# ATMOSPHERIC EMISSIONS FROM ROAD TRANSPORTATION IN PHAYAO PROVINCE

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## ABSTRACT

*From the preliminary survey, traffic is a major source of pollution in Phayao, a small city located in the north of Thailand with a population density of 76 people per km$^2$. The study aimed to develop an emissions inventory of the traffic in this small agricultural town. The studied pollutants include hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen ($NO_X$), carbon dioxide ($CO_2$) and particle matter (PM). The emissions were calculated by using emission factors (EF) together with secondary data collected from various government organizations and primary data to acquire traffic volume. The Traffic volumes were obtained from 33 survey points throughout the Phayao province, covering a total distance of 622 km from 17 major and minor roads. The investigation found that there were over 175,000 vehicles a day. The first three types of vehicles were light duty, motorcycle, and passenger car (over 67,000, 57,000, and 36,000 units per day, respectively). The amounts of HC of 390 tons/year, CO of 3,279 tons/year, $NO_X$ of 979 tons/year, $CO_2$ of 195,206 tons/year, and PM of 182 tons/year were estimated. Emissions were mostly produced along main road during the daytime due to the higher levels of traffic congestion compared to other roads. Rate of emissions created from this city is proportionally close to Nakhon Ratchasima province, a comparative site.*

**Keywords:** Air emissions inventory, environmental database, Phayao, small city, traffic.

## INTRODUCTION

Air pollution is an important environmental issue both locally and internationally. It can affect both human health and wellbeing. It is understood that large cities are often associated with high levels of air pollution especially from transportation sector but in many cases, the amounts of air pollution exceeding the standard limits were found in small towns [1]. Phayao, a small province located in northern Thailand with an area of 6,335 km$^2$, is an example that air quality parameters were found to exceed the standard [2]. Phayao's population density is 76 persons per m$^2$. Service and agriculture are the main sectors for Phayao's economy, regularly accounting for over 30% for both sectors. There are a small number of industries. Most of them are for processed agricultural products [3]. In general, Phayao is like other small towns in ASEAN.

To find solutions for solving problems effectively, one of the necessary tools for air quality management is a database or air emissions inventory (AEI) [4]. AEI is a list that report types and amounts of pollutants releasing from pollution sources into the atmosphere in the area of interest. It is a useful basis for air quality control and planning agencies. AEI should be prepared and updated regularly covering all areas with accurate method and information.

For Thailand, most of AEI are for large cities and there is no systematic update on a regular basis. AEI of Thailand was initially developed in 1992 for Bangkok and its vicinity [5]. Then, AEI had been generated in several areas for different types of pollution sources and types of pollutants, e.g., (1) Development of AEI in Bangkok and its vicinity in 1997, from point sources, mobile sources, and area sources for the release of $NO_X$, $SO_2$, CO, PM, VOC, HC and $CH_4$ [6], (2) Study of the relationship between the air quality, measured on the main road in Nakhon Sawan province in 2004, and vehicle volume, wind speed, wind direction, temperature and relative humidity [7], and (3) AEI development in Nakhon Ratchasima municipality using secondary data obtained from related agencies and primary data from the field survey (applying questionnaire and EF) in 2009 [8].

Traffic is the main source of many atmospheric pollutants. For a small town like Phayao with mainstream economy from agriculture, traffic is preliminarily observed and found as a major source of air pollution. Hence, this study investigates the traffic volume, amount of air pollutants generated, and the spatial and temporal variation for the efficient control of emissions from the significant origins both space and time.

