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URBAN BLACK CARBON: TREND OF RESEARCH AND ASSIMILATIVE CAPACITY IN THE MEDIUM SIZE CITY

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ABSTRACT: Black carbon (BC) in the ambient air, mostly produced by incomplete combustion, has a negative impact on human health. This study was conducted to examine the trends of BC measurements in urban areas and to determine the spatiotemporal variation and assimilation capacity of BC. Three BC measurement locations in Magelang Regency Indonesia were identified in areas of relatively mixed land use. BC analysis was conducted using an EEL Smoke Stain Reflectometer derived from gravimetric TSP measurements. BC assimilation capacity using an indirect comparative approach of BC content with $PM_{2.5}$ and TSP air quality standards. Bibliometric study showed a lack of studies on the assimilation capacity of black carbon in urban areas. Based on BC field measurement, it has the highest concentration during the daytime. The emission load of BC from the waste, domestic, industrial, and transportation (area-line) sectors were found to be 25.826 tons/year, 41.361 tons/year, 1.176 tons/year, and 311.879 tons/year, respectively. Based on modeling, the BC ambient concentration was accumulated in areas not too close to the main roads. Current BC assimilation capacity remains adequate; however, it is estimated that, years later, its assimilative capacity will be exceeded. Based on the TSP air quality standard regulations in Indonesia, the BC concentration still has an assimilative capacity of around 6-9 µg/m3 (the upper limit) and 1-3 µg/m3 (the lower limit). Meanwhile, based on WHO guidelines, referring to PM2.5 parameter, the BC concentration no longer has an assimilative capacity. Therefore, it is necessary to handle emissions from its sources.

Keywords: Black carbon, Spatiotemporal variation, Assimilation capacity, Air quality

1. INTRODUCTION

Air pollution results from a combination of industrial, transportation, biomass burning, and domestic emissions. Particle emissions, particularly fine particles, are a significant parameter in air pollution. For example, in Morocco, only particulate pollutants exceeded ambient air quality standards between 2009 and 2012 (1). In Northern Thailand, forest fires and agricultural waste burning have caused an increase in fine particles PM_{10}, 1-3 times higher than ambient air quality standards (2). One important particle component in the fine fraction is black carbon (BC).

Formed from an imperfect combustion process, BC typically originates from the combustion of fossil fuels, such as gasoline, coal, and diesel (3). BC has a long residence time in the air (4), and, therefore, it can be transported through a long-range transport mechanism (5), which can increase the accumulation of local BC concentrations (6). The average residence time of BC particles in the atmosphere varies from several days to weeks (7). Temporal-spatial variations in atmospheric BC can be caused by variability in emission sources and meteorological factors, the latter affecting the spatiotemporal variability of atmospheric BC (8). BC is also well able to absorb sunlight; therefore, it plays an important role in the direct warming effect in the atmosphere (9).

Estimated total global black carbon emissions in 2000 were around 7500 Gg/year (10). Generally, the BC content in air aerosols is very large near the source and the proportion is smaller in aged aerosols (11). Factors that determine the diurnal variability of BC in ambient air are emission, deposition, chemical reactions, and mixing all of which contribute to the diurnal variability of surface pollutants (12). BC concentrations fluctuate diurnally and seasonally (13) and are also influenced by winds related to topography (14).

Black carbon emissions are often linked to emissions from the transportation sector, with heavy vehicles being a major contributor. Research in

Thailand shows that diurnal BC concentrations are influenced by the density of roadside vehicles (HDVs) (15). The main sources of BC are vehicles and industry (16) comprising 70% of BC in Indore, India (17). In Kazakhstan, BC sources from specific industries are from combined heat and power (CHP) power plants (18). Meanwhile, in urban areas, fossil fuels contribute 80% to BC emissions, while biomass burning contributes only 20% (19).Black carbon is also produced from biomass burning where the BC emission factor in $PM_{2.5}$ from biomass burning is 0.939 ± 0.417 g/kg (20)

Based on measurement results in many countries, the atmospheric level of BC in developed countries is generally lower than that in developing countries (21). Therefore, residents in developing countries are more likely to experience health impacts due to exposure to BC. Global BC exposure is an average of 1.4 µg/m^3, with the highest being China at 2.8 µg/m^3, followed by South Korea (2.7 µg/m^3) and India (2.0 µg/m^3). Meanwhile, in North America and Europe, the level of BC pollutant exposure is <0.5 µg/m^3 (22). The annual concentration of BC in China (over 40 years) ranges from 0.31 – 3.14 ug/m^3 (23). The mortality risk of BC is higher in winter than in summer (24). According to previous data, exposure to BC is a cause of cancer, respiratory diseases, and cardiovascular dysfunction (25).

To date, BC measurements related to assimilation capacity have not been conducted in cities in developing countries, which is surprising given the increasing sources of BC, especially from the transportation sector, which uses fossil fuels. In Indonesia, monitoring of BC in ambient air, generally conducted to characterize measured $PM_{2.5,}$ is lacking. The average concentration of BC in 16 major provincial capital cities in Indonesia in 2010–2017 was 2.32 µg/m^3, whereas the average BC/$PM_{2.5}$ ratio was 20.8% (26). BC measurements in Jakarta showed that BC levels did not decrease, even during the rainy season, and were generally in the range of 1.90–11.39 µg/m^3 (27).

BC levels in $PM_{2.5}$ during forest fires in Riau were an average of 6.2 µg/m^3 with a BC/$PM_{2.5}$ ratio of 9.74% (28). Meanwhile, the impact of forest fires in Palangkaraya since 2011–2020 showed BC levels at 0.02–7.74 µg/m^3 with a BC/$PM_{2.5}$ ratio of approximately 14%. Several other BC measurements have been conducted near industrial (29–31) and urban areas (26)(32). BC research has also been linked to the estimation of BC loads after replacing kerosene fuel with LPG gas in Indonesia (33).

