# Thermal impact of blue infrastructure: Casestudy Cheonggyecheon, Seoul (Korea)

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## 1. Introduction

Higher densities tend to experience a relatively hotter surface temperature, compared to their peri-urban surroundings. This artificial heat stress in cities is denoted the Urban Heat Island (UHI) effect. Urban geometry, landscape, land surfaces and anthropogenic waste heat are cited as the UHIs' key contributors. However, magnitude and distribution of the UHI effect varies in different cities due to different regional climates, urban land use patterns and scales of investigation.
Seoul, the capital of the Republic of Korea, is influenced like many other large cities by the urban heat phenomena. The urban heat phenomena are typical for a metropolitan area that is significantly warmer than its surrounding rural areas due to human activities. Special geographical and political conditions are combined with a high population density, remarkable high-rise buildings and small open spaces are characteristic for Seoul. The city of Seoul (9.8 Million inhabitants) is located in a valley surrounded by mountains in the north and south. Furthermore, in 1972 a restricted development zone (RDZ) precinct was established by the government. This is essentially a Greenbelt that has a size of 1,567 km². This greenbelt is more than two times larger than the city of Seoul. Seoul has an area of 605 km². All urban development within the RDZ has been prohibited during the last four decades.
The calculated land surface temperature (LST) in this paper was obtained by using the satellite Landsat-7. It was carried out a calibration of the data on the probe specificity, the emission and the transmittance. The resolution of the images is 30 meters. Satellite maps are available for free at the NASA based remote sensing plattform (Earthexplorer 2015).

2. The abstract

After the full urbanization of the Seoul during the late 1980s several new towns where established outside the Greenbelt. Several push-and-pull factors have followed and influenced the rapid urbanization of the capital region of Korea. Currently more than 23 Million inhabitants are living in the Seoul Metropolitan Area (SMA). This has become one of the biggest urban agglomerations in the world. The greenbelt has had a significant impact on the whole of the SMA. Due to the containment by the greenbelt, an intensive urbanization has occurred within the constrained Seoul City. This has resulted in a limited number of green areas and water bodies in the Seoul. The number of green spaces per inhabitant is one of the lowest in the world. Next to the 600m wide Han-River that flows from east to west through the central part of the city, there are no open streams or water bodies.
Therefore, the establishment of new green or water bodies in the Seoul City is of great importance. One of the most remarkable projects is the redevelopment of a 5.84 km long and 24 m wide two-tier expressway to a river stream (Fig .1 and 2).
We investigated the micro-climate changes and urban-scale cooling load reduction which has resulted from the so called Cheonggyecheon water stream. This stream is located in central Seoul and runs from the northern central business district into the Han-River. After the Korean war (1950-1953) the Cheonggyecheon river was for more than 50 years covered with pavement and concrete overpass structures. The reconstruction of the expressway was carried out from 2002 to 2005. To estimate the thermal impact of the expressway into a water pathway remote sensing analysis (Landsat 7 ETM+) was undertaken. 20 Landsat-7 ETM+ images from 2000 till 2012 were used to compare the land surface temperature (LST) distribution during the time the expressway was

there and through to the reconstruction and the establishment of the river stream. A built-up area of two km width surrounds the new water pathway and this was used as a reference area. The investigation could show that the establishment of the Cheonggyecheon stream forced a considerable thermal impact, i. e. an average decrease in the land surface temperature by seven degrees Celsius.
The results indicate that the cooling benefits of the restored stream areas are promising in the locations. The calculation method will be explained as fellow.

