The Data Collection and Monitoring Plan of Effect of Urban Heat Island on St George Rainway

EVSC 400 Environmental Science Capstone

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Instructor: Dr. Tara Holland

Present to:

Julie McManus, City of Vancouver Green Infrastructure Implementation,

Kelly Gardner, CityStudio

Presented by

Cheney Yang

Daixue Guo

Junyan Wang

Zhouzeng Jiang

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Executive Summary

Background

To become a water-sensitive city to meet Vancouver's challenges has never been more urgent. Strong economic, environmental and social imperatives are driving change. The Raincity strategy is a step in this transition, building on the actions and leadership around the green rainwater infrastructure over the past two decades. To achieve the Raincity strategy, the project group planned to construct Green Rainwater Infrastructure (GRI), highlighting an important opportunity to improve urban water management and improve the entire region through common interests. For coastal cities like Vancouver, proper management of freshwater resources and solving flood prevention problems are top priorities.

There are GRI implementations on St. George Rainway. The study site of the St. George Rainway is located in St. George from Kingsway to the False Creek Flats (Fig. 1 and Fig. 2). The goal of our group is to collect, monitor and analyze data of Urban Heat Island (UHI) effect on St. George Rainway. Based on our data planning, we hope we can help the project group decide the future GRI implementation and test whether the GRI implementation on St. George Rainway should be kept, fixed or improved.

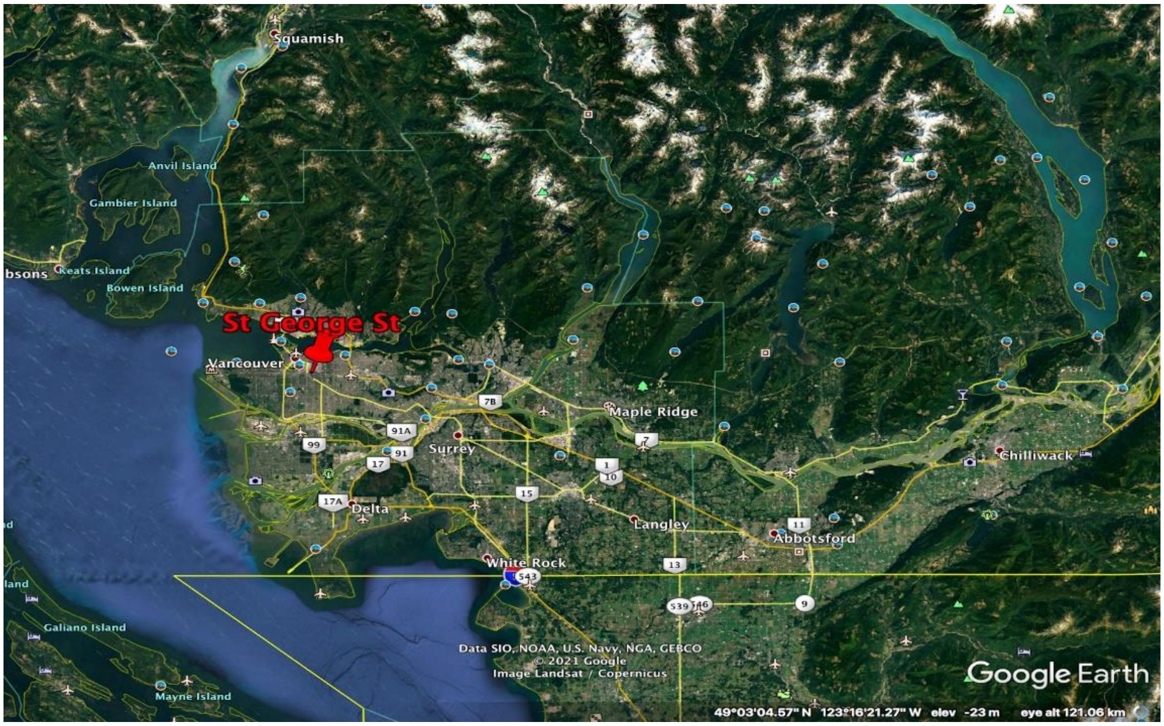


Figure 1: The map of site relative to Vancouver

Figure 2: The map of the project site ----St. George Rainway

Objectives

1. Build a monitoring plan for the GRI's efficiency to the UHI effect from 4 aspects: 1) Building heat; 2) Human health; 3) Plant's evapotranspiration; 4) Land surface temperature.