Considering the variability and increasing burden of BC emission sources, a study is needed regarding the assimilation capacity of BC pollutants. The presence of black carbon in medium-sized cities in developing countries, associated with assimilation capacity, has not been widely explored, particularly in increasingly developed and spatially diverse regions. This study seeks to uncover the temporal-spatial presence of black carbon and its assimilation capacity, using medium-sized cities in Indonesia as an example. This study serves as an interim alternative, without epidemiological studies, to using black carbon air quality standards based on the proportion of BC content in $PM_{2.5}$ and TSP.

2. RESEARCH SIGNIFICANCE

This study analyzes black carbon (BC) research trends in urban areas and analyzes the assimilation capacity of black carbon as a basis for determining ambient air quality standards, specifically for BC. Bibliometric analysis further confirms the relevance of this study, as current BC research largely focuses on concentration levels, source contributions, biomass combustion, and health impacts, while studies addressing BC assimilation capacity are still very limited. Therefore, this study fills an important research gap by integrating emission inventories, dispersion modeling and indirect approach on air quality to evaluate BC assimilation capacity in a semi-urban area with mixed land use.

3. METHODS

3.1 Location of The Study

Magelang Regency is one of the regencies in Central Java Province, Indonesia, and has an area of 1,129,983 km^2. Geographically, Magelang Regency is located between 110°01'51"–110°26'58" East Longitude and 7°19'13"–7°42'16" South Latitude (Fig.1). Administratively, the Magelang Regency borders the Special Region of Semarang Regency, Yogyakarta Province, Wonosobo Regency, Boyolali Regency, Purworejo Regency, Temanggung Regency, and Magelang City. The Magelang Regency land use is dominated by plantation areas and food crops (68%), followed by settlements (10%). The industrial area is located in the Tempuran subdistrict (approximately 30 industries) and occupies 0.4% of the total land area of the Magelang Regency. Rainfall at this location is varied; in 2023, the highest rainfall was in March (386 mm), and the lowest in September (no rain).

3.2 History of BC Measurements in The Region

To examine the history of BC measurements in ambient air and the focus of research thus far, a bibliographic analysis of approximately 2866 articles was conducted using VOSviewer. The results of this analysis were used to identify research opportunities in the field of BC assimilation capacity in ambient air

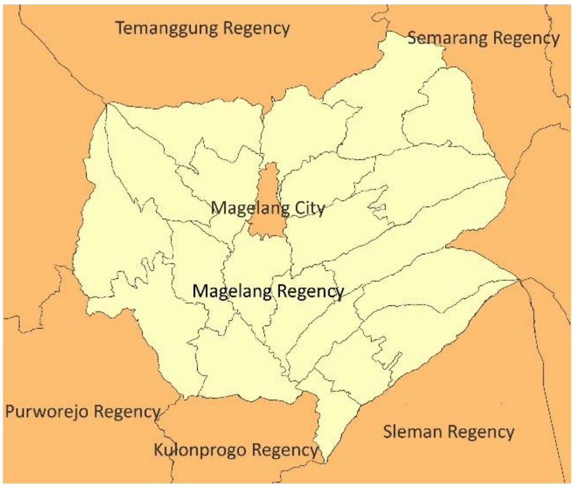

Fig.1 Study location

3.3 Ambient Air Particulate Measurement

BC measurements were performed based on total suspended particulate (TSP) measurements in ambient air at three measurement locations. The particulate sampling points are shown in Table 1 and were intended for locations representing mixed areas, settlements, and remote areas. Measurements were performed three times at each sampling location (three days at each point). TSP measurements were performed gravimetrically using an ambient air sampler (Staplex, NY, USA) at a flow of 0.9 m^3/min.

Table 1. TSP sampling locations

Location	Coordinates	
	Latitude	Longitude
Site 1	7°32'29.98"S	110°10'04.50"E
Site 2	7°32'28.74"S	110°09'46.50"E
Site 3	7°32'15.58"S	110°09'23.27"E

The flow rate was calibrated using a Digital Orifice Flow Meter OFD-1 (Sibata, Saitama, Japan). A quartz filter (QMC-pre-fired, 110 mm) was used. The measured results were corrected using a blank filter. To obtain temporal variations, TSP sampling was conducted periodically during four periods: (06.00 AM - 11.00 AM; 12.00 PM - 04.00 PM), night time (05.00 PM - 10.00 PM; 11.00 PM - 05.00 AM). Between sampling periods, the filter sample in the air sampler is removed and replaced with a new one. This period also allows the instrument to cool down for approximately 1 hour. Therefore, the effective measurement time is 20 h/day. Meteorological parameters, such as ambient temperature, barometric pressure, and wind speed, were also measured. However, for analysis, secondary data for meteorological parameters were also used.

The location selection for sampling was carried out by considering critical areas which are mixed areas (industry, main road, dense population). The results of particulate measurements have been published previously (34). During this measurement period, the area was in the critical phase of the dry season.

3.4 Black Carbon Analysis

The filter of the ambient particulate measurement sampling result was chopped into a circle with a diameter of 50 mm for the analysis of BC using an EEL Smoke Stain Reflectometer (Laboratory at National Research and Innovation Agency). A blank filter was also analyzed as a correction factor. The BC concentration was proportional to the TSP concentration, and its spatiotemporal variation was analyzed.

