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METEOROLOGICAL OBSERVATION ON MITIGATION OF THE SUMMER THERMAL STRESS: A CASE STUDY OF CHEONGGYE STREAM RESTORATION PROJECT

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Abstract The purpose of this study is to clarify the effects after the restoration of Cheonggye stream in Seoul, in order to pursue effective methods to mitigate the summer thermal stress in mega-city. The results of field observation in the summer of 2004 and 2007 summer showed that the stream-effect as a cooling source was confirmed. In the south of the stream, temperature changes were smaller than in the north of the stream. The asymmetric pattern of temperature distribution across the stream is associated with wind direction as well as urban morphology. In particular, around 19:30 LST, the maximum difference between air temperature on the bridge and surrounding streets was over 2.5°C. The appearance of the obvious low temperature was proportional to the extent of stream-effect, and it was also affected by wind speed and direction. In cloudless night, the temperature difference continued until the sunrise. In 19:30-0:00 LST, the temperature difference was over 1°C on the north side of the stream, and the discernible reduction in air temperature was spread to the extent about 70-80 m. On the other hand, the temperature difference was around 0.5°C on the south side of the stream, and the discernible reduction in air temperature was spread to the extent only 30-50 m.

From those results, the authors suggest that the environment design of wind path over the stream should be developed in order to improve the stream-effect. In addition, the authors indicate the bank along the stream side may obstruct the diffusion of cooler air-mass above the stream.

Key words: Seoul, the Cheonggye stream, restoration, the stream-effect, meteorological observation

1. Introduction

Seoul, as the capital city of Korea and the largest city in Korea, rebuilt its capital in the shortest time recorded in world history after the Korean War (1950-1953). Now, the area of Seoul Metropolitan city is 605.52 km^2 (1997). Seoul Metropolitan city as a mega-city with 10.26 million populations (2000) has advanced at an unprecedented pace in urban expansion over the past few decades. This has caused the annual mean temperature increase. Figure 1 shows the rise in annual

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mean temperature in Seoul is as much as that in Tokyo, a mega-city with 12.26 million populations (2005). Furthermore, the monthly mean temperature in both the maximum and minimum temperature in January (the coldest month) has risen over 2.0°C since 1954 (Fig.2).

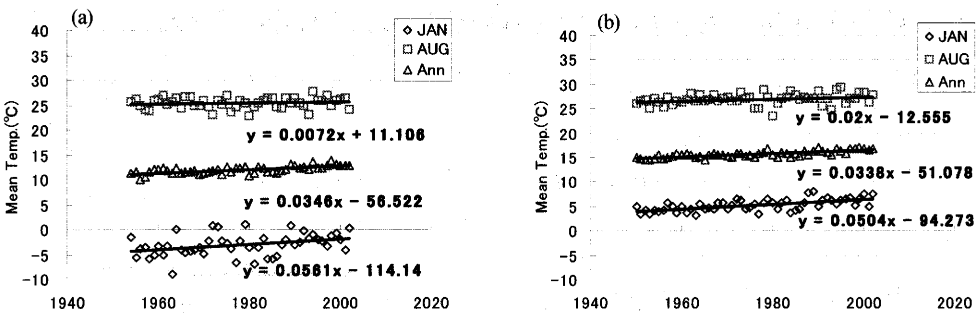

Fig. 1 Increase of the annual mean temperature and monthly mean temperature in (a) Seoul and (b) Tokyo (1954-2004) (The warmest month is August, whereas January is the coldest one).