2. Provide a suggestion of data collection site.

Overall, this report provides a monitoring plan for the GRI's efficiency to the UHI effect within the St. George Street communities. By reading the article, doing the literature review, and simulating the previous research, we suggested it can study the GRI's impact on UHI from 4 aspects: building heat, human health, plant's evapotranspiration, and land surface temperature, based on their relative importance to the UHI effect. Our approach includes some factors that have significant influences on UHI and provides a suggestive monitoring plan for detecting how the local UHI will be affected after St. George Rainway's implementation.

Summary of Literature Review

Regarding human health, the research integrates tree canopy cover, urban surface temperatures, and population demographics as spatial measures to find a relationship between potential risks of heat exposure to humans and UHI (Venter et al., 2020). While another study focuses on how environmental characteristics such as thermal design, vegetation volume, and coverage are critical in affecting thermal discomfort, heat loads, physical and mental health problems (Baldwin et al., 2020). Heat data can be monitored by calculating average building height, density, and street width and establishing the building's albedo through satellite images (Touchaei & Wang, 2015). Evapotranspiration data can be collected based on a long-term scale of trees-monitoring plan to calculate how evapotranspiration will influence the surrounding temperature Zhou et al.'s (2014). Lastly, research suggests using a Landsat-8 thermal infrared band and the combination of at-sensor radiance, brightness temperature and the black body target temperature radiation to analyze land surface temperature (Wu & Zhang, 2019).

Overview of Data Collection, Analysis, and Monitoring Plan

Due to the global pandemic, field trips and data collection in the field have become difficult. This report will only provide a data collection and monitoring plan for the GRI's efficiency in reducing the UHI effect on St. George Rainway. Based on our acknowledgment and studies that have been successfully conducted in other cities, our monitoring plan suggests 4 main kinds of data need to be collected: *a.* collecting human heat data regarding heat-sensitive physiological illnesses and subjective mental sensation associated with the UHI effect; *b.* building data-based heat structure of a building (height, density, etc.) and its material through satellite images; *c.* building plants' evapotranspiration function through long-term monitoring of trees to mitigate UHI; and *d.* using thermal infrared remote sensing technology to analyze land surface data, which potentially affected by the water body and surrounding land cover. Combining all these aspects will provide a comprehensive study and monitoring plan for the GRI's efficiency to the UHI effect.

Our plan is multifaceted and covers the urban planning part (Building heat), human wellbeing (Human illness report), plant diversity (evaporation), and water condition (land surface temperature). Combining these aspects can provide a comprehensive study and monitoring plan for the GRI's efficiency to the UHI effect.

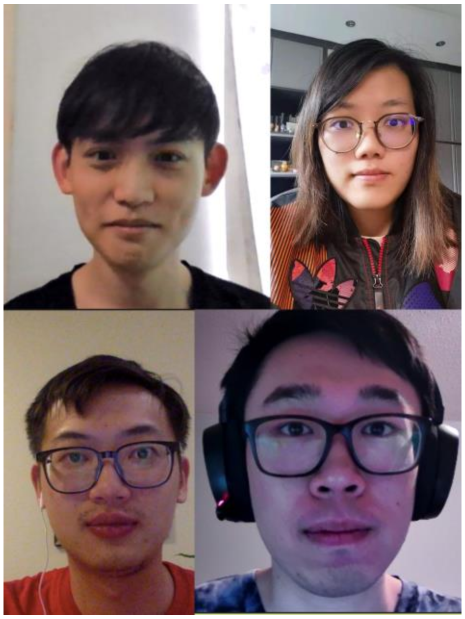
Report Authors

Cheney Yang a fourth-year environmental science student from applied biology concentration. The field he is studying includes environmental risk assessment regarding species and human health, taxonomy, and physiology, especially for the vertebrate. He enjoys volunteer work to see how others look at the world and enriches himself with practical skills. He focuses on the interaction between the environment and living organisms and brings these thoughts to the project.