3.5 Emission Inventory

The identification and quantification of emission sources were conducted within the administrative boundaries of the Magelang Regency, where the inventory of BC emissions only focused on dominant sources, namely transportation, industry, waste, and domestic sources. In this study, an emissions inventory was created using a combination of semi-top-down and semi-bottom-up methods. The top-down method was used to inventory the area sources, whereas the bottom-up method was used to inventory the large point sources (industrial chimneys).

3.5.1 Municipal solid waste

The quantity of waste burned at the source was used to compute the waste-sector emissions inventory with Eq. (1).

$$Ms = P_c \times P_{frac} \times MSW_{GR} \times \delta \times \eta \times 365 \quad (1)$$

where:

M_s = Amount of waste burned (kg/year)
P_c = Population (capita)
P_{frac} = Fraction of population burning waste
MSW_{GR} = Waste generation factor per capita (kg-waste/capita-day)
δ = Fraction of combustible waste
η = Combustion/oxidation efficiency (fraction)

Indonesia generates 1.0 kilogram of garbage per person each day **(35)**. The Pfrac value for underdeveloped nations can be presumed to be derived from the population whose trash is neither collected nor incinerated in open dumps. The fraction of incomplete waste combustion, Ƞ, is 1 for the incineration process, but for open burning of garbage, it is 0.58 **(35)**. We assume the fraction of combustible waste by 0.6 considering the composition of Indonesian municipal solid waste. BC emission factor related to waste burning used here is 0.76 kg/ton waste **(36)**.

3.5.2 Domestic sector

The domestic sector emissions were categorized as area source emissions, with LPG fuel combustion as the main source of pollution originating from household activities. The domestic sector emissions inventory requires data on total LPG fuel consumption, population distribution, and emission factors as follows in Eq. (2):

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

where:
E_i = Pollutant emissions i from households (kg/year)
A_c = Fuel consumption c for household sector (kL/year for kerosene and tons/year for LPG)
EF_{ci} = Pollutant emission factor i for fuel c (kg/kL for kerosene and kg/ton for LPG)

Furthermore, the emission loads from all subdistricts were added to obtain the conventional air emission load for the Magelang Regency. We adopt the emission factor for LPG consumption as 0.8 g/kg fuel (37).

3.5.3 Industry sector

The calculation of the industrial sector emission load in this study was performed accounting for number of workers and the type of industry using the Industrial Pollution Projection System (IPPS) method. Mathematically, the industrial sector emissions load is expressed in Eq. (3).

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

where:
PL = emission load (tons/year)
PI = pollution intensity (lb/1000 workers/year)
TEM = number of workers (people)
2.204,6 = conversion from lb to ton

BC is present in the particulates; therefore, the conversion factor follows the particulates, namely, 0.29% of total particulates (38) with fuel-oxidizer equivalent ratio 0.8.

3.5.4 Transportation sector

The transportation sector emissions inventory was conducted using vehicle fuel consumption and vehicle kilometers traveled (VKT) obtained by an odometer survey at official workshops and transportation agencies. The emission load was estimated using three approaches: line emission load for main roads, area source emission load for small roads, and total emission load.

Vehicle emissions from the main road network were calculated using line source guidelines, where vehicles on this road section were assumed to have fixed traffic characteristics. The line source VKT is calculated with Eq. (4) and Eq. (5).

$$VKT_{j\ line} = \Sigma Q_{ji} l_i \quad (4)$$

$$E_{ij} = VKT_{ji} EF_{cj} (100 - C)/100 \quad (5)$$

where:
$VKT_{j\ line}$ = VKT of vehicle category j on route i calculated as line source (km/year)
Q_{ji} = Vehicle volume in category j on road section i (vehicles/year)
l_i = Length of road section i (km)
E_{ij} = Emission of pollutant c for vehicle category j on road section i
C = Efficiency of emission control equipment (%)
C = 0, if no control equipment is installed

Minor roads were treated as source areas for emissions. This was because data on traffic volumes and road networks for minor roads were unavailable. Total VKT of area sources = Total VKT of moving sources – VKT of line sources

The formula for estimating total VKT is described in Eq. (6).

$$VKT_{b,c} = VKT_{b,c\ odo} \times N_{b,c} \quad (6)$$

where:
$VKT_{b,c\ odo}$ = VKT for category b vehicles using c fuel based on odometer survey (km/year)
$VKT_{b,c}$ = VKT of all category b motor vehicles that use c fuel (km/year)
$N_{b,c}$ = Number of category b motor vehicles using fuel c

For the emission factor of BC, we select generic emission factor from EMEP (39), which portion of BC to TSP is around 0.153. Table 2 shows the BC emission factor from different fleets.

Table 2. Emission factor for black carbon in transportation sector

Motorcycle	Gasoline car	Diesel car	Bus	Truck
(g/km)				
0.03672	0.00153	0.08109	0.2142	0.2142

Roads are considered as line sources passed by Light Duty Vehicle (LDV) and Heavy-Duty Vehicle (HDV) category vehicles, but for transportation as area sources it is assumed that only LDVs pass by.

3.6 BC Assimilative Capacity

To date, there is no threshold regulation for BC in ambient air. Several studies have reported the impact of BC on health risks at increment concentrations. Therefore, in this study, the assimilation capacity was determined by referring to the quality standards for TSP and $PM_{2.5}$ mass concentrations. The BC content in $PM_{2.5}$ is around 5-10% (40), while the ratio of $PM_{2.5}$ to TSP is approximately 50% (41). Therefore, hypothetically, the quality standard for BC concentration in ambient air is 2.5-5% of the TSP air quality standard or 5-10% of the $PM_{2.5}$ air quality standard.

The air pollutant dispersion model with AERMOD View 9.6.0 is used to observe the distribution of emissions so that the accumulation of BC pollutants can be obtained and at the same time become the site with the least assimilation capacity. The meteorological data were collected from openweather.com. The model was run for the same period as the measurements of BC concentrations in ambient air.

