Chapter 17

Estimation of PM2.5 Trajectory Using Atmospheric Dispersion Models and GIS in the Tokyo Metropolitan Area

Kayoko Yamamoto and Zhaoxin Yang

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.70608

Abstract

The present study aims to use atmospheric dispersion models and geographical information system (GIS) to make estimations of the trajectory of PM2.5 (particulate matter) discharged from specific generation sources, by grasping the atmospheric concentration within the Tokyo metropolitan area in Japan. It is expected that such estimation results should contribute to the risk assessment concerning the influences of PM2.5 on human health and ecosystem. Using ADMER in the first stage, estimations of the atmospheric concentration distribution of PM2.5 throughout the entire Tokyo metropolitan area from 2009 to 2014 were conducted. As a result, areas with high atmospheric concentration of PM2.5 focused in the same area each year, and it was revealed that the entire Tokyo and Saitama had high atmospheric concentrations. Additionally, as a result of setting Tokyo the detail estimation range, it was grasped that the atmospheric concentrations are high in Shinjuku ward and Tachikawa city in Tokyo. Based on the results in the first stage, using METI-LIS in the second stage, estimations of the trajectory of PM2.5 discharged from specific generation sources were conducted in Tachikawa city. As a result, it was made clear that PM2.5 had spread within 500 m of the specific generation sources, and the atmospheric concentrations were intensively high.

Keywords: PM2.5 (particulate matter), estimation of trajectory, risk assessment, air pollution, atmospheric dispersion model, geographic information systems (GIS)

1. Introduction

Humans produce a variety of waste due to production and consumption activities. If the amount of such waste is not so large, it can be processed through the natural purification effect. However, in addition to waste disposal increasing beyond the natural processing capacity, new types of waste materials that cannot be naturally processed are also being produced.

Such pollution of the natural environment has progressed, and this has led to the disruption of ecosystem, damage to human health, as well as various pollution issues including air pollution. Worldwide, especially in Asian countries which have achieved rapid industrialization, the amount of air pollutant discharged has rapidly increased along with the expanding scale of economic activities. Though air pollutants can be lessened by exchanging fuel used by main generation sources such as automobiles and plants with fuel that is less of a burden on the environment, there have been few reduction measures. It is necessary to accurately grasp the actual condition of air pollution and take appropriate measures to handle this issue.

Based on the background mentioned above, the present study aims to use atmospheric dispersion models and geographical information system (GIS) to make estimations of the trajectory of air pollutants discharged from specific generation sources by grasping the atmospheric concentration within the Tokyo metropolitan area in Japan. As a target air pollutant for estimations in the present study, PM2.5 (particulate matter), which has been a serious concern to human health, will be discussed. The estimations in the present study will be conducted using two types of atmospheric dispersion models in two stages. In the first stage, wide-range and long-term estimations will be conducted in the entire estimation target area. By means of the estimation results, the areas with high atmospheric concentration of PM2.5 will be selected, its generation source will be investigated, and the PM2.5 trajectory will be estimated. In the second stage, by means of the estimation results of the first stage, detailed estimations in smaller areas surrounding specific generation sources with high atmospheric concentration of PM2.5 will be conducted, and its trajectory will be estimated in detail. Based on such estimation results, the information concerning the measures to reduce PM2.5 that is more effective than before can be provided, and the estimation methods of PM2.5 trajectory proposed in the present study can be used for other air pollutants as well as in other areas. Additionally, it is expected that such estimation results should contribute to the risk assessment concerning the influences of PM2.5 on human health and ecosystem.

2. Related work

Regarding studies that grasped the behavior of air pollutants using atmospheric dispersion model, there have been many with dioxin as its subject. Some of the representative studies in recent years include that of Sasaki et al. [1], Teshima et al. [2], Hoa [3], Viel [4], Ripamonti et al. [5], Ashworth et al. [6], Ishii and Yamamoto [7], Sun et al. [8], and Zhang et al. [9], in which simulations of the behavior of dioxins in the atmosphere were conducted with incinerators as its generation source. Maantay et al. [10], Chen et al. [11], Kawashima et al. [12], Onofrio et al. [13], Zhou et al. [14], and Chandra et al. [15] conducted simulations of dioxins in the atmosphere. Additionally, Armitage et al. [16], Huang and Liang [17], and Zhou [18] conducted simulations of the behavior of dioxins underwater in places including the sea, canals, and lakes.

Among the related studies above, Maantay et al. [10] and Viel [4] demonstrated the effectiveness to combine atmospheric dispersion model and GIS to estimate the behavior of dioxins in the atmosphere. Additionally, Ishii et al. [7] combined two types of atmospheric

http://dx.doi.org/10.5772/intechopen.70608

dispersion models and GIS to grasp the dispersion conditions of dioxins in both wide-rage and small-range areas with high concentration and proposed a method to evaluate environmental risks.