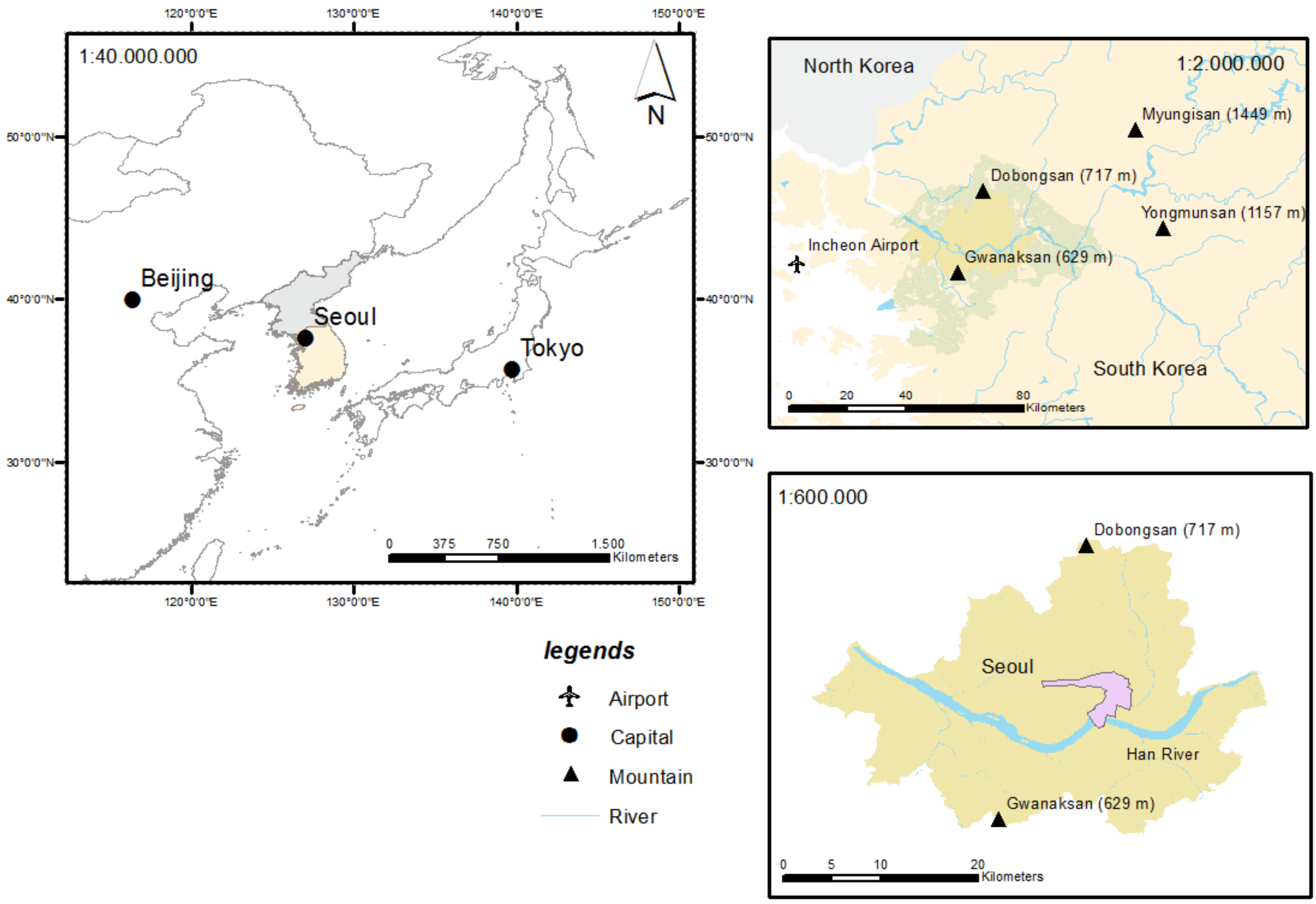


*Fig. 1: The Cheonggyecheon area if investigation (purple, 3rd image) in Seoul, Korea (Source: calculated via ArcGIS 10.1 by & Philipp, C.).*