Daixue Guo is a fourth-year environmental science student from water science concentration. Her background includes watershed ecology, river geomorphology as well as experience of field research. She is an only girl in this group, so she takes responsibility for details. She is good at Google earth, she made site maps. She always provided suggestions about the logical flow of this report.

Junyan Wang is a fourth-year year environmental science student from the environment earth system concentration. He can provide the information about how the Urban Heat Island effects will influence the surrounding areas and build the monitoring plan for the building heat and plants' evapotranspiration part. Also, as the team leader, he communicates with the client and instructor for the future advice and shares with the group members.

Zhouzeng Jiang is a fourth-year environmental science student from earth-system concentration. His background in physical geology, biology and outdoor experience provide the team with some new perspectives on spatial analysis.



Cheney Yang	Daixue Guo
Zhouzeng Jiang	Junyan wang

1. Introduction

This report aims to help the green rainwater infrastructure (GRI) project group collect and monitor data of the effect of urban heat island (UHI) in St. George Rainway. After analyzing these data, we hope the results can help the GRI project group decide the future direction of GRI implementation, whether the current GRI implementation needs to be fixed and improved, or it is so sufficient and efficient that the GRI project group can just keep it. We will report the collecting and monitoring data planning from the following aspects. Firstly, we will give a literature review about how to collect and monitor UHI data and how other green rainwater infrastructure projects collect and monitor data. Secondly, we will do a data Collection, Analysis, and Monitoring Plan of the effect of UHI in our project site, St. George Rainway. Thirdly, we plan to collect, monitor and analyze the data of the effect of UHI from mainly four aspects, including human health, building heat, plant's evapotranspiration and land surface temperature. Fourthly, we will find and list the limitations of our plan from the four aspects. Last but not least, we will suggest how the GRI project group presents data collection and monitoring in St. George Rainway based on our report.

2. Literature Review

2.1. Introduction

Green Rainwater Infrastructure (GRI) is 'a multi-functional Internet supporting ecological and social activities and processes, most of which have not been built', which includes trees, private and public gardens, parks, riparian zones along urban drainage lines, undeveloped ridges, and various urban agricultural spaces, such as food and community-based gardens (Schäffler & Swilling, 2013). U. S. Environmental Protection Agency (2008) points out with the development of urban areas, the landscape has changed, which means buildings, roads and other infrastructure have replaced open land and vegetation. Surfaces that used to be permeable and moist often become impermeable and dry (U. S. Environmental Protection Agency 2008). This development leads to the formation of UHI, which is a phenomenon in which urban areas have higher atmospheric or surface temperatures than their rural surroundings (Zhou et al., 2014; U.S. Environmental Protection Agency, 2008). Not only can UHI change ecosystems such as net primary production, biodiversity, water, air quality, and climate, but it can also affect human health and wellbeing, such as the increased risk of morbidity, mortality, and violence (Zhou et al., 2014). In order to decrease UHI, Zhou et al. (2014) and U. S. Environmental Protection Agency (2008) claim the urban areas need to recover vegetation, increase the natural cooling effect from shade and evapotranspiration, find appropriate urban building materials which have low ability to absorb solar energy, build some green infrastructures and so on. UHI effect can be a parameter to test the efficiency and sufficiency of GRI Implementation. This literature review aims to find some methodologies that help collect and monitor data of UHI effects. The literature review collects and monitors UHI data from 4 aspects, including human health, building heat, evapotranspiration, and land surface temperature.

2.2. Method

2.2.1. Human Health Data

Tan et al.'s (2010) research studied how UHI will affect human health in Shanghai. They used the temperature data and combined them with the death recordings provided by the Shanghai government. They found out that the human mortality rate is higher in the central city area than the suburban area when there is an increasing temperature situation by the UHI. Another study was done in Oslo, Norway, integrating tree canopy cover, urban surface temperatures, and population demographics as spatial measures to analyze potential risks of heat exposure to humans (Venter et al., 2020). The researchers indicated a relationship that each tree in the city would mitigate a heat-sensitive person getting potential risks of heat exposure by one day (Venter et al., 2020). A similar ratio can be calculated based on this, regarding coverage of trees, drop in temperature, and morbidity rates from target groups. To be specific, heart attacks, asthma, skin, and subcutaneous tissue disorders are highly connected to extreme heat stress (Venter et al., 2020).

