VIETNAM JOURNAL OF HYDROMETEOROLOGY

Check for updates

Research Article

Application of numerical models in estimating particulate matter emissions ($PM_{2.5}$ and PM_{10}) from road traffic: A case study in Ha Noi, Viet Nam

Cung Hong Viet[1], Pham Van Sy[2], Tran Van Tra[3], Le Van Linh[3], Truong Ba Kien[1], Ngo Thi Thuy[1*]

[1] Viet Nam Institute of Meteorology, Hydrology and Climate Change; hongviet97@gmail.com; tide4586@gmail.com
[2] Climate Change Department; phamsymt@gmail.com
[3] Water Resources Institute; tranvantra@gmail.com; linhlevan6527@gmail.com

*****Corresponding author: tide4586@gmail.com; Tel: +84–363003245

Received: 2 August 2022; Accepted: 24 September 2022; Published: 25 September 2022

Abstract: The article is developed to analyze the characteristics of particulate matter pollution in Hanoi using observation data at automatic monitoring stations. The estimation method of particulate matter emissions from road traffic is also implemented by the coupled model so-called WRF–SMOKE. The model is applied to estimate $PM_{2.5}$ and PM_{10} emissions from road traffic in Hanoi city for 2021. The results are 325,045.8 tons/year (average 27,087.2 tons/month) and 523,565.9 tons/year (43,630.5 tons/month) respectively. Overall, the comparisons of the estimation result with EDGAR global emissions data and particular matter observation show similarity in terms of spatial and temporal distribution as well as the ratio between PM_{10} and $PM_{2.5}$. This comparison performs the applicability of the numerical coupled model in estimating particular matter emissions.

Keywords: WRF-SMOKE; Emissions; Air pollution; Particulate matter; Road traffic; Hanoi.

1. Introduction

At present, air pollution in general is considered a worrying problem globally due to its impacts on many different fields and social objects. There are significant impacts on human health. It is proved by many studies that the presence of harmful substances in the air contributes to increased mortality or chronic diseases in children. Some common health problems include cardiovascular disease, respiratory disease, and nervous system disease [1–7]. In addition, air pollution can affect the digestive system, urinary tract, and pregnancy [8–10]. Furthermore, extreme weather events caused by air pollution cause harmful effects on the ecosystem (acid rain). Simultaneously, secondary costs such as medical examination and treatment costs, treatment costs, and pollution control... are economic burdens caused by air pollution.

Air pollution is emitted from many different sources. In particular, one of the main sources is transportation activities. Many major cities in the world are currently facing air pollution. Typically, emissions from transport activities in some big cities in Europe account for a relatively high proportion such as in Paris (France) at 29%, Madrid (Spain) at 39%, and London (UK) is 50% [11]. Moreover, this kind of emission in Bangkok city (Thailand) is 60% [12].

Currently, most of the studies on emissions in Viet Nam are applying inventory data sets developed at global and regional scales. Those results in low reliability and accuracy (due to regional variations). Furthermore, forecasting the AQI requires input data which is emission inventory data. At the same time, the implementation of emission inventory has been regulated by the Government in many legal documents. Therefore, the implementation of the estimation study will contribute to the development of emission inventory methods for vehicles and practical results to the construction of a unified emission inventory data set under conditions in Viet Nam.

In this study, pollution emissions specifically particular matter (PM) PM_{10} and $PM_{2.5}$ are inventoried from the traffic sources for Hanoi city. The coupled model namely WRF–SMOKE is used to estimate the particular matter emission that contributes to air pollution in Hanoi urban area. The results of PM_{10} and $PM_{2.5}$ emissions are then compared to that of EDGAR global data and the observation data of PMs concentration as well.

2. Methods and data

2.1. Study area

Hanoi is a city located in the Red River Delta region, with an area of 3,324.92 km^2. Hanoi has a tropical monsoon climate with four distinct seasons a year. In particular, the summer is usually hot, with many thunderstorms and storms. Winters are cold, with a low level of precipitation. The transition time between these two seasons falls between April and October. Hanoi has an average of 1,500–1,700 hours of sunshine annually with an average annual temperature of approximately 23^{o}C. In particular, due to the influence of global warming and urban effects, on summer days, the highest outdoor temperature of the day can reach > 50^{o}C.

The air quality index (AQI) observed at monitoring stations of Hanoi city shows a fluctuation within the unsafe level for human health. In Hanoi, dust pollution in winter and early spring is higher than in other seasons of the year. This is also a common phenomenon for many years and has a regular pattern, particular matter pollution increases in the period from December, January to February and may last into March. This rule has also been shown. quite clearly in the past time when the PM concentration of Hanoi is having significant fluctuations, especially the increase in dust concentration of $PM_{2.5}$ and PM_{10}.

The urbanization process in Hanoi is increasing rapidly (2nd largest population in the country with about 8,053,663 people) [13] leading to an increase in population and a general need for transportation and personal mobility. The number of vehicles operating in Hanoi has increased significantly (including registered vehicles inside and outside the city). This leads to frequent traffic jams occurring at many hours of the day. In parallel, the process of vehicle management is not synchronized between localities. Vehicles such as motorbikes are not registered, and their performance cannot be assessed, making the amount of air pollution worse. [10] performed that road transport activities contribute up to 25% to $PM_{2.5}$ emissions in Hanoi.

2.2. Research data

The necessary data include (i) monitoring data of $PM_{2.5}$ and PM_{10} parameters in Ha Noi; (ii) Survey data on traffic volume (motorcycles, cars under 9 seats, cars 12–24 seats; light trucks 2 axles and heavy trucks over 9 seats) corresponding to different road types (main urban roads; secondary urban roads; main rural roads and secondary rural roads); (iii) Remote sensing data and geographic information; (iv) Global meteorological data and (v) Global emissions data.