## METHODOLOGY

This investigation covers the main and secondary traffic routes in Phayao province as shown in Figure 1. Air pollutants from traffic sources in the scope of this study include CO, $CO_2$, PM, HC and $NO_X$ by using transport information of Phayao Province in 2012 for estimation. The transport information both inbound and outbound was obtained from Highway office 2, Department of Highways collected from 33 survey points (green marks in Figure 1) by speed cameras. To cross-check with the acquired secondary data, 24-hour traffic information was observed from Highway no.1 (main road) and road no.1021 (minor road) (yellow marks in Figure 1). Other information to complete the estimation was vehicle speed (supported by Phayao Highway Police Station), vehicle registration data (supported by Department of Land Transport in Phayao), and fuel consumption (supported by Department of Energy Business, Ministry of Energy). Vehicle types are classified in accordance with EF as follows: (1) motorcycle: MC, (2) 7-passenger car: PC, (3) light duty vehicles: LD, (4) heavy duty bus: HDB, and (5) heavy duty truck: HDT.

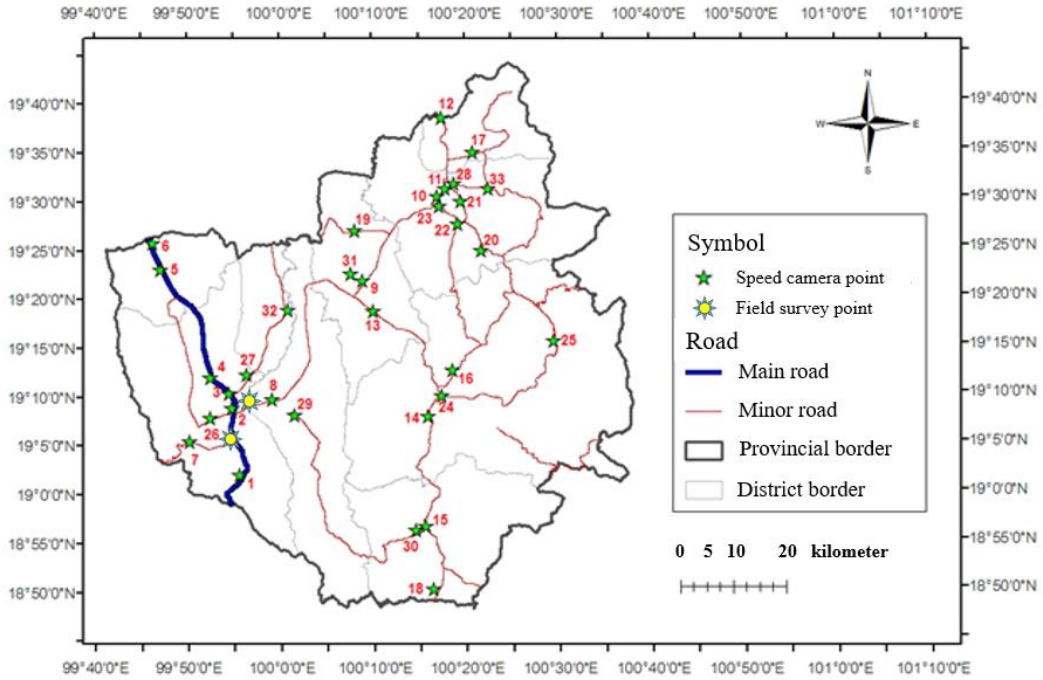


**Figure 1,** Traffic routes of Phayao province for the estimation of air emissions

The basic equation for estimating amounts of air emissions is as follows [9]:

$$E = A \times EF \quad (1)$$

where: E is the amount of pollutant discharged into the atmosphere,
A is the rate of activity that pollutes the atmosphere,
EF is the emission factor.

The rate of activity that pollutes the atmosphere is traffic volume and distance. The calculations for the pollutant emissions of each road is then derived from the following equation:

$$E = \sum [EF \times (N \times Y \times F) \times \text{distance}] \quad (2)$$

where: N is the traffic volume of the vehicle,
Y is proportional to the year of the vehicle,
F is proportional to the type of fuel.

For PM emitted from MC and PC, the latest EF values were 0.086 and 0.101 g/kg/ton, respectively, available from PCD [6]. EF values for other pollutants within the scope were available from a project conducted in Bangkok, Thailand by ESMAP [10].