In a similar manner, representative studies in recent years with PM2.5 as its subject include that of Mueller et al. [19], Saide et al. [20], Chen et al. [21], Solazzo et al. [22], Lee et al. [23], Saraswat et al. [24], and Rizza et al. [25], in which simulations of the atmospheric behavior of PM2.5 were conducted. Simulations of the atmospheric behavior of PM2.5 were conducted with the generation source being traffic by Lang et al. [26], daily activities by Louge et al. [27], and incinerators by Kodros et al. [28]. However, studies on Japan are very rare, whereas most focus their target on China, North America, and Europe.

In contrast with the studies mentioned above, the present study will focus on PM2.5 discharged from specific generation sources that has been seldom targeted in Japan and demonstrate the originality by proposing detailed trajectory estimation methods using both two types of atmospheric dispersion models and GIS. Additionally, by means of two-stage estimations targeting wide areas and narrow areas with high atmospheric concentration, the atmospheric concentration distribution of PM2.5 can be accurately grasped. Moreover, using both atmospheric dispersion models and GIS for the two-stage estimation method in the present study, the effectiveness is demonstrated by quantitatively and spatially grasping the dispersion conditions of PM2.5 discharged from specific generation sources. More specifically, the areas with high atmospheric concentration will be extracted by estimating the atmospheric concentration distribution of PM2.5 throughout the entire estimation target area using atmospheric dispersion models. Furthermore, in these areas, reflecting the land use by means of GIS, the trajectory of PM2.5 discharged from specific generation sources will be estimated in detail.

3. Estimation method

3.1. Overview of atmospheric dispersion method and GIS

With the present study, since estimations of PM2.5 trajectory are made in two stages, two types of atmospheric dispersion models will be used. In the wide-area estimations involving the entire estimation target area of the first stage, the explosion risk evaluation atmospheric dispersion model (AIST-ADMER Ver.3) by the National Institute of Advanced Industrial Science and Technology [29–31] is used. This is an atmospheric dispersion model suitable for estimating wide-ranged and long-term atmospheric concentration distribution of chemicals according to the amount of PM2.5 discharged from generation sources as well as meteorological conditions.

In the localized and detailed estimations with selected specific generation sources as the target in the second stage, the low-rise industrial source dispersion model (METI-LIS Ver.3.2.1) by the Ministry of Economy, Trade, and Industry [32–34] is used. This model estimates the atmospheric concentration of chemicals surrounding specific generation sources. Additionally, this model takes into consideration the downwash that occurs when the air current is disturbed due to buildings surrounding the specific generation sources. By entering the data on height of the buildings near the specific generation sources, the model takes into consideration the buildings' influence on chemical dispersion, and estimations of small-ranged and detailed atmospheric concentration dispersions can be made.

Additionally, the ArcGIS Ver.10.2 of ESRI will be used as GIS. Upon the estimations of PM2.5 trajectory, using GIS, an overlay analysis with the estimation results which are obtained from two types of atmospheric dispersion models and digital map data, as well as statistical processing will be conducted.

3.2. Overview of estimation method

The flow of the estimation method in the present study is as shown in **Figure 1**, and the details will be explained below.

1. In the present study, the estimation target area is selected in the beginning, the data concerning PM2.5 discharged from generation sources is gathered and processed, and the generation source data is prepared.
2. The above data concerning PM2.5 discharged from generation sources and meteorological data are entered into the atmospheric dispersion model, ADMER in the first stage, and the atmospheric concentration of PM2.5 in the entire estimation target area is estimated.

   Based on the estimation results, the areas with high atmospheric concentration are selected, and detailed estimation range, where a detailed estimation of atmospheric concentrations is conducted, is set. By using ADMER in this way, the PM2.5 trajectory of the entire estimation target area can be grasped on a macro scale, and areas with high atmospheric concentration can be set as a detailed estimation range to be confirmed.
3. Based on the estimation results of the first stage, the estimation target area is selected for the second stage. The meteorological data and digital map data concerning the estimation target area of the second stage are gathered and processed, and entered into the atmospheric dispersion model, METI-LIS. In the second stage, as downwash and stack-tip downwash due to buildings are taken into consideration, the PM2.5 trajectory can be accurately estimated. Additionally, the trajectory of PM2.5 discharged especially from specific generation sources is estimated.

3.3. Selection of estimation target area

For the present study, the Tokyo metropolitan area (Ibaraki, Tochigi, Gunma, Kanagawa, Saitama, Chiba, and Tokyo) was selected as the target area for the estimations of PM2.5 trajectory. **Figure 2** shows the Tokyo metropolitan area. In the estimations of the entire target area using ADMER in the first stage, the entire Tokyo metropolitan area will be the target area. In the second stage using METI-LIS for estimations of the atmospheric concentration of chemicals surrounding specific generation sources, areas with high atmospheric concentration of PM2.5 will be selected from the entire Tokyo metropolitan area based on the estimation results of the previous stage. Furthermore, the cause of high atmospheric concentrations in those areas will be considered, and the trajectory of PM2.5 discharged from specific generation sources will be estimated in detail.