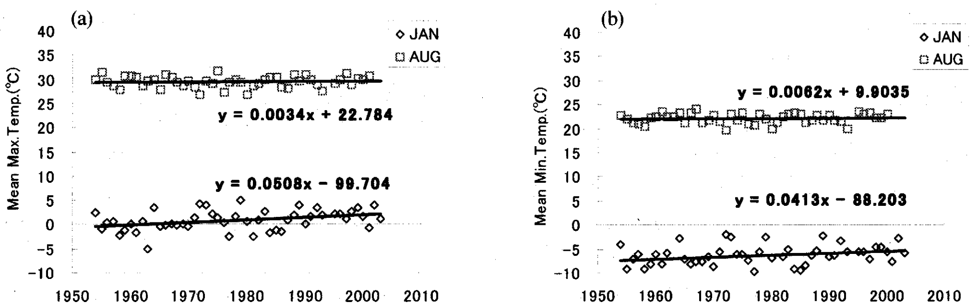

Fig. 2 Increase of (a) monthly mean maximum temperature and (b) monthly mean minimum temperature in January and August in Seoul (1954-2004) (The warmest month is August, whereas January is the coldest one.).

Some experts reported much of those rises may be related to the increase in the global mean temperature as described by *The Japan Times* (Sept. 24, 2001). However, the global mean surface temperature has increased by between 0.3°C and 0.6°C since the late 19th century, a change that is unlikely entirely natural in origin. Actually, many Japanese researchers warn that urban warming in large cities continues, due to the "heat island effects" (e.g. Mikami 2005; Ojima 2006).

One of the most known phenomena associated with inadvertent climate change is the urban heat island (UHI), in which the air temperature in the urban canopy is higher than that in the surrounding rural area. The UHI intensity varies with urban size, urban surface characteristics, anthropogenic heat release, topography, and meteorological conditions (e.g. Landsberg 1981; Oke 1987). Currently, many studies indicate that the three big causes of urban warming are an increase in heat emissions from human activity, a reduction of green spaces and water surface area, and heat retention in surfaces such as concrete and asphalt.

Now, the diverse researches on monitoring techniques for document and characterize the effects of large green space and water spaces in an urban area, including "Klimaatlas" in urban planning such as creating "wind paths" to let the ocean wind cool the metropolis, have been developed to mitigate the UHI in Asian mega-cities (Architectural Institute of Japan 2000). Moreover, in areas with water bodies, if the water is cooler than the air, especially under hot weather conditions, the effect appears as a decrease in air temperature (Munn *et al.* 1969; Naot and Mahrer 1991). In addition, the discernible reduction in air temperature may be spread to the extent about 150-500 m from the river, is estimated in Japan (e.g. Murakawa *et al.* 1988).

A project to restore an inner-city stream (called the Cheonggye stream) in Seoul began on July 1st 2003, was completed in 2005. The restoration project involved demolishing the elevated highway, opening the cement/asphalt pavement, and renewing the stream environment. Now, The Cheonggye stream has been recognized as an ecological city stream and also as a prototype for the restoration of streams in cities as described by the Seoul Metropolitan Government (*Back to a future: Seoul* 2005). However, direct observations on environmental improvements after reviving the city's landscape are rare. The needs to analyze and predict the effects of ecological structure of the city in order to find the most effective methods to recover and improve the changed urban thermal environment are acute.

The purpose of this study is to clarify the effects after the restoration of Cheonggye stream in Seoul, in order to pursue effective methods to mitigate the summer thermal stress in mega-city, based on field meteorological observations. In this paper, we present the observed changes in air temperature around the stream, as the first report. The study will give appropriate guidelines for developing the urban planning of mitigating UHI in Asian Mega-cities.

2. Meteorological Observations

Study region

For the past 600 years, "Cheonggye -Cheon" ("Cheon" means river in Korean) had been the center of Seoul's structural foundation, running east and west of Hanyang (the name of former

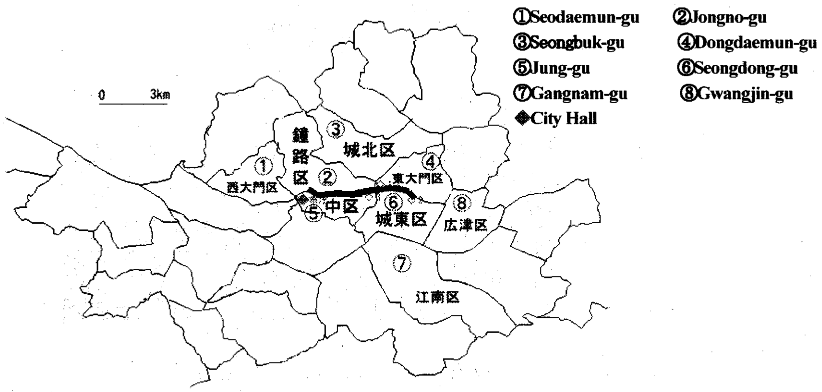

Fig. 3 Location of Cheoggye-Cheon.

