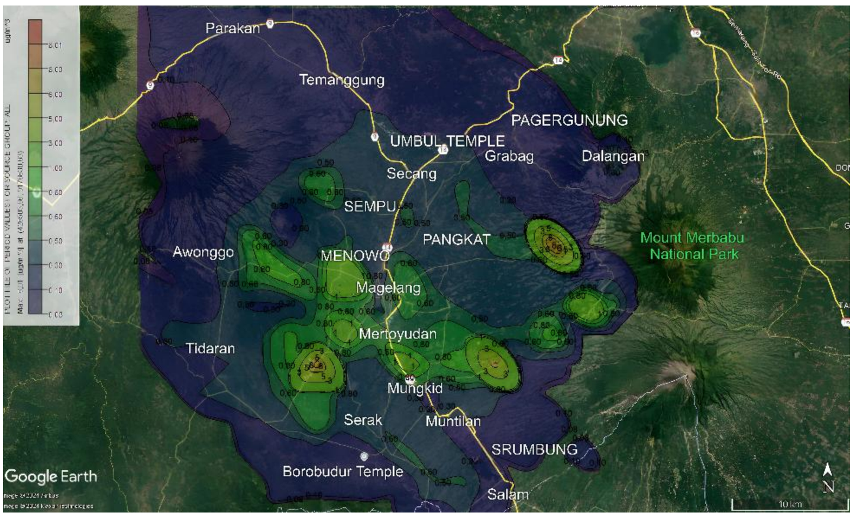

Figure 4. SO_2 concentration isopleth map

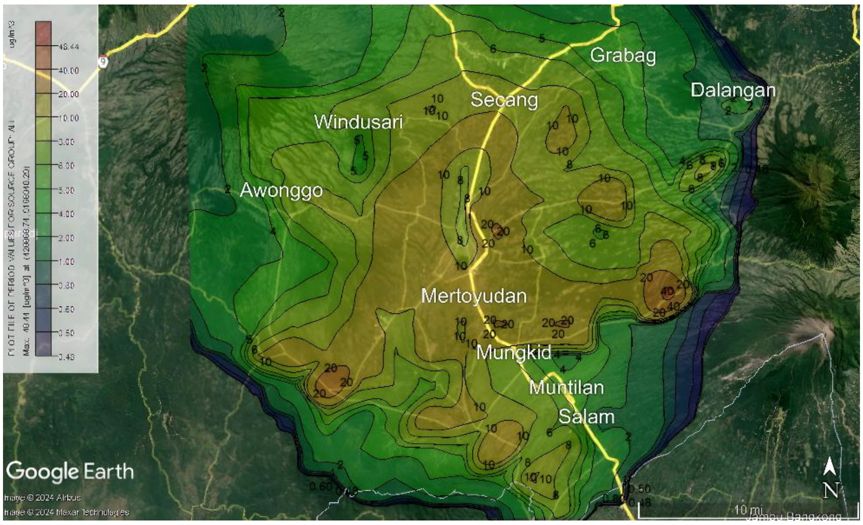

Figure 5. NO_2 concentration isopleth map

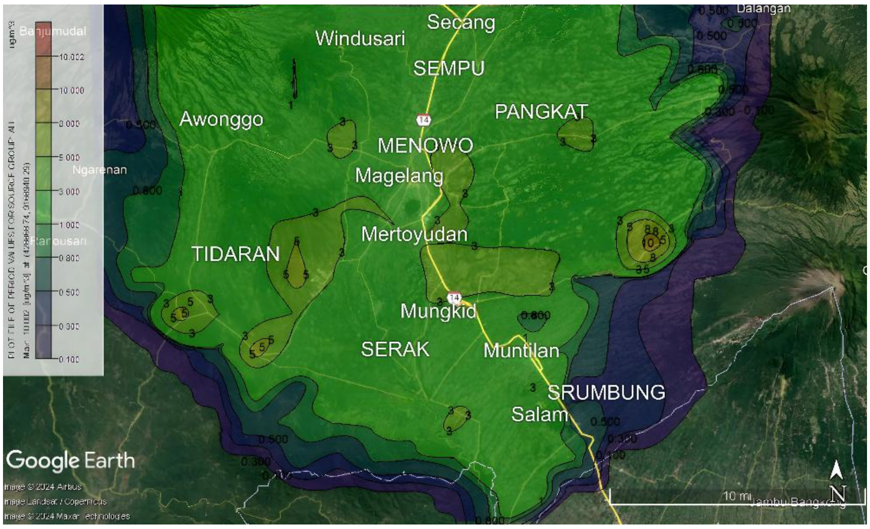

Figure 6. PM concentration isopleth map

The distribution does not only collect on the roadside as the main source of NO_2. However, there is an accumulation, especially in the center of Magelang Regency where there is access to cross-provincial connecting roads.

Similar to the distribution of NO_2 emissions, the distribution of PM emissions (Figure 6) is also relatively even. However, the concentration value in emissions is much smaller than NO_2. The maximum value of the modeling results and the peak location of pollutant accumulation for each parameter are shown in Table 7. The overall model results show a concentration of emissions in the center of Magelang Regency. Threshold in ambient air quality standard is the optimum ability of the environment to provide a good life and fulfill the requirements of life. The maximum concentration value when compared to the ambient air quality standard shows that both SO_2, NO_2 and PM parameters are still fulfilling their assimilative capacity.

Table 7. Peak concentration of dispersion model

Pollutant	Max (μg/m^3)	AAQS (ug/m^3)*	(%) AAQS	Sub-district
SO_2	8.01	75	10.68	Pakis
NO_2	48.44	65	75.52	Sawangan
PM	10.00	230	4.34	Sawangan

*Indonesian Regulation

However, the NO_2 parameter is predicted to remain 24.48% of the Ambient Air Quality Standard (AAQS). Based on the source, the high NO_2 emission load is contributed by transportation activities in the form of fuel combustion and household activities, namely LPG combustion. Emission control in the transportation sector is difficult because it involves national policies, not just regional policies.

3.7. Model Validation

Model validation are used to ensure that the model used is close to or equal to the actual situation. We used correlation method and the RMSE (Root Mean Square Error) method.