EF of this project depends on the type of vehicle in each year and the speed of the car calculable from the following equation:

$$EF = a \times V^b \quad (3)$$

where: V is vehicle speed,
a and b are constant values as shown in Table 1

When the emission value of each route was obtained, it was used to create a database of air pollution sources in the grid form at 1-kilometer spatial resolution by using geographic information system (GIS) program. Also, a 24-hour temporal

profile of the number of cars was created hourly. As explained earlier, the information about the number of cars was available for 33 survey points, collected regularly by government agency, throughout the city from 7.00 am – 7.00 pm. To cover the full 24 hour period for the whole week, the additional survey was conducted for Highway no.1 (the main road in this city) and road no.1021 (as the representative of minor roads in this city).

**Table 1.** Constants a and b for estimating emission factors (EF) for vehicles [10]

| Vehicle type | Fuel type | Year | HC (g/km) | | CO (g/km) | | $NO_X$ (g/km) | | $CO_2$ (g/km) | | PM (mg/km) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | a | b | a | b | a | b | a | b | a | b |
| Passenger car | Gasoline 91 | Euro I (Pre-2000) | 4.436 | -0.834 | 11.676 | -0.528 | 1.406 | -0.213 | 681.84 | -0.406 | - | - |
| | | Euro II (2001-2004) | 0.497 | -0.629 | 0.373 | 0.114 | 2.123 | -0.641 | 642.7 | -0.374 | - | - |
| | Gasohol 95 | Euro I (Pre-2000) | 47.01 | -0.89 | 25.92 | -0.17 | 3.26 | -0.18 | 685.8 | -0.43 | - | - |
| | | Euro II (2001-2004) | 0.23 | -0.53 | 1.45 | -0.12 | 1.96 | -0.54 | 718.26 | -0.39 | - | - |
| | | Euro III (2005-2011) | 0.02 | -0.3 | 0.1 | -0.03 | 0.8 | -0.9 | 491.55 | -0.34 | - | - |
| | Gasohol 91 | Euro II (2001-2004) | 2.56 | -0.8 | 4.14 | -0.14 | 1.09 | -0.18 | 532.42 | -0.36 | - | - |
| | | Euro III (2005-2011) | 0.03 | -0.27 | 0.61 | -0.25 | 0.03 | -0.15 | 634.6 | -0.41 | - | - |
| | LPG | Euro I (Pre-2000) | 8.23 | -0.68 | 9.11 | -0.27 | 1.64 | -0.04 | 1010.7 | -0.52 | - | - |
| | | Euro II (2001-2004) | 1.17 | -0.52 | 116.78 | -1.49 | 2.72 | 0.04 | 996.16 | -0.49 | - | - |
| | | Euro III (2005-2011) | 6.04 | -0.7 | 3.45 | -0.67 | 5.19 | -0.2 | 440.62 | -0.29 | - | - |
| Motorcycle | Gasoline 91 | Pre-2003 | 33.56 | -0.663 | 41.61 | -0.429 | 0.087 | -0.004 | 161.3 | -0.317 | - | - |
| | | 2004-2008 | 3.215 | -0.386 | 16.077 | -0.084 | 0.141 | -0.023 | 87.48 | -0.294 | - | - |
| | Gasohol 91 | 2009-2011 | 0.767 | -0.407 | 1.772 | 0.128 | 0.045 | 0.307 | 102.4 | -0.254 | - | - |
| | | 2009-2011 | 0.734 | -0.406 | 3.109 | -0.021 | 0.049 | 0.357 | 61.034 | -0.178 | - | - |
| Light duty vehicles | diesel | 2000 & Later | 0.83 | -0.49 | 3.46 | -0.31 | 3.28 | -0.35 | 834.7 | -0.3 | 116.77 | 0.07 |
| Heavy duty truck | diesel | 2000 & Later | 11.46 | -0.8 | 37.66 | -0.77 | 43.77 | -0.51 | 4731.1 | -0.51 | 1710.5 | -0.19 |