Similarly, indirect factors are affecting human health as well. Saelens and Handy argued that a friendly green infrastructure should fully consider walking and cycling areas, density, connectivity of a street, neighborhood safety, and satisfaction, known as the Neighborhood Environment Walkability Scale (NEWS) (2008). For instance, people who move with difficulty or have a disability would result in below-average walking speed, theoretically exposing more heat (Baldwin et al., 2020). Despite reducing UHI, built environment characteristics such as thermal design, vegetation volume, and coverage are critical in affecting thermal discomfort and heat loads, and physical and mental health by increased physical activity and less stress and social cohesion (Baldwin et al., 2020).

Another way of evaluating GRI regarding human health is total plant evapotranspiration (ET), which has been shown as a key mechanism to mitigate UHI (Marasco et al., 2014). Increasing vegetation in a form of parks and trees in urban areas plays a role in lowering urban temperatures through evaporation (Marasco et al., 2014). Theoretically, ET will consume part of energy from urban heat storage and the atmospheric sensible heat fluxes to mitigate heat stress (Marasco et al., 2014).

2.2.2. Building Heat Data

There is an example of collecting and monitoring UHI data by four steps in Montreal, Canada (Touchaei & Wang, 2015). Firstly, they collected the satellite images from the Montreal government to calculate the average building height, building density, and street width. Secondly, they collected data about the building material to find the building's albedo and find the building heat system's resources. Then they used the Building Energy Model (BEM) to estimate the heat released by the building. Thirdly, they collected the climate report and prediction data from the Montreal government. Lastly, they used the satellite images of the building's distribution to calculate the Sky View Factor (SVF), since SVF is essential in calculating the canopy's energy balance. After doing four steps, they combined all the data they collected and could get a current UHI effect situation. Touchaei & Wang's (2015) method can be used to find out the UHI data before the GRI's implementation using the previous satellite images to find out the building's distribution. Then comparing the climate report with the data calculated by the BEM and SVF can find out how the UHI will affect temperature before the implementation of GRI. However, this method has some limitations. This method only studies how the surrounding buildings can cause UHI. They only concern about the heat flux that the building materials and the clouds can transport. Since GRI contains lots of plants that can reduce the UHI effect, the original plant data before and after the GRI implementation should be considered.

2.2.3. Evapotranspiration Data

In Saaroni et al.'s (2018) and Zhou et al.'s (2014) research, they all analyzed how the UHI can be affected by the green plant's evapotranspiration rate. In Zhou et al.'s (2014) research, they collected data of trees in 32 major cities in China in different seasons. They tried to understand how the temperature will be influenced by the UHI and reduced by the trees. However, Zhou et al.'s (2014) research area is a country which is a relatively larger site than some specific sites. Comparing the data between the plants and temperature, the larger study area's data cannot show the relationship precisely than the small study area. There is another study which has a smaller study site done by Saaroni et al (2018). They scaled their study area by 1 to 10 km. Then they collected the temperature data in short (two weeks per time), medium (one season per time), and long (one year per time) term to find out how the plant's evapotranspiration will influence the surrounding temperature. The time scale is essential for the data collection, since the temperature decreases due to the GRI implementation in the short term, which cannot represent the GRI's efficiency in reducing the UHI effect.

2.2.4. Land Surface Temperature (LST) Data

Waterbody has a cooling effect on LST as an ecosystem service, Wu and Zhang (2019) introduced, which is a notable method to reduce the UHI in the city. The study area includes Suzhou Bay and the two districts on both sides of the bank. The overall area is 72.11 km^2, of which the entire open water area accounts for 32.34% (Wu & Zhang, 2019). In order to study the water's cooling effect on land surface temperature (LST), the Landsat-8 images without cloud cover are a common choice because thermal infrared remote sensing technology can produce fast and efficient visual spatial patterns. (Wu & Zhang, 2019; Cai et al., 2018). The U.S. Geological Survey (USGS) provides the Landsat-8 thermal infrared band to produce the LST map, and the combination of at-sensor radiance, brightness temperature and the radiation of black body target temperature provides the successful temperature data in the satellite (Wu & Zhang, 2019).Their result indicates that the water body's farther away from the water body has a weaken cooling effect on LST (Wu & Zhang, 2019).