4. RESULTS AND DISCUSSION

4.1 Bibliometric Analysis

The number of references used for the bibliometric analysis (from Scopus database) was 2866 articles from year 2000–2025, based on the research topics on urban BC. The dominant research topics are carbon research in the aerosol, air pollution, air mass, ultrafine particle, vehicle emissions, and pollutant activity (Fig. 2).

There has been little research on black carbon in south east countries, with only 37 articles in the period 2007–2025 using the same categories. The latest research is related to urban black carbon concentration, biomass burning as source, seasonal variations, source contribution and intervention measures, carbonaceous aerosol composition, and fine particulate matter (Fig. 3). For the search on assimilative capacity only 36 articles were found (2000 – 2025).

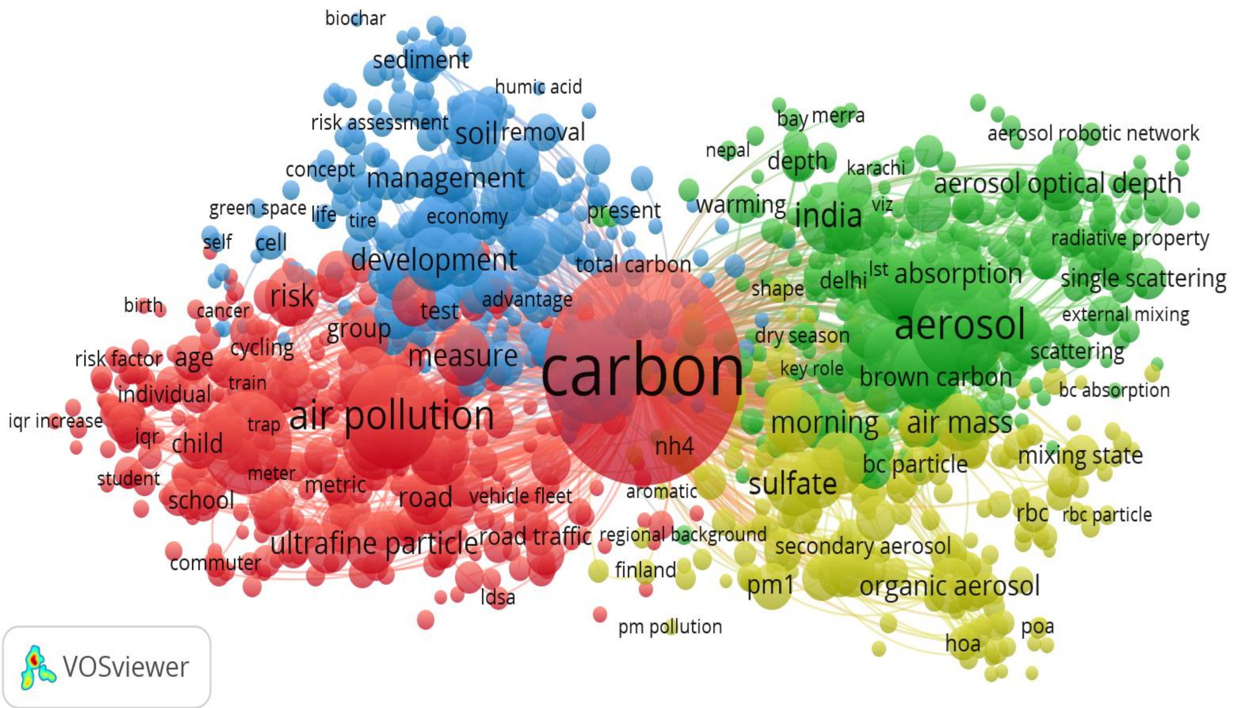

Fig.2 Bibliometric analysis related to research topic on urban black carbon

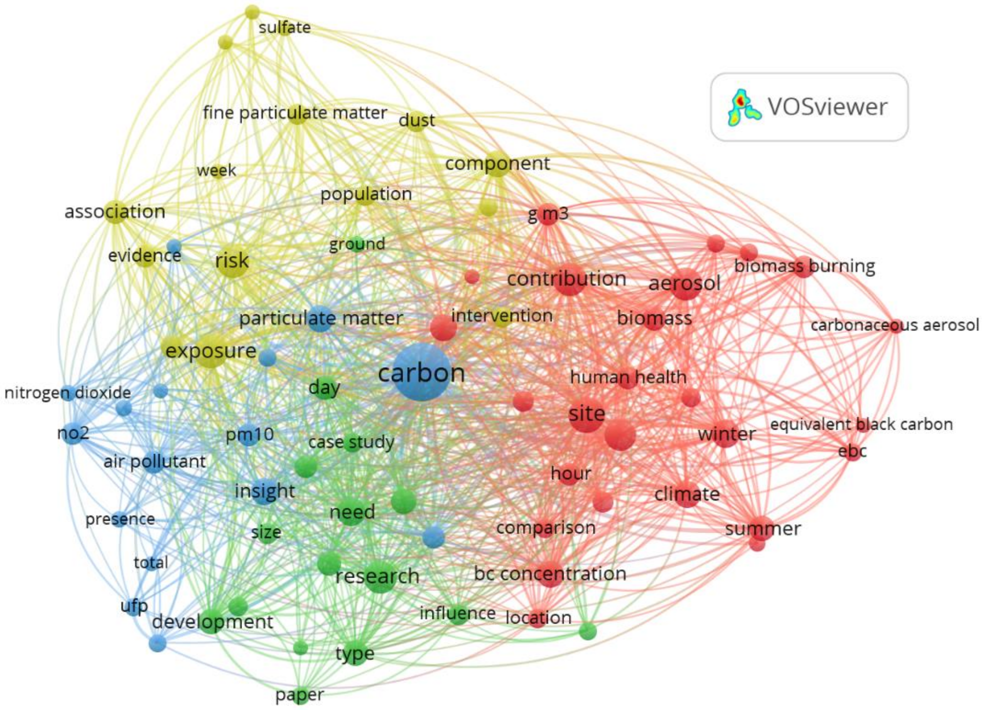

Fig.3 Bibliometric analysis related to south east countries

4.2 Ambient BC Concentration

Based on the monitoring results at the three locations (Fig. 4), the concentration of BC tended to be high at site 1, which was a mixed site. For sites 2 and 3, the patterns were almost identical. In general, the concentration of BC tends to be low in the afternoon and evening, which indicates that the source of BC emissions contributes significantly in the morning and afternoon. The ratio BC in the TSP (represented by red dot in secondary axis) varied significantly, ranging from 2%–13%. There is an exception at site 2 at 17:00–22:00, which is high (23%), and there is a possibility of local source contamination. The concentration of BC in ambient air varies widely between 0.5 - 40 µg/m^3 (42), this indicates that several study areas have varying BC source complexities.

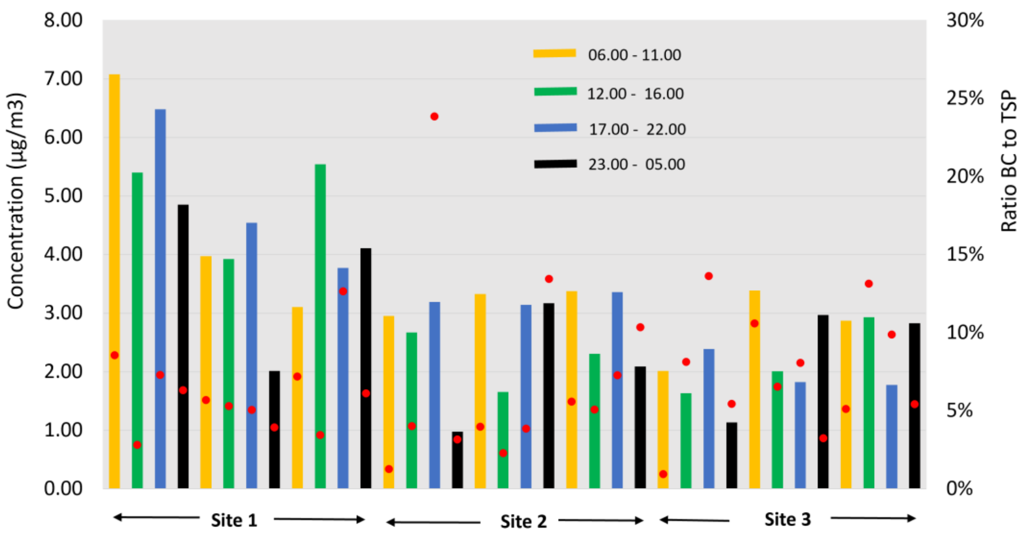

Fig.4 BC concentration at three sites

4.3 Emission Inventory