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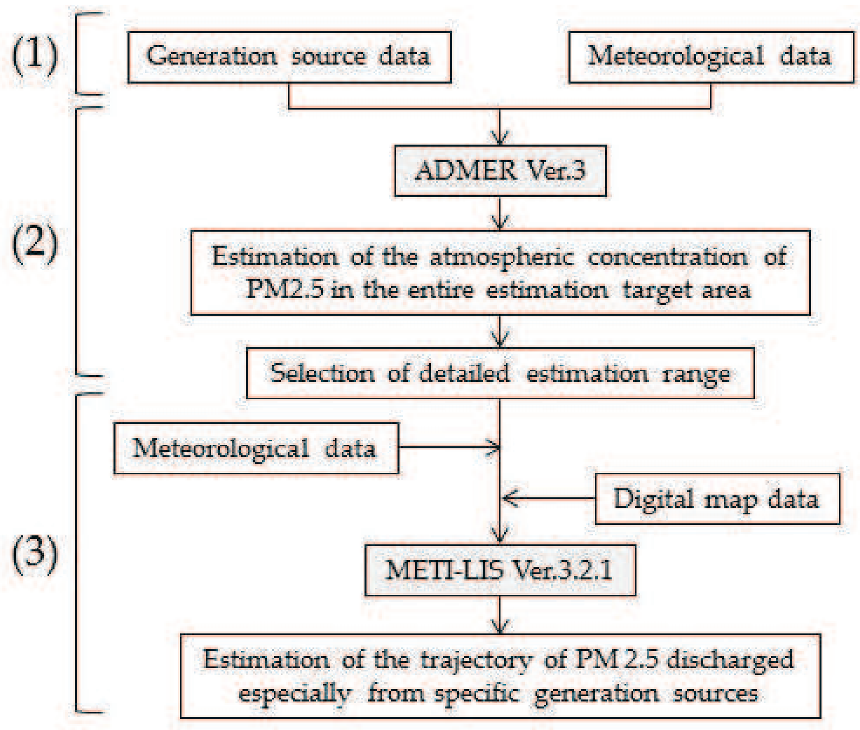

Figure 1. Flow of the estimation method.

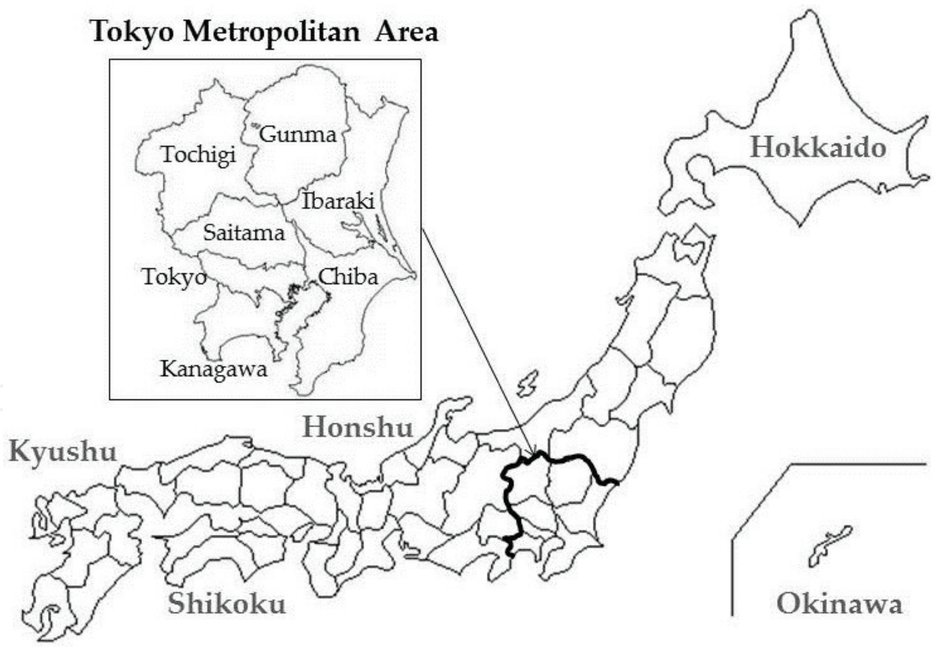

Figure 2. Tokyo metropolitan area as estimation target area.

4. Gathering and processing data

Data shown in **Table 1** are used in the present study. Generation source data and meteorological data will be entered into the atmospheric dispersion models, while measured data of

Type	Name	Source
Generation source data	Data of the amount of discharged PM2.5 (2009–2014)	Ministry of Trade, Economy, and Industry
Meteorological data	AMeDas and rainfall data for ADMER (2009–2014)	National Institute of Advanced Industrial Science and Technology
	Tokyo weather data (2014)	Japan Meteorological Agency
Digital map data	Administrative division data (2012) Base map information (scale level of 2500)	Ministry of Land, Infrastructure, Transport, and Tourism
Measured data of PM2.5	Monthly and annual data of the atmospheric environment (2014)	National Institute of Environmental Studies

Table 1. List of data used.