The main obstacle in dispersion modeling is the unobtainable background concentration. Therefore, in this validation, the results of ambient air quality measurements that are relatively far from the location affected by air pollution were selected (4 locations). The results of the model validation are shown in Table 8.

Table 8.Validity test result

Parameter	R^2	RMSE (μg/m^3)
SO_2	67.83%	9.59
NO_2	65.21%	11.86
PM	72.97%	32.35

It should be noted that these validation results do not guarantee accuracy for all locations because only locations that are relatively free from air pollution were selected. With the specified background concentration estimation, the difference between the results of the dispersion model and the results of ambient air measurements at 4 location points (for max 24-h) shows an acceptable value as seen from the R^2 value between 60 - 70%.

3.8. Assimilative Capacity Implication

The calculation of assimilative capacity of air pollutants by ordinal scale in Magelang Regency is represented by Air Pollutant Standard Index or ISPU for short with guidelines referring to KepMenLH No. 14/ /2020 (Kusnandar, 2020) at locations where ambient air quality monitoring is conducted. However, not all sub-districts have ambient air quality monitoring data, so the assimilative capacity with ISPU value in these sub-districts has not been estimated (Table 9).

Unhealthy ISPU is located in Tempuran sub-district with an index of 109 with the contributor being PM (224% of AAQS). The main sources are industrial activities and road dust. Meanwhile, Secang sub-district shows an index of 68 which is contributed by PM (115% of AAQS).

The source may come from industry, household and transportation. ISPU with a good category is located in Tegalrejo, Mertoyudan and Mungkid sub-districts with indexes of 48, 5 and 3 respectively. For Mertoyudan and Mungkid sub-districts, the air quality is still in good condition while Tegalrejo sub-district shows the concentration value of parameters that are close to the AAQS such as PM (64.47%), SO_2 (58.33%) and NO_2 (60.04%). These pollutants can be sourced from industrial, household and waste burning activities.