2.2.1. $PM_{2.5}$ and PM_{10} monitoring data in Ha Noi

As of 2016, the automatic air quality monitoring network in Hanoi includes 12 stations with 10 stations operated by the Department of Natural Resources and Environment (since 2017), 01 under the Vietnam Environment Administration (since 2010) and 01 private air quality monitoring station belongs to the US Embassy in Vietnam. By July 2019, the French Embassy in Vietnam installed a $PM_{2.5}$ monitoring station at the embassy campus. By May 2020, THT (Korea) Co., Ltd. sponsored and installed 24 automatic sensors to monitor air quality in the Hanoi area. Up to now, there are 37 air quality stations in Hanoi city [14]. In this study, the observed data on air quality at stations is summarized in Table 1.

Table 1. Monitoring data of $PM_{2.5}$ and PM_{10} collected in Ha Noi.

No.	ID	Monitoring station	Monitoring parameters	
			$PM_{2,5}$	PM_{10}
1	CCBVMT	Hanoi Environmental Protection Department	2018, 2021, hourly	2017–2018, hourly
2	MK	Minh Khai (Bac Tu Liem)	2018	2017–2018, hourly
3	HD	Hang Dau	2018, daily	2017–2018, hourly
4	HK	Hoan Kiem	2018, daily; 2021, hourly	2017–2018, hourly
5	KL	Kim Lien	2018, daily; 2021, hourly	2017–2018, hourly
6	MD	My Dinh	2018, daily; 2021, hourly	2017–2018, hourly
7	PVD	Pham Van Dong	2018, daily; 2021, hourly	2017–2018, hourly
8	TC	Thanh Cong	2018, daily; 2021, hourly	2017–2018, hourly
9	TMai	Tan Mai	2018, daily	2017–2018, hourly
10	TMo	Tay Mo	2018, daily; 2021, hourly	2017–2018, hourly
11	NVC	Nguyen Van Cu	2010–2019, 2021, hourly	

2.2.2. Vehicle volume data

The data of vehicle volume includes:

Vehicle volume distribution was retrieved from a field survey on the main roads of Hanoi (see Annex Table 1). The traffic survey data is observed 3 times a day from September to November 2021 (07:00–08:00, 11:00–12:00, 16:00–17:00).

Mean daily vehicle volume extracted from COMPASSTECH [16] and Nippon Koei Co., Ltd – Japan [17] (Annex Table 1). The survey location is presented in Figure 1.

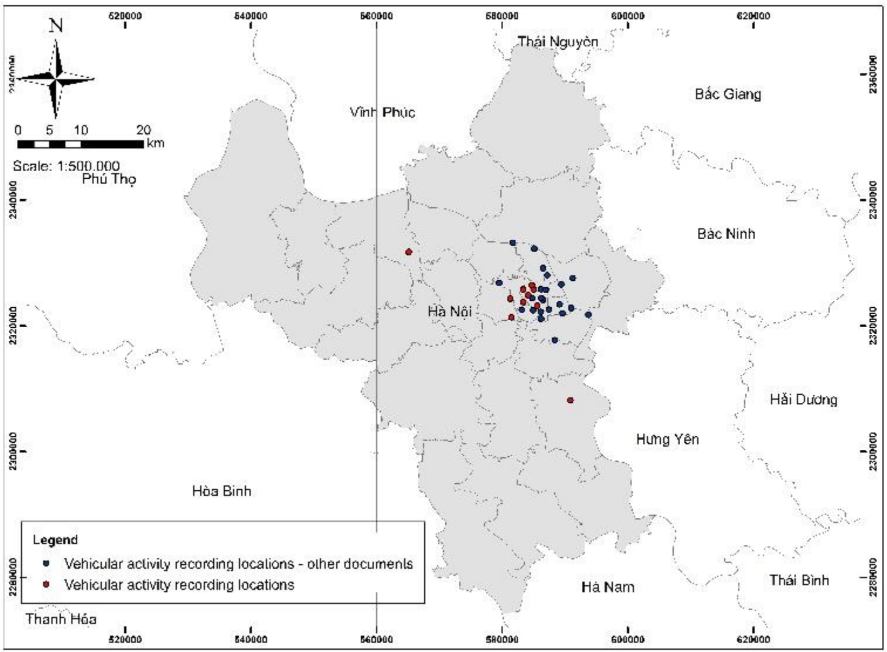

Figure 1. Map of locations with vehicle traffic measurement data.

2.2.3. GIS and remote sensing data

The original data used by the research team to edit the road network is data extracted from the website: http://download.geofabrik.de/index.html. This website includes Viet Nam topographic datasets for various features such as shapefiles. In this case study, the research team used the shapefile of the road object of the dataset, then edit, and classify the types of roads in Ha Noi following the polyline lines under the requirements of the SMOKE model. This editing work was done using ArcGIS software.

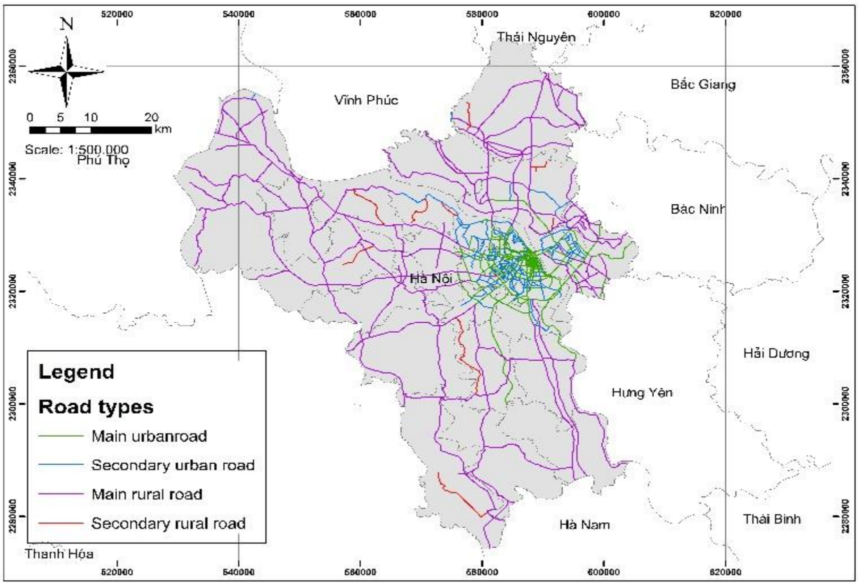

Figure 2. Road network in Ha Noi used in the study.

