# SPATIO-TEMPORAL CHARACTERISTICS OF ONE-MINUTE RAINFALL IN TOKYO

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## ABSTRACT

*In this study spatio-temporal characteristics of one-minute rainfall are investigated based on the 9-year rainfall data from 117 gauges over the whole Tokyo Metropolis. As for the results, it is likely (more than 70%) that rainfall events having intensity of more than 3mm/min will grow to heavy rainfall intensity of more than 20mm/hour. Interestingly, the highest frequency of low rainfall intensity (1 to 2mm/min) appears in October while heavy rainfall intensity (more than 3mm/min) occurs most frequently in August. Low rainfall intensity is rather frequent in the mountainous area than that in the plain. In contrast, the frequency of heavy rainfall intensity in the plain is higher than in the mountainous area. It is further noted that the frequency of heavy rainfall intensity in plain areas is spatially uneven distributed. It concentrates only in some localized areas in the downtown of Tokyo*

## 1 INTRODUCTION

Climate change is the one of the most critical global problems nowadays. The well-documented evidences of the climate change can be seen in the increases of frequency and severity of floods. As with many other megacities around the world, Tokyo has been seriously suffering from urban floods for years. For example, a heavy rainfall of intensity 107 mm/h occurred on 5.7.2010 in Itabashi ward. By the rainfall 92 houses were flooded above floor level, and 92 houses were flooded up to floor level. Floods such as this are mainly caused by heavy intensive rainfall, which are possibly further intensified by urban heat island, global warming and so on.

So far the water retention capacity of the land in Tokyo has declined because of the increased amount of impervious surface areas and the expansion of sewage system. As a result, the flood concentration time is significantly shortened and the flood peak discharge is drastically increased in urban catchments. Therefore a flood control plan based on the actual rainfall condition in the Tokyo metropolis is required, which includes appropriate management of flood control facilities and quick disaster responses. However, characteristics of the short-term rainfall intensity in Tokyo still remain poorly understood. So far, there has been no study about spatio-temporal characteristics of short-term rainfall over Tokyo.

In this study, we investigated this issue by the analysis one-minute rainfall data provided by the Tokyo Flood Disaster Prevention Information System, which has been observed at 117 gauges throughout Tokyo since 1999. The system's main purpose is to observe river water level, tide level, etc, and supply this information for use in disaster management. The rain gauges network is one of the densest in the world (Arakawa, 2007).

The data was initially corrected by removing abnormal values and considering them as missing data or predicted data. For example, missing cord was putted if the data was more then 11 mm/min, and 0 mm/min was putted if the data's before and after data and the same time data of around gauges were 0 mm/min. At the same time, the spatio-temporal characteristics of the missing or abnormal data was already investigated (Boda, 2009).

The remaining data was then analyzed, and its spatio-temporal characteristics ware considered, to allow us to detect trends in the occurrence of urban torrential downpours.

## 2 DATA

In Figure 1, the gauges are classified into three kinds of area according to altitude. In this paper, plain area and mountainous area are defined as area with altitudes of less than 50 m (blue points in Figure 1) and more than 100 m (red points in Figure 1) respectively. The plain area in Tokyo is the center of Tokyo Metropolis and includes the busiest parts of the city with high buildings.

Figure 1 shows that the gauges density in the plain area is higher than that of the mountainous area. The observation period of one-minute rainfall data is from April 1999 to April 2008, and the unit of measurement is 1 mm.The data used in this study is from 101 gauges having less than 5 percent missing values.