### 3. Methodology - Remote sensing analyses

It was possible with the described method below to calculate the land surface temperature based on different land use types. NASA (National Aeronautics and Space Administration) began its civil satellite-based remote sensing program in 1972. Landsat-7 with its advanced optomechanical sensor system (Enhanced Thematic Mapper) ETM+ was launched in 1999 and provides optical remote sensing data in eight spectral bands (Visible-reflected light- bands in the spectrums; blue, green, red, near-infrared [NIR], and mid-infrared [MIR] (bands 1-5, 7), two thermal infrared channels [TIR] (band 6.1 and 6.2) and the panchromatic (band 8) (NASA 2014). We used band 6.1 for the calculations found in this paper. The available satellite images consist of pixels with a size of 30x30m (digital numbers, DN) to determine the blackbody temperature of the sensor (brightness temperature, TB) from the DN. Planck's equation also has to be combined with the satellite specificity. The satellite specificity of  and 6 (Thermal Infrared band, TIR band) means that the radiation only in the interval between 10,31 and 12,36 micrometer. However, this is not independent of wavelength, but is described according to the Relative Spectral Response (RSR) (Teillet, et al., 2001).
Planck's equation was derived for the ideal case of the blackbody temperature. Real objects always emit a lower energy flow, which means that for the same measured radiance the true LST is always greater than TB. The emissivity from the interval (0, 1) represents the material and surface specificity of each pixel. This determination is in principle possible for probes with multiple thermal channels (multi-channel methods). ETM+ has only one TIR channel, so in the calculations used for this work, a different approach was used: the Classification-Based Emissivity Method (CBEM) (Li, et al., 2012). The land cover types (LCT) of two benchmarks where used and each LCT was assigned an eps-value. Based on a review of the literature different emission levels were derived for the LCT of the two benchmarks. An independence of temperature and wavelength is provided, and geometric effects

are not considered here. Radiation is absorbed when passing through a transparent medium, and is defined as the ratio of transmitted to emitted radiation density and transmittance t. The ETM+ sensor receives only a reduced proportion of the emitted radiation on the ground. However, this also changed the led of the atmosphere directly to the probe thermal radiation. To eliminate these distortions, a number of methods have been developed (Weng, 2009; Li 2012). In this work, the decision was made after extensive testing to favor the mono window algorithm (MWA), which was first described in 2001 (Qin, et al., 2001). Since this initial description some revisions and comments have been made to MWA. The MWA requires, in addition to the TB values from the satellite images, the total water content of the air column from the ground surface to the sensor, the air temperature on the ground and the effective average atmospheric temperature. These three parameters derived from simultaneous measurements of meteorological balloons around the test areas. In the present work, the balloon measurements of the Gimpo Airport (15 km south west of the area of investigation) were used and provide the vertical profiles of air temperature and relative humidity (Wyoming 2014).

For performing an accurate and comprehensive investigation, the different LUT of the greater Chengycheon area were reconstructed with the software Envi (2015). Seven remote sensing images Landsat-7 were used (Band 6.1) and six land use types were separated (Fig. 3):

- urban: buildings, factories, offices, banks, shopping malls, restaurant and small shops, residential blocks
- street: paved area
- vegetation: natural means or planned parks
- grass: grassland, play grounds
- Barren land: open areas, construction areas
- water: river, lakes, water boundaries

The evaluation will be measured in an average land surface temperature which has been obtained by eight Landsat-7 images. Every season is covered by two images between 2000 - 2012 (Fig. 5).

*Fig. 2: Cheonggyecheon before the reconstruction (2001, left) and after the reconstruction (2005, right) (KIM & HAN 2012:152).*

**4. Variation of temperature of different Land use types**

Figure 4 shows the land surface temperature (LST) of the area of investigation surround the Cheonggyecheon river. Six land use type (see Fig. 3) for 34 Landsat-7 images (2000 till November 2012) were investigated separately. The land use types (LUT) where distinguished as urban, street, grass, green, barren land and water. The raw blackbody Landsat-7 images from the NASA (Earthexplorer 2015) were transformed by an atmospheric correction. All images were taken between 02:10 to 02:16 UTC. The water areas were the coldest land use type and paved areas (urban and street) are the hottest land use types within the area of interest. The temperature of the different LUT ranges in the image of Figure 5 from the 15 June 2011 between 13.2 (water) to 53.2°C (urban).
Figure 5 represents the temperature profile of the 34 Landsat-7 remote sensing images by subtraction of the Cheonggyecheon area before the reconstruction in 2005 (gray) and after the reconstruction (blue). Primarily it could be observed that the surroundings show a higher temperature than the area of the Cheonggyecheon.
The Cheonggyecheon area was before the reconstruction covered with a expressway (land use type *street*) and that area was, based on the urban design, in average 2 K colder than a surroundings. After the reconstruction (from land use type *street* into *water*) was the Cheonggyecheon stream in average 8 K colder than the surroundings. The average LST different between the reconstructed Cheonggyecheon stream and his surroundings was different in winter (average temperature different 5 K) and summer (average temperature different 11 K). The investigation of the different LUT shows that it is possible to separate warmer and colder areas in the investigation area. It’s furthermore possible to see the LUT/LST relation for winter, spring, summer and autumn. The trend between the different land use types (LUT) is in summer higher than in winter. This trend is more or less consistent through different time period of investigation 2000-2012.