Note: "-" data not available

**RESULTS**

It was discovered that traffic volume in the main street is almost the same throughout the whole week (16,800 – 17,815 cars/day) while daily change in secondary roads was found. On Saturday, traffic had the highest volume (17,363 cars). Traffic on Sunday was slightly lower (14,900 cars) and traffic on Thursday was the smallest (12,980 cars). Average results of traffic change for 24 hours from 33 routes in Phayao is shown in Figure 2, estimated by using the traffic survey data of the city from 7 am to 7 pm combining with traffic volume fraction from the field survey. Peak traffics were found in rush hours from 07.00-08.00 am and 04.00-06.00 pm. Most dense traffic was found at survey points 2, 3, 4 and 6. These points are the entrance areas to the district, resulting in heavy traffic. Then the traffic gradually reduced to very low levels during the night.

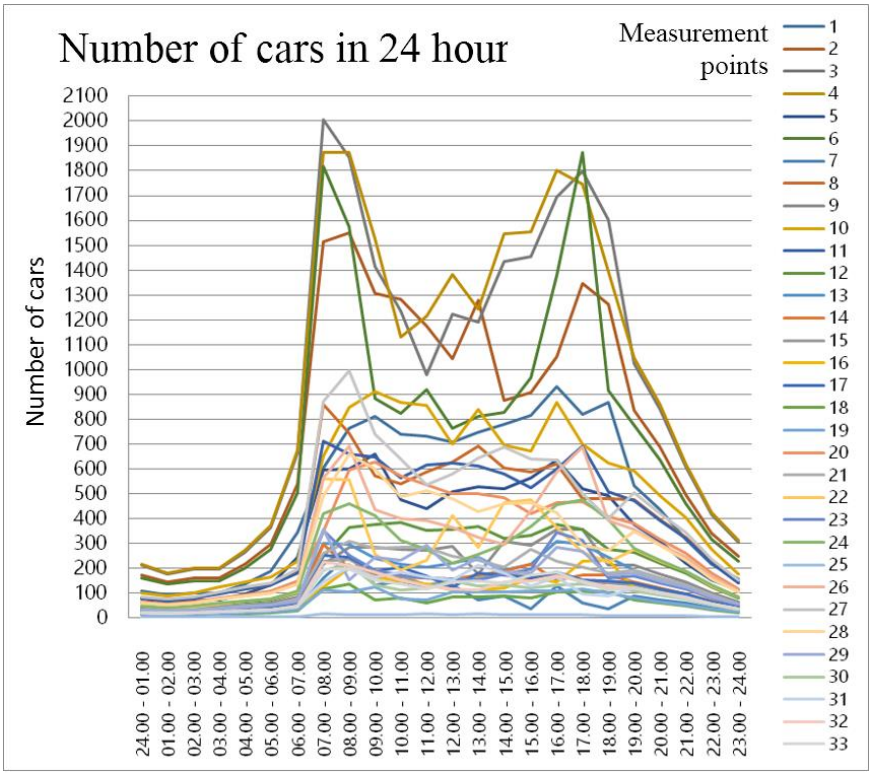


**Figure 2**. Traffic volume in 24 hours from 33 survey points in Phayao Province

From all collected data, EF for vehicles in Phayao province is calculated and presented in Table 2.