Also, the land surface cover characteristics are important factors to create a final LST image and affecting the water's cooling effect, it includes the normalized difference vegetation index (NDVI), building density (BD) and sky view factor (SVF) (Touchaei, 2015; Cat et al., 2018). LST map can provide an intuitive display to see the temperature changes in this area. Besides, the grid method is also suggested to collect the LST data (Wu & Zhang, 2019). Wu's team (2019) created 1236 polygon grids with a size of 200m to analyze the impact of water cooling effect on the correlation between urban form factors and LST. The finding is that LST will decrease as the NDVI, SVF increase.

Moreover, by Allhaier, Flerchinger & Su(2012), the surface temperature is a state variable, which is continuously adjusted to adapt to changes in hydraulic and meteorological forcing in a way that always maintains an energy balance (Equation 1): Rn = LE + H + G, where Rn is net radiation (W*m^-2), LE is latent heat used for evaporation(W*m^-2), H is the heat exchange between surface and air(W*m^-2)) and G represent the ground heat flux(W*m^-2). Allhaier et al. (2012) also found that less energy can be used to heat the land surface if the evaporation process used more energy.

2.3. Conclusion and Discussion

In this literature review, we found three methodologies to collect and monitor UHI effects. The first method is to collect data on human health from direct ways and indirect ways. For direct ways, human health has a relationship with temperature change, including death rate, heart attacks, asthma, skin, subcutaneous tissue disorders and other potential risks. Indirectly, a friendly green infrastructure should fully consider walking and cycling areas, density, connectivity of a street, neighborhood safety, and satisfaction. Under the UHI effect, these indicators would change. It is a difficult, complex, time-consuming method to collect all the data. It can be a long-term method to monitor UHI effects. The second method is to analyze how the UHI can be affected by the green plant's evapotranspiration rate. Based on Saaroni et al. (2018) and Zhou et al. 's (2014) research, this method is good for small area analysis. The last method is to test a water body with a cooling effect on LST as an ecosystem service. Water cooling effects significantly impact the relationship between LST and land cover, such as building height, SVF. By analyzing the previous surface temperature data, and current LST, the GRI efficiency on reducing UHI effect can be monitored. We chose these three methods because they are from different aspects to collect and monitor UHI effect, including human, ecosystem and physical properties of urban material. Through these three aspects, we can monitor UHI effects in multi-directions.

3. Data Collection, Analysis, and Monitoring Plan

3.1. Method 1: Collecting the Building Heat Data

For collecting the temperature and UHI effect data before the GRI implementation, we can use four steps to analyze and get the data about the UHI effect before GRI has been installed. Firstly, using the satellite images and field trips to get the building height, building size, street width, then calculating the plan area density and frontal area density. Secondly, researching the data about the building energy model for St George Rainway, for example, the building material's reflection rate and consuming fossil fuel by heat providing. Thirdly, using the data from the climate report and climate prediction in the city of Vancouver. Lastly, getting the building distribution data from the satellite image and google map, because we need to know the correct Sky View Factor (SVF) which requires the city planning strategy. Then we combine all the data and information we get from the previous steps. We can find a relationship between the temperature from the real climate report and the climate prediction based on temperature from the city energy models, including the plan/frontal area density and SVF. By comparing these two temperatures, we can know the UHI effect's impact on St. George Rainway before the GRI implementation.

After collecting the UHI data before GRI has been installed, we need to collect the data after the GRI has been established for comparison. The simplest approach is field observation to find GRI's cooling effect. The observation area scale for St. George belongs to the regional scale (1-10km). The time scale for the observation can be set as short, medium, and long term. Short-term observation is two weeks per time, medium-term is one season per time, and long-term can be one year per time. The short-term data can be directly compared with each other to study the effect of UHI. The medium and long term-data can be used in the form of graphs to study the long-term impact and efficiency of GRI on UHI.