Based on historical population data from 2019 to 2023, it grew by approximately 0.6% per year, with a population of 1,322,174 people in 2023. Based on statistical data from 2020, households in the Magelang Regency are dominated by people with high incomes (44%) and middle incomes (35%), and the remainder have low incomes (21%).

Based on the region, of the approximately 21 districts in Magelang Regency, 11 are not served by the city transportation system to the landfill, resulting in the potential for traditional waste burning. Waste generation in 2022, based on data from the Magelang Regency Environmental Service, reached 252,762.64 tons/year with a waste generation rate of approximately 0.527 kg/cap/day. Domestic waste generation is estimated to increase by approximately 0.533 kg/cap/day to 0.584 kg/cap/day by 2033. Based on the results of a field survey, 90% of the population not served by the waste system burns their waste. Using the emission factor, the amount of BC emissions from the waste sector was estimated to reach 25.83 tons/year resulted from 33,981 ton/year domestic waste burning.

Domestic activities were assumed to be in the form of LPG consumption by each household based on the level of welfare, which was divided into three classes: upper, middle, and lower. The level of LPG use reached almost 197 kg/households/year, 126 kg/households/year, and 57.9 kg/households/year for the upper, middle, and lower classes, respectively. With the use of LPG in accordance with the level of welfare, LPG emission factors, and number of households, the generation of BC emissions from the domestic sector was 41.36 tons/year. Fig. 5 shows a summary of BC emission load from waste burning and LPG use in all districts.

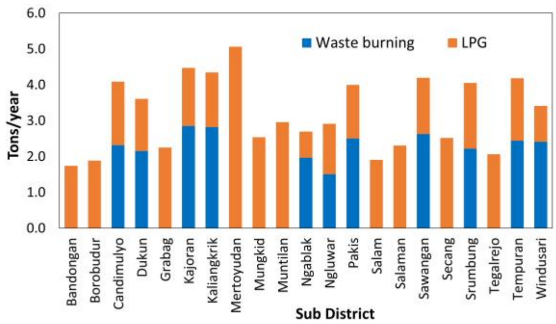

Fig.5 BC emission load from waste burning and LPG use in all districts

Industrial activities in the Magelang Regency do not spread across all districts but there is a buildup of industries in the Tempuran District. A map of industries is depicted in Fig.6.