PM2.5 will be processed into GIS data and used for spatial analysis. For data of the amount of discharged PM2.5, the data concerning the amount of discharged chemicals announced on the basis of the Pollutant Release and Transfer Register Law (PRTR Law, enacted in 2001) will be used in the present study.

According to the PRTR Law, it is necessary for the businesses themselves to grasp the amount of hazardous chemicals discharged from businesses into the environment (atmosphere, water, and soil) and included in waste substances to be released outside business facilities, and report it to the national government. Additionally, based on the above reported data and statistics, it is essential for the national government to tally and announce the amount of chemicals discharged and transferred. As businesses with the responsibility of notification according to the PRTR Law are restricted by category of business and plant, employee scale and transaction volume, the amount of chemicals discharged from the generation sources exempt from the law are estimated and announced by the national government.

5. Estimation in the entire estimation target area

5.1. Estimation targets

With the entire Tokyo metropolitan area as the estimation target area in the first stage, the atmospheric concentrations of PM2.5 will be estimated using ADMER. By setting the estimation target area to 34° 50′ 00′′ - 37° 12′ 30′′ north latitude and 138° 18′ 45′′ - 140° 56′ 15″ east longitude in accordance with the Tokyo metropolitan area, the grid will be set to 5*5 of the tertiary grid square (1 km grid) meaning a 5 km grid square units of area, and the grid number for the entire Tokyo metropolitan area will be 42*57 (2,394). Moreover, the estimation target period for the first stage is 6 years from 2009 to 2014. This is because a period with available data concerning the estimation target area was selected.

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5.2. Estimation results

5.2.1. Results for the entire estimation target area

The atmospheric concentration distribution of PM2.5 was estimated using ADMER, and the estimation results for each year are shown in **Figure 3**. As shown in the figure, the areas with high