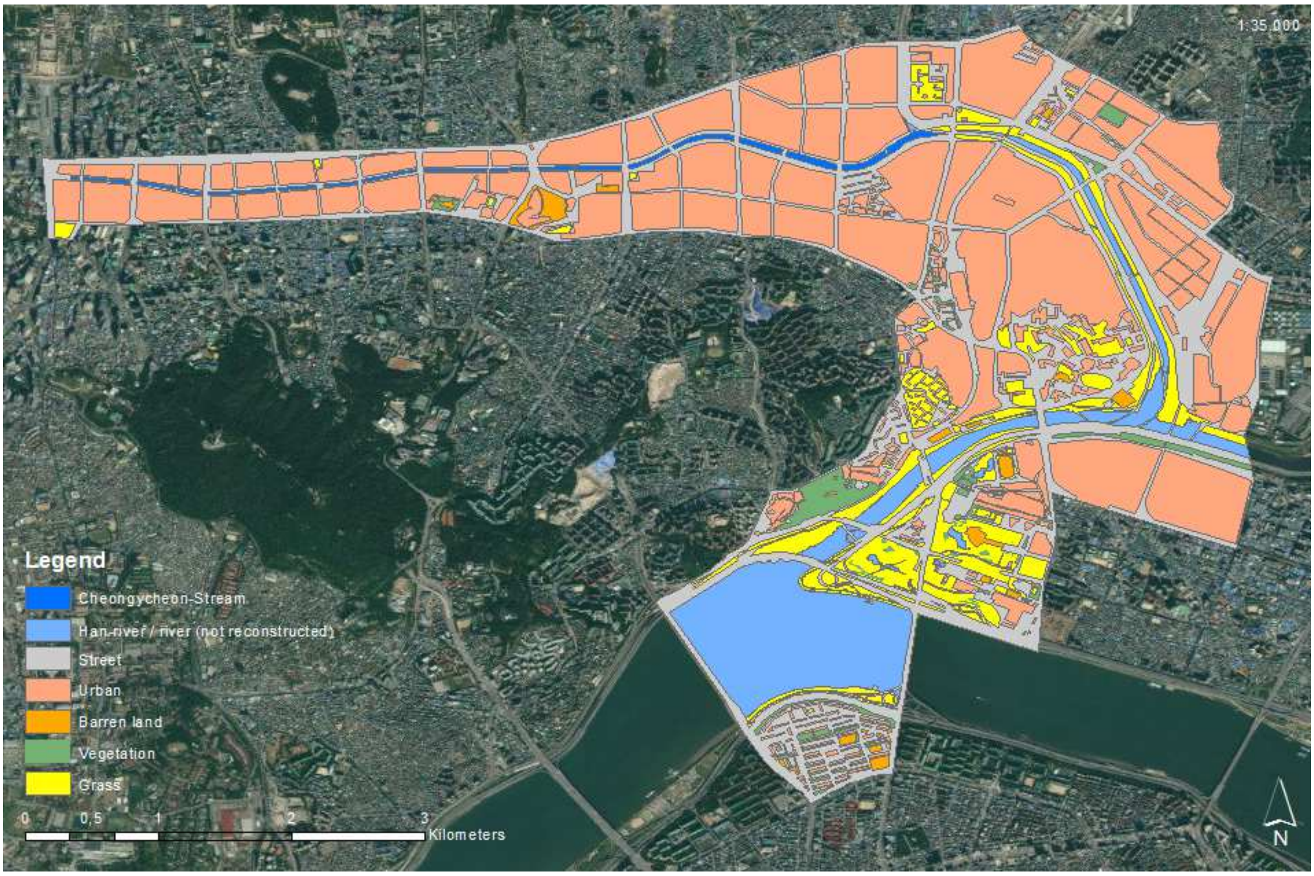


*Fig. 3: Reconstructed land use types of the greater Chengycheon area by using the software ENVI (Source: calculated via ArcGIS 10.1 by & Philipp, C.).*