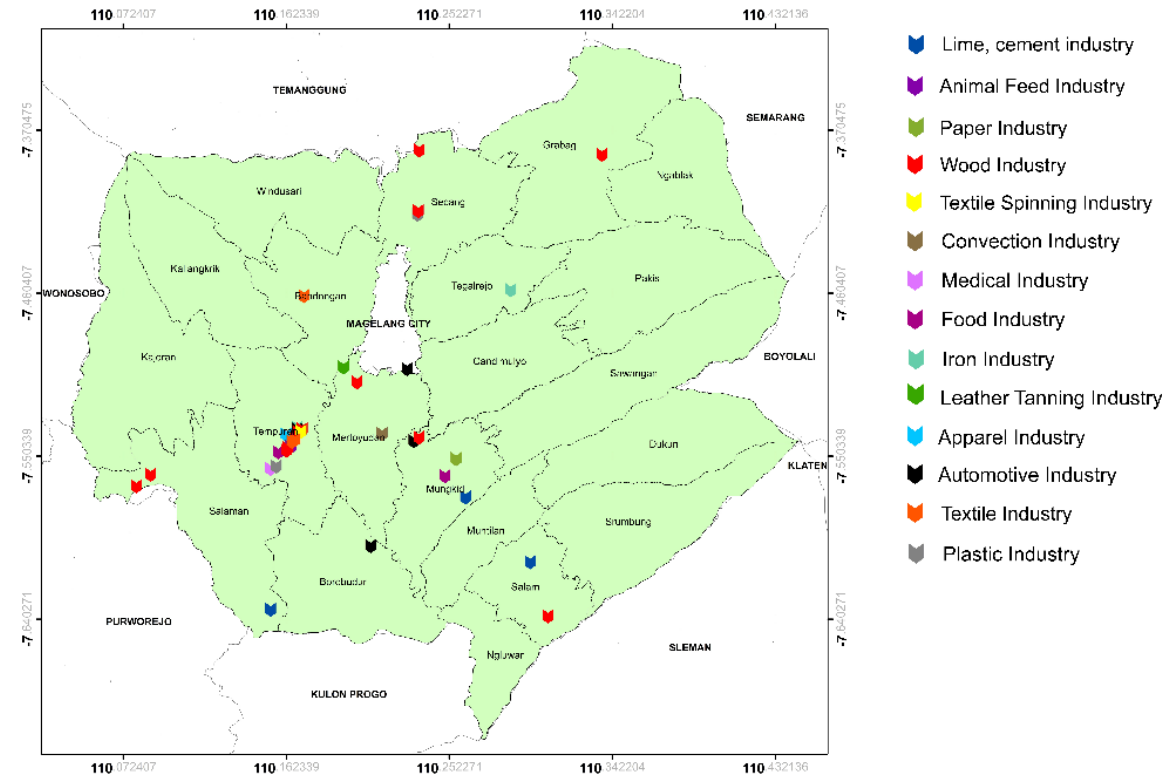

Fig.6 Distribution of industry in Magelang regency

The calculation of the industrial sector emission load in this study was performed using number of workers and types of industry, namely, the IPPS method, where the IPPS factor of the industrial sector emission load for particulate matter (PM) was 47.56. The overall BC emission load from the industrial sector is 1.176 tons/year with the distribution of emission loads based on sub-districts. Fig.7 shows the proportion of BC emission load based on sub-district. Tempuran District, which contributes the most to black carbon emission load, has the largest number of industries and is a mixed area with residential and commercial areas. The second contributor, Salam District, has a large number of industries, especially wood processing industries. These wood industries usually use steam generated from coal-fired boilers for the drying process.

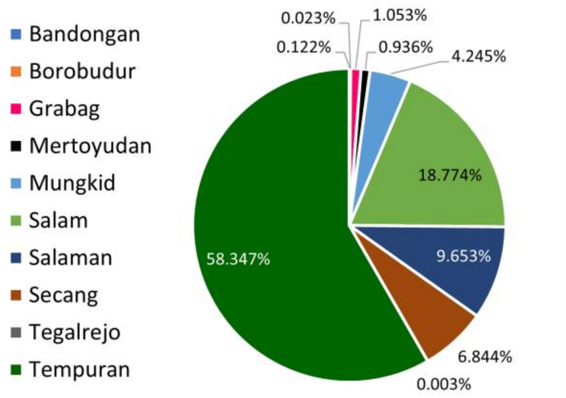

Fig.7 Percentage of BC emission load from industrial activities in each district

Transportation activities, the main contributors to NO_2, are divided into two categories: line and area sources. In 2022, nine large roads (line sources) had traffic counting values for motorcycles, cars, buses, and trucks of 336,954; 98,579; 4,458, and 19,281 units/day, respectively. Based on data from vehicle repair shops, the average VKT for motorcycles, cars, buses, and trucks were 18,705 km/year, 23,800 km/year, 41,930 km/year, and 92,769 km/year, respectively. In 2022, the largest number of vehicles was motorcycles at 391,582 units; however, historically, the highest vehicle growth was cars at 7.25% per year. The BC emission load from line transportation sources was estimated at 86.9 tons/year (Fig. 8). Meanwhile, the BC load for area source transportation was estimated at 224.97 tons/year.

The high contribution of BC emissions from the transportation sector (total 82%) indicates the need for BC emission control both at the regency and provincial level. This is because line transportation is a connecting road between regencies within a province.

