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Measuring Green Space Efficacy in Hangzhou, China

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Measuring Green Space Efficacy in Hangzhou, China

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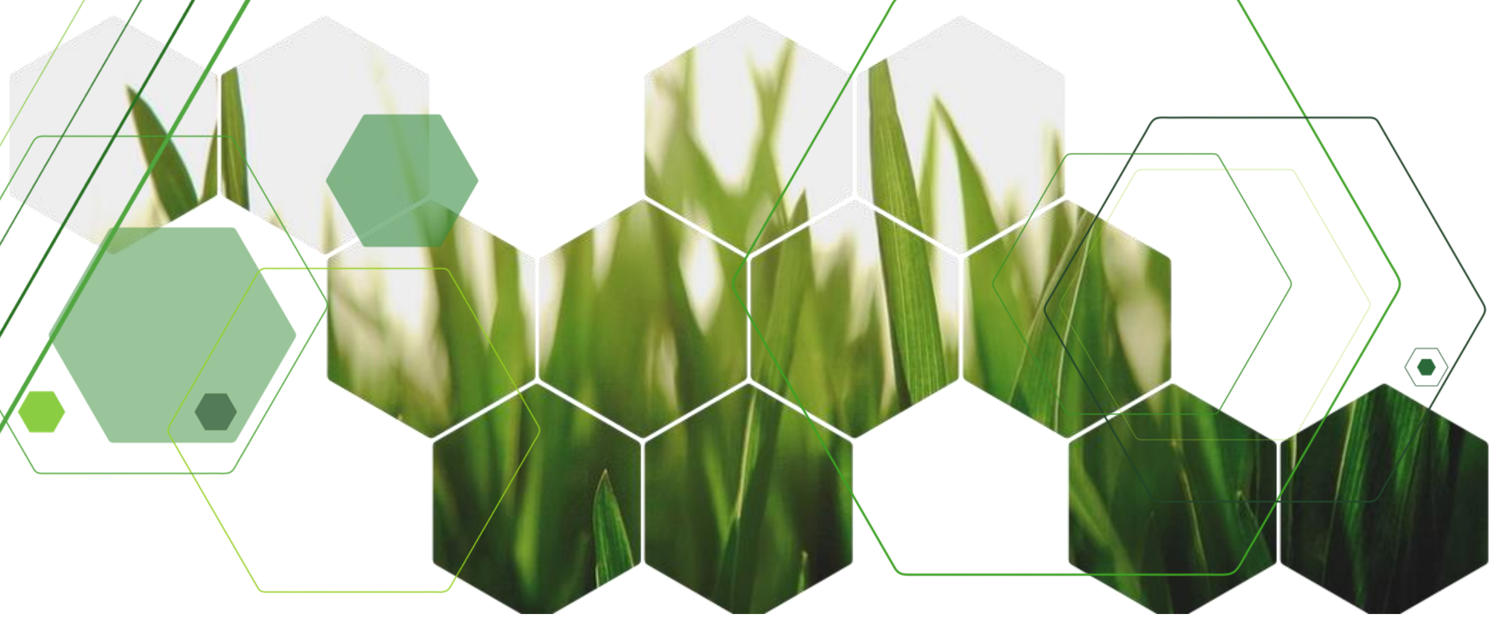

Abstract

Urban green spaces are often claimed to mitigate environmental health issues associated with urban development, although empirical evidence is lacking. This Interactive Qualifying Project analyzed the efficacy of parks in reducing pollution concentrations and increasing the well-being of Hangzhou's residents. By measuring particulate matter and canopy coverage, surveying park-goers, and conducting ArcGIS spatial analysis, we conclude that parks are effective at improving quality of life but are not effective at reducing air pollution, demonstrating that other variables mediate pollution concentrations.

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Authorship

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Executive Summary

Much of the world is trending towards a more urban society, and China is near the forefront of this charge, urbanizing at an unprecedented rate. Green space planning presents an opportunity to better use spatially limited areas for development while improving the lives of those in the city. Hangzhou itself is known across China for its concerted effort to introduce and maintain green space within its borders. This effort can be seen in the numerous existing parks throughout the city. Green spaces are claimed to increase the output of ecosystem services, leading to a reduction or redistribution of particulate matter in the air, though empirical evidence is lacking. They are also thought to confer many social benefits such as stress relief and social cohesion. However, more research needs to be done on solidifying these claims, for if city planners want to be able to build optimized green spaces, they need to know exactly how well green spaces solve problems such as unhealthy levels of air pollution, stress inherent in urban life, and the like.

The goal of this project was to determine the environmental and social benefits of green spaces in Hangzhou. To accomplish this goal, we focused on four main objectives. First, we developed a green space indicator system through the adaptation of existing indicator systems found in the literature. Our indicator set is comprised of several variables including PM2.5 concentration, PM10 concentration, canopy coverage, existence of green space maintenance, presence of amenities, and public approval rating. Second, we determined which green spaces in Hangzhou we would measure using our indicator system. These locations were chosen so that we could study various combinations of landscape characteristics, size, and vegetation types. Third, we recorded air quality in all eight predetermined green spaces and conducted surveys in two of the selected green spaces. Finally, we conducted spatial analyses for the data we obtained using GIS software.

Through our research, we were able to reach many conclusions. We determined that green spaces do not definitively improve air pollution on a localized basis. Using our GIS maps in conjunction with the literature review, we have proposed that proximity to pollution sources, infrastructure design, and canopy density are large factors in distributing pollutants throughout parks. From our survey, we found that the majority of respondents wanted to see open grass and improvements in restrooms in the urban parks. Nearly all respondents were satisfied with Hangzhou's parks, yet people harbor misconceptions about the ability of vegetation to reduce air pollution.

We recommend more research be conducted to determine other factors that contribute to pollution movement and concentrations. In this recommendation, we explore ways research could be carried out that would compensate for possible sources of error that were not accounted for in our research. We suggest factors that should be analyzed in the development of green spaces that could improve the pollution distributions in parks. Additionally, we consider how parks can be designed to further fulfill the desires of citizens and satisfy users. We believe that our research provides evidence that individuals firmly believe green spaces can effectively reduce ambient air pollution in cities while providing evidence that tempers these claims. This research similarly provides evidence that the design of parks and surrounding urban infrastructure influences pollution movements and must be considered when designing green spaces.