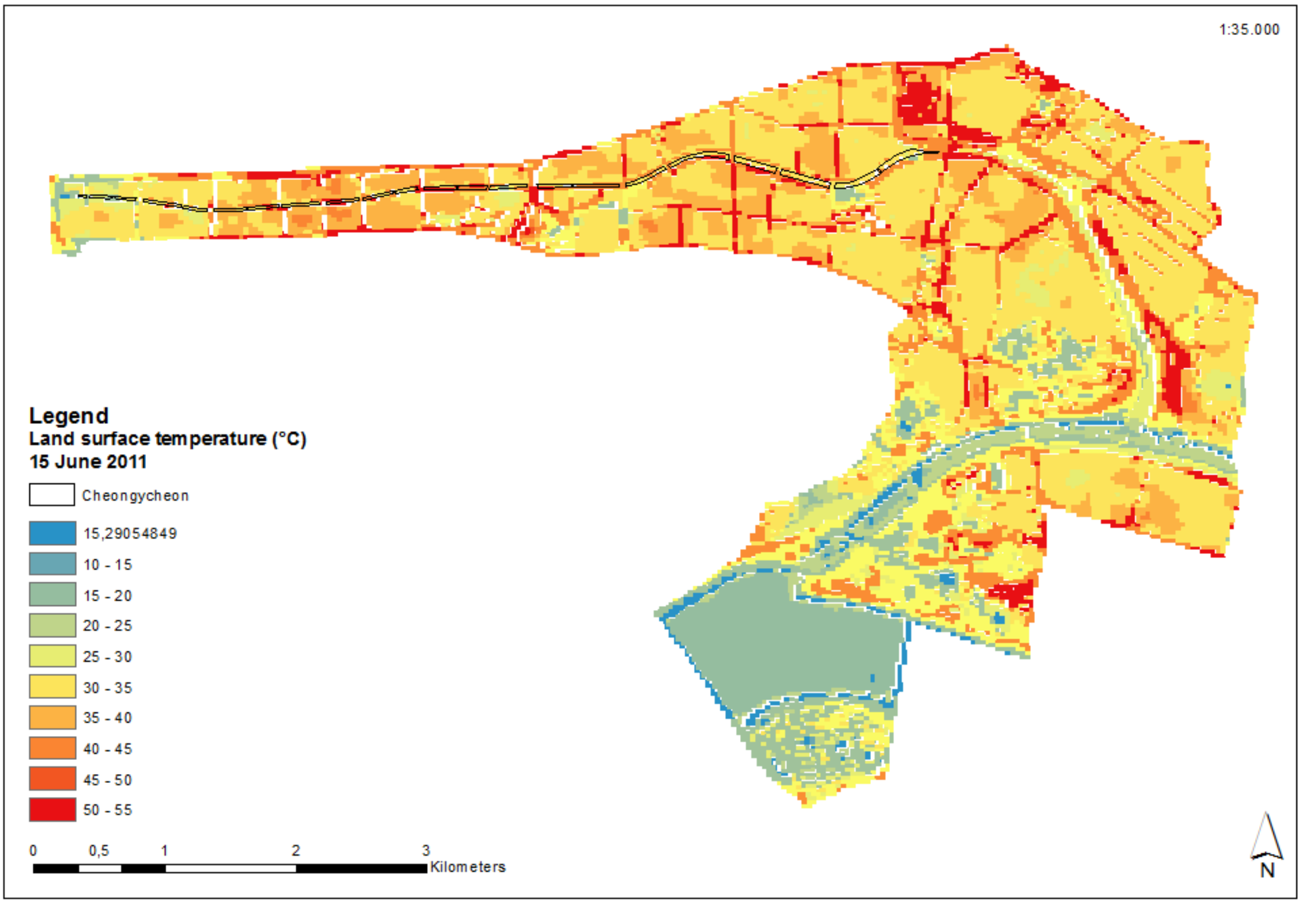


*Fig .4: Land surface temperature of the Cheonggyecheon research area (10 June 2010) (Source: calculated via ArcGIS 10.1 based on Landsat 7 images from Earthexplorer 2015 by Philipp, C.).*