The Ministry of Environment proposed term of atmospheric air condition class defined as WPPMU class (PP 22/2021 article 175), although so far there are no guidelines for calculating it yet. This atmospheric air condition class should be determined based on a study of the air pollutant assimilative capacity. In this study, the use of the emission inventory method with pollutant dispersion in estimating the assimilation capacity of air pollutants needs was exercised, however the method should be improved. The emission inventory method from its source requires accurate emission source activity data, especially for emission loads and emission source locations that affect the uncertainty of the results. Estimating background concentrations as an addition to air dispersion concentrations requires adequate ambient air quality measurements both temporally and spatially. However, most ambient air quality measurements carried out by local governments are not sufficient as evidence of validation of the air pollutant assimilation capacity study. For this reason, there needs an effort for implementing sufficient and real-time air quality monitoring in order to determine the atmospheric air condition class.

Table 9. ISPU calculation result

Sub-district	C (ug/m^3)		Index	Description
Tempuran	PM	168	109	Unhealthy
	SO_2	20		
	NO_2	2		
Tegalrejo	PM	48	48	Good
	SO_2	43		
	NO_2	60		
Secang	PM	86	68	Moderate
	SO_2	19		
	NO_2	27		
Mungkid	PM	-	3	Good
	SO_2	3		
	NO_2	5		
Mertoyudan	PM	-	2	Good
	SO_2	2		
	NO_2	3		

The assimilation capacity of PM in this study is still quite large compared to that in India between 23 - 53 μg/m^3 (Singh and Perwez, 2015). While the assimilation capacity of SO_2

is relatively moderate because it is around 60% of ambient quality standards. The critical condition is the assimilation capacity of NO_2, which is very small, about 4% of SO_2. This is comparable to research in Vietnam (Dung and Khue, 2021) where the assimilation capacity of NO_2 is around 5-6% of SO_2. This estimated assimilation capacity will change with the season, as reported in Manali India (Panda and Nagendra, 2017) where in summer the assimilation capacity of NO_2, PM, SO_2 pollutants increases by 4%, 8%, 21% respectively against winter conditions.

4. Conclusion

The results of the emission inventory in Magelang Regency show that the transportation sector is the dominant contributor to emissions compared to the waste, household and industrial sectors with 2-3.5 times higher emission loads. The percentage of emission parameters produced is NO_2 by 76% then PM 20% and SO_2 4%. The NO_2 parameter is dominantly produced in the transportation and household sectors, while the SO_2 and PM parameters are dominantly produced by open waste burning and industry. Dispersion modeling shows that the distribution of emissions is evenly distributed throughout Magelang Regency and shows a accumulation of emissions, especially for the NO_2 parameter which is centralized on the arterial and collector road network. Compared to the Ambient Air Quality Standard in Indonesia, the maximum concentration values for SO_2, NO_2 and PM parameters still meet the air quality standard. However, the NO_2 parameter needs to be considered because the concentration value has reached 75% of the AAQS. Based on the assimilative capacity of air pollutants, Tegalrejo, Mungkid and Mertoyudan sub-districts are still in good condition, while Secang and Tempuran sub-districts need mitigation and emission reduction efforts to maintain air quality because the air quality index shows Moderate and Unhealthy quality, respectively. The government needs to increase reliable ambient air measurements and robbust emission inventory to determine air pollution status and to support air class determination studies. With increasingly complex human activities and worsening air quality, this assimilation capacity study is important to support the determination of WPPMU.

Author Contribution Statement

H.S.H: Conceptualization, Methodology, Funding Acquisition, Writing Review Editing; B.P.S: Data curation, Project administration, Writing- Original draft preparation, Supervision; O.R.M.: Investigation, Vizualization Writing review; N.K.: data analysis, drafting article.

Data Availability Statement

The data presented in this work/study are available in the article. All detailed data calculation this study are available upon request.

Declaration of Competing Interest

The authors declare that they have no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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