**Table 1. The outline of the data**

| | | |
|---|---|---|
| number of gauges | | 117 gauges in whole Tokyo |
| average distance | | about 4km |
| unit of rainfall | | 1mm |
| started period | | 1978～ |
| observation interval | 1.1978～3.1999 | 10min |
| | 4.1999～ | 1min |

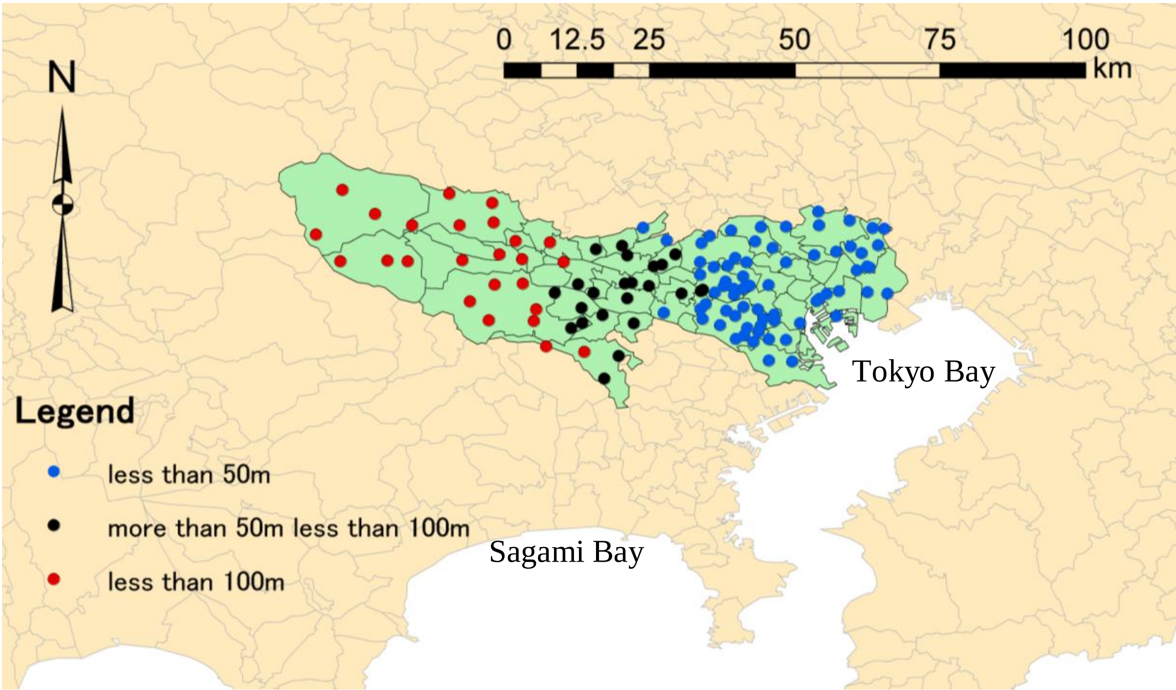


**Figure 1. Study area and rainfall gauges**

## 3 SPATIO-TEMPORAL CHARACTERISTICS OF RAINFALL

### 3.1 One Minute Rainfall Intensities

Because little has been done to actually explore characteristics of short-term rainfall intensity using one-minute rainfall data, the relationship between one-minute and one-hour rainfall intensities is first examined. Table 2 shows the proportion of one-minute rainfall intensities (1, 2, 3 mm/min) that grow to intensities above 20mm/h or 30mm/. In fact, when the Tokyo government forecasts that the rainfall intensity will grow to more than 30mm/h in central Tokyo, a heavy rain warning is issued. As Table 2 indicates, only 12% of all rainfall having intensity of 1mm/min grows to more than 20mm/h. This implies that almost all rainfall intensity of 1mm/min is drizzle and these do not tend to become heavy rainfall. On the other hand, more than 70% of all rainfall events having an intensity of 2mm/min or 3mm/min grow to 20mm/h. This means that most rainfall with intensity of more than 2mm/min grows to a downpour. Therefore, rainfall intensity of more than 2mm/min will be the focus of the rest of this paper.

**Table 2. The relationship between one-minute and one-hour rainfall intensities**

| | | 1 minute rainfall | | |
|---|---|---|---|---|
| | | **1mm/min** | **2mm/min** | **3mm/min** |
| **1 hour rainfall** | **more than 20mm/h** | 12% | 70% | 86% |
| | **more than 30mm/h** | 2.0% | 22% | 30% |

### 3.2 Spatial Distribution of the Frequency in Warm and Cold Months

Figure 2 and Figure 3 shows the frequency of 2mm/min rainfall intensity in warm and cold term respectively. In this paper the warm term is defined from May to October, and cold term is defined from November to April.