**Table 2**. Emissions factors (EF) for vehicles in Phayao province

| Vehicle type and year | Consumption rate (km/l) | V (km/hr) | HC (g/km) | CO (g/km) | $NO_X$ (g/km) | $CO_2$ (g/km) | PM (g/km) |
|---|---|---|---|---|---|---|---|
| LD 2000 & Later | - | 104 | 0.085 | 0.820 | 0.646 | 207.215 | 0.162 |
| HD Bus 2001 & Later | - | 90 | 0.313 | 1.178 | 4.411 | 476.759 | 0.727 |
| HD Truck 2001 & Later | - | 85 | 0.229 | 1.565 | 4.233 | 483.017 | 0.335 |
| PC Gasoline 91 Euro 1 (Pre-2000) | 21.635 | 108 | 0.086 | 0.985 | 0.477 | 103.757 | 0.101 |
| PC Gasoline 91 Euro 2 2001-2004 | 20.687 | 108 | 0.026 | 0.636 | 0.106 | 111.560 | 0.101 |
| PC Gasohol 91 Euro 2 2001-2004 | 23.119 | 108 | 0.060 | 2.138 | 0.460 | 100.074 | 0.101 |
| PC Gasohol 91 Euro 3 2005-2011 | 25.067 | 108 | 0.009 | 0.185 | 0.014 | 94.384 | 0.101 |
| PC Gasohol 95 Euro 1 Pre-2000 | 19.651 | 108 | 0.718 | 11.747 | 1.390 | 90.729 | 0.101 |
| PC Gasohol 95 Euro 2 2001-2004 | - | 108 | 0.018 | 0.828 | 0.160 | 114.599 | 0.101 |
| PC Gasohol 95 Euro 3 2005-2011 | 22.170 | 108 | 0.004 | 0.088 | 0.012 | 102.417 | 0.101 |
| PC LPG Euro 1 Pre-2000 | 15.426 | 108 | 0.343 | 2.609 | 1.394 | 88.147 | 0.101 |
| PC LPG Euro 2 2001-2004 | 15.976 | 108 | 0.101 | 0.107 | 3.290 | 101.871 | 0.101 |
| PC LPG Euro 3 2005-2011 | 14.407 | 108 | 0.231 | 0.153 | 2.063 | 114.403 | 0.101 |
| MC Gasoline 91 Pre-2003 | 31.119 | 45 | 2.690 | 8.129 | 0.086 | 48.243 | 0.086 |
| MC Gasoline 91 2004-2008 | 46.650 | 45 | 0.740 | 11.677 | 0.129 | 28.567 | 0.086 |
| MC Gasoline 91 2009-2011 | 51.462 | 45 | 0.163 | 2.885 | 0.145 | 38.935 | 0.086 |
| MC Gasohol 91 2009-2011 | 63.67031 | 45 | 0.156 | 2.870 | 0.191 | 30.996 | 0.086 |

Then, the amounts of HC of 390 tons/year, CO of 3,279 tons/year, $NO_X$ of 979 tons/year, $CO_2$ of 195,206 tons/year, and PM of 182 tons/year were estimated (Table 3). The amount of each type of air pollutant emissions in each road was interpreted by

using GIS. Illustration of PM is selected to present (Figure 3) while all other emissions have the same tendency. The three most common air pollutants are Highway no.1 (major road), road no.1021 and no.1091 (two roads connecting with Highway no.1).

**Table 3.** The amount of air pollution on the roads of Phayao Province.

| Road no. | Distance (kilometer) | Quantity (tons/year) | | | | |
|---|---|---|---|---|---|---|
| | | HC | CO | $NO_X$ | $CO_2$ | PM |
| No.1 | 59.065 | 96 | 801 | 390 | 70,026 | 62 |
| No.120 | 19.599 | 3 | 28 | 12 | 2,054 | 2 |
| No.1021 | 87.502 | 61 | 518 | 180 | 37,795 | 34 |
| No.1091 | 77.192 | 30 | 252 | 72 | 13,783 | 13 |
| No.1092 | 27.955 | 7 | 63 | 16 | 3,224 | 3 |
| No.1093 | 28.673 | 17 | 142 | 13 | 2,540 | 3 |
| No.1120 | 6.447 | 1 | 12 | 2 | 465 | 0 |
| No.1126 | 17.246 | 3 | 27 | 7 | 1,326 | 1 |
| No.1148 | 50.409 | 29 | 226 | 39 | 9,462 | 11 |
| No.1160 | 29.264 | 12 | 104 | 16 | 3,241 | 3 |
| No.1179 | 29.573 | 17 | 143 | 38 | 8,553 | 8 |
| No.1186 | 6.389 | 3 | 24 | 4 | 846 | 1 |
| No.1188 | 43.294 | 22 | 184 | 29 | 5,880 | 6 |
| No.1193 | 35.089 | 33 | 280 | 53 | 12,042 | 12 |
| No.1202 | 33.567 | 22 | 189 | 45 | 10,553 | 10 |
| No.1210 | 15.113 | 14 | 121 | 15 | 3,357 | 4 |
| Nol1251 | 55.642 | 20 | 165 | 48 | 10,059 | 9 |
| Total | 622.019 | 390 | 3,279 | 979 | 195,206 | 182 |