1.0 Introduction

Due to rapid urbanization, the world's urban population is expected to rise by 2.5 billion people by 2050 (United Nations, 2015). The current situation of environmental degradation, economic inequality, and daily stress seen by people living in large cities is only a harbinger of the worsening of these issues concurrent with the rise of the world population. These worries are leading urban planners to consider how smart cities can be successfully implemented in countries across the world. These cities incorporate technology into city infrastructure to improve the health of urban environments. Smart city planning can reduce pollutant emissions and promote clean energies, while providing better public spaces and more social inclusion.

Hangzhou, China has undergone a period of rapid urbanization since the 1970s, creating a need for a more intelligent and well-managed city (Yang, Yue, Xu, Wu, & He, 2014). Due to this urbanization, the population of Hangzhou has multiplied nearly sevenfold, increasing from 1.03 million in 1970 to 7 million in 2016 (Hinsbergh, G, 2017). This rapid expansion has challenged the city's ability to meet the high quality of life expected in developed cities while still maintaining high citizen satisfaction and healthy environments in green spaces. While green spaces have been assumed to alleviate these problems, their supposed benefits still lack evidence. Further empirical research is needed to ensure landscape design maximizes environmental and social benefits.

There is no universal definition of a smart city, and each iteration of the term focuses on different components of a city (Alawadhi, S. et al., 2011; Dameri, 2013; Hollands, 2008; Hall et al., 2000; Lombardi, et al, 2012; Ishida, 2002). Many agree, however, that the quality of life and environment in cities constitutes a major consideration in their development (World Council on City Data (WCCD), 2017; CITYkeys, 2017). Green spaces and parks can be one solution to address these challenges (Wolch, Byrne, & Newell, 2014). These green areas have the potential to benefit the environment by filtering pollutants out of the air, replenishing groundwater, and moderating temperatures in the city. They have also been credited with improving the mental health of visitors by providing areas for social interaction and stress reduction (Beyer et al., 2014). Although some literature proposes negative effects of green spaces (Vos et al., 2013; MacKenzie, 2015; Gallagher, 2015), the aforementioned benefits have allowed them to remain an area of interest among smart city planners.

Research has been conducted to study how parks can improve environmental health of cities and the mental of their citizens (Maas, Verheij, Groenewegen, de Vries & Spreeuwenberg, 2006; McPherson & Rowntree, 1993; Nowak & Crane, 2002; Pataki et al., 2011). Little research has been done to enumerate which specific benefits green spaces most prominently effect. The goal of this project was to determine the environmental and social benefits of green space in Hangzhou. To achieve this goal, we studied how air pollutants vary inside green spaces compared to surrounding urban areas with particulate matter measurements and we assessed the public's satisfaction with parks in the city by surveying citizens. Our data do not suggest that all green spaces have lower pollution concentrations than surrounding urban areas. Instead, the proximity to pollutant sources, infrastructure layout, and canopy density appear to be important factors in the movement of pollutants. We also concluded that Hangzhou's residents are satisfied with the city's parks and the amenities found in them, and hold strong beliefs that green spaces improve air pollution. Based on these results, we provide recommendations for the improvement of green spaces in Hangzhou.

2.0 Background

Humankind is transitioning into an urban-focused future (Albino, Berardi, & Dangelico, 2015; Harrison et al., 2010). The rapid growth and development of cities and urban regions provides the opportunity to foster innovation and use new technologies, while simultaneously presenting challenges and problems for city operations. Smart cities are a particularly powerful way to develop these urban spaces and solve the associated challenges. In this chapter we will review what constitutes a smart city, what the benefits of green spaces are and ways to measure their efficacies, and how Hangzhou, China's green space quality is related to its past and future implementation of smart city initiatives.

2.1 Defining a Smart City

There is no one definition for a smart city (see Appendix B for a summarized list). There is variation in definitions ranging from the individual initiatives to the name itself (Albino et al., 2015). Depending on the culture, organization, or goal, the name used for a smart city may change. Some primary examples include: intelligent city, digital city, wisdom city, green city, sustainable city, and eco-city among others. Some experts will disagree on the distinctions among these naming conventions; some consider a smart city and a sustainable city the same thing, while others claim they are entirely separate. The definition of the term is usually dependent on what a city or organization aims to accomplish by creating a smart city.

The term smart city first appeared in the 1990s from The California Institute for Smart Communities (Alawadhi et al., 2012). The initial goal of smart cities was to make a community smart by incorporating information technology on a city-wide level. The term was not initially popular due to a substantial push for urbanization and a lack of technology and was employed by different cities and organizations, all with different goals in mind.

IBM, a world leader in the development of smart cities has popularized the concept and has used three main terms to describe them: Instrumented, Interconnected, and Intelligent (Harrison et al., 2010). Instrumented refers to the collection of real world information and data through a series of sensors, kiosks, meters, personal devices, appliances, cameras, smartphones, and medical devices, as well as through the Internet and social media. This is the on-the-ground collection of data, which ranges from recording traffic patterns with traffic cameras to asset management through the use of radio-frequency identification tags. Interconnected builds on the data collected from Instrumentation by connecting the world through a chain of data. This is done by connecting different organizations' collected data. Finally, Intelligent builds on the interconnected data by analyzing and predicting trends in information. Through the use of artificial intelligence and deep learning algorithms, the data collected from the aforementioned traffic cameras, for example, can be compared with other interconnected traffic data, predicting the driving time to a given destination at any particular moment. The Instrumented, Interconnected, and Intelligent categories create the building blocks of technological interactions within a city and have created a unique definition of a smart city, focusing primarily on the superior use of technology.

The Institute of Electrical and Electronics Engineers (IEEE) (2017) uses several categories to define the components of a smart city. These components include Smart Governance, Smart Mobility, Smart Living, Smart Environment, Smart People, and Smart Economy. While they do not give a formal definition for any of these categories, this format is currently the most commonly adopted outline of smart cities. The implicit definition gives a broad structure that almost any city can use to define its own indicators for each category.

Interestingly, the IEEE's definition of a smart city incorporates social aspects of a city such as Smart Living and Smart People rather than focusing solely on the technological aspects.

For the purposes of this project, we have adopted a similar definition to that of the Smart City Research Center of Zhejiang Province at Zhejiang University (see Appendix A). With their goals in mind, we define a smart city to be a community that uses technology to improve the lives of its citizens, increase efficiency, facilitate mobility, conserve energy, reduce pollution, utilize and share available data, and maintain a high level of natural (eg., from earthquake) and political (eg., from protests) resilience. A smart city incorporates both technological characteristics like IBM's, as well as broad city welfare oriented features like those of the IEEE's. By combining the technological and social aspects, an effective smart city can be achieved.