Seoul) and connecting the south and north (Fig. 3). Cheoggye-Cheon was once a living river used for everyday by the public and was covered in 1958-1961 to solve pollution and floods caused by increased population. Now, the restored historical Cheonggye stream has a water depth of about 40 cm and runs 5.8 km eastward through a central region of Seoul. The green areas and walkways were made just near the stream (Fig. 4).

(a) (b) (c)

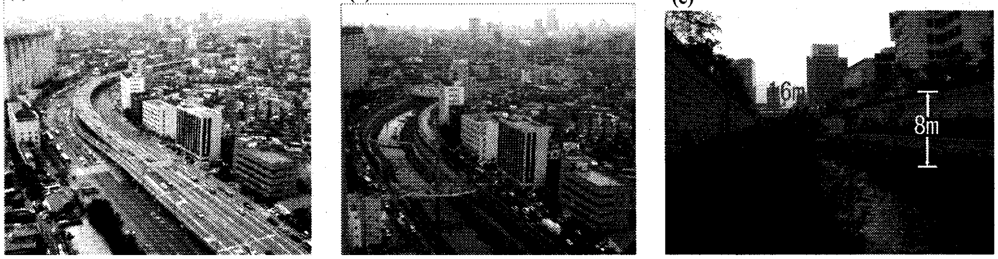

Fig. 4 (a) Cheonggye overpass (Date: Jun. 2003)
(b) Restored Cheonggye stream (Date: Aug. 2005)
(c) Cheonggye stream (Date: Aug. 2007)

Observations

Intensive observations were made in the Cheonggy stream area in 2003, 2004 and 2007. In order to study on the stream-effect, 14 thermal recorders (data-logger) installations were deployed across the stream over a distance of about 120 m.

Thermal recorders measured temperature and humidity every 10 minutes, which were put in the breezy shutters. Figure 5 shows the photo of thermal recorder installation, which was attached at a height of 2.0 m above the ground level to trees lining the street. The data-logger is with an energy saving device and the installation is not needed maintenance.

In addition, surface temperture of the vicinity of the Cheonggye stream was measured using thermal-graphy (Fig. 6) in 2003 and 2004.

Fig. 5 Thermal recorder installation.

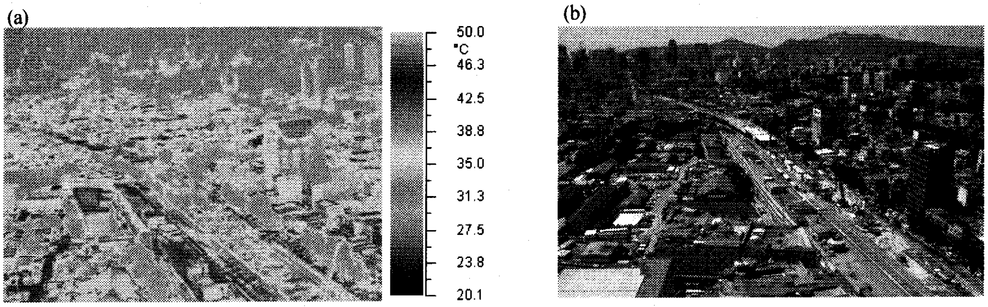

Fig. 6 (a) Surface thermal image by thermal-graphy and (b) picture of observation location

3. Results and Discussion

Temperature mitigation

According to a project report from KMA (Korea Meteorological Administration 2001), before the stream restoration, the temperature in the stream area was higher than the averaged temperature over Seoul. Because the Cheonggye stream area is one of the central urban areas of strong urban heat island intensity in Seoul. The average temperature difference was 1.0℃. Furthermore, the temperature difference was larger in the eastern part of the stream area than in the western part.