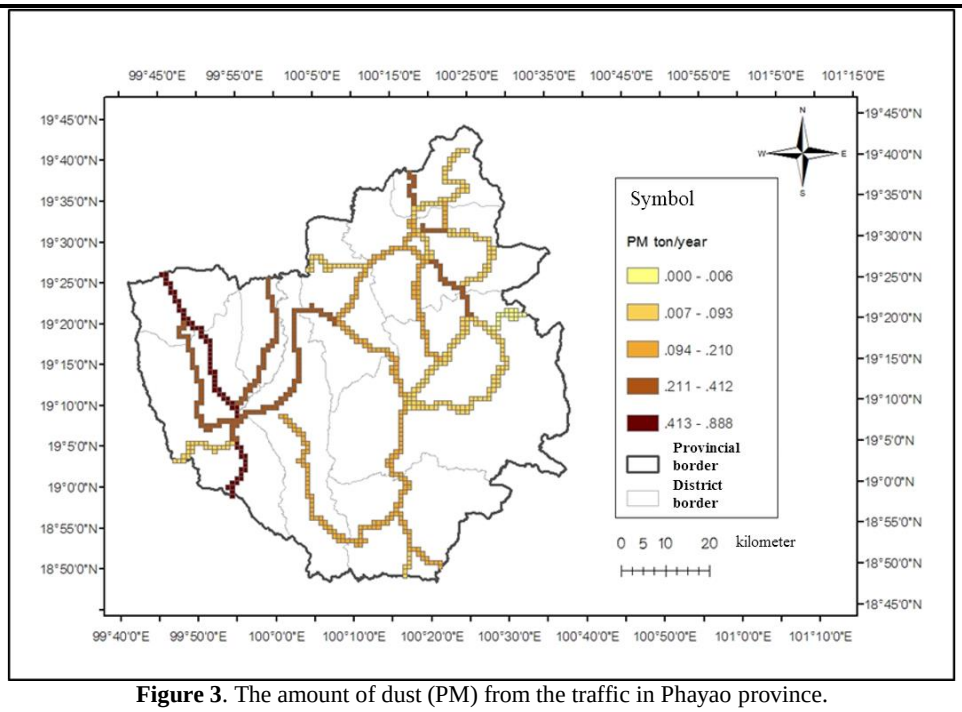


**Figure 3**. The amount of dust (PM) from the traffic in Phayao province.

The amounts of air emissions of each type of car were separately presented in Table 4. Each air pollutant was released from different vehicle types as follows: (1) HC emitted from MC is highest (79%), and from HDB is lowest (1%); (2) CO emitted from MC is highest (78%), and from HDB is lowest as well (<1%); (3) $NO_X$ emitted from HDT is highest (43%), and from HDB is lowest (6%); (4) $CO_2$ emitted from LD is highest (50%), and from HDB is lowest (3%); (5) PM emitted from LD is highest (42%), and from HDB is lowest (5%).