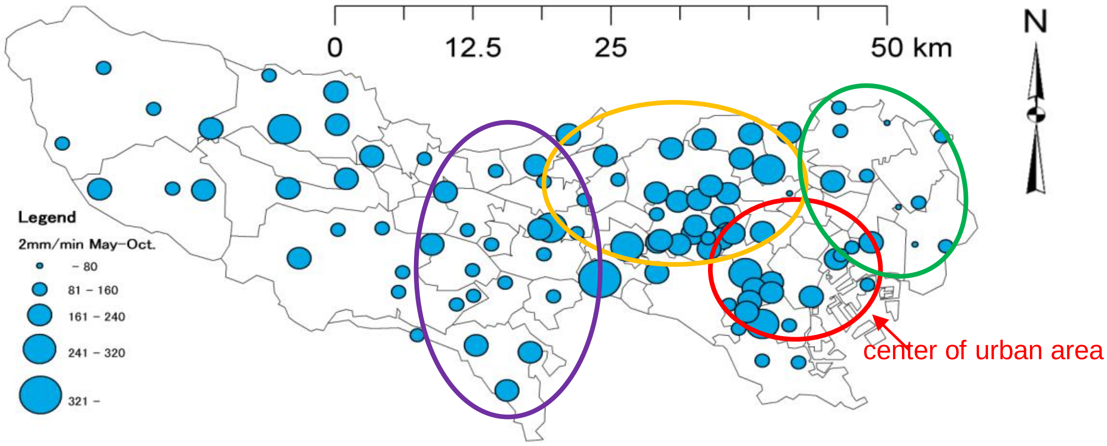


**Figure 2. 2mm/min rainfall frequency in warm term**

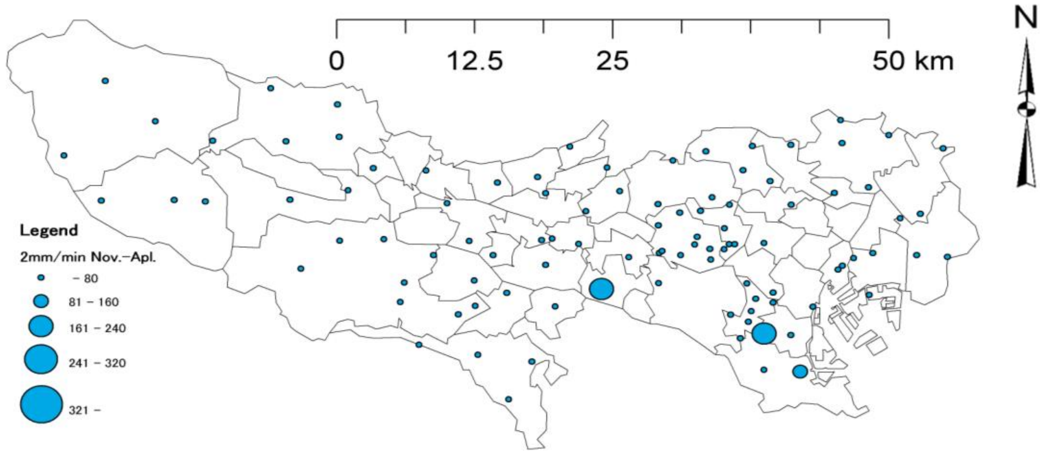


**Figure 3. 2mm/min rainfall frequency in cold term**

Firstly, as Figure 2 indicates, rainfall intensity 2mm/min during the warm term is more frequent in the plain area than that in the mountainous area. It is further noted that the frequency of heavy rainfall intensity in plain area is spatially unevenly distributed. It is mainly concentrated in some localized area in the downtown of Tokyo and around the downtown area. The red circle in the Figure 2 is the center of the urban area in Tokyo. In the area there are about 90 % of all 322 skyscrapers which are higher than 100 m of the Tokyo Metropolis. It can be presumed that the high frequency rainfall in the center of the urban area is partly because of urbanization. Therefore the area north-west of the urban center area (orange circle in Figure 2) also have high frequency of rainfall intensities of 2mm/min. Some study have claimed that the area is where the sea wind from Tokyo bay and the sea wind from Sagami bay are apt to meet in (Sawada, 2005). It might be possible that the phenomenon is one of the reasons why rainfall events occur so often in the area. On the other hand the area north-east of the urban center area (green circle in Figure 2) have less frequencies of rainfall 2mm/min. There are few high buildings in this area, and convergences rarely occur in the area. Therefore the area between plan area and mountainous area (purple circle in Figure 2) also have less frequency.

Secondly, Figure 3 shows that the frequencies of rainfall intensities 2mm/min in the cold term are lower than in the warm term, and it is uniform in the whole Tokyo Metropolis.

### 3.3 Monthly Frequency of Rainfall in the Plain Area and the Mountainous Area

The 101 gauges were classified into the plain area with an altitude less than 50 m and the mountainous area with an altitude more than 100 m (Figure 1). Figure 4 shows the monthly frequencies of rainfall intensity 1mm/min, 2mm/min, and 3mm/min for each area. It was shown by the average frequency rainfall. As Figure 4 indicates the highest frequency of low rainfall intensity (1 to 2mm/min) appears in October. It is attributed to drizzled rain caused by autumn rain front . Interestingly, there is a difference in the pattern of frequency increase from June to October between the plain and mountainous area. In the plain area the frequency increases gradually from June to September, and