2.2.4. Global meteorology data

Input data using Global Convection Analysis data source NCEP FNL. Daily data with obs 6 hours apart has a grid resolution of $1^o - 1^o$. This reanalysis is initialized with the forecast data in the Global Forecast System (GFS), however, the reanalysis product will initialize relatively slower than forecast products. The data set parameters include surface pressure, sea surface temperature relative humidity, wind, vertical movements, vortex, soil, ice cover, and ozone. Data source NCEP's reanalysis data with data series from 1999 to the present is freely available at https://rda.ucar.edu/datasets/ds083.2/. This is the input data source for launching the WRF model in the study.

2.2.5. Global emissions data

The global emissions inventory used by the study for the comparison is EDGAR (Emissions Database for Global Atmospheric Research) version 5.0 with data series available continuously from 1970 to 2015. EDGAR 5.0 was selected because it has full information on pollutant types. The EDGAR dataset provides data not only for greenhouse gases but also for common GHG compounds, especially including particular matter ($PM_{2.5}$ and PM_{10}). Furthermore, EDGAR 5.0 provides separate emission data for each type of pollutant with each specific industry/sector, such as the power industry; energy and transition industries; gas; air; road traffic; railway, pipeline and off–road transportation operations; ship; build; fuel extraction…

The study utilizes emission data from road traffic sources that EDGAR calculated in 2015 for $PM_{2.5}$ and PM_{10}. In particular, monthly averages to consider the distribution as well as changes in values during the year. The data is available on the website: https://edgar.jrc.ec.europa.eu/dataset_ap50#sources. This is the data source for testing the emission estimation results of the WRF–CMAQ model system.

2.3. Methodologies

2.3.1. Estimating vehicle volume

Types of roads are divided into 04 categories: (i) main urban road; (ii) secondary urban road; (iii) main rural road; (iv) secondary rural road. Vehicles are divided into 05 categories: (i) motorbikes; (ii) cars (< 9 seats); (iii) cars (12–24 seats); (iv) light trucks (02 axles); (v) heavy trucks (> 02 axles). The CMAQ model manual [15] is used as the basis for the above classification work.

The research team measured traffic data at locations and routes with vehicular traffic representing each type of road corresponding to administrative regions. Survey frequency at each site is 03 times a day in the morning (07:00–08:00), noon (11:00–12:00) and afternoon (16:00–17:00). Regarding the measurement method, in each measurement, traffic activity is recorded through the smartphone's camera with appropriate resolution. The video files are then processed and the media counts are counted.

However, due to limitations in time and human resources and devices, the survey work of the research team could not be representative of all the roads in Ha Noi, the mean daily vehicle loads extracted from references [16–17] are used. However, this data is the average value of day and could not present the hourly distribution of vehicle load. Therefore, an integrated estimation is proposed to retrieve daily vehicle flow as follows:

Step 1: Count vehicle load in 1 hour at 3 durations in a day of roads from observed videos. The results are vehicle load distributions of roads in Annex Table 1.

Step 2: Extract vehicle load of roads from references [1615] and [17] as mentioned in Annex Table 2.

Step 3: For the roads where vehicle distribution and mean daily vehicle load are both estimated in Step 1 and Step 2, the hourly vehicle flow is interpolated.

Step 4: For the road where only the mean daily vehicle load is estimated, the vehicle flow is estimated using the hourly distribution of similar roads in terms of type and location.

2.3.2. Coupled model WRF–SMOKE

SMOKE model (Sparse Matrix Operator Kernel Emissions) was developed by the MCNC Environmental Modeling Center (EMC) to estimate emissions (manmade and biogenic) using sparse–matrix algorithms [18]. The model outputs contribute to air quality simulation and forecasting. The SMOKE model provides processes to estimate pollutant emissions such as CO, NO_x, NH_3, SO_2, PM_{10}, $PM_{2.5}$, and so on. The model transfers emission inventory data to emission loads that are inputs of air quality models.

The SMOKE model uses two approaches to compute traffic emissions. The first approach precomputes traffic emission before running SMOKE. The second approach run SMOKE with inputs of vehicle miles traveled (VMT), vehicle load (VPOP), meteorology and MOVES outputs. In which, MOVES is a module used to simulate bulk emission or emission rates of motor vehicle.

To couple WRF with SMOKE in gases pollutant emission, the meteorological outputs from WRF model (spatial and temporal temperatures and relative humidity) are processed using MCIP (Meteorology–Chemistry Interface Processor) output files. These meteorological inputs are then set up for MOVES to get the emission rate. This output will be used to compute the pollutant emission from mobile sources using processes of temporal and spatial allocation, chemical speciation and layer assignment.

2.3.3. Modelling method

The input data for calculation of emissions matters, specifically vehicles and road types, will be researched and classified to choose an appropriate emission factor. The emission estimation process using the combined model WRF–SMOKE allows the integration of emission data processing methods by sparse matrix algorithms on a high–performance computer system based on variations in meteorological conditions.

Meteorological factors that affect the emission of vehicles are extracted from the output of the WRF model such as temperature, humidity and wind. The WRF model in the study was edited with the following parameters and implementation procedures:

- Domain coordinates: 104.3809–107.5417°E; 19.57395–22.14902°N;
- Number of grid points for the calculated domain: 84 – 84;
- Number of grid cells in each dimension: 83;
- Center of the domain: 21.02899°N–105.412°E;
- Size of grid cells: 2 km × 2 km;
- Vertical levels: 38.