2.1.1 Smart City Benefits

Smart city initiatives have the potential to improve the lifestyle of citizens in urban areas (Batagan, 2011). In a study of European cities, smart solutions were credited with:

- Increasing the employment rate for men and women aged between 20 and 64 years, while employing a larger number of young people, older and low-skilled people, coupled with a better integration of legal immigrants; [sic]
- Improving the conditions for research and development in order to increase investment levels and stimulate research, development and innovation of new indicators;
- Reducing greenhouse gas emissions, increasing the share of renewables in final energy consumption and achieving increased energy efficiency;
- Improving education levels by reducing dropout rates and increasing the proportion of persons aged 30-34 years with university degrees or equivalent qualifications; [sic]
- Promoting social inclusion by reducing poverty and eliminating the risk of poverty (p. 28).

It has also been suggested that smart city initiatives can better utilize existing infrastructure, effectively reducing the number of new construction projects (Harrison &

Donnelly, 2011). Economically, smart initiatives may promote commercial enterprises through the dissemination of real-time data and information relevant to city services.

The assemblage of data, a characteristic common in smart cities, often changes the behavior of citizens and agencies (Harrison & Donnelly, 2011). Such information distribution provides the opportunity to make informed decisions. Police forces can reduce the frequency of violence-related hospital admissions by changing patrolling strategies, drivers can take safer routes by seeing traffic and weather reports, and consumers can change their energy usage with real-time reports on their consumption.

By implementing smart city initiatives, the quality of life for urban citizens can be greatly enhanced (Landa, 2017). As advancements are made, “we will likely see less waste, better water treatments and retention, better housing options for growing populations, more jobs, more schools, organizations, and public utilities, improved air quality, and more” (para. 6).

2.2 Smart Green Spaces

As a factor of smart cities, smart urban planning strives to foresee problems and difficulties in the way land and resources are used in a city (Tao Zhang, personal communication, September 18, 2017). By designing with these factors in mind, future negative consequences can be prevented. Efficient utilization of resources is key to this development, while growth of infrastructure must consider environmental well-being while promoting quality of life and social inclusion (Greco & Cresta, 2015). Smart urban planning encompasses a number of subcategories including green spaces. While research has confirmed that green spaces and parks can have positive effects on the mental health of citizens, their impacts on the environment in cities is still inconclusive (Maas, Verheij, Groenewegen, de Vries &

Spreeuwenberg, 2006; McPherson & Rowntree, 1993; Nowak & Crane, 2002; Pataki et al., 2011; van den Berg, Maas, Verheij & Groenewegen, 2010).

2.2.1 Green Spaces

Green spaces include areas that introduce vegetation into cities, including parks, sporting fields, riverbanks, trails, gardens, streetside trees, green walls, and cemeteries (Wolch, Byrne, & Newell, 2014). Green spaces have been proposed to provide a variety of different ecosystem services to cities, including but not limited to air purification, temperature reduction, noise reduction, and stormwater infiltration, all while improving the mental and physical health of the city's citizens.

2.2.2 Pollution and Environment Health Benefits

Cities and urban areas with dense populations often have above average air pollution rates (Pandis et al., 2016). Pollution rates are typically measured in terms of mass of particles per unit volume and encompass particles of varying shapes, sizes, and chemical compositions (United States Environmental Protection Agency, 2016). The most common identifications of these particles are PM2.5 and PM10, where PM stands for particulate matter and the number that follows identifies the micron diameter of the particles, inclusive of particles with a smaller diameter.

Particulate matter can be of solid or liquid phase and is small enough to be inhaled, enter the bloodstream, and cause various health problems (United States Environmental Protection Agency, 2016). Particles under ten microns in diameter, when taken in by the body, can have negative effects on both the respiratory and cardiac systems including difficulty in breathing and irregular heartbeats among others (Janssen et al., 2011). The accepted safe concentration of particulate matter is 35 ($\mu g/m^3$) according to the World Health Organization (WHO) (2006). Above this value, health risks increase and adverse effects can occur. Particulate matter can also cause environmental problems such as acidic lakes and streams, forest and soil deterioration, and most commonly smog, and therefore necessitate the reduction of pollutants in the air (Hardoy, Mitlin, & Satterthwaite, 1992; United States Environmental Protection Agency, 2016).

According to the American Clean Energy Act of 2009, green spaces can improve air quality significantly, most importantly reducing air pollution particles such as PM2.5, PM10, ozone, and carbon dioxide (Pataki et al., 2011). A study was conducted in New York City that determined green spaces in the city removed 0.47% of PM10 (Nowak & Crane., 2002). Other studies have been conducted that reinforce this finding, showing green spaces have the tendency to decrease particulate matter concentrations (McPherson & Rowntree, 1993; Nowak, Crane, & Stevens, 2006; McDonald et al., 2007).

Many of these benefits can be attributed to the vegetation present in these green spaces (Nowak, 2017). For instance, particulates in the air can be absorbed by trees or deposited on their surfaces, improving the air quality. These effects were studied in New York City in 1994 when an estimated 1,821 metric tons of air pollution were removed by trees. The benefits trees provide differ depending on a variety of factors, with large healthy trees 77 cm in diameter or greater removing 70 times more pollutants than small healthy trees less than 8 cm in diameter. Specifically, increasing tree cover and decreasing mixed-layer heights can improve air quality.

There is a general misconception that trees are beneficial to air quality in each and every case, however (Vos et al., 2013). Urban planners tend to turn to trees to alleviate centralized pollution sources when, in fact, they may be aggravating the problem. Research has shown that urban landscape features can negatively affect the way pollution moves and ultimately lead to an increase of local pollutant concentrations (MacKenzie, 2015; Gallagher, 2015; Vos et. al, 2013). These features, including but not limited to walls, cars, and trees, can be considered barriers that hinder natural wind flow, thus reducing natural ventilation (Gromke, 2011; Gromke & Ruck, 2012; Wania et al., 2012). For example, streets that are lined with trees have the potential to trap pollutants, as green canopies form an “umbrella” above the streets that prevents the escape of pollutants, thus worsening the quality of the air locally. This phenomenon can be influenced by the density of vegetation that form the canopy. If there is a high vegetation density then there will be less space for pollutants to escape; the park would end up having a higher relative level of pollution compared to its surroundings.

The differences in vegetation function have been acknowledged in the source-sink theory that states sources supply assimilates to sinks and sinks accept and accumulate the assimilates (Venkateswarlu & Visperas, 1987; Fatichi, Leuzinger, & Körner, 2014; Liu et al., 2014). Canopy density, vegetation structure, and vegetation age contribute to the sink effect. This relationship mirrors that of supply and demand in economics, where pollution from a source is the supply and the demand is from trees taking in the pollution. If the amount of pollution produced from a source is greater than the amount that can be absorbed by surrounding vegetation, it overflows and spreads to surrounding areas. However, if the amount of pollution from a source is less than the amount that can be absorbed by surrounding vegetation, most of it will be taken in and the air around the green space will be cleaned.