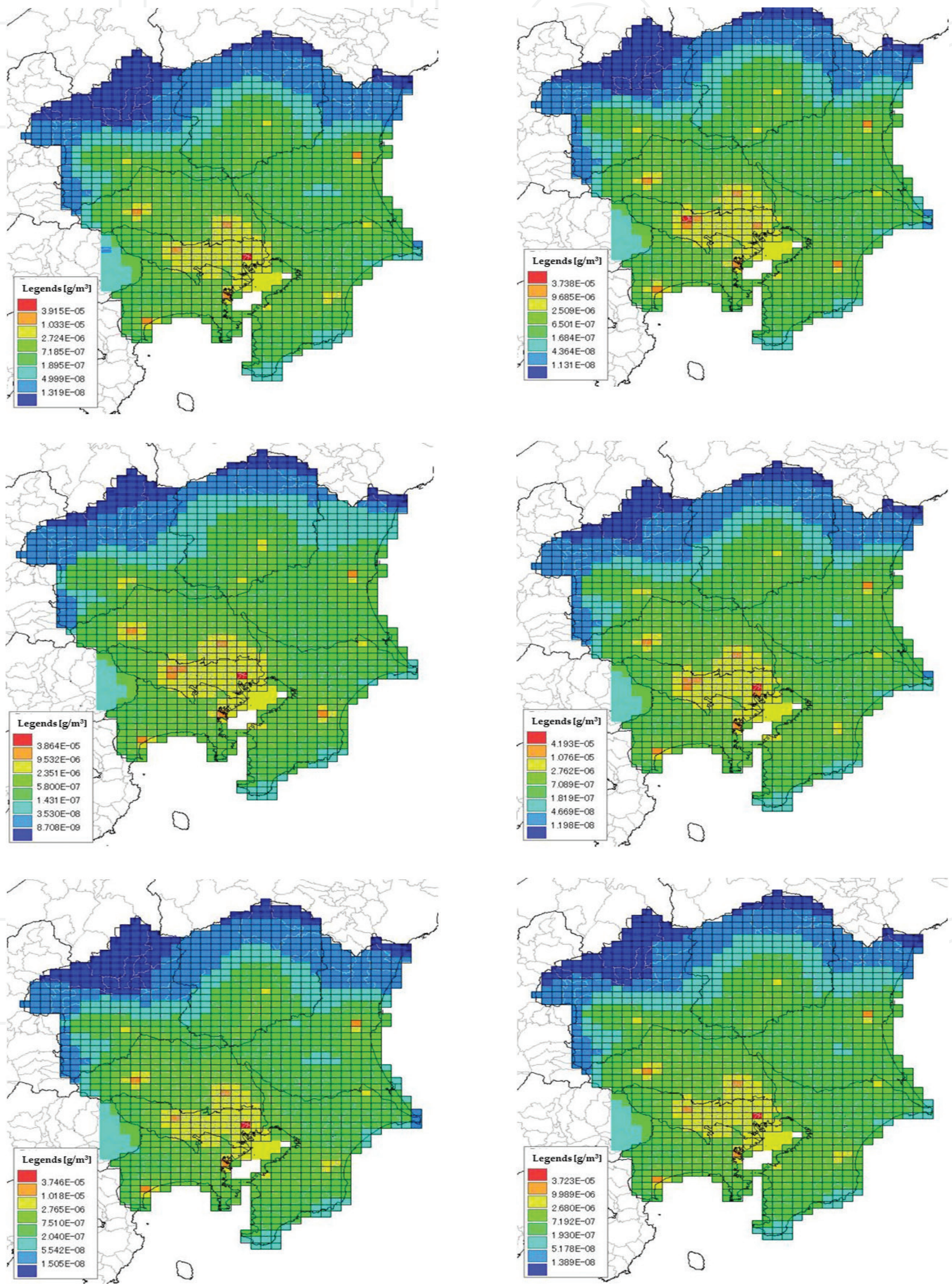

Figure 3. Atmospheric concentration distribution of PM2.5 in the Tokyo metropolitan area (2009–2014).

atmospheric concentration were focused each year, and the entire Tokyo and Saitama as well as some parts of Ibaraki, Kanagawa, and Chiba had high atmospheric concentrations of PM2.5. For Ibaraki, Kanagawa, and Chiba, an investigation of generation sources was conducted. As areas with high atmospheric concentration of PM2.5 are located in urban central parts, main generation sources are considered to be transportation including automobiles and railroad vehicles.

5.2.2. Estimation results for detailed estimation range

Based on the estimation results in the previous section, because it was made clear that Tokyo and Saitama had high atmospheric concentrations of PM2.5, Tokyo was set as the detailed estimation range, and the atmospheric concentration distribution was estimated. One reason for this is that there are many measurement stations of PM2.5, and there is an abundance of data to aid the grasping of the atmospheric concentration distribution of PM2.5. The second reason is that the atmospheric concentration of PM2.5 in Tokyo has been decreasing every year making great improvements (55% reduction of atmospheric concentration in 10 years from 2001 to 2011). However, the rate for meeting environmental standards is low, and the atmospheric concentrations of PM2.5 in Tokyo are slightly above the environmental standards (annual average of below 15 μg/m^3).

After setting the detailed estimation range to 35° 27′ 30″ - 35° 55′ 0″ north latitude and 138° 52′ 30″ - 140° 0′ 0″ east longitude in accordance with Tokyo, a grid of 100 m*100 m is created. Then, the atmospheric concentration distribution of PM2.5 is estimated using ADMER, and the estimation results for each year are shown in **Figure 4**. From the figure, it is clear that atmospheric concentrations are high in Shinjuku ward and Tachikawa city each year.