**Table 4.** The amount of air pollution per year from each type of vehicle

| Vehicle type | Quantity of emissions (ton/year) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | HC | (%) | CO | (%) | $NO_x$ | (%) | $CO_2$ | (%) | PM | (%) |
| PC | 16 | 4 | 168 | 5 | 139 | 14 | 29,800 | 15 | 28 | 15 |
| MC | 308 | 79 | 2,565 | 78 | 61 | 6 | 14,163 | 7 | 35 | 19 |
| LD | 40 | 10 | 385 | 12 | 303 | 31 | 97,384 | 50 | 76 | 42 |
| HDB | 4 | 1 | 14 | 0 | 54 | 6 | 5,865 | 3 | 9 | 5 |
| HDT | 23 | 6 | 156 | 5 | 423 | 43 | 48,285 | 25 | 34 | 19 |

**DISCUSSIONS**

Most information on the development of traffic pollution in Phayao Province is reliable because it is obtained from government agencies with direct responsibility. The data had been collected regularly covering the whole area of this city. However, there are some limitations: (1) Traffic volume data in Phayao Province obtained from Department of Highways were only from 7.00 am – 7.00 pm. Traffic volume in the absence of data was fulfill by the use of field survey data but it was from only two roads. There could be some discrepancies from this estimation, (2) Vehicle registration data of Phayao were applied for calculation. Nonetheless, for the real situation, there had to be vehicles from other cities coming pass through roads of this city. That is an unavoidable error. The AEI development of this study is rational because the car speed of each road is also considered. So, the duration of cars on the road can be estimated. Not only vehicle types but their ages are under consideration. To analyze the reliability of this study. Comparing the air emissions with the work of Kotula [8] is made as shown in Table 5. The results of the study are certainly different due to the differences of EF, transportation distance, and vehicle volume. An important reason that the rate of air emission in the municipality of Nakhon Ratchasima is higher than in Phayao is the number of HDB and HDT. In Nakhon Ratchasima municipality there are 41,030 cars, while in Phayao province there are 3,050 cars. Please note that the large diesel vehicles have higher air pollution than other vehicles. This comparative results are reasonable since percentage of air emissions in Phayao is close to the percentage of traffic volume of Nakhon Ratchasima (27.8%). This is, however, a comparison to assess the initial credibility which is at an acceptable level. If the analysis to compare the difference in each type of emissions is required, the same set of data for both areas for the same calculation method (such as the number of each vehicle type, car speed) is necessary.

**Table 5.** Comparison of air pollution values with another study

| Study area | Number of vehicle (unit) | Quantity of emissions (ton/year) | | | | |
|---|---|---|---|---|---|---|
| | | HC | CO | $NO_x$ | $CO_2$ | PM |
| Nakhon Ratchasima province [8] | 695,299 | 2,737 | 13,429 | 8,216 | 386,682 | 569 |
| Phayao province (this study) | 193,374 | 391 | 3,290 | 980 | 195,497 | 182 |
| % compared to [8] | 27.8 | 14.3 | 24.5 | 11.9 | 50.6 | 32.0 |

**CONCLUSION**

From this study on the development of AEI of traffic for Phayao, a small city in ASEAN; HC, CO, $NO_X$, $CO_2$ and PM were found to be 390, 3,279, 979, 195,206 and 182 tons/year, respectively. These amounts of discharges per area are 62, 518, 155, 30,814, 29 kg/year·$km^2$, and per person are 0.8, 6.8, 2.0, 402.9, 0.4 kg/person·year. Most of air pollution from traffic is certainly from on the major road (Highway no.1) as expected with the amount of releases of HC, CO, $NO_X$, $CO_2$ and PM equivalent to 96, 801, 390, 70,026, 62 tons/year, respectively. Nearby residents should be aware and pay special attention to respiratory health. Vehicles that were the major cause of air pollution in the study area were passenger cars over 7 persons (LD) and trucks (HDT). Analysis of changes in air emissions over time found that the most polluting periods were peak hours from 7.00 – 8.00 am and from 4.00 - 5.00 pm. Overall, the results of this study show the amount of emissions and the change in spatial and temporal nature of air pollutant emissions from traffic of a small city. This is a useful information for efficient and effective air quality planning.

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