# Cooling power of urban river under the background of urbanization

## Abstract

## Introduction

### 1.1. UHI

* With population explosion and economic development, urbanization has witnessed significant expansion globally.
* According to the prediction from the United Nations, this trend will continue in the following decades and the urbanization rate is estimated to be up to 68 % by 2050 (United Nations. 2019).
* As has been observed in numerous cities over the world, urbanization has caused multiple adverse effects on local environment, such as water and air pollution, ecosystem degradation and urban heat island (Wang et al., 2020; Ahmad et al., 2021).
* Urban heat island is a phenomenon by which temperatures tend to be higher in urban areas compared to the surrounding rural areas.
* Elevated temperatures have been found to increase energy consumption and pose a threat to public health in cities, especially in summer (Guan et al., 2017; Nieuwenhuijsen et al., 2018).
* Therefore, certain measures are necessary to address the associated negative effects.

### 1.2. 水体降温效应

* 目前，主要的城市降温措施包括改变表面材料、优化土地覆盖、促进通风等。
* 对于土地覆盖与利用，蓝绿空间的影响关注较多。
* 由于水体的热特性，其对周边热气候有显著影响。在白天的大多数时候，水体对周边环境有降温效应。
* 降温范围（举例）
  + 在一些地方，水体降温效应被发现强于绿地（举例）。
* 湖泊和河流是城市水体的主要类型，两者具有不同的形态特征。在城市内，多数湖泊面积较小，并分散于城市内各处，而河流呈狭长型线性布局，多数贯穿整个城市。
* 由于上述不同，河流与湖泊对周边环境的温湿效应存在差异。比如，在我国东北城市长春和吉林市，河流对周边环境的降温效应显著强于湖泊和绿地 (Xue et al., 2019)。
* 相对湖泊，河流相关研究较少
* Primary measures to address excessive urban heat include altering surface materials, optimizing spatial layout of land cover, and promoting ventilation (Azhdari et al., 2018; Taleghani，2018; He, 2020).
* In terms of land cover, the impacts of blue and green space have received much attention.
* 【可选】Blue space contains lakes, pools, rivers, etc.
* Compared to impermeable surfaces, water has a low thermal conductivity and a high specific heat capacity. They cause the water surface to absorb less heat during the day, resulting in lower temperatures.
* These temperature contrasts can contribute to the heat transfer between water surfaces and surrounding urban areas. Consequently, the waterfront areas get cooler.
* According to a research in Shanghai, the contrast of surface temperature between lakeside and inland areas can be more than 5 °C (Du et al., 2016).
* 【可选】Meanwhile, researches have also demonstrated that the cooling ability of water bodies can be stronger than green spaces (Dugord et al., 2014; Tan et al., 2017).
  + 【参考Water as an urban heat sink: Blue infrastructure alleviates urban heat island effect in mega-city agglomeration】
* In urban areas, rivers and lakes are 2 major types of water bodies with different characteristics.
* A large proportion of lakes are polygonal or circular in shapes and located dispersedly within a city, while rivers have a narrow and linear layout, mostly traversing the entire urban area.
* Therefore, rivers and lakes have differences in their thermal effects on the surrounding environment.
* In the northeastern Chinese cities of Changchun and Jilin City, the cooling effects of rivers on the surrounding environment are found to be stronger than those of lakes and green spaces (Xue et al., 2019).
* 【可选】Compared to the cooling effects of lakes, the understanding of river cooling effects on the surrounding urban areas is limited.

### 1.3. 城市化对UHI的影响

* 伴随着快速的城市化过程，土地利用正在广泛地改变，主要是植被减少。【需补充】
* 相应地，城市气候特征及其与环境因素的关系也会发生一定变化【需补充】
* 已有研究发现，不同城市化地区的水体降温效应有较大差异【可选】
* 因此，在城市化背景下，水体对周边的热效应会发生显著变化，其驱动因素也会随着时间而变化。
* 目前，相关研究对动态的城市化过程对水体热效应的影响的研究不足，需要从这一角度进行研究。
* Along with the rapid urbanization process, the spatial patterns of land cover have experienced widespread changes in many cities, which are mainly accompanied by the decline of vegetation cover.
* Therefore, the current characteristics of urban climate may change during this process.
* Consequently, current river cooling effect of urban areas and its driving mechanism are supposed to be different from those before urbanization.
* However, earlier investigations on river cooling effect are mostly based on data of a certain year and inter-annual variations of river cooling effect in the context of urbanization have not been well investigated.

### 1.4 研究目的

* Chongqing is a metropolitan city with a population of more than 10 million. Like most Chinese cities, Chongqing has experienced a continuous urbanization process for more than 30 years.
* In this study, we select Chongqing as an example to analyse the inter-annual change of river cooling effect and its influencing factors during the past 20 years.
* The main objectives of this study are:
* (1) to explore the inter-annual change of river cooling effect in the metropolitan area of Chongqing;
* (2) to analyse the key influencing variables of river cooling effect and their temporal variations during the urbanization process of last 20 years.

## 2. Data and Methods

本研究的分析方法如下：首先基于遥感数据计算地表温度，设置500米宽的缓冲区，计算缓冲区内的降温指标。该阈值的设置是基于温度指标与环境因素的相关性得到的。通过将降温指标与环境因素进行相关分析，相关性最高的则为500米。在每1000米河岸长度设置一个缓冲区。然后计算各缓冲区对应的环境因素和降温指标，进行相关分析，流程图如下：

### 2.1. Study area

* Chongqing is located in the upper reach of the Yangtze River in southwest China. The Yangtze River flows through this city, and its major tributary, the Jialing River, converges with it in the urban area.
* The urban area of Chongqing is located in a subtropical monsoon climate zone.
* Summer periods in Chongqing normally last from June to September, which are characterized by high temperature and high humidity. There can be more than 40 heatwave days in a year with maximum air temperature being larger than 35 °C on average, mostly distributed in July and August. The highest air temperature can reach up to 43 °C.
* In the past 20 years, the city of Chongqing has undergone rapid expansion, with the built-up area increasing from 177 km² in 2000 to 670 km² in 2020, and the urban population growing from 5.4 million in 2000 to 10.3 million in 2020.