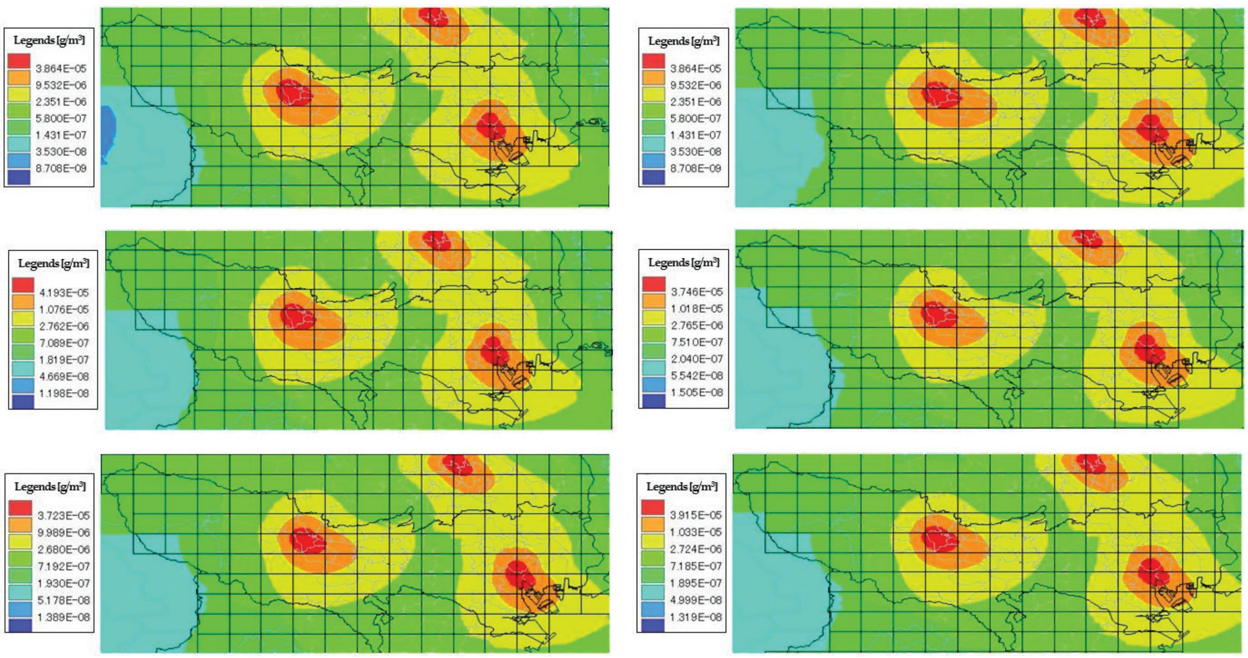

Figure 4. Atmospheric concentration distribution of PM2.5 in Tokyo (2009–2014).

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5.3. Discussion

From the estimation results in this section, it is clear that the areas with high atmospheric concentration of PM2.5 focus in the same areas each year. Especially in the entire Tokyo and Saitama, as well as in certain parts of Ibaraki, Kanagawa, and Chiba, the atmospheric concentrations were high. Moreover, as shown in **Figure 5**, in order to verify the validity of the estimation results of atmospheric concentration of PM2.5 in the present study, the levels of estimated atmospheric concentration and measured atmospheric concentration for 2014 are compared. The measured atmospheric concentration is from the environment numerical database of the National Institute for Environmental Studies.

As shown in **Figure 5**, the estimation results of atmospheric concentrations of PM2.5 in the Tokyo metropolitan area showed excellent reproducibility. With the atmospheric dispersion model, the consistency reference for the ratio of estimated and measured atmospheric concentration is set to be around ½- to 2-fold. Though the estimated atmospheric concentration in Tokyo and Saitama was above the measured atmospheric concentration level, the former for Ibaraki, Tochigi, Gunma, Kanagawa, and Chiba was below the latter. For Tokyo and Saitama, the amounts of PM2.5 discharged from businesses and plants in addition to the amount from automobiles and railroad vehicles were also large. Though the amounts of PM2.5 discharged from these generation sources are fixed according to the categories in ADMER, it could be that the estimated atmospheric concentration is higher than the measured atmospheric concentration level, as there is a possibility of the actual amount of discharged PM2.5 being less. On the other hand, in Ibaraki, Tochigi, Gunma, Kanagawa, and Chiba, the main generation sources for PM2.5 are considered to be transportation such as automobiles and

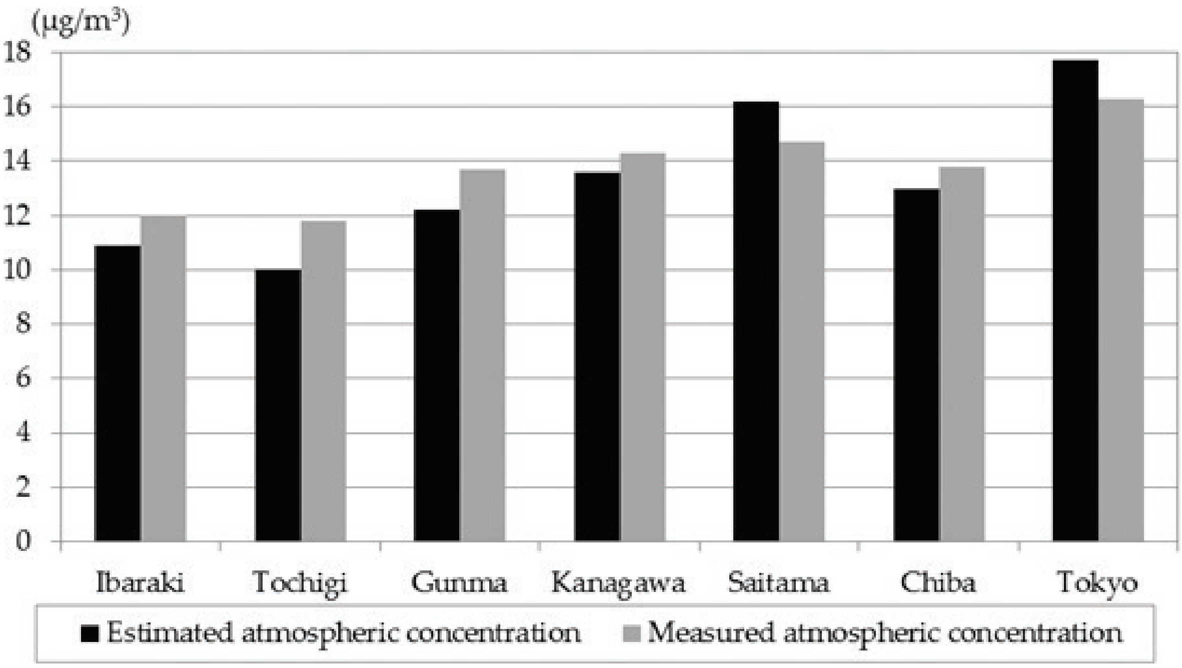

Figure 5. Comparison between the measured atmospheric concentration and estimated concentration in the present study in the Tokyo metropolitan area (2014).

railroad vehicles, as well as businesses and general households. Additionally, as the amounts of PM2.5 transported from other areas and naturally discharged into the environment are not taken into account, the estimated atmospheric concentration may have been lower than the measured atmospheric concentration level.

