INTERNATIONAL JOURNAL OF
INNOVATIVE RESEARCH AND KNOWLEDGE
ISSN-2213-1356 www.ijirk.com

The Influence of Urban Rivers on Heat Island Phenomenon

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Abstract
The objective of this study was to analyze and to assess the influence of urban rivers that can affect the temperature reducing in a particular area of the city. Approach methodology was by reviewing previous research results, concerning the effectiveness that urban rivers may have in reducing the UHI effect and also the role that the urban landscape on the banks of a river can play in decreasing potential cooling. The results indicated that the presence of urban landscape on the banks of a river influential in moving the cooling influence from the urban river toward the city.

Keywords: *urban heat island, urban rivers impacts, heat mitigation*

Introduction

The UHI, here defined as the air temperature difference between a rural grass field and the urban canopy layer temperature [1], is mainly caused by a different energy balance in cities compared to rural areas. The rapid urbanization has turned the cities into densely populated urban areas with less greenery and more impervious surfaces. Loss of vegetation increases the heat storage in the ground layer and building fabrics and contributes to the higher level of air and surface temperature in urban areas compared to their rural surrounding areas [2]. The occurrence of UHI phenomenon has resulted undesirable effects to the urban climate and degrade the living quality [3,4,5,6]

A phenomenon of UHI that urban temperatures are higher than those in the rural surroundings, is of increasing concern to urban planners, scientists and the public due to its negative impacts on urban life, such as increasing air pollution [7] and urban heat waves [8]. Thus, how to mitigate the UHI effects has become one of the focuses of urban planning and sustainable development. Urban parks which mainly composed of vegetation and water bodies can effectively mitigate UHI effects [9,10,11], by making the park interiors cooler as well as extending their cooling effects to the surrounding areas.

In tropical region, the rapid growth of urbanisation and socio-economic activities has modified its urban climate. This is due to the anthropogenic factors resulting from many physical and social urban activities. Further, the natural climatic condition of hot-humid tropics experiencing hot weather, high humidity and low wind velocity often leads to thermal discomfort in outdoor environment [12]. Urban landscapes comprises of various characteristics that give impact to the urban atmosphere. The configuration of urban fabrics, natural and man-made surfaces, urban geometry, street layout, architectural complexity, urban materials and human activities characterised the urban landscape morphology. This characteristic severely impacted many environmental catastrophes especially to the local climate. As a result, the composition of urban atmosphere such as microclimate parameters has changed with space and time due to the urban development [13].

Within the hot-humid climate is on the contrary. As a region that experienced warm and humid climate all year round with various climatic variability, plus the influence of urban design factors; the daytime UHI always exacerbates outdoor thermal discomfort for hot-humid climate. Few tropical studies have shown that generally daytime UHI is more pronounced than nocturnal UHI [14,15]. This is because, due to high solar absorption in daytime with combination of urban thermo physical characteristics [15], building structures and urban impervious surfaces tend to store heat [4] where it has increased the urban temperature. However, despite the thermal discomfort cause by heat island effects, the natural landscape of hot-humid tropics that surrounded by the abundance of tropical rainforest should be utilised to offer shading and evaporative cooling towards providing thermal advantage [3].

Mitigation strategies to reduce the effects of urban heat through proper planning of landscape design and utilisation of natural vegetation have received growing interest among both researchers and tropical urban landscape designers recently. Due to its ability to improve urban temperature without earning higher cost [16] in design implementation despite any other non-economical mitigating measures, the utilisation of natural vegetation can play a role as passive elements in design [17]. By way of the interplay of design creativity and scientific knowledge of natural elements, landscape approaches potentially act as a soft technology in balancing the equilibrium of urban thermal environment. In addition, the modification of urban temperature by landscape design approach can be implemented from the regional to the local or micro scale [18], thus, make it the most comprehensive mitigating approach to reduce heat island effects. According to [19], in general, climatic factors that affect outdoor thermal comfort are (1) surface and air temperature; (2) relative humidity; (3) solar radiation; and (4) wind velocity. Therefore, the interaction of these climatic elements and its relation with local climate should be fully understood in order to define appropriate approach in improving urban thermal environment. Previous studies in temperate countries have shown that there is significant climate modification through design recommendations [18].