The results of field observation in the summer in 2004 (during the stream restoration) proved that the stream-effect as a cooling source was confirmed. Figure 7 indicates that the surface temperature around the Cheonggy stream changed because of the restored stream. The drop in air temperature above the stream in summer created the surface temperature difference between the water surface and asphalt pavement, and the surface temperature difference was affected by the meteorological elements.

It was estimated that after the stream restoration, the temperature difference between the averaged temperature over the stream area and the averaged temperature over Seoul became

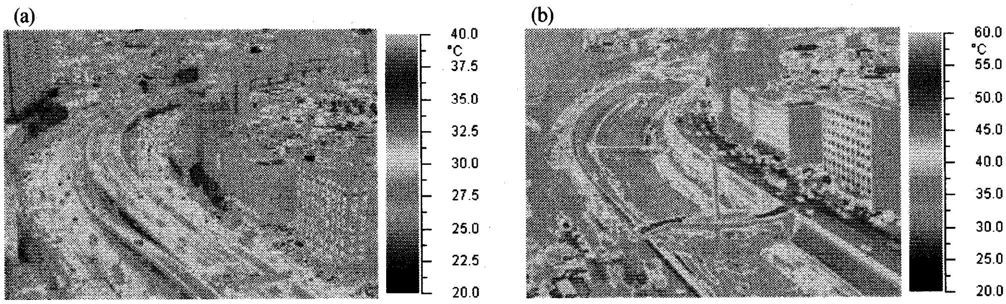

Fig. 7 Changes of surface temperature.
(a) before the stream restoration (2003/06/21 12:00)
(b) during the stream restoration (2004/08/11 12:00)

smaller. The mean temperature difference was 0.6°C in August 2005 (the stream restoration was already completed in August 2005). The temperature decrease has been caused by the changes of surface temperature and the stream wind.

Figure 8 indicates that the stream effect on air temperature is evident in the temperature distribution along a street traversing the stream. The observational results in summer in 2004 and 2007 showed that the Cheonggye stream was obviously responsible for the temperature decrease after the stream restoration. The stream effect on air temperature changed with distance was recognized. In the south of the stream, temperature changes were smaller than in the north of the stream. The asymmetric pattern of temperature distribution across the stream associated with wind direction as well as urban morphology.