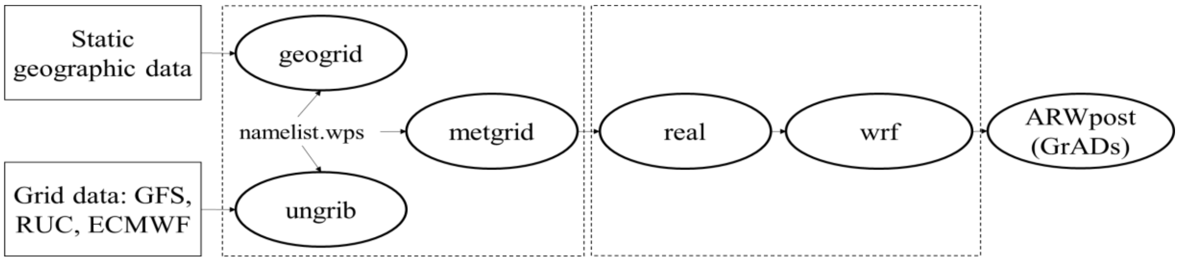

Figure 3. Processing stages of WRF model.

The formula for estimating PM emissions from vehicles will be implemented by multiplying the distance travelled data in each day of vehicles by the number of vehicles and the emission factor of the respective vehicle type. The input meteorological data for the SMOKE model will be downscaled in terms of the calculation domain for the Hanoi area using the WRF model from the GFS global data.

As regards the practice of national and international studies on the estimation of PM emissions from vehicles, it can be seen that an inventory or emission estimate can be made through the application of a variety of different modeling methods. Each type of model developed will be suitable for each specific parameter and research area. Studies on emissions inventory in Viet Nam have generally updated advanced technologies in the world. In which, modeling method is widely applied to calculate, estimate emissions or simulate, evaluate and forecast emissions distribution. Therefore, the use of modeling to estimate emissions of pollutants in the air is completely appropriate and has a solid reference base.

The transportation emission estimation can be made by simple calculation through the following formula [18]:

$$E = A * EF \tag{1}$$

where E is the emission level (tons/day); A is the active data of each type of vehicle (km/day); EF is the emission factor of each type of vehicle (tons/km).

Mathematical models also use the above formula to estimate emissions. Furthermore, the models also allow for estimating emissions according to defined calculation domains, thereby supporting post-processing to estimate and present in the form of maps and charts. Considering the research objectives, the combination of the weather forecasting and research model (WRF) with the sparse matrix emission model (SMOKE) has been applied in many research cases in Vietnam. Therefore, the use of the combined models above in the field of emission estimation for Viet Nam is appropriate and highly applicable.

2.3.4. GIS and remote sensing method

The input data of the SMOKE model require preprocessing stage using GIS and remote sensing technology. The administrative boundary data to be determined by GIS include coordinates, population, area, and district code. Data on cadastral boundaries and road networks that need to be determined by GIS include generating and classifying road networks according to specific road types, lengths and corresponding road codes in each district.

A distributional map of PM emissions from traffic vehicles of Ha Noi will be created based on the combination of the output of the SMOKE model and the application of ArcGIS software together with the emission estimation results.

3. Results and discussion

3.1. Status of $PM_{2.5}$ and PM_{10} concentration in Hanoi

According to the air quality overview report in Hanoi released by the Ha Noi Department of Natural Resources and Environment, the local air quality has changed over time. In general, air quality usually improves between May and October (rainy season) and decreases from November to April (dry season) every year. Indicators of dust $PM_{2.5}$ and PM_{10} are always recorded with the highest number of days exceeding the standard, especially at monitoring stations near traffic areas. During the day, PM concentration tends to increase between 07:00–09:00 and 16:00–23:00. As regards types of monitoring (Monitoring types include: residential, countryside, craft village, urban and sub-urban, traffic), traffic monitoring witnessed the worst air quality condition [19].

The analysis results of the hourly average and 24–hour average of $PM_{2.5}$ monitoring data also show quite obvious changes over time. During the rainy months (May to October), the measured $PM_{2.5}$ concentration is usually lower than in the rest of the months. During this time, although the temperature is high, the humidity is maintained at a high level (above 85%) causing showers that help disperse PM in the air. At the same time, the period when the concentration of $PM_{2.5}$ exceeds the limit (average of 24 hours) of QCVN 05:2013/BTNMT gradually decreased over the years, but generally remained at a high level (Figure 4).

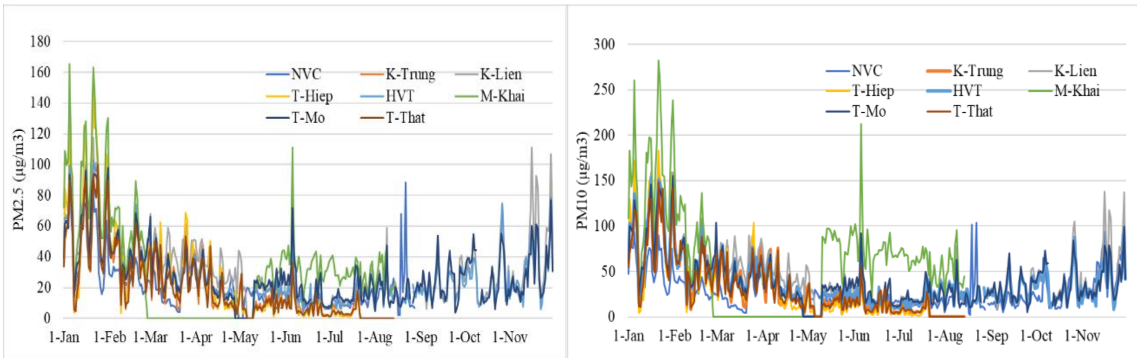

Figure 4. Average daily $PM_{2.5}$ (left) and PM_{10} (right) at some stations in Hanoi in 2021.