then it increases rapidly to October. While in the mountainous area the frequency of rainfall increases rapidly from June to July and then increases gradually from July to October. It is considered that in the mountainous area the major factor of rainfall is not only autumn rain front. On the other hand heavy rainfall intensity (more than 3mm/min) occurs most frequently in August. The cause of this is likely that in August thunderstorms often occur and lead to heavy rainfall.

Next according to the Figure 4 low rainfall intensities are more in the mountainous area than in the plain. In contrast, the frequency of heavy rainfall intensity in the plain is higher than in the mountainous area. It can be seen clearly from Figure 5. The figure shows the spatial distribution of the frequency of one-minute rainfall intensity; 1mm/min, 2mm/min, and 3mm/min. This result used 101 gauges in a period of 9 years. According to Figure 5 there is a wide difference in the map between low rainfall (1mm/min) and heavy rainfall (2mm/min and 3mm/min). Moreover, as Figure 4 indicates, the difference in the frequency of heavy rainfall between plain and mountainous area is large particularly from July to October. Especially in October the frequency of heavy rainfall intensity (2mm/min) in the plain area is about three times the frequency of that in mountainous area.

## 4 SUMMARY

In this study, we investigated one-minute rainfall data provided by the Tokyo Flood Disaster Prevention Information System, which have been observed at 117 gauges throughout Tokyo since 1999.

As for the results, it is likely (more than 70%) that rainfall events having a one-minute intensity of more than 3mm/min will be associated with a one-hour intensity of more than 20mm/hour. Low rainfall intensities are more frequent in the mountainous area than in the plain area. In contrast, the frequency of heavy rainfall intensities in the plain area is higher than that in the mountainous area. It is further noted that the frequency of heavy rainfall intensities in side the plain area is spatially unevenly distributed. It concentrates mainly in some localized areas in the downtown of Tokyo. Interestingly, the highest frequency of low rainfall intensity (1 to 2mm/min) appears in October while highest rainfall intensities (more than 3mm/min) occur most frequently in August. This result could be used to establish a flood control plan which is based on the actual rainfall condition, or to examine some areas which urgently need flood control facilities.