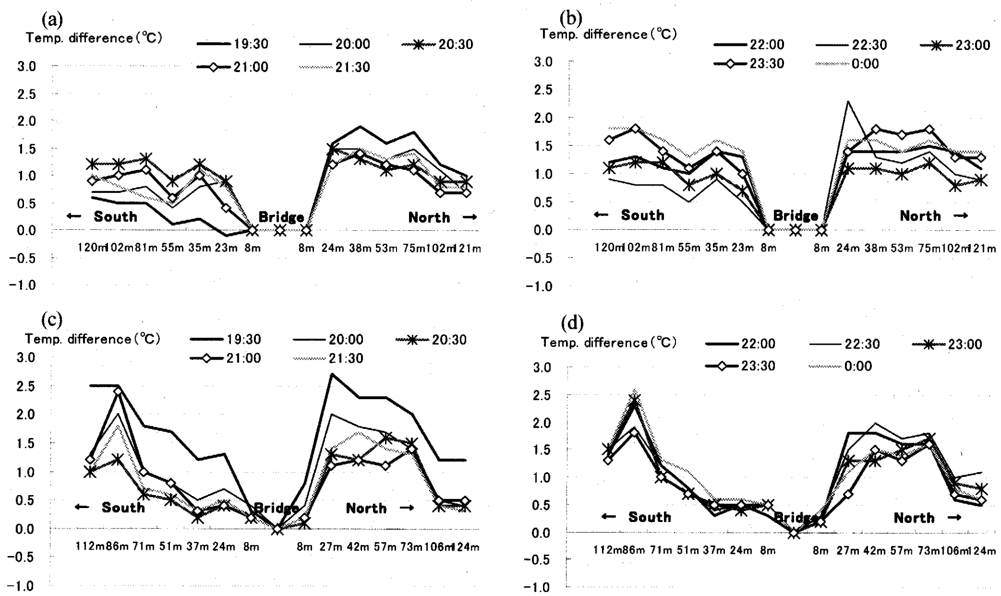

Fig. 8 Changes of temperature difference along a street traversing the stream. Above: during the stream restoration (a) 2004/08/12/19:30-21:30 and (b) 2004/08/12/22:00-0:00. Below: after the stream restoration (c) 2007/08/23/19:30-21:30 and (d) 2007/08/23/22:00-0:00

The stream effects

Murakawa *et al.* (1988) pointed out that the discernible reduction in air temperature could be spread to the extent about 150-500 m from the river. As the Cheonggye stream is an urban stream running through the center of the capital from east to west, it can not be practically restored as a natural stream so that the water surface is not wide, its average depth is only 40 cm (amount of water supply: 120,000 m^3/1 day; average speed of water: 0.25 m/s). After the stream restoration, the discernible reduction in air temperature has been only spread to the extent about 50 m (south side)-80 m (north side) from the stream (Fig.8). But, the air temperature along the street within 80 m on the north side of the stream decreased obviously. This result is due to the action of both southerly wind and wind from the stream.

After 19:30 LST, the stream effects become evident on both side of the stream. In cloudless night, the maximum air temperature difference between air temperature on the bridge (over the stream) and on the north side of the stream was over 2.5°C around 19:30 LST in the summer in 2007. The appearance of the obvious low temperature was proportional to the extent of stream-effect, and it was also affected by wind speed and direction. In particular, the temperature difference continued until before the sunrise. In 19:30-0:00 LST, the temperature difference was over 1°C on the north side of the stream, and the discernible reduction in air temperature was spread to the extent about 70-80 m.

On the other hand, the extent of the stream-effect on both sides is different (Fig. 8). There is little effect of the wind from the stream when the wind is in the south. The temperature difference was around 0.5°C on the south side of the stream, and the discernible reduction in air temperature was spread to the extent only 30-50 m. It was also cleared up by the residents-interview that the changes in local thermal environment at the south side of the stream were little

It is speculated that an inner-city stream or river will modify its nearby urban climate. However, in this study, changes in local thermal environment associated with the restoration of an inner-city stream appeared along the street within 80 m from the stream. Although the width of the stream is only 16 m, the effect of the wind from stream is evident on the north side of the stream, the stream-effect may become wider spread after a well-ventilated building distribution conducted along the stream.

From these results, the authors suggest that the environment design of wind path over the stream should be developed in order to improve the stream-effect. In addition, the authors indicate the 8 m high bank along the stream side may obstruct the diffusion of cooler air-mass above the stream (Fig. 9).

Even though the project was completed in September 2005 (although the stream restoration was already completed in August 2005, the official announcement of its completion was not made until September 2005), the public has tried their utmost to make an appropriate new waterside space and maximize the usage of the changed environment. All field observations will continue. Further study is certainly needed to explore the complicated relationship between the local urban heat island mitigation and the effect of the wind from the Cheonggye stream.

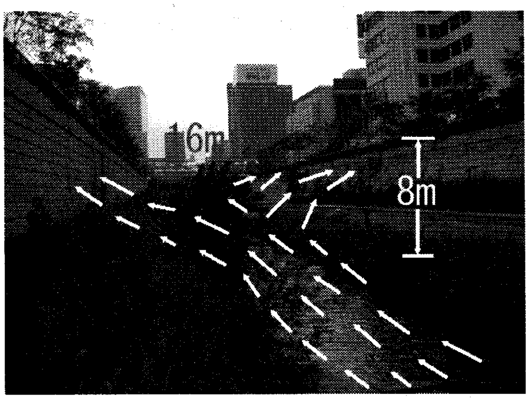

Fig. 9 Image of cooler air-mass above the stream.

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(*: in Japanese, **: in Japanese with English abstract, ***: in Korean)