Meteorological conditions have also been seen to affect particulate matter concentrations (Vos et al., 2013; Wang & Ogawa, 2015; Wu, Xie, Li, & Li, 2015). Relationships between meteorological conditions around green spaces and particulate matter concentrations have also been studied and analyzed. It has been proven that temperature, humidity, wind speed, wind direction, and precipitation all affect concentrations of particulate matter. High temperature and humidity correlates to increased particulate matter concentrations. Particles grow heavy under these conditions, making them fall to the ground. Additionally, air currents carry and displace pollutants dependent upon their speed and directions. When wind speed is low, pollutants can only be displaced over short distance. When the wind speed is high, however, it can displace large volumes of pollutants long distances. Precipitation also affects the concentration of particulate matter. Particulate matter tends to decrease with precipitation through wet deposition when particles become trapped by falling rainwater.

2.2.3 Mental and Social Health Benefits

While research does not confirm whether or not green spaces have distinctly positive or distinctly negative effects on air pollution, positive impacts on the mental health of citizens have been seen. The creation of green spaces is important to consider when designing a city, as they can have very beneficial effects on the mental well-being of city residents (Maas, Verheij, Groenewegen, de Vries & Spreeuwenberg, 2006; Van Den Berg, Maas, Verheij & Groenewegen, 2010; Groenewegen et al., 2006; Thompson et al., 2012). Van den Berg et al. (2010) found that people living near green spaces were able to recover more quickly from stressful and traumatic events in their lives. Thompson et al. (2012) found more general stress reduction in people who had access to green spaces. Other studies have identified mental fatigue recovery, neighborhood social cohesion, and reduction in aggression as additional benefits of green spaces (Beyer et al., 2014). Still others have found that green spaces can reduce chronic stress in adults (World Health Organization Regional Office for Europe, 2016). Not all of these effects can be assuredly linked to green space exposure, however (World Health Organization Regional Office for Europe, 2016; Parliamentary Office of Science and Technology, 2016). Stress reduction effects have only been proven for short-term exposure, and little research exists showing mental health benefits stemming from long-term green space exposure.

Besides mental benefits and stress relief, an aesthetically attractive green space may also improve the well-being of citizens by enhancing environmental satisfaction (Groenewegan et al., 2006). To be aesthetically attractive, routine maintenance must be carried out often. This ensures the green space constantly looks attractive to visitors. One of the ways green spaces can enhance environmental satisfaction is by fulfilling visitors' expectations. Research has found that most people visit parks for the purpose of rest and relaxation (Chen et al., 2009). If parks are designed to address the purpose of visitation and the public's preferred amenities, the happiness of visitors will increase.

2.2.4 Equity Issues of Green Spaces

While many Western communities have been trending towards greater inequality in regards to green spaces, large urban areas in China have not seen this issue even with more pronounced residential segregation than the West (Xiao, Y., Lu, Y., Guo, Y., & Yuan, Y., 2017; Xiao, Y., Wang, Z., Li, Z., & Tang, Z., 2017). In a case study of Shanghai, it was observed that many wealthy communities took on the full cost of community-based green spaces, allowing the government to focus on residential communities unable to afford maintenance of parks (Xiao, Y., Wang, Z., Li, Z., & Tang, Z., 2017). Conversely, Western governments tend to use high property tax rates in an attempt to provide high quality maintenance and amenities to all parks. However, some citizens make large donations or contributions to their local green spaces, creating a divide between the quality of public green spaces. Areas with greater wealth see larger amounts of private funding for park maintenance than poorer areas. China's government, however, aims to put money directly into the maintenance and improvements of parks in needy areas, leaving wealthy or club based communities to adjust housing costs for the distribution of funds into green spaces (Frantz, K., Webster, C., & Glasze, G., 2002). This strategy is likely only viable due to the drastic segregation of Chinese residential communities based on wealth, yet it still affects social equality with respect to green spaces in the end.

2.3 Smart City and Green Space Indicators

It is important that city leaders understand their city's performance and draw comparisons with other cities in order to identify areas for potential improvement (Karayannis, 2014). However, differences among cities and their measurement and reporting techniques hinder the ability to accurately analyze smart city green space benchmarks. The growing interest in green space development has led to the advent of systems and certifications to assess them (CITYkeys, 2017; Green Business Certification Inc., 2017; U.S. Green Building Council, 2017a).

Indicators can be used on a part of a city or a city as a whole, depending on the data available (Bureau of Indian Standards, 2016a). Indicators can also be measured and analyzed on a larger scale, ranging from a regional to even a national scale. Sets of indicators have the potential to be enhanced through the analysis of other indicator systems. This method can help develop a more comprehensive indicator system. Once relevant data have been collected, cities should evaluate the results in the context of the city.

2.3.1 CITYkeys

With funding from the European Union HORIZON Program, CITYkeys (2017) has collaborated with various cities to create and validate principal smart developmental indicators and data compiling methods that monitor and compare smart city solutions across Europe, some of which are directly related to green spaces. The VTT Technical Research Center of Finland, Austrian Institute of Technology of Austria, and Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek of the Netherlands are research institutions that worked in conjunction with five cities - Rotterdam, Tampere, Vienna, Zagreb and Zaragoza - to determine which qualities of smart city development need to be measured by indicators. Together, they identified and measured existing project results and provided recommendations aimed towards smart city development. Other European cities contributed to the project as well with the intention of compiling as much feedback as possible about the use and challenges of smart city project evaluation frameworks.

CITYkeys (2017) developed an indicator system comprised of 99 indicators (Bosch & Rovers, 2017, p. 5). Each indicator was divided into a main theme with a title, a unit of measure, where the indicator was synthesized, and if it was influenced by or borrowed from another source. Each indicator expresses an aim, goal, or standard that can be used to assess a wide range of smart city policies and projects.

2.3.2 Bureau of Indian Standards

The Bureau of Indian Standards (BIS) (2016b) of New Delhi, India is designed to help cities assess their performance of city-provided services in addition to quality of life. The system considers sustainability as one of its guiding principles. Guidance for the development of the system has roots in "ISO 37120:2014 Sustainable Development of Communities: Indicators for city services and quality of life," another smart city indicator system, but expands further with additional indicators synthesized by the Bureau.