In particular to hot-humid climatic zones, many researchers [3,5,12,17agreed that solar shading is the most crucial requirement to be incorporated in to design. Hence, the aim to minimise heat gain and cover urban surface as much as possible through solar shading should be the first priority in the urban landscape design of tropical climate. Another requirement is modification of urban ventilation by promoting wind velocity and to directing it to the necessary area [5]. As humid tropics experienced light winds, the landscape approach should consider proper designs that allow optimum ventilation [5,12]. Selection of appropriate plant materials and planting configuration based on plant morphological characteristics should be taken into account in the design phase [20].

Small urban rivers have affected in reducing the UHI effect and also examines the role that the urban form on the banks of a river can play in propagating or reducing this potential cooling. The level of cooling is related to the ambient air temperature, increasing at higher temperatures. There are dependencies and relationships linked to the river water temperature, incident solar radiation, wind speed and relative humidity. A mean level of daytime cooling of over 1.5 °C was found above the river in spring, but this was reduced in summer when the river water temperature was warmer. The urban form on the river bank influenced the levels of cooling felt away from the river bank [21].

The condition of shading and cooling via evapotranspiration from vegetation, green spaces will also usually improve the surface porosity, thereby increasing the available capacity for water storage and so water availability for evaporative cooling. The reintroduction of water through the deliberate incorporation of porous surfaces, e.g. porous paving, or the presence of water bodies, such as ponds or rivers, has the potential to reduce the UHI by returning the surface moisture availability to values similar to rural areas. The process of evaporation has been studied, and resulting cooling for various cities demonstrated with models validated for a range of locations [22]. However, there is limited published research on the microclimate effects in the immediate locality of river corridors, with current published data limited to tropical climates. The process of daylighting a large stretch of watercourse in Seoul, Korea, provided the opportunity of a before and after study demonstrating cooling of the urban microclimate [23]. Another study in Nanjing, China [23] of the urban climate highlighted the cooling effects in the locality of a lake, river and sea.). And this matter has provided the core question for the current study: what is the cooling role of urban river in the microclimates around them?

Material and Methods

This study is a review of previous research, by reviewing some research on the roles of evapotranspiration of the urban river in alleviating the UHI effect, which is based on the results of the mentioned investigation and also from the previous published works. These kinds of results can offer helpful to urban landscape in the river bank corridor planning and design for the most effective cooling by an urban river.

Result and Discussion

Table 1: Summary of studies related to cooling effects of urban rivers

No.	Publication year	Autor	Aim to Research	Method	Objek	Iklim	Scale	Result
1.	1990	Saburo Murakawa, Takeshi Sekine And Ken-Ichi Narita [24]	The influences of a river on the micro-climate in an urban area from the results of observations about the distributions Of temperature at sections of the rivers and at the horizontal and vertical spaces around the rivers.	On-site easurement of temperature distribution within horizontal and vertical extent of a thermal river effect	Ota River flowing through Hiroshima City	Subtropical continental humid	Micro	The drop in air temperature above the river exceeds 5 °C on sunny days in warmer seasons, and is proportional to the surface temperature difference between the river water and the asphalt pavement. These thermal effects were discernible at least a few hundreds meters horizontally and more than 80m vertically. However, temperatures were also affected by the building density and wind direction and velocity.
2.	2008	Y.-H. Kim, S.-B. Ryoo, J.-J. Baik [23]	The restored-stream effects on urban thermal environment Cheonggye stream in Seoul, Korea.	On-site Measurement,	Cheonggye river	Subtropical continental humid	Meso	After the stream restoration, the near-surface temperature averaged over the stream area dropped by 0.4°C, with the largest local temperature drop being 0.9°C.
3.	2009	Hirofumi Sugawara, Ken-ichi Narita, Min Sik Kim [25]	Climatic influence of urban river for its better understanding and more efficient measure.	On-site Measurement	Kanda river, Tokyo	Subtropical continental humid	Micro	There are two kinds of cooling mechanism in urban river; cool water surface and wind path. The later wind path mechanism activates the vertical ventilation and introduces the cool sea breeze into the city area. The wind path effect is more efficient than that of the cool water for the air temperature at the river side area..
4.	2010	Jingcheng Xu, Qiaoling Wei, Xiangfeng Huang, Xiaoyan Zhu, Guangming Li [26]	Proposed a new equation to predict and evaluate human comfort in littoral zones surrounding urban waterbodies.	On-site Measurement	Huangpu river	Subtropical continental humid	Micro	Due to the temperature reduction and humidity increase effects from the evaporation of surface water, urban waterbodies can improve human comfort in littoral zones in high temperature periods of hot summer days.
5.	2011	Ganbo Han, Hong Chena, Li Yuana, Ying Caia, Mengtao Hana [27]	To investigate into regulation law, micro-climatic conditions of a block alongside the river	On-site Measurement	Yangtze River	Subtropical continental humid	Micro	The air temperature near Yangtze River is 2°C lower and the wind velocity is higher than that inside the urban block. Areas close to Yangtze River bank provide more comfortable environment.