3.2. Method 2: Collecting the Human Health Data

The UHI effect can affect human health. In the following method, we are planning to set the data collection and monitoring plan about how the UHI will affect human health. In St. George Rainway, the project group can collect temperature data based on previous data and get death recordings from the BC health government, and then find the relationship between the increased temperature caused by UHI and human health. To be specific, related mortality and morbidity from people who are above a certain age (e.g., 75+) can be analyzed through publicly available health statistics including databases from CareConnect or local hospitals. By connecting UHI and local human health, reasonable trends can be developed to better describe efficiency of the study site.

Based on the fact that environment characteristics are critical in affecting thermal discomfort, physical and mental health, a survey of scoring stress levels among local residents to the environment, or general happiness/wellbeing (1 to 10) can be introduced through Simple random sampling (SRS). Stress levels here represent mental aspects of measuring the acceptability of the community. The target population should include both seniors (with a fixed age range and experiencing certain disabilities) within and outside the study site.

3.3. Method 3: Collecting Evapotranspiration Data

For collecting the plant's evapotranspiration data, the most common method is to collect the plant's density and type on St George Rainway. The temperature data should be directly collected at each corresponding evapotranspiration data collection site by using thermometers. The method by Peters et al. (2011) can be used to test the evapotranspiration data. The gas analyzer should be set in our study site to measure the air's water vapor amount. The water vapor amount near the GRI can be seen as the plant's transpiration rate (TT). Since the total plant's evapotranspiration (ET) is the sum of the TT amount and the rainfall interception loss through the plant's canopy (IT). The Rutter canopy interception model can monitor the IT (Rutter et al., 1971). To be specific, water storage in the canopy should be collected every hour since the major source of water storage in the canopy is through precipitation. The canopy water storage losing can be seen as the transpiration of plants. Using the data collected after precipitation minus the data collected before precipitation to get the rainfall loss through the plant's canopy. After all the needed data is collected, add the water vapor amount and the rainfall loss to get the plant's evapotranspiration data.

3.4. Method 4: Collect surface temperature data

By observing from the satellite map, there is no water body exposed under the sunlight, instead, the St George Stream was hidden under the road surface. However, it still sees a pool and a lot of manhole cover on the road, which means that most of the water finally flows to the underground creek surface. It is suggested to collect the LST map from USGS, which provides an overall thermal preview of the entire study area. In addition to testing water quality, it is also necessary to set up surface temperature testing facilities along the St. George Rainway after the introduction of the GRI. The St. George Rainway project mainly focuses on a small area, only including the rainway and its surrounding communities (*The St. George Rainway, n.d.*). Therefore, it is possible to build up some small weather stations and use calibrated/electronic thermometers, pyranometers and hygrometers to test land surface temperature, solar radiation and humidity. At the same time, it is suggested that these weather stations need to be equipped with solar energy and information transmission devices. The benefits include no need for manual measurement, saving time and reducing energy consumption on the road; real-time data transmission to the database, easy to organize and save, suitable for long-term research.

3.5. Setting: Importing the Plan to Study Site

After ensuring what types of data need to be collected, the next step is to import our plan on the St. George Rainway. The Figure 3 below shows the data collection site. Firstly, the blue area represents where the building density, height, and street width data should be collected for a short time, and in the long term, the building density area can be enlarged to study how the building density far away from the St. George Rainway can influence the UHI effects. Secondly, the green pins represent where the plants and total evapotranspiration data should be collected. Thirdly, the yellow pins represent the land surface temperature data that should be collected since all three sites have different surroundings: 1. trees and grassland surround the first site; 2. surrounded by grassland and houses; 3. houses and few trees surround the third site. Lastly, the temperature data can be collected from the previous climate report for the temperature data before the GI implementation. For the current temperature data, people can retrieve it from the Landsat thermal infrared band from the USGS.

Then, using the temperature data as the dependent variable to build the graphs to show how the building density can influence the temperature, how the plant's evaporation rate can influence the temperature and what is the water's potential cooling effect on UHI. Temperature data can also be another dependent variable, and human illness conditions can be another independent variable. Find the relationship between them by graphs. Morever, the LST in three different sites are expected to be different as their different land surface cover, it includes the SVF and NDVI.