This system divides its indicators into a variety of different categories, including but not limited to Education, Economy, Energy, and Environment, encompassing most if not all aspects of a city (BIS, 2016b). Within these umbrella categories, indicators are further broken up into core indicators, supporting indicators, and profile indicators, defined as such:

> **Core Indicators** – Indicators that are required to demonstrate performance in the delivery of city services and quality of life
> **Supporting Indicators** – Indicators that are recommended to demonstrate performance in the delivery of city services and quality of life
> **Profile Indicators** – Indicators that provide basic statistics and background information to help cities determine which cities are of interest for peer comparisons. Profile indicators are used as an informative reference (BIS, 2016b, p. 10).

One of the main categories for the system was Environment. The core, supporting, and profile indicators express standards under Environment can be evaluated to assess a wide range of green space qualities. Based on the CITYkeys and BIS indicator systems, we have synthesized six key green space indicators related to environmental quality, park vegetation, and public approval to be used in Hangzhou to determine the city's quality and efficacy of its green spaces (see Appendix C).

2.4 Hangzhou's Smart City Green Space Movement

Based on their understanding of the causes and consequences of air pollution, Hangzhou planners have developed and started to implement green space promotional programs to help control pollution rates and concentrations. Hangzhou has outlined such plans in a section in the Hangzhou Planning Bureau's Master Plan (Hangzhou Planning Bureau, 2010). This plan was devised in part in order to stimulate positive environmental changes in and around the city to provide a better quality of life for its citizens.

2.4.1 Impacts of Hangzhou's Urbanization

Hangzhou is located in the northern part of the Zhejiang province, and its population has grown from 5.8 million in 1990 to 7 million in 2016 (Hinsbergh, 2017). Due to this fast growth, the city has expanded its boundaries by incorporating more townships into the Hangzhou metropolitan area. The city now covers 3068 km^2 of land, but consisted of only 430 km^2 in the 1980's (Li, Lu, & Kang, 2016). The rapid increase in land use correlates to massive increases in the city's gross domestic product (GDP), growing from only 1382.56 billion CNY in 2000 to 9206.16 billion CNY by 2015 (Han, Ma, & Li, 2017). Both are likely the result of the recent industrial boom in Hangzhou and can be seen in the swift evolution of the city's boundary as seen in Figure 2.1 (Song, Thisse, & Zhu, 2012).

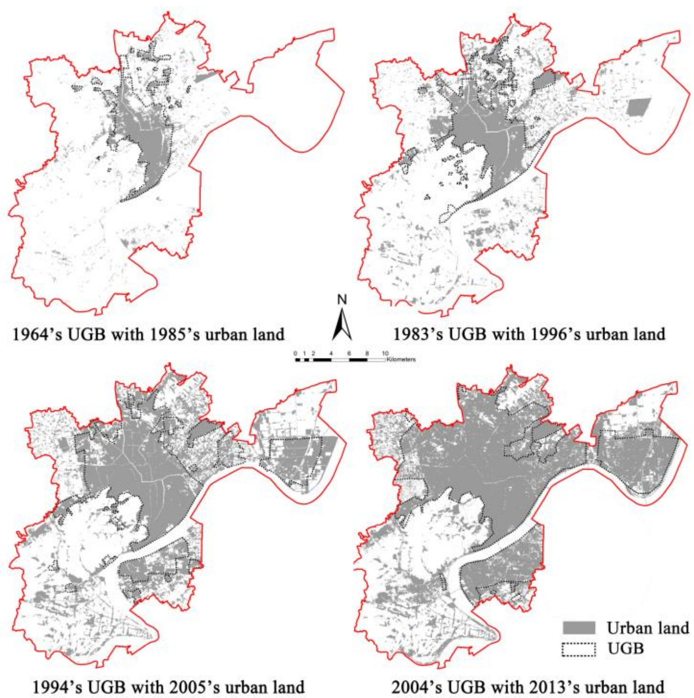

Figure 2.1 Urban Growth Boundary (UGB) expansion between 1964 and 2013 (Wu et al., 2017, p. 12).

Hangzhou's recent expansion and construction zone developments have led to an increase in air pollution (Walsh, 2015). In 2011, 2012, and 2013, the number of days where the smog levels were considered to be unhealthy was 157, 159, and 239, respectively. The green spaces that can be found scattered throughout the city, in addition to their prominence in construction zone IV, have the potential to improve these conditions and curb the pollution in the city. As such, plans have been established to promote green spaces and parks throughout Hangzhou.

2.4.2 Green Spaces in Hangzhou

Hangzhou is known nationally as a Garden City due to its expansive green space program (Wolch, Byrne & Newell, 2014). Currently, about 40% of the city is green space, and there is 15 m^2 of green space per capita. Efforts have been undertaken to demolish factories to create parks and to plant greenery in dilapidated and unused parts of the city and along roads. In a study conducted by Chen, Adimo, & Bao (2009) it was determined that the people of Hangzhou mostly visit parks for relaxation purposes; having more green space gives more people the opportunity to fulfill these desires. Hangzhou's citizens are also willing to do their part in maintaining the spaces. Chen et al. (2006) identified that 89% of the citizens they surveyed considered conserving and maintaining green space to be of high importance. Of that 89%, 84% were willing to have their taxes increased to help conserve green spaces. It appears that Hangzhou's residents are very satisfied with the city's urban green spaces and want them to be conserved as best as possible.

2.4.3 Hangzhou Planning Bureau's Master Plan

The Hangzhou Planning Bureau (2015) has developed a master plan that has sections outlining the advancement of forestation in residential, industrial, and academic areas in Hangzhou. The plan outlines a vigorous push to increase plant diversity and presence in the city to increase "ecological effectiveness and landscape effectiveness of plants" (para. 2). It proposes that, in the main city, "green land of no less than 2000 square meters [should]be seen in every area with a radius of 500 meters" (para. 3). In addition to stressing the importance of green space for the main city, initiatives are described for the numerous sub-cities in Hangzhou. For instance, in the Linping sub-city, park green land "will be equally distributed...along the [main] Canal" (para. 5). These plans, if implemented fully, have the potential to allow Hangzhou to reach its goal of becoming an ecologically smart city.

2.5 Summary

The city of Hangzhou is striving to implement smart city green space initiatives through improving its existing urban landscape. These efforts are intended to increase the efficacy of green spaces with regards to improving air quality compared to urbanized areas and satisfying citizens. A comprehensive collection of relevant indicators taken from existing systems and synthesized through literature review is needed to understand the quality of green spaces in Hangzhou. Applying these indicators to Hangzhou can provide insight into the past and future development of its smart city green space initiatives. In our next chapter, we discuss how we applied international indicators of smart urban planning to Hangzhou to determine how effective its green spaces are.