6. Estimations in detailed estimation target area

6.1. Estimation target

From the estimation results of ADMER in the previous section, it was made clear that the atmospheric concentrations of PM2.5 were especially high in Shinjuku ward and Tachikawa city. Shinjuku ward is made up of some of the most prominent busy streets in Tokyo, and there are many commuters due to the many train lines. The fuel combustion from automobiles and railroads vehicles is considered to be the main cause of the high atmospheric concentration of PM2.5 in Shinjuku ward. Additionally, as there are many high-rise buildings in Shinjuku ward and these prevent air circulation and the dispersion of PM2.5, it is thought that this results in long-term high atmospheric concentration of PM2.5. In Tachikawa city, there are many commercial facilities as well as offices that are clustered together, and there are many commuters due to the many train lines like Shinjuku ward. For this reason, the PM2.5 discharged from the combustion of fuel from automobiles and railroad vehicles is considered to be one of the causes for Tachikawa city being an area with high atmospheric concentration. Moreover, business facilities and plants are considered to be main generation sources of PM2.5.

From the reasons stated above, as the estimation target area of the second stage, Tachikawa city was selected. Because PM2.5 discharged not only from fuel combustion due to automobiles and railroad vehicles, but also from specific generation sources such as business facilities and plants. Accordingly, in order to estimate the trajectory of PM2.5 discharged from specific generation sources, two areas within Tachikawa city (area A and area B) were extracted. **Figure 6** shows the distribution of specific generation sources in the estimation targets of the second stage. 80 m grid square units is set for area A and 100 m grid square units is set for area B. Additionally, to make identifying building and road placements in the estimation target area easier, the outer peripheral lines and arterial roads downloaded from the basic map information were displayed. Moreover, the estimation target period of the second stage is 2014 in which the latest data can be obtained.

6.2. Estimation results

The estimation results of atmospheric concentration distribution of PM2.5 in area A and area B using METI-LIS are shown in **Figure 7**. The estimation results are shown in 80 m grid square units for area A and 100 m grid square units in area B. From the estimation results, it is clear that PM2.5 spreads within a range of about 500 m from the specific generation sources, and the atmospheric concentration distributions are higher. In such areas, a downwash occurs due to buildings, which in turn prevents PM2.5 from spreading by the wind.

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Figure 6. Detailed estimation target area.

6.3. Discussion

In this section, the trajectory of PM2.5 discharged from specific generation sources was estimated. The measured atmospheric concentration levels show the total amount of PM2.5 discharged in the areas surrounding the measurement station. Therefore, as the measured atmospheric concentrations which indicate the amount of PM2.5 discharged from specific