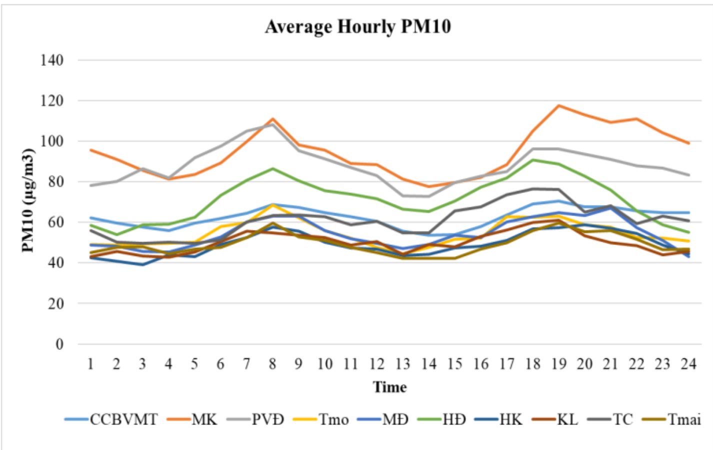

Figure 5. Variation curve of daily average PM_{10} concentration at 10 stations managed by Hanoi Department of Natural Resources and Environment (May 2017 – December 2018).

The assessment of PM_{10} observation showed that the hourly and 24–hour average concentrations at the stations changed significantly over time. During months with low precipitation and low temperatures (from July to October), the observed concentration of PM_{10} is usually lower than that of the dry season months with higher air temperature (December to June) (Figure 4). The general trend of the day (Figure 5), the concentration of PM_{10} usually peaks between 7:00–9:00 and 18:00–20:00. This is the rush hour with high traffic density.

3.2. Vehicles volume corresponding to road types

Measurement data show that the main urban road and the secondary urban road have a proportion of hundreds of vehicles participating on the road that are equivalent. Specifically, motorbikes are the main means of transport with the proportion accounting for over 70%. For the main rural road (highway), this figure is lower because vehicles operate at high speeds. However, the number of motorbikes is still quite large.

Considering the traffic flow, the traffic is usually high during the commute time and at the end of the day on main urban roads. These times are usually 07:00–09:00 and 17:00–19:00. In contrast, the period of reduced vehicle traffic usually falls around 1–2 hours in the afternoon, around 12:00–14:00, and then gradually increases. This trend is quite evident in motorbikes and cars (< 9 seats).

In the area of main rural roads, the number of motorbikes still accounts for the majority with a proportion of over 80%. Next are cars with less than 9 seats with a proportion of about 10%. Among the remaining vehicles, the proportion is small and there is no big difference in proportion. The proportion of means of transport of the main rural road as well as the daily flow variation is similar when compared with the urban road. Moreover, the traffic of motorbikes and cars with fewer than 9 seats increases significantly between 07:00 and 09:00 in the morning and 17:00. The types of trucks, including light trucks and vans, are not too large, but maintained with fairly even traffic throughout the day. Therefore, emissions from trucks of all kinds are still significant.

In the area of secondary rural roads, the proportion of motorbikes is lower than that of main rural roads, at 65%. Instead, there is an increase in cars under 9 seats as well as light trucks. The proportion of cars over 9 seats and heavy trucks is also higher than that on main rural roads. The secondary rural road variables are quite similar to other types of roads in terms of motorbikes and cars with fewer than 9 seats. However, the traffic of cars over 9 seats and trucks is higher and remains high throughout the day.

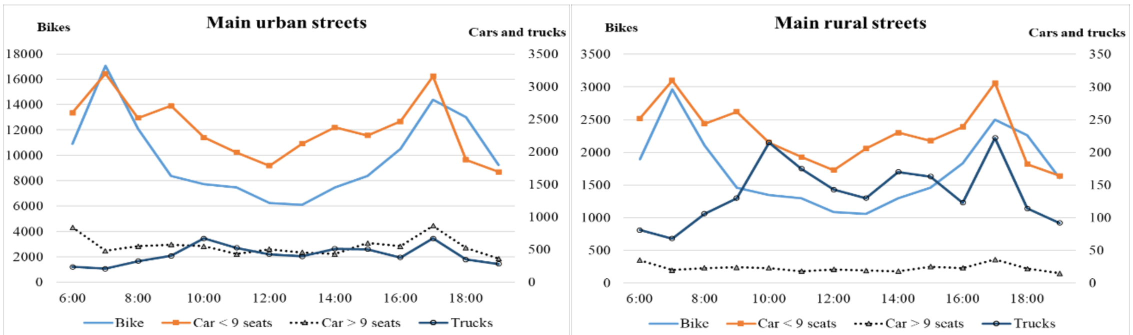

Figure 6. Vehicle loads on some types of roads in Hanoi.

3.3. Estimating results of $PM_{2.5}$ and PM_{10} emissions in Hanoi

Table 2 illustrates the estimated results of emissions of two types of PM from the traffic source in Hanoi by month in 2021. Total emissions in 2021 of vehicles in Ha Noi for $PM_{2.5}$ is 325,045.8 tons/year (average 27,087.2 tons/month) and for PM_{10} is 523,565.9 tons/year (43,630.5 tons/month).

Table 2. Estimated results of $PM_{2.5}$ and PM_{10} emissions from traffic sources in Ha Noi in 2021.