Figure 3: The data collection sites selection on St. George Rainway

4. Limitations

1. After collecting the SVF data and finding the relationship between the radiation absorbed by the roof and temperature, it only considers the flux of radiation in the cloud but does not include the GRI. The weathering prediction forecasting cannot predict the correct cloud amount and the radiation flux in the cloud precisely during the cloudy weather, as mentioned in Touchaei & Wang's (2015) research.

2. The data collection for the plant's evapotranspiration rate before the GRI implementation may have some difficulties. Because the GRI has its own evapotranspiration effects to reduce the temperature and UHI effects. Then we cannot collect the evapotranspiration data before the GRI implementation.

3. The growth of plants needs water resources. The water resources consumed by plants can cancel out a part of water vapor produced by plants' transpiration. Therefore, even if one site in our study area has a higher evapotranspiration rate, it does not mean the evapotranspiration rate is actually efficient due to the water consumption during plants' growth.

4. Water bodies' cooling effect on land surface temperature is potentially not obvious in St. George Rainway. The method used to determine the water's cooling effect on surrounding land surface temperature is based on Wu and Zhang's research (2019), their study object is Suzhou Bay and two districts on the both sides on of the bank, and Suzhou Bay is an open-water area and occupies 32.34% of the entire study area. However, there is no long-term exposed water stream along the street. Instead, the St George Creek were hidden deep underground (St George Rainway | Shape Your City Vancouver).

5. Although heat stress is linked to human health, especially for some typical cardiovascular and respiratory diseases, age plays an important role as well. Under similar physical fitness and exposure to heat stress, older people would have higher chances of suffering related illnesses, which is hard to regulate an appropriate age for the target population. Similarly, since both range of age and types of diseases are limited, sample size within a region can be inadequate to summarize the whole population. Lastly, it would take years to analyze health reports corresponding to UHI, which is inefficient from this perspective. A survey form of sampling heat stress can be a more direct way of collecting larger sample size and it theoretically takes less time to analyze. However, compared to the previous method, results are highly influenced by subjective sensation, which requires a more objective of survey design. Moreover, it can be fluctuated by trifles. How to standardize the procedure of pacifying sensation can be critical.

5. Next Steps

1.The difference between building heat data's trend before and after the GRI implementation to identify the GRI implementation's efficiency. The GRI can be shown as effective if the trend of building heat data increasing rate after the GRI implementation is smoother than the data before GRI implementation.

2.The next step for the plant's evapotranspiration data analysis is similar to the building heat data. The evapotranspiration data's trends should be analyzed. Also, each different site will have a different evapotranspiration efficiency. Comparing all the data to determine which surrounding environment and GRI setting can have the highest evapotranspiration rate, also, the water resource consumption by plants should be considered. Then, for the future, a similar GRI setting can be added in St. George Rainway to enhance its effect on reducing the UHI effect.

3. After the introduction of the St. George Rainway, the land surface temperature for the surrounding communities should decrease, especially after rain, rainwater gathers in the rain-way to form a temporary open water and it is expected to stay longer than the rainwater on the road to cooling LST. It is recommended that the method of studying the cooling effect of water bodies be applied to more rivers, including streams and river water irradiated by sunlight. Finally understand the water bodies' cooling effect on UHI.

4. Due to the variety of heat-sensitive diseases, it is suggested that the project can cooperate with general practitioners (GP) and community hospitals to get related data with patient's knowledge. Furthermore, the overall mortality and morbidity of some acute diseases can be found based on BC Data Scout™ or CareConnect programs. Referencing the COVID pandemic situation, an online survey through QR code can be randomly assigned to local residents between the ages of 18 to 75 years old. A pre-test of sensation can be made such as 'have you lost your temper within 12 h' to determine if a participant is emotionally 'normal' to do the survey. Weekly surveying is recommended to improve accuracy.

6. Acknowledgment

We would like to acknowledge our appreciation to people who participate in this report. Firstly, we are grateful for the opportunity CityStudio Vancouver provides us to challenge a more sustainable, livable and inclusive place for introducing St. George Rainway and rain city strategy. Secondly, our appreciation goes to Dr. Tara Holland (EVSC400 Professor) and Julie McManus (Client of City of Vancouver) for guiding and supporting our project. Lastly, we would like to give special thanks to our guest speakers and students who communicate and share their thought throughout the course.

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