3.0 Methods

In this project, our goal was to determine the environmental and social efficacy of green spaces in Hangzhou. We will discuss our methods for achieving each of our objectives within this goal and describe the reasoning behind applying them in this chapter.

3.1 Determining Green Space Indicators

To measure the efficacy of green spaces in Hangzhou, we identified qualitative and quantitative indicators. By identifying indicators for green spaces, we formed the basis for a measurement tool to assess the social and environmental efficacy of such areas in Hangzhou.

3.1.1 Literature Review

To develop a set of indicators for Hangzhou's green spaces, we studied existing indicator systems that have been implemented in other cities. Utilizing best practices verified the reliability of the indicators we selected and provided credibility to the legitimacy of our claims. We reviewed several systems including the CITYkeys and Bureau of Indian Standards indicator systems as discussed in Section 2.3 to compile our list of variables as seen in Appendix C.

We chose to measure PM2.5 and PM10 levels to see how well parks could reduce air pollution. Specifically, we were testing the theory that green spaces can reduce pollution in a localized fashion. This theory posits that air within a green space would be cleaner than air in the rest of a city because of filtration caused by plants in the space. Additionally, we identified distance from roads and other pollution sources as another potential factor. To test the theory that canopy coverage traps pollutants, we chose to classify the density of canopy coverage in the parks. These theories can be seen in Section 2.2.2.

Another purpose of this study was to determine what Hangzhou's citizens want out of the city's green spaces and how well those green spaces match their preferences. Our survey assessed which general park features they like and determined how satisfied Hangzhou's citizens were with the city's parks. We compared the survey takers' wants with our own observations of landscape features, maintenance, and amenities present in parks. We constructed these indicators to test the assertions made in Section 2.2.3.

3.2 Determine Areas to Measure in Hangzhou

To measure our indicators, it was first necessary to determine locations in Hangzhou that would be suitable for measurement. Then, we optimized existing sampling methods to systematically collect data in each park.

3.2.1 Park Selection

We selected eight green spaces, two large and six small, to study that were in and around the Xihu District of Hangzhou. We defined large green spaces as having a total land area greater than or equal to 2 km^2 and small green spaces as having a total land area less than 2 km^2. Each selected park was in a different area with varying landscapes and visitation. We selected West Lake and the Xixi National Wetland Park as the large parks we would study based on their differing landscapes and popularity among locals and tourists. The mountainous terrain and urban infrastructure on either side of West Lake provided insight into the movement of pollution out of urban areas into natural landscapes, while the terrain of the Xixi Wetlands provided insight into how pollutants settle over large, flat areas. First, we selected Wushan Scenic Area and Liuheta Culture Park for their dense vegetation and mountainous terrains. Second, we selected Wanxiang Park and the Zhejiang University Zijingang Campus for their open spaces. Third, we selected Shu Yuan Park and Jialvyuan Park for their medium canopy coverage. The parks we selected were distributed around residential, commercial, and industrial areas of the city, as seen in Figure 3.1. This selection method allowed us to draw comparisons between the influences of each of these factors in pollution distributions as discussed in Section 2.2.2.

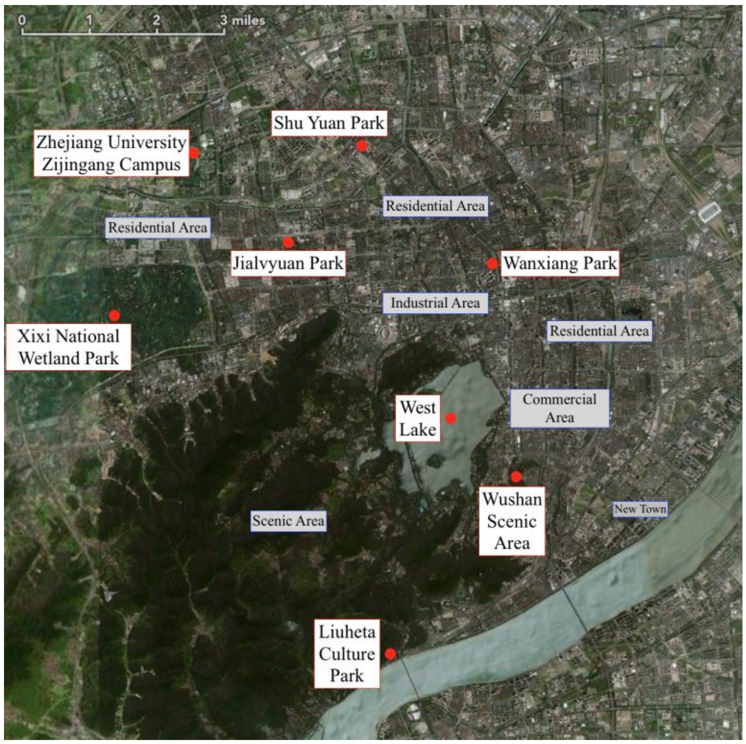

Figure 3.1 Parks selected for data collection and analysis. November 9, 2017.

3.2.2 Sampling Method

We used ArcGIS software to divide the green spaces into hexagonal data collection areas. Dividing a space into a grid for data collection purposes has been employed in similar research and was the model used for this research (Nowak, Hoehn, Crane, & Stevens, 2010; Fan, Li, Han, Cao, & Dong, 2017; Farkas & Safari Books Online, 2017). In a hexagonal grid system, the distance from the center of each hexagon to the center of each adjacent hexagon is equal, allowing us to collect data uniformly throughout the parks. Therefore, we were able to reliably interpolate data in our GIS maps. Since the areas of each park varied greatly, we utilized a different grid resolution for each green space. To collect a manageable amount of data in a practical amount of time and have approximately the same number of data points for each park, we calculated the size of the hexagons using the following formula, assuming 25 data points:

$$length\ of\ hexagon\ side\ = \sqrt{\frac{2 * (area\ of\ green\ space/25)}{3\sqrt{3}}}.$$

We superimposed the hexagonal grids with the calculated side lengths on maps of each park and adjusted the side lengths as necessary to best populate the area. The grids covered the entirety of the parks and stretched into the surrounding urban area outside the perimeter of the green spaces. These additional areas extending into the city allowed for comparisons between locations inside and outside the green spaces. Each data collection point received a numerical identification number for the purposes of data collection. We determined the accessibility of the hexagons outside the perimeters of the parks at the time of data collection. For instance, if a hexagon fully encompassed an inaccessible location, such as on a highway or at the top of a mountain, we omitted the hexagon and filled the vacancy during the interpolation process described in Section 3.4.