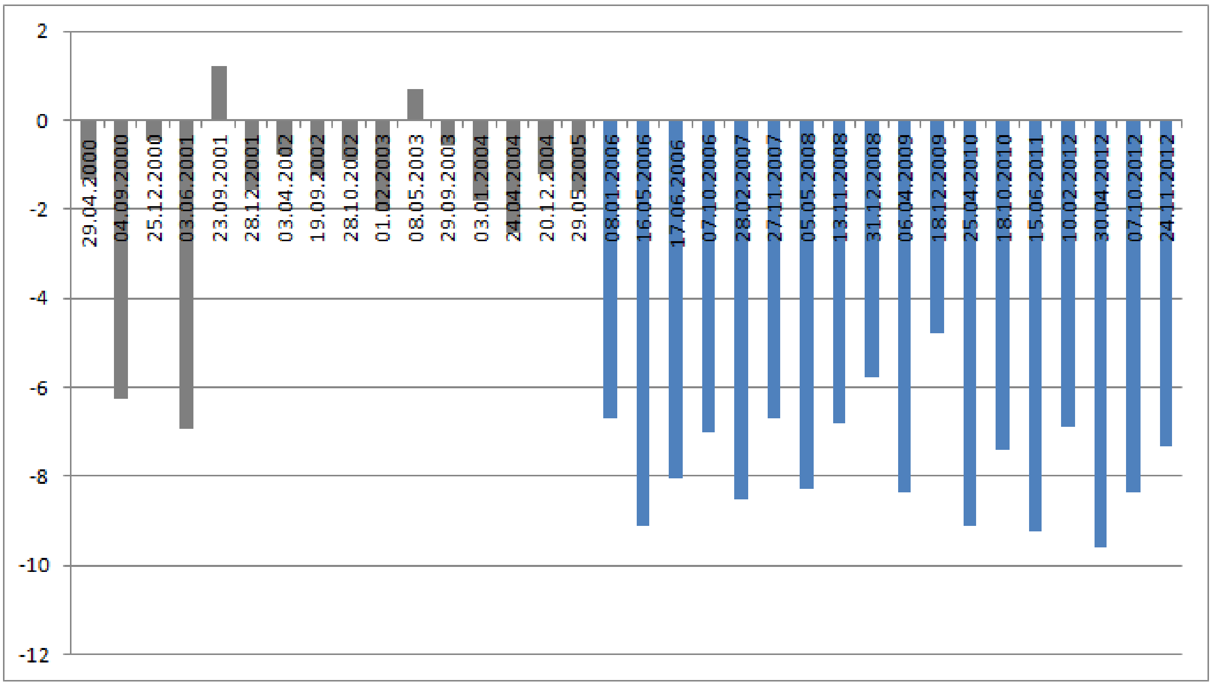


*Fig. 5: Land surface temperature decrease after the reconstruction of the Cheonggyecheon (gray: covered by a expressway, green: open water stream) (Source: calculated via ArcGIS 10.1 based on Landsat 7 images by Wannous, J. & Philipp, C.).*

## 5. Conclusion

This chapter discloses the synopsis of the analysis on the influence of the land use types of the land surface temperature change after the reconstruction of the Cheonggyecheon (2005) from an express way into a water stream. The methodology based on remote sensing data of Landsat-7 is also applicable for other urban areas worldwide where a remarkable land use changed is recognized. The major finding of the analysis was that the Cheonggyecheon area became significant colder after the reconstruction (paved street into water). These aim follow directly into the conclusion that we can highly identify a cooling effect of the water stream within the Seoul City. The CBD of Seoul has been developed high densely, hence the cooling effect of the river and the existing vegetation is negligible compared with the heat accumulation. And therefore we observed the temperature of each land use type can manipulate the temperature of the certain area with its density, land coverage and individual heat gain. To reduce the densification of land usage in certain area the city authority has to develop alternative allocation with proper infrastructure and amenities. The existence of rare water areas (e.g. lakes and rivers) and green areas (e.g. parks) in respect with the urban and climatic condition of Seoul should be encouraged and therefore has to be maintained to prevent future occurrence (Fig .6).

*Fig. 6: Reconstructed Cheonggyecheon (Source: picture taken by Philipp, C. on 29 July 2014).*

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