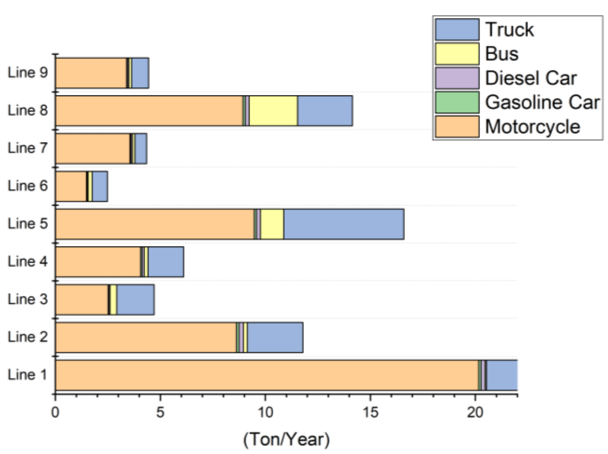

Fig.8 BC emission load from line sources transportation

The total BC emission load, including waste emissions, domestic emissions, vehicle emissions, and emissions from the industrial sector (Fig. 9), was obtained as follows:

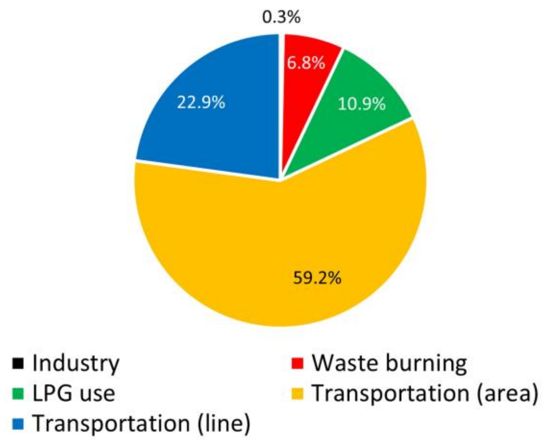

Fig.9 Total ratio of emission load of BC

4.4 BC Assimilation Capacity

Based on field measurements at three locations (see Fig.10), when compared to the upper limit of BC in the TSP air quality standard (Indonesian regulations/IDN_H), the BC assimilation capacity for all three locations still accomodates around 6-9 μg/m^3 BC. However, the lower limit (IDN_L) for all three locations can only accommodate 1-3 μg/m^3 of BC concentration. When compared to the WHO air quality standard for $PM_{2.5}$ (43), the BC assimilation capacity is already minus 0.81 to minus 3.82 μg/m^3 (WHO_L and WHO_H). This means that there should be restrictions on BC in the ambient air at all three locations (based on WHO regulation).

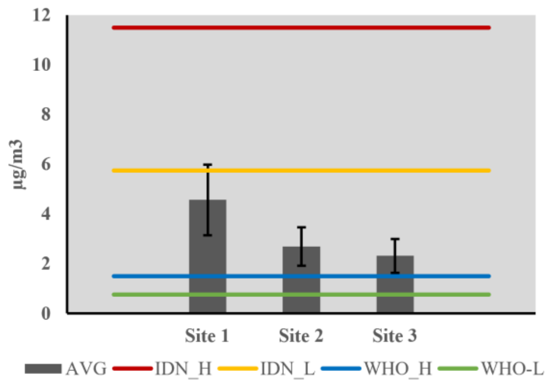

Fig.10 BC Assimilation Capacity in Three Locations

The modeling scenario was conducted for an area of 42 x 42 km with a grid spacing of 2.1 km (see Fig.11). Windrose during sampling is shown in Fig.12.