To collect the data points, we traveled to the center of each hexagon. To locate the data collection points in the parks, we utilized the Apple Maps applications on our mobile phones to track our location in accordance with the predetermined data points. If a predetermined data collection point was inaccessible due to vegetation, landscape, buildings, or the like, we took measurements as close to the center as possible while still staying in the bounds of that point's hexagon. We measured and recorded data throughout the parks at each location and compiled them in a spreadsheet according to the location's identification number. For information on sampling methods in each park, see Appendix D.

3.3 Measuring Indicators

Once we determined the green spaces to be examined, we measured the indicators in each park. We recorded particulate matter concentrations, canopy coverage, and the presence of maintenance and amenities. We also conducted surveys in select parks to understand the public's opinion on green spaces in Hangzhou.

3.3.1 PM2.5 and PM10

To determine pollution levels across the parks and green spaces, we measured the PM2.5 and PM10 levels at the specified collection sites. We used a Kong Qi Jian Ce Yi PM2.5 and PM10 air quality detection device to measure pollution levels at the center of each hexagon. When recording the particulate matter readings, we waited at the location for the device to read a constant measurement before recording the values. This process took approximately 30-60 seconds at each hexagon. We transferred field observations and location data to ArcGIS for geographic analysis and generated heat maps from the data distributions to identify patterns in particulate matter concentrations throughout the parks and surrounding areas. Two different types of pollution heat maps were produced for each park: PM2.5 concentrations and PM10 concentrations. More on the creation of the maps can be found in Section 3.4.

3.3.2 Canopy Classifications

In addition to particulate matter data, we observed a variety of different canopy classes within the selected green spaces as discussed in Section 2.2.2. We determined canopy coverage based on the density of vegetation. Similar types of vegetation structures tend to have similarly sized canopies. We gave each class a numerical identifier from zero to three and input the data into GIS software to create canopy coverage layers. This allowed us to draw geographic comparisons with the pollution data we collected. Descriptions of these classes can be seen in Table 3.1, along with their corresponding numerical identifiers.

Table 3.1 Canopy Class Descriptions

Canopy Class	**Description**	**Numerical Identifier**
No Canopy	Comprised of roadways or bodies of water - no vegetation or small vegetation such as grass or small bushes and shrubs; no canopy existing.	0
Low Coverage	Comprised of a mixture of small and medium vegetation such as large bushes and shrubs mixed with small trees; low density vegetation canopy.	1
Medium Coverage	Comprised of medium vegetation such as more trees and larger bushes and shrubs in a higher density; medium density vegetation canopy.	2
High Coverage	Comprised of large vegetation such as tall trees and the like; high density vegetation canopy.	3
N/A	Area was not accessible.	--

3.3.3 Maintenance and Amenities

To assess the maintenance of the green spaces, we recorded the presence of maintenance crews actively maintaining the spaces. We noted any obvious signs of a lack of maintenance such as litter, overflowing trash cans, excessive leaves, and active construction. Additionally, we recorded amenities that were present in the parks, including restrooms, restaurants, statues, and various signage. We compared this information to the results of the surveys discussed in Section 3.3.4 to draw conclusions about the ability of parks to meet the expectations and desires of citizens.

3.3.4 Park Visitors' Opinions

To understand Hangzhou's current quality of green space, we surveyed its citizens. These opinions were important in helping us determine the public's satisfaction with Hangzhou's green spaces. In addition, we asked if they believe that the parks help reduce air pollution. Even if the parks ended up to not actually substantially reducing pollution, the peace of mind offered might be enough to be beneficial to Hangzhou's citizens. This is to see if park goers in Hangzhou are satisfied with and receiving health benefits from Hangzhou's green spaces. In order to collect the opinions of the public, we conducted two surveys: a preliminary version and a revised version based on the results of the initial survey.

The preliminary survey occurred at Zhejiang University Zijingang Campus to test the responses that we may receive, as well as to identify sources of error in the survey (see Appendices E and F). We walked around popular areas of the campus, including the academic and student housing areas, as well as the main cafeteria on campus and provided QR code links to the survey for students to take on their mobile devices. We modified this survey upon review of the first survey's responses to better address the goals of our research.

The revised survey consisted of questions revolving around the satisfaction citizens had with parks, and the features they appreciate most in green spaces (see Appendices G and H). We conducted the revised survey in the area surrounding the Longxiangqiao Metro Station at West Lake, a popular attraction in Hangzhou. To receive a substantial number of responses, we conducted this survey on a Saturday morning and afternoon, a busy time in the area. The team, along with the Zhejiang University post-graduate students and Hangzhou Dianzi University undergraduate helpers, asked visitors to participate in the survey as they left the metro station and walked around the shopping area. This resulted in 100 survey responses based on a convenience sampling method. We used Qualtrics survey software to create an online version of the survey that we distributed to respondents with QR codes on mobile devices. We also distributed the survey on paper copies for those without mobile devices. Lastly, we compiled and organized the data into Qualtrics software for further analysis.

3.4 Data Analysis

ArcGIS software allowed us to visualize our collected data on surface layers. The maps started with a satellite imagery base map containing 15m TerraColor imagery at small and mid-scales (~1:591M down to ~1:72k) and 2.5m SPOT Imagery (~1:288k to ~1:72k) provided by Environmental Systems Research Institute (ESRI, 2009). Using additional maps from ESRI, we could visualize roads, waterways, and elevations to understand the physical layout of the green spaces. With the collected data matched to the correct hexagons, we used Empirical Bayesian Kriging to interpolate the data based on the center points of each hexagon. Any hexagon that was inaccessible and therefore lacking a collected data point was not considered in this process. The kriging method creates a continuous surface map, estimating the missing data points (Tyagi & Singh, 2013). These values come from analyzing the spatial structure of the points and generating a semi-variogram, a model fit through the measured data points helping to visualize the spatial autocorrelation (ESRI, 2009). Due to inaccessible data points in the green spaces, we could not create a density map based on the equidistant center points of the hexagons. Instead we analyzed the separation of the missing points and their relation to neighboring points and assigned weights based on the spatial autocorrelation. Using this method we generated three different types of surface layers for each park; PM2.5 concentrations, PM10 concentrations, and canopy coverage. By comparing the three layers, we were able to find trends and patterns in the particulate matter concentrations among the parks. Based on the satellite imagery, we made observations on the surrounding buildings and roadways to explore additional pollution patterns. Using the maps, we were able to identify relationships between our observations and our indicators.

