Global warming and urbanization affect springwater temperatures in Tokyo, Japan

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Abstract. Due to global warming and urbanization, air temperature in Tokyo has risen 1.6 degrees in the past 30-40 years which has also affected springwater temperatures. From 2005, we have proceeded with the observations of springs in Tokyo metropolis, Japan which had been conducted by Environment of Tokyo from the end of the 1980s to 2001. In the rainy season (October) and dry season (February), we have observed springwater temperatures in 25 springs. The field surveys have revealed that most springwater temperatures has steadily risen in the past 30 years. As of February 2013, water temperatures of 19/11 springs have risen with 5% level in the rainy/dry season. As of February 2006, water temperatures of 10/13 springs have risen with 5% level in the rainy/dry season i.e., 9/2 springs have acquired/lost the significance as of February 2013. One possible reason is the recent hot summer/cold winter in Tokyo.

1. Introduction
Global warming has attracted much attention because it affects present and future climate. Moreover, urban areas are influenced by anthropogenic heat release such as heat islands. Both of them influence subsurface temperature in the urban area which has been studied for a long time [1, and references therein]. Needless to say, monitoring of the underground is important to capture the environmental change brought about by global warming, heat islands, and so on. The measurement of springwater temperatures is one of such monitoring methods.

Tokyo is capital of Japan, and is one of the largest cities in the world. Air temperature in Tokyo has risen 1.6 degree for recent 30-40 years which has also affected springwater temperatures [2]. In this regard, Environment of Tokyo had conducted the observations of 30 springwaters in Tokyo metropolis from the end of 1980s [3], however, it stopped observations in 2001. We, therefore, have proceeded with the observations from 2005. In the rainy season (October) and dry season (February), we have observed 25 springwater temperatures among 30 (see section 3). Actually, water temperatures of many springs have been rising in recent 20 years [2, 4]. The continuation of this trend was also confirmed by recent study [5].

Taking over these observational studies [4, 5], the present study demonstrates the latest observational data of 25 springwater temperatures until February 2013, and discusses the present status of springwaters in Tokyo metropolis.
Figure 1. Distribution of springs investigated, along with the elevation. We could not investigate springs of 4, 5, 13, 17 and 18 after 2005 (see section 3). The star shows the position of Tokyo District Meteorological Observatory.

2 Study area
The study area is the foothills of the Kanto mountains including Musashino upland (figure 1). The latter consists of three terraces which are covered by permeable volcanic ash so called Kanto loam with a thickness of 5-10 m [6]. Below Kanto loam, a sand and gravel layer holds shallow unconfined aquifer system. The Pleistocene sediments, consisting of alternating layers of silt, sand and gravel form a large semiconfined aquifer system beneath the unconfined aquifer [7]. Most springwaters drain from the unconfined aquifer at the terrace scarp or at the valley head where Kanto loam is thin [8].

Tokyo is located in the mid-latitude, with four seasons in a year. From 1981 to 2010, monthly mean temperature in August/January is 27.4/6.1 degree at Tokyo District Meteorological Observatory (figure 1). Much precipitation is observed in the warm period, i.e., June (167.7 mm/mon) and September (209.9 mm/mon). The annual precipitation and annual mean temperature are 1528.8 mm/y and 16.3 degree, respectively.

3 Data and method
In the rainy season (October) and dry season (February), we have observed air temperature, springwater temperature, electric conductivity, pH and RpH at each spring. We have taken sample water of 100 ml, and have measured the concentration of SiO$_2$ in the laboratory. In this paper, we only show and discuss the results of springwater temperatures.

Originally, Environment of Tokyo had carried out field surveys at 30 springs in figure 1, however, we have investigated 25 springs among 30 because the springs 4 and 5 are located in the dangerous situation. Also, we cannot enter the springs 13, 17 and 18 without special permission. Nonetheless, springwater temperature data of these five springs are displayed in figure 2. In section 4, we carried out the comparison with previous study [4], where we do not include these five springs for comparison.

4 Results and discussion
Figure 2 shows the interannual variation of springwater temperatures at 30 springs from 1980s to 2013.
Figure 2. Interannual variation of water temperatures at rainy/dry season at 30 springs in Tokyo. One/two diamond(s) on the right corner represent that the trend is respectively significant at the 5%/1% level in the rainy season. One/two star(s) on the right corner are same as diamond(s) but for the dry season.
Figure 2. (continued)
From this figure, we can perceive that springwater temperature is generally warmer in the rainy season than in the dry season. This is probably because springwater temperature reflects seasonal variation of air temperature in Tokyo, although the seasonal change is relatively small in most springs. As of February 2013, water temperatures of 19/11 springs have risen with 5% level in the rainy/dry season (table 1). It is surprised that the decreasing trend at spring No.2 (Mita Hachiman) in the dry season is significant at the 5% level (figure 2), which is also included in table 1(b).

Figure 3 displays the springs whose water temperatures have risen with 5% level both in the rainy and dry seasons until February 2013. Such springs are mainly distributed in the central part of the study area, i.e., Musashino upland (figure 1). Most springwaters show rising trend in the dry season (figure 2), therefore, large circles in figure 3 will increase in the near future.

### Table 1. Comparison of the results of this study and previous study [4].

|                  | This study | Previous Study [4] |
|------------------|------------|--------------------|
|                  | 1%  5%     |                    |
| Rainy season     |            |                    |
| 1%               | 3  6       | 1  6               |
| 5%               | 0  0       | 0                  |
| Not significant  | 3  6       | 0                  |
| Dry season       |            |                    |
| 1%               | 4  3       | 6                  |
| 5%               | 0  2       | 4                  |
| Not significant  | 6  10      | 10                 |
Figure 3. Distribution of springs whose water temperatures have risen with 5% level both in the rainy and dry seasons until February 2013.

Table 1 shows the comparison of the results of this study and previous study [4], which carried out the same analysis until 2006. As of February 2006, water temperatures of 10/13 springs have risen with 5% level in the rainy/dry season, i.e., 9/2 springs have acquired/lost the significance as of February 2013. One possible reason is the recent hot summer/cold winter in Tokyo.

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