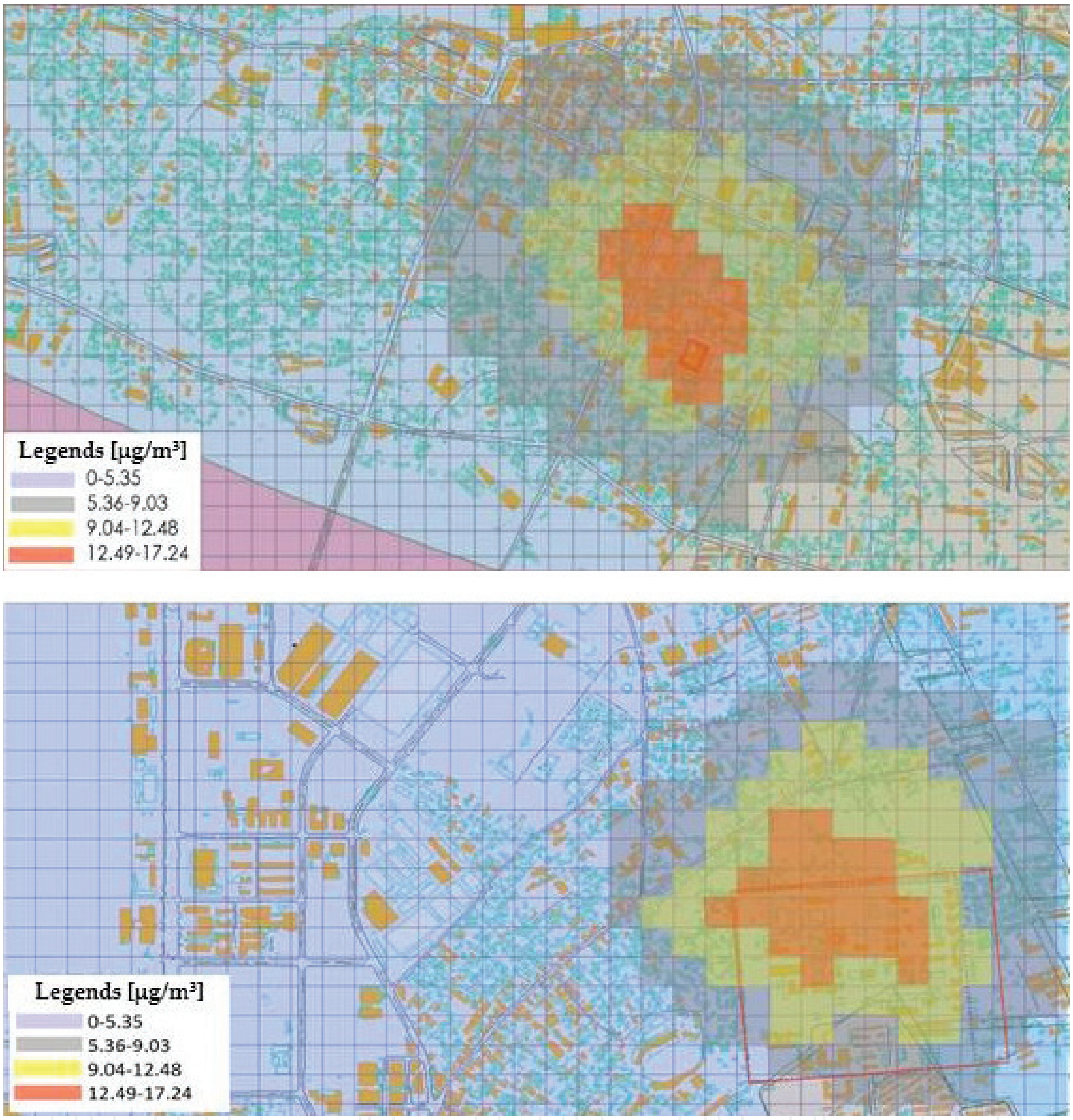

Figure 7. Atmospheric concentration distribution of PM2.5 in Tachikawa city (2014).

generation sources do not exist, the levels of estimated atmospheric concentration and measured atmospheric concentration cannot be compared. In the vicinity of estimation target area A, though there are many buildings, it is considered to have little effect on the dispersion of PM2.5 as most are low-rise buildings. Additionally, in estimation target area B, though there are few buildings within the premises of specific generation source, because there are many surrounding buildings, this causes a downwash in the dispersion of PM2.5 which may reduce the atmospheric concentration.

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7. Conclusion

The conclusion of the present study can be summarized into the following four points:

1. By means of the estimation method proposed in the study, estimations of the trajectory of air pollutants discharged from specific generation sources were conducted. PM2.5 was selected as a target air pollutant. Regarding its trajectory, a wide-range estimation for the entire estimation target area was conducted using ADMER in the first stage, and a narrow-range and detailed estimation using METI-LIS in areas surrounding specific generation sources was conducted in the second stage. By using two types of atmospheric dispersion models and GIS, it is possible to grasp the atmospheric concentration distribution of PM2.5 discharged from specific generation sources, and estimate its trajectory.

2. Using ADMER in the first stage, estimations of the atmospheric concentration distribution of PM2.5 throughout the entire Tokyo metropolitan area from 2009 to 2014 were conducted. As a result, areas with high atmospheric concentration focused in the same area each year, and it was revealed that the entire Tokyo and Saitama, as well as some parts of Ibaraki, Kanagawa, and Chiba had high atmospheric concentrations of PM2.5. Additionally, as a result of setting Tokyo the detailed estimation range, it was grasped that the atmospheric concentrations are high in Shinjuku ward and Tachikawa city in Tokyo.

3. Using METI-LIS in the second stage, estimations of the trajectory of PM2.5 discharged from specific generation sources were conducted in Tachikawa city, which was estimated to be a high atmospheric concentration area from the results in the first stage, with the estimation period being 2014 in which the latest data can be obtained. As a result, it was made clear that PM2.5 had spread within 500 m of the specific generation sources, and the atmospheric concentrations were intensively high. This verified the fact that a downwash occurs due to buildings and that this prevents the wind from spreading PM2.5.

4. If data concerning generation sources can be created, the estimation method proposed in the present study can be applied to any air pollutant besides PM2.5 as well as in other areas. Additionally, because the atmospheric concentration distribution of PM2.5 can be grasped using the estimation method of the present study, the information concerning the measures to reduce PM2.5 that is more effective than the past may be provided. It is expected that such estimation results should contribute to the risk assessment concerning the influences of PM2.5 on human health and ecosystem.

Author details

Kayoko Yamamoto* and Zhaoxin Yang

*Address all correspondence to: k-yamamoto@is.uec.ac.jp

University of Electro-Communications, Tokyo, Japan

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