However a further study focusing on finding a signal from urbanization should be conducted. Heat island is one of several factors potentially related to heavy rainfall (other examples are global warming and air pollution). Therefore heavy rainfall should be analyzed by taking into consideration many factors as well as weather situation; low pressure, typhoon, seasonal rain front, thunderstorm, and so on. Furthermore, high density rainfall data from nearby areas of Tokyo Metropolis are needed to efficiently analyze the causes of heavy rainfall in central Tokyo.

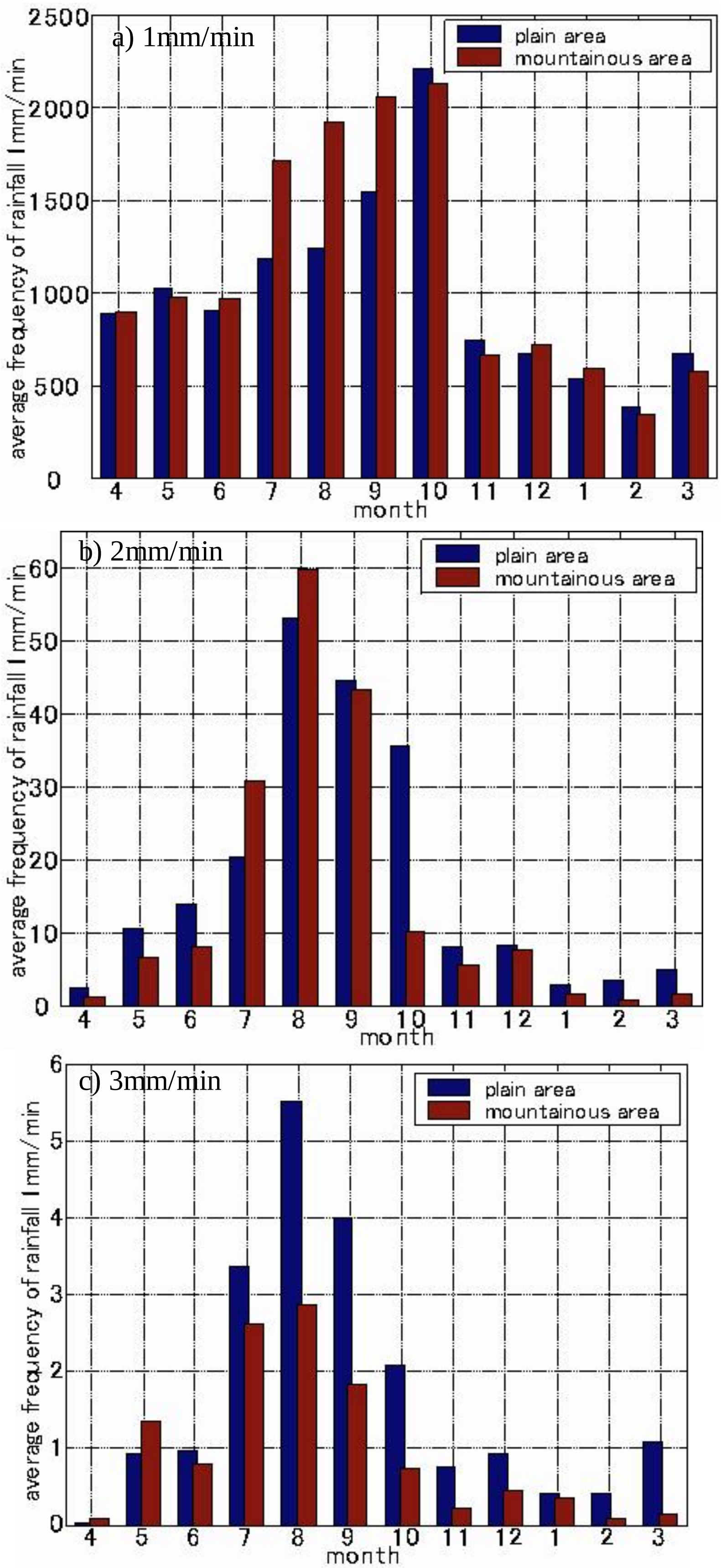


**Figure 4. Frequency of rainfall intensity 1mm/min in plains areas and mountainous areas**

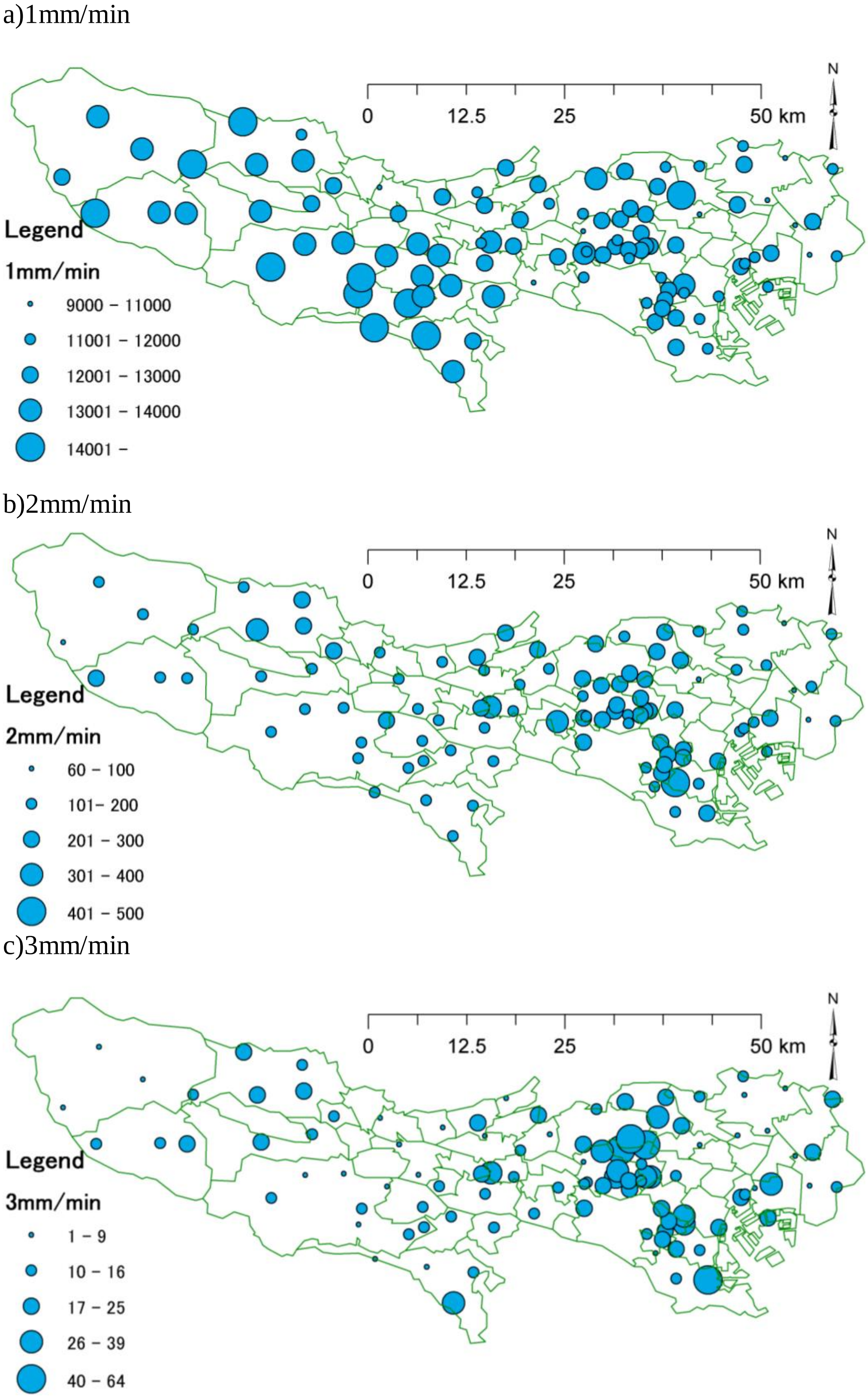


**Figure 5. Spatial distribution of the frequency of one-minute rainfall intensity**

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