### 2.2. Data

* In order to analyse the river cooling effect, satellite images from Landsat-5 TM and Landsat-8 OLI/TIRS surface reflectance products are utilized to calculate land surface temperature in Chongqing. These data are obtained from United States Geological Survey (http://earthexplorer.usgs.gov).
* During the study period of 2000 - 2021, one cloud-free image with a spatial resolution of 30 meters is selected for each year.
* It's worth noting that summer in 2012 is not covered by Landsat 5 and 8 data sets and no satisfactory cloud-free data is available in 2018. Therefore, the years of 2012 and 2018 are excluded in the following analysis.
* The corresponding dates for the selected images of individual years are shown in Table XXX.
* In addition, near-infrared and shortwave infrared 1 bands of Landsat images are employed to extract water bodies. Red and near-infrared bands are used to calculate Normalized Difference Vegetation Index (NDVI) of the study area.
* Shuttle Radar Topography Mission 3.0 (SRTM-V3) product with the spatial resolution of 30 meters serves as a tool for terrain analysis of the riverside area. It can be downloaded from USGS Earth Explorer.
* Land cover data are sourced from the CLCD 2021 land cover dataset of China with a spatial resolution of 30 meters and temporal resolution of one year (Yang et al., 2021).
* This dataset is computed from Landsat data based on the Google Earth Engine platform.
* It covers the spatial distribution of land cover in China from 1985 to 2021, categorizing land cover types into nine classes.
* Currently, this dataset has been applied in various research areas, such as ecosystem service and land use change analysis (Deng et al., 2023; Liu et al., 2023).

### 2.3. Land surface temperature

### 2.4. Indexes of water cooling effect

* In order to accurately quantify the cooling effect of rivers, we firstly divide the riverbanks at the interval of 1 kilometer.
* As a result, a total of 185 riverbank segments are generated along the Yangtze and Jialing Rivers, with 40 segments on the south bank, 50 on the north bank of the Yangtze River, and 50 segments on the south bank, 45 on the north bank of Jialing River.
* For each riverbank segment, 25 annular buffer zones are established from the riverbank to the inland area, spaced at 20-meter intervals. The average surface temperature within each buffer zone is then calculated for the following analysis of river cooling effect.
* As a cooling source, a river has a cooling effect on the surrounding area, and this effect is tightly related to the distance from the riverbank.
* Specifically, the temperature gradually rises with increasing distance from the riverbank until a certain point where the trend of temperature rise stops, as shown in Figure 1.
* In this study, it is defined as the turning point. The non-linear temperature curve between riverbank and the turning point is employed to calculate relevant indexes of river cooling effect.
* River Cooling Distance (RCD) is defined as the distance between riverbank and the turning point, while River Cooling Intensity (RCI) is defined as the corresponding temperature contrast between both sides, as shown in the following equation:
* (1)
* where Ttp is the surface temperature at the turning point, while Trb is the temperature at the corresponding riverbank.
* Besides, the index of Cumulative River Cooing Intensity (CRCI) is defined as the accumulated cooling from riverbank to the turning point. This index is investigated here to analyse the overall cooling effect within the riverside area. The equation is given by:
* (2)
* where *Ti* is the averaged temperature of the *i*th buffer zone from the riverbank and n is the total number of buffer zones along non-linear temperature curve.

### 2.5. Calculation of impact factors

* The potential influencing factors of river cooling effect can be classified into 3 types: geographical location, topography, and spatial pattern.
* Variables of geographical location consist of latitude, longitude and the angle between riverbank and the prevailing wind direction in summer. It’s worth noting that the direction of riverbank for each segment is calculated based on the central point.
* Topography is considered as the urban area is marked by moderate fluctuations in elevation. The selected topography variables in this study consist of averaged slope, averaged elevation and standard error of elevation.
* The effects of indexes related to spatial patterns on urban thermal environment have been widely reported (Estoque et al., 2017; Shen et al., 2022).
* Here we propose to select indicators those are closely related to urban climate and are capable of reflecting typical morphological characteristics of individual segments.
* Specifically, Normalized Difference Vegetation Index (NDVI), Mean Shannon’s diversity index (SHDI), percentage of green space (PLAND\_GS), percentage of impervious surface (PLAND\_IS), mean aggregation index of green space (AI\_GS) and mean aggregation index of impervious surface (AI\_IS) are chosen.
* Mean aggregation index represents the degree of agglomeration for particular patch types.
  + 【参考Quantifying spatial morphology and connectivity of urban heat islands in a megacity: A radius approach】
* Among these variables, landscape indexes are calculated based on land use data using ‘landscapemetrics’ package in the R language.

### 2.6. Statistical analysis

首先计算河流特征描述符，绘制了散点图以检查它们与 RCI 和 RCD 的关系。对于空间格局变量和位置变量，我们进行了 Pearson 相关分析以检验它们与 RCI 和 RCD 的线性关系。然后建立了两个逐步[多元回归](https://www.sciencedirect.com/topics/social-sciences/multivariate-regression" \o "从 ScienceDirect 的 AI 生成的主题页面了解有关多元回归的更多信息)模型，分别以RCI和RCD为因变量，探讨变量对RCE的相对贡献。

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