6.	2012	Nyuk Hien Wong, Chun Liang Tan, Andrita Dyah Shinta Nindyani, Steve Kardinal Jusuf,Erna Tan [28]	to find the clear extent of the cooling effect from the waterway horizontally.	On-site Measurement	River in Singapore	Tropic warm humid	Micro	The study found that the air temperature merely reduce by 0.1°C on every 30m away from the waterway. The high humidity climate and the low wind condition might be one of the possible reasons with it.
7.	2012	Ranhao Sun, Liding Chen [29]	To identify the Urban Cool Island intensity (UCI) of water bodies inside sixth ring-road of Beijing; quantify the relationship between the UCI effects Of multiple water design bodies and landscape geometry.	On-site Measurement	River	Subtropical continental semi-humid	Micro	The the UCI intensity per unit area of a water body. that: (1) the mean UCI intensity and efficiency was 0.54 °C/hm and 1.76 °C/hm/ha, respectively; (2) the UCI intensity was positively correlated with WA and PB, and negatively correlated with LSI and DIST; and (3) the UCI efficiency with Water body area (WA), the Land Scape Index (LSI) and water body's distance away from downtown (DIST).
8.	2014	Daewuk Kim, Jae-Gyu Cha, Eung-Ho Jung [30]	the quantitative determination of the changes in thermal environment of surrounding residential areas according to the urban river refurbishment	Reviews of literature and model verification with Envi-met (v 3.1)	River	Subtropical continental humid	Micro	The effect of the temperature decreased by 1.33˚C river refurbishment on the surrounding area, the effect reached to position in 60 meters from the river.
9.	2015	Golnoosh Manteghi [31]	This paper provides a theoretical background for the problem and reviews the related literature.	Review jounal: water fitur			Macro and Micro	The water bodies do not do a priori act in shape of cooling elements in urban areas as it was believed before, specifically overnight time and evenings in the final quarters of summer, when the water on the surface is pretty warm.
10.	2016	Golnoosh Manteghi, Hasanuddin Lamit, Dilshan Remaz, Ardalan Aflaki [32]	The aim of the study presented is to quantitatively investigate the influence of water body and vegetation on temperature distribution in the typical city area.	Simulation programme, Envi-met	Malaca river	Tropic warm humid	Micro	The average temperatures for the 2 scenarios of greenery and water are lower than pavements. For the surrounding area, the closer it is to water of greenery, the lower its temperature. 0.5 °C difference of average temperature was observed at points around greenery and water. This difference was caused by green areas, which ultimately lead to reduction of cooling energy and

								thermal comfort for residents.
11.	2016	Du Hongyu, Song Xuejun, Jiang Hong, Kan Zenghui, Wang, Zhibao, Cai Yongli [33]	Quantify the Range of Water Cooling Island (WCI) effects, temperature and gradient, the factors that impact effects of WCI	Remote sensing	Water bodies inside the outer ring road of Shanghai	Subtropical continental humid	Meso	The geometry, proportion factors (vegetation around water bodies and impervious surface) on the WCI effects of water bodies.
12.	2017	Ashley N. Moyer, Timothy W. Hawkins [34]	To assess the magnitude of the urban heat island (UHI) for a relatively small urban area as well as to assess the impact that a fairly large river flowing through the urban area has on the UHI.	The intensity of the UHI was calculated for every hourly temperature reading for all 19 urban stations using the rural station as a reference.	Susquehanna River	warm temperate, fully humid, hot summer	Meso	Results indicate an average yearly UHI of 2.25 °C that is strongest at night, in summer, in the most urbanized areas, and closer to the river. For every 1000 m increase in distance from the river, the UHI decreased by 0.6 °C to 0.3 °C depending on season.