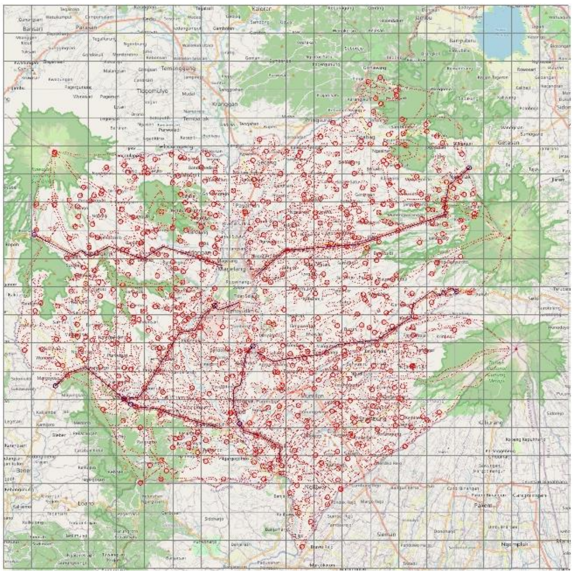

Fig.11 The model area with emission sources

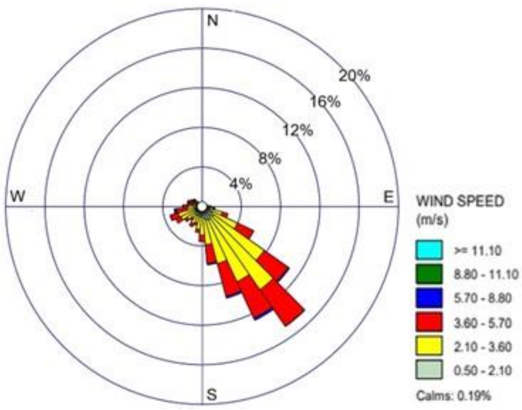

Fig.12 Windrose during sampling

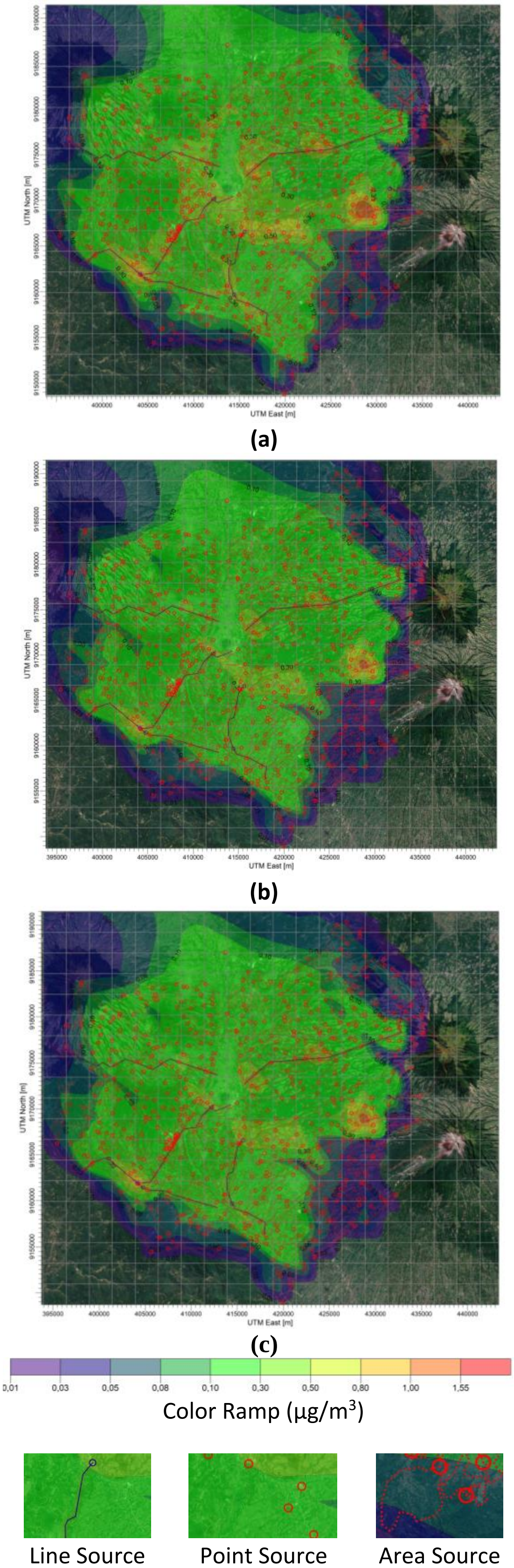

Fig.13 Spatial distribution of bc emissions in three periods 12a (28–30 Aug), 12b (31 Aug–2 Sept) and 12c (3–5 Sept)

Fig. 13a, 13b, 13c show the distribution of BC emissions after being modeled with the AERMOD during the sampling period. It was accumulated in areas that are not too close to the main roads. The distribution of BC emissions tends to the North West (see wind direction in Fig.12), where there is a concentration of industrial locations and the main road from the Magelang Regency to Yogyakarta Province. The maximum ambient black carbon concentrations based on the emission distribution modeling results were 1.54 μg/m^3, 1.22 μg/m^3 and 1.23 μg/m^3 for sampling period 1, period 2 and period 3, respectively.

The output results of this model are lower than the average results of field measurements. comparing the model results with the field measurements at the same coordinates/site shows ratios of 52%, 41%, and 41% for site 1, 2, and 3 respectively. This might be due to several reasons, firstly there are still many sources of BC in the Magelang Regency that have not been inventoried, secondly there is a contribution of BC pollutants from the neighboring city (Magelang city) which is outside the scope of the study, and last there is a background BC concentration that has not been added as the final BC concentration. Because the results of the BC model dispersion concentration are lower than those from measurement results, corrections need to be made to use the dispersion model as a basis for calculating assimilation capacity.

It is estimated that the concentration of BC will be much lower during the rainy season. Based on the distribution of these emissions for 2024 and from field measurements, the assimilation capacity of BC remains adequate when compared with the ambient BC value category as in (44) where the average ambient BC results in Magelang Regency were at a low level (<4 μg/m3).

4.5 Managing Black Carbon Emissions

Along with the development of urbanization, where the transportation sector is still the main contributor of pollutants, it is feared that, in the next few years, its capacity will be exceeded if there are no strategic steps taken to mitigate conventional pollutant emissions, particularly those of BC. Therefore, reducing emissions at the primary BC source is inevitable to prevent BC assimilation capacity from reaching its maximum.

Black carbon emission control primarily involves controlling emissions at the source, specifically vehicle emissions, industrial emissions, and biomass burning, through regulations such as tightening emission standards, incentives for industry to reduce emissions (45), the use of clean fuels for transportation, and reducing biomass burning and domestic black carbon emissions (46). BC content in the atmosphere can be reduced through effective long-term clean air actions (47), moreover atmospheric BC content can be reduced through a comprehensive program, namely mitigation at the city and regional levels (17). Atmospheric controls include planting clustered vegetation and arranging buildings in urban areas to avoid obstructing black carbon ventilation at the source (48) .

5. CONCLUSION

Based on a bibliographic analysis, minimal research has been conducted on the assimilation capacity of BC in urban areas. More research is needed related to ambient carbon measurements, particle research in air, human exposure, pollutant activity, and trajectory studies. BC sources are mixed in the urban areas of Indonesia. Three BC measurement locations were identified in areas of relatively mixed land use. Considering the many sources of BC, it has the highest content during the day. The burdens of BC emissions from the waste, domestic, industrial, and transportation (area-line) sectors were 25.826 tons/year, 41.361 tons/year, 1.176 tons/year, and 311.879 tons/year, respectively. Based on modeling during the sampling period, the BC ambient concentration was accumulated in areas that are not too close to the main roads. Current BC assimilation capacity remains adequate; however, it is estimated that, in the coming years, its assimilative capacity will be exceeded. Based on the TSP air quality standard regulations in Indonesia, the BC concentration still has an assimilative capacity of around 6-9 μg/m^3 (the upper limit) and 1-3 μg/m^3 (the lower limit). Meanwhile, based on WHO guidelines, referring to $PM_{2.5}$ parameter, the BC concentration no longer has an assimilative capacity. Therefore, it is necessary to handle emissions from its sources.

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