Month	$PM_{2.5}$ emissions (tons)	PM_{10} emissions (tons)
1	22,282.9	37,781.3
2	26,389.1	42,213.2
3	27,131.3	43,441.3
4	28,100.1	45,166.8
5	28,207.9	45,080.1
6	27,468.6	44,286.5
7	27,275.1	43,620.9
8	27,398.1	43,891.4
9	27,623.9	44,360.0
10	28,410.8	46,104.1
11	28,048.2	44,945.9
12	26,709.8	42,674.4
Total	**325,045.8**	**523,565.9**

The spatial estimation results show that the main emission areas of $PM_{2.5}$ and PM are concentrated in the citadel districts (Figure 7). This is an area with a large population density and many traffic vehicles. Furthermore, this area often happens to be congested at peak hours. In addition, areas with high emission levels are also the locations of highways, national highways, and provincial roads with a large number of vehicles such as cars over 9 seats along with trucks.

In terms of spatial distribution, in the central area, PM_{10} has wide coverage with a higher value than $PM_{2.5}$. Specifically, with an emission value of over 5 tons/month, the emission map of $PM_{2.5}$ only covers the area of Hai Ba Trung, Dong Da, Hoang Mai, and Thanh Xuan districts. PM_{10} covers a wider area to the west including the aforementioned districts along with Bac Tu Liem, Nam Tu Liem and Ha Dong. In contrast, $PM_{2.5}$ tends to cover more widely than PM_{10} in the south of the city, along National Highway 1A extending from Thanh Tri district to Ha Nam province. According to measured traffic data, this is the main rural road area with trucks participating in high volume and maintaining high volume during the day. In temporal distribution, the period with high emission levels is April – May and October – November, from June to September, emissions have decreased and maintained at a lower level. This variation is similar to the characteristics of $PM_{2.5}$ and PM_{10} in Ha Noi mentioned in Section 3.1.

3.4. Comparation between $PM_{2.5}$ and PM_{10} emissions estimating results with the global data EDGAR

The calculation from the EDGAR model shows that the main emission zones of both $PM_{2.5}$ and PM_{10} are in citadel districts including Bac Tu Liem, Nam Tu Liem, Tay Ho, Cau Giay, Ba Dinh, Hoan Kiem, Dong Da, Hai Ba Trung, Ha Dong, Thanh Tri, Hoang Mai (Figure 7). These areas have an average monthly $PM_{2.5}$ and PM_{10} emission values of 4–19 tons/month. In terms of temporal, the period of widespread emissions in both value and spatial remained from November to May with wider emission areas including Long Bien and Gia Lam to the East, and Hoai Duc to the west.

High–level emission areas are mainly in central districts, which is similar to EDGAR data. The variation in the area is not much. The most obvious increase can be seen in the southern region, including Thanh Tri and Phu Xuyen districts, with an increase in the months of the year. Besides, it can be seen that there is another high emission zone located in the northwest of the city, extending along route 32 starting from Bac Tu Liem district to the Son Tay area (adjacent to Vinh Phuc province). This is the area with the majority of motorbikes and cars with less than 9 seats, especially the traffic flow of cars over 9 seats as well as light trucks and large heavy trucks remain high during the day.

Even though there are some emission differences due to resolution, these spatial and temporal variations are quite similar to that obtained from EDGAR (Figure 8).

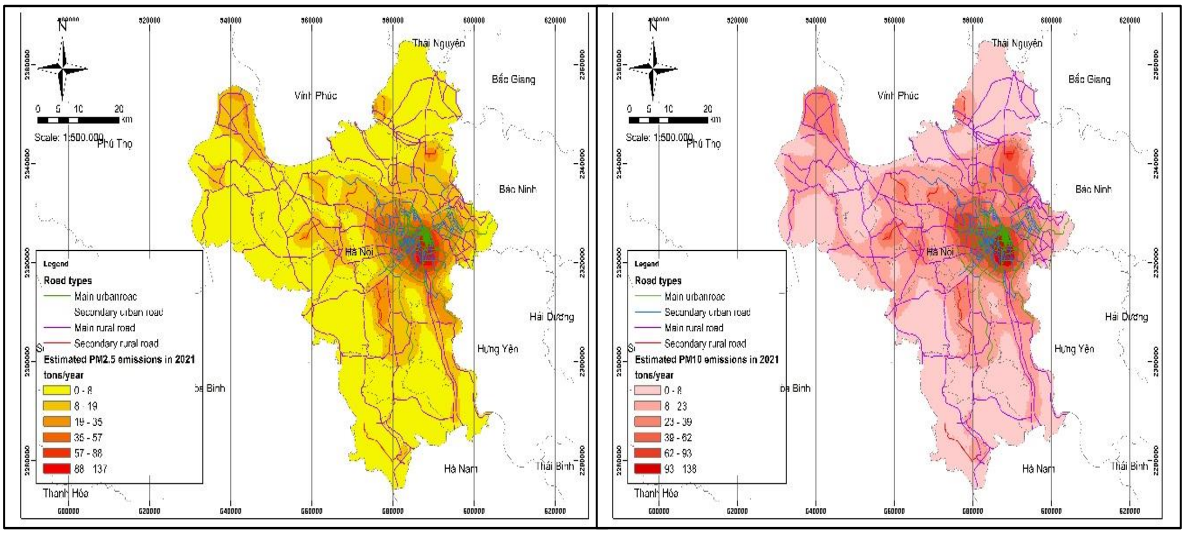

Figure 7. Estimated results of $PM_{2.5}$ and PM_{10} emissions from traffic sources in 2021.

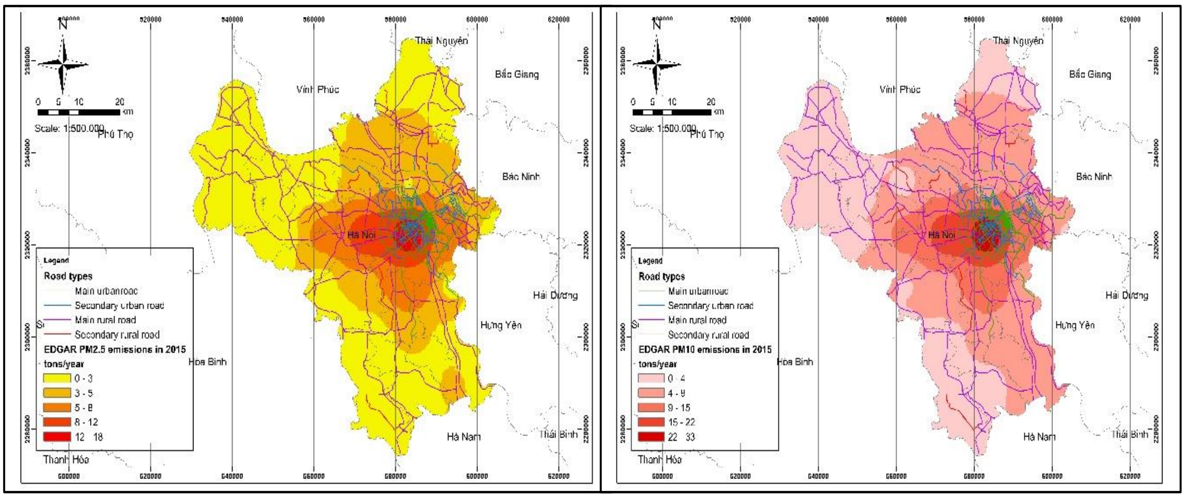

Figure 8. EDGAR $PM_{2.5}$ and PM_{10} global emissions data from transport sources.

Since there is no data on EDGAR in the same year as our study i.e., 2021, the ratio between $PM_{2.5}$ and PM_{10} emission in a year is used to be to be a reference for our calculation with the assumption that these two particular matters have a closed relationship [20]. The ratios are around 1.8 in EDGAR estimation and 1.6 in our calculation.

Table 3. Comparison of total $PM_{2.5}$ and PM_{10} emissions from transportation sources between estimated results and EDGAR.

No.		$PM_{2.5}$ emissions (tons/year)	PM_{10} emissions (tons/year)
1	WRF–SMOKE	325,045.8	523,565.9
2	EDGARv5.0	115,054.55	213,852.3

A comparison of monthly emissions of districts in Hanoi city is also conducted to see the spatial correlation between EDGAR and SMOKE estimations. The monthly emission of cells in a district is averaged to get a representative value. Figure 9 shows a close relationship between WRF–SMOKE model with EDGAR data in both $PM_{2.5}$ and PM_{10} emission estimation.

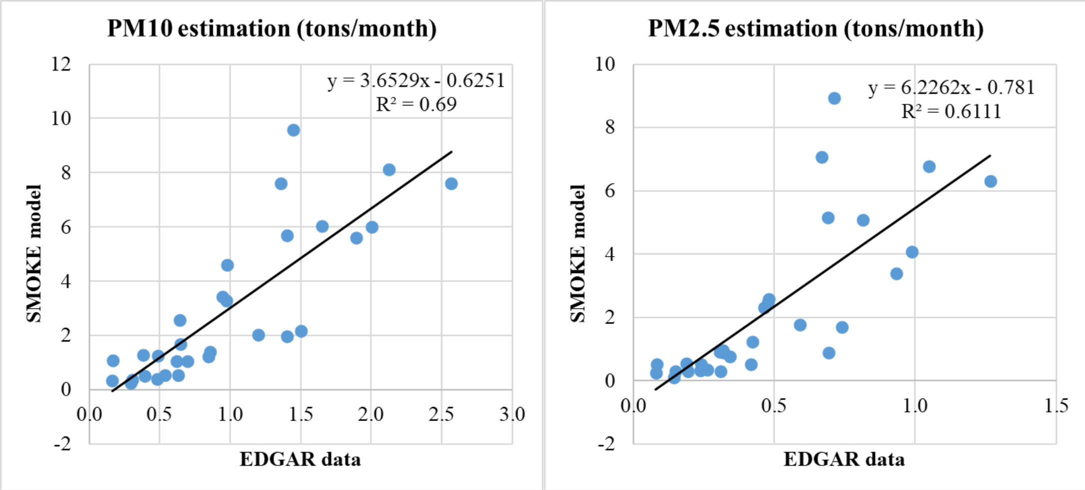

Figure 9. Correlation of EDGAR and SMOKE estimation for districts of Hanoi.

4. Conclusion

The study estimated $PM_{2.5}$ and PM_{10} emissions from transportation sources at 325,045.8 tons/year (averagely 27,087.2 tons/month) and 523,565.9 tons/year (averagely 43,630.5 tons/month). The results are relatively similar to the spatial scale of EDGARv5.0 as well as the correlation between the emission data of $PM_{2.5}$ and PM_{10}. The estimated data was higher than that of EDGAR data due to the difference in the time of calculation (the article calculated for 2021, the EDGAR calculated for 2015). Furthermore, the WRF–SMOKE combined model is suitable to estimate emission inventories for other provinces.

Since the study was implemented in 2021 when Hanoi experienced the COVID–19 pandemic, the emission inventory was retrieved containing several uncertainties in terms of traffic load and air pollution measurements. The vehicle countings might not be representative of the traffic status of Hanoi. The PM emission results, thus, may be biased values. Furthermore, the data source's limitation is one of the biggest challenges in air pollution simulation.

Author contribution statement: Provided human and financial sources for the survey; Designed the study, Revised the manuscript: N.T.T.; Wrote drafts, Did calculation: C.H.V.; Designed the study: P.V.S.; Designed the study and Revised the manuscript: T.V.T.; Contributed to SMOKE calculation: L.V.L.; Contributed to WRF simulation: T.B.K.

Acknowledgements: The study was supported by a grant from the project TNMT.2019.05.03 "Short–term air quality forecasting in Hanoi citadel area", funded by the Vietnam Ministry of Natural Resources and Environment (MONRE). The authors would also like to thank the members of the Water Resources Institute and the Climate Change Department for technical support and discussions that improved the quality of the publication.