A lot of researchers proposed that evaporative cooling of surface water is still one of the most effective methods of passive cooling in urban spaces and buildings urban waterbodies can improve human comfort [26, 28]. Enriched evaporation is capable of lowering the air temperature and hence mitigates the process of UHI and arises the inhabitants` thermal comfort. Arisen evaporation may be reached via increasing the vegetation or the surface water`s amount.

A large number of studies have analysed the influences of the open water bodies/ water features or rivers) on the urban regions climate [26, 29]. The studies declare that temperatures closed to and downwind from urban river are getting reduced about 1-2 °C in comparison to surrounding areas, with the highest amount of temperature reduction observed through the day [27,30].

The large water bodies, such as oceans and large lakes, have the ability to affect land temperatures. However, research is regarding how smaller water bodies, especially rivers, can affect the microclimate of the surrounding urban areas [21]. In Japan, cooling from the Ota River was noted to occur close to 300 m away from the 270 m wide river [24]. On a smaller scale, cooling from a 22 m wide river in Sheffield, UK was recorded up to 30 m from the river banks [21]. Hongyu et al. (2016), found the cooling of water bodies can vary depending on their geometry, with lakes demonstrating larger cooling effects than rivers[33]. Further research on water bodies shows that they provide increased cooling in downwind areas [34].

Murakawa (1990) suggest that the water body of the river operates as the cooling source in summer on the micro climate of the surrounding area. The comparation the air temperature between the river and the city area, the temperature of the air around the 270 m wide river were about 3-5 C cooler (between 12-5 pm) than the surrounding region on a sunny day because the surface temperature of a paved road with asphalt rises very high as it absorbs solar radiation. However, temperatures were also affected by the building density and wind direction and velocity. Concerning the effects of the river as a cooling source, cooler temperatures are more widely spread when the density of buildings is lower and both streets and rivers are wider[24].

The restored-stream effects on urban thermal environment could contribute to the scientific basis of urban planning which aims to make a large city comfortable to live in and nature and environment-friendly. the restored stream affects local thermal environment, including temperature mitigation and changes in sensible heat flux. It is estimated that after the stream restoration the near-surface temperature averaged over the stream area dropped by 0.4°C, with the largest local temperature drop being 0.9°C [33].

Manteghi (2015) suggest that water bodies have also been proven to be influential methods of decreasing urban temperatures. A water body temperature is capable of being lower than the surrounding urban environment around 2-6°C. According to these findings; one may conclude that the rise of evapotranspiration in cities, that has roots in vegetation and water body, can efficiently mitigate the influence of the urban heat island [32]. Greenery and water surface temperature are lower than pavements. For the surrounding area, the closer it is to water of greenery, the lower its temperature. 0.5 °C difference of average temperature was observed at points around greenery and water. This difference was caused by green areas, which ultimately lead to reduction of cooling energy and thermal comfort for residents around water bodies.

In a number of cities, water is an indispensable part of daily life; like the cities next to riverside. As an example Xu et al. 2010 applied observations to assess the effect that a water body has on thermal comfort, for all the hot days that have temperatures over 35 °C. their results show that these water bodies hugely cool their littoral zones [26].

This is in line on the findings from the research of Sun and Chen (2012), in the study which focused on the impact of the geometry of the water body [29]. With implementation of large-eddy simulation that study concluded that a number of smaller normally shaped bodies of water have the highest beneficial impact when it comes to the matter of lowering extreme temperature over the course of the day [35]

It is also quite clear that the design for the surrounding urban landscape is vital in maximizing the downwind cooling effect [34]. The cooling impact of the urban water body depends on the way radiant energy is separated into heat fluxes[29]. The direction and speed of wind are vital in spreading the cooling impact of urban water bodies. Wind conditions can make various patterns for temperature distribution, so can urban morphology [23]. The wind is moving the above the water body to the surroundings and makes a plume of warmer or colder air downwind in city and inside rural areas. Urban streets which run downwind or a public square that is located next to a water body space acquires better thermal situations than obstructive streets [21, 27, 35].