3.5 Summary

We created a comprehensive indicator system for the city of Hangzhou to use to determine the efficacy of green spaces. We selected appropriate parks for measurement and analysis, and used best practice methodologies to collect relevant indicator data. In the following chapter, we will discuss the data and information we obtained from completing the methods described above.

4.0 Results and Analysis

Our research was conducted to determine the efficacy of green spaces in Hangzhou with regards to air pollution reduction and satisfaction of citizens. This chapter provides the results of our data collection at each green space, the results of our survey of the city's residents, and an in-depth analysis of our findings. We begin by analyzing observed patterns in particulate matter concentrations and vegetation structures along with potential explanations for how they may be affecting air pollution in parks. We then discuss the social characteristics of parks along with our survey results. Finally, we review the connection between environmental and social health improvements.

4.1 Particulate Matter Patterns

Spatial analysis has revealed patterns in particulate matter concentrations in parks and green spaces in Hangzhou. We identified the most prominent patterns in the green spaces, including the proximity of parks to pollution sources, park vegetation structures, land elevations, and the layout of city features. Each of these criteria was seen to affect pollution distributions in green spaces. For all relative particulate matter concentration maps, see Appendix I.

4.1.1 Infrastructure

We observed correlations between air pollutant concentrations in parks and the surrounding infrastructure. Specifically, we found that infrastructure is a key aspect of a landscape in determining how pollution is directed as it moves. Such patterns are best shown in Wanxiang Park and the Zhejiang University Zijingang Campus. A band of high concentrations of particulate matter was oriented in an east-west direction in Wanxiang Park, with decreasing concentrations to the north and south as seen in Figure 4.1. This can be explained by the large roads and intersections on the north and south ends of the park, Huancheng North Road and Tiyuchang Road. As discussed in Section 2.2.2, infrastructure such as buildings and roadways affect the airflow in urban areas. Assuming wind and air flow in the east-west direction, we hypothesize that air was able to flow freely along the large roadways, thus moving pollutants away from the park. Between these roadways, tall residential buildings are located on the left and right sides of the park. These buildings may have obstructed air from flowing through the center of the park, accounting for the dense presence of pollutants in the park's center. In this case, pollution concentrations did not display localized improvements compared to the surrounding areas. Given Wanxiang Park's small size, the park may have been dominated by the large urban surroundings, preventing any significant positive impacts on particulate matter concentrations.

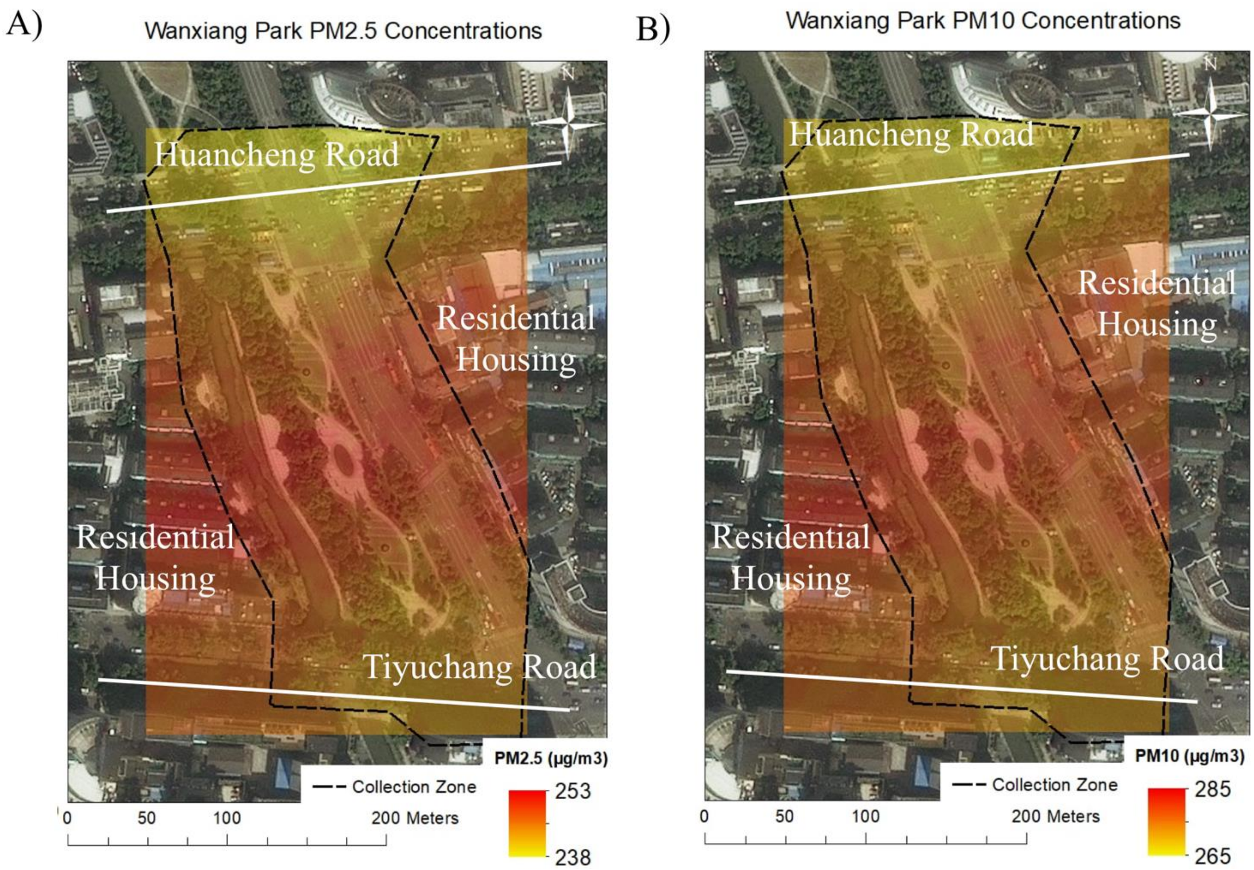

Figure 4.1: (A) PM2.5 and (B) PM10 concentration distributions for Wanxiang Park. Data collected November 14, 2017, Map created December 4, 2017.

We saw a similar phenomenon at the Zhejiang University Zijingang Campus. High pollution concentrations could be seen in the north near the raised Liushi Expressway, with a largely high concentration surrounding large campus housing buildings, seen in Figure 4.2. South of the dense buildings, the pollution concentrations began to dissipate over the more open areas of the campus. We believe the dense, large buildings obstructed the flow of air, trapping pollutants in the immediate area. Since we saw localized improvements in air quality in comparison to the surrounding areas, it can be concluded that the infrastructure layout in and around the campus contributed to lowered pollutant concentrations in select areas of the green space.