Competing interest statement: The authors declare no conflict of interest.

References

1. Thomke, F.; Jung, D.; Besser, R.; Roder, R.; Konietzko, J.; Hopf, H.C. Increased risk of sensory neuropathy in workers with chloracne after exposure to 2,3,7,8–polychlorinated dioxins and furans. *Acta Neurol. Scand* **1999**, *100(1)*, 1–5.
2. Kagawa, J. Evaluation of biological significance of nitrogen oxides exposure. *Tokai J. Exp. Clin. Med.* **1985**, *10(4)*, 348–353.
3. Balmes, J.R.; Fine, J.M.; Sheppard, D. Symptomatic bronchoconstriction after short–term inhalation of sulfur dioxide. *Am. Rev. Respir. Dis.* **1987**, *136(5)*, 1117–1121.

4. Vermylen, J.; Nemmar, A.; Nemery, B.; Hoylaerts, M.F. Ambient air pollution and acute myocardial infarction. *Lancet* **2001**, *358*, 1602.
5. Sawicka–Kapusta, K. Damage to the liver, kidney, and testis with reference to burden of heavy metals in yellow–necked mice from areas around steelworks and zinc smelters in Poland. *Toxicology* **2003**, *186(1–2)*, 1–10.
6. Ghio, J.; Huang, Y.C. Exposure to concentrated ambient particles (CAPs): a review. *Inhal. Toxicol.* **2004**, *16(1)*, 53–59.
7. Marilena, K.; Elias, C. Human effects of air pollution. **2018**, *51(2)*, 362–367.
8. Bellinger, D.C. Teratogen update: lead and pregnancy. *Birth Defects Res. A Clin. Mol. Teratol*, **2005**, *73*, 409.
9. Kimbrough, R.D.; Carter, C.D.; Liddle, J.A.; Cline, R.E. Epidemiology and pathology of a tetrachlorodibenzodioxin poisoning episode. *Arch. Environ. Heal.* **1977**, *32*, 77.
10. Amann, M. et al. Future air quality in Hanoi and northern Vietnam, 2019.
11. London Councils. Demystifying Air Pollution in London, 2018.
12. Wangwongwatana, S. Air Quality Management: Thailand's experiences. 2013.
13. General statistic office, 2019.
14. Bang, H.Q.; Khue, V.H.N. Air emission inventory. 2019. (In Vietnamese)
15. CMAQ user's guide. Available online: https://github.com/USEPA/CMAQ/blob/main/DOCS/Users_Guide/README.md (accessed in 2021).
16. COMPASS TECH. 2021. Available online: https://compasstech.asia/traffic–luu–luong–tuyen–duong–tai–ha–noi
17. Nippon Koei Co., Ltd – Japan. Report of traffic survey "Road project overseas market cultivation in Vietnam", 2019.
18. The institute for the Environment – The University of North Carolina at Chapel Hill, SMOKE v4.7 User's Manual, 2019.
19. Hanoi Department of Natural Resources and Environment. Report No. 3252/STNMT–CCBVMT dated 11/05/2021 of Hanoi Department of Natural Resources and Environment on reporting and providing information and data for the development of the State of the Environment Country Report, 2021.
20. Sahanavin, N.; Prueksasit, T.; Tantrakarnapa, K. Relationship between PM_{10} and $PM_{2.5}$ levels in high–traffic area determined using path analysis and linear regression, *J. Environ. Sci.* **2018**, *69*, 105–114.

Annex

Annex Table 1. Observed vehicle load (in Oct 2021).

No.	Road type	Measured locations	Coordinates
1	Main urban road	Beltway 2 street – Cau Giay intersection	21,0308; 105,8021
2		Tay Son street	21,0072; 105,8232
3		Nguyen Chi Thanh street	21,0225; 105,8098
4	Secondary urban road	Tran Duy Hung street	21,0129; 105,8021
5		Kim Ma street	21,0308; 105,8179
6		Doi Can street	21,0368; 105,8155
7		To Huu street	20,9911; 105,7838
8	Main rural road	Upper Beltway 3 street – Tran Duy Hung intersection	21,0178; 105,7821
9		Provincial road 427, Ha Hoi ward, Thuong Tin district	20,8712; 105,8733
10	Secondary rural road	Tam Hiep gas station, Tam Hiep ward, Phuc Tho district	21,0854; 105,6271

Annex Table 2. Vehicle loads extracted from references [16–17].

No.	Road type	Measured locations	Coordinates
1	Main urban road	Vinh Tuy bridge	21,0037; 105,8753
2		Chuong Duong bridge	21,0377; 105,8605
3		Nhat Tan bridge	21,0895; 105,8193
4		325 Nguyen Van Cu street	21,0467; 105,878
5		95 Giang Vo street	21,0311; 105,8294
6		83 Lang Ha street	21,0182; 105,8162
7		210 Xa Dan street	21,0159; 105,8324
8		72 Nguyen Trai street	21,0012; 105,8173
9		129 Giai Phong street	21,0018; 105,8414
10		Au Co street	21,0611; 105,8327
11		Mai Dong street	20,9964; 105,8622
12		O Cho Dua street	21,0183; 105,8294
13		Nguyen Thai Hoc street	21,030; 105,8367
14		Le Van Luong street	21,0018; 105,7998
		Tran Duy Hung street	
15		Tran Khat Chan street	21,0092; 105,8578
16		Ho Tung Mau street	21,0404; 105,7654
17		Nguyen Huu Tho street	20,9709; 105,8382
18	Secondary urban road	Yen Phu street	21,0511; 105,839
19		Tran Dien street	20,9886; 105,8294
20		Le Trong Tan street	20,9984; 105,8287
21	Main rural road	Thang Long bridge	21,098; 105,7864
22		Phap Van – Thanh Tri bridge	20,9578; 105,8499
23		Thanh Tri bridge	20,9938; 105,9019