Various wind speeds may result in various results. Another method of influencing the wind over the city is to enrich the terrain roughness, e.g., higher buildings result in higher roughness length and decrease the wind rate over the city. Hence, different urban features will have specific self-related impacts. Some of the studies did not focus on the spreading of cooling impact from water due to the surface character or wind field [35]. Hathway and Sharples (2012) emphasized the vitality of open spaces close to water body sites for the distribution of the temperature in comparison to obstructive or enclosed streets [21].

Murakawa et al (1991) suggested that the horizontal impact of the water body on the microclimate is depending on density of buildings and rivers and street's width. Murakawa et al (1991) understood that over streets that are around 100 meters wide and face a river, horizontal cooling moves up to 400 m in. Over the course of narrower streets (around 10 m wide) which had heavy traffic on them, the horizontal cooling could not move further from 50-150 m [24].

The water body size and water distribution over the city has its role. Quietly huge water bodies also seem to acquire a relatively powerful cooling impact on the surroundings. This is in line on the findings from the research of Sun and Chen (2012), in the study which focused on the impact of the geometry of the water body. With implementation of large-eddy simulation that study concluded that a number of smaller normally shaped bodies of water have the highest beneficial impact when it comes to the matter of lowering extreme temperature over the course of the day [35].

Kim et al. (2008) in Seoul, South Korea, had done a similar research in which a channelled stream was going to be restored inside the central district. In this case, the UHI was normally pretty intensive. Over the case of the study temperatures got measured before, during and after the act of stream restoration over three years during August in comparison to one urban reference site. The distribution of calculated effect measurements in the central district prior and after restoration can lead to a quantitative impact size. After the act of restoration, the urban district was averagely around 0.6 ºC – 1 ºC cooler in comparison to the urban area around 200 m distant [23].

Furthermore, large studies tend to focus on the impacts of river and consider the heat transfer processes into urban environment; they do not focus on the effect of specific urban landscape in the river corridor and the propagation of cooling from the river into the urban environment. Therefore, there is a need to assess the microclimate effects of urban rivers in Hot Humid regions in order to evaluate their effectiveness in contributing to resilience to heat waves and how the urban landscape affects this.

Strategies of urban geometry design in the urban areas can promote the cooling impacts from urban river. By reviewing various other studies inside microclimate and urban design and the role that urban rivers have inside cities, it is quite clear that a lot of studiers focus on water bodies in the parks, squares or gardens and few studies that focused on the influence of the urban landscape in the river corridor and urban geometry, considering high of the buildings and width of the streets to work on the cooling effects from the river down to the patterns of the streets inside inner parts of the patterns that streets have. There are a number of researches that studied the impact of the effects of vegetation alongside river, street geometries and building or other related variables in the urban landscape in the river corridor, but there is still a gap between street geometries, vegetations, buildings and river.

Conclusion

This review concentrated on studies working on the climate mitigation influences of urban rivers. In summer, different kinds of urban rivers have the capacity to cool the ambient temperature for the air. The horizontal impact of urban river on the microclimate is depending on density of buildings, rivers and street's width. The design for the surrounding urban landscape in the river corridor is vital in maximizing the downwind cooling effect. The cooling impact of the urban river depends on the way radiant energy is separated into heat fluxes. The direction and speed of wind are vital in spreading the cooling impact of urban rivers. Wind conditions can make various patterns for temperature distribution, the wind is moving the above the urban river to the surroundings and makes a plume of warmer or colder air downwind in city areas. Urban streets and buildings which run downwind or a public square that is located next to a urban river space acquires better thermal situations to spreading the cooling impact in the city. Therefore, in order to maximise the benefits of this cooling close consideration of the urban landscape design is required. Highly vegetated banks showed much lower temperatures by evapotranspiration and shading than those banks consisting of only hard engineering materials. The nature of this surrounding material can have a greater impact on air temperatures than the presence of the river alone. Opening up the streets to the river or the provision of a square gave greater cooling from the bank than streets shut off from the river. The other microclimate factors, such as material albedo and shading, may have been an influence. Therefore, further work into these aspects is required to provide detailed design guidance to gain the most effective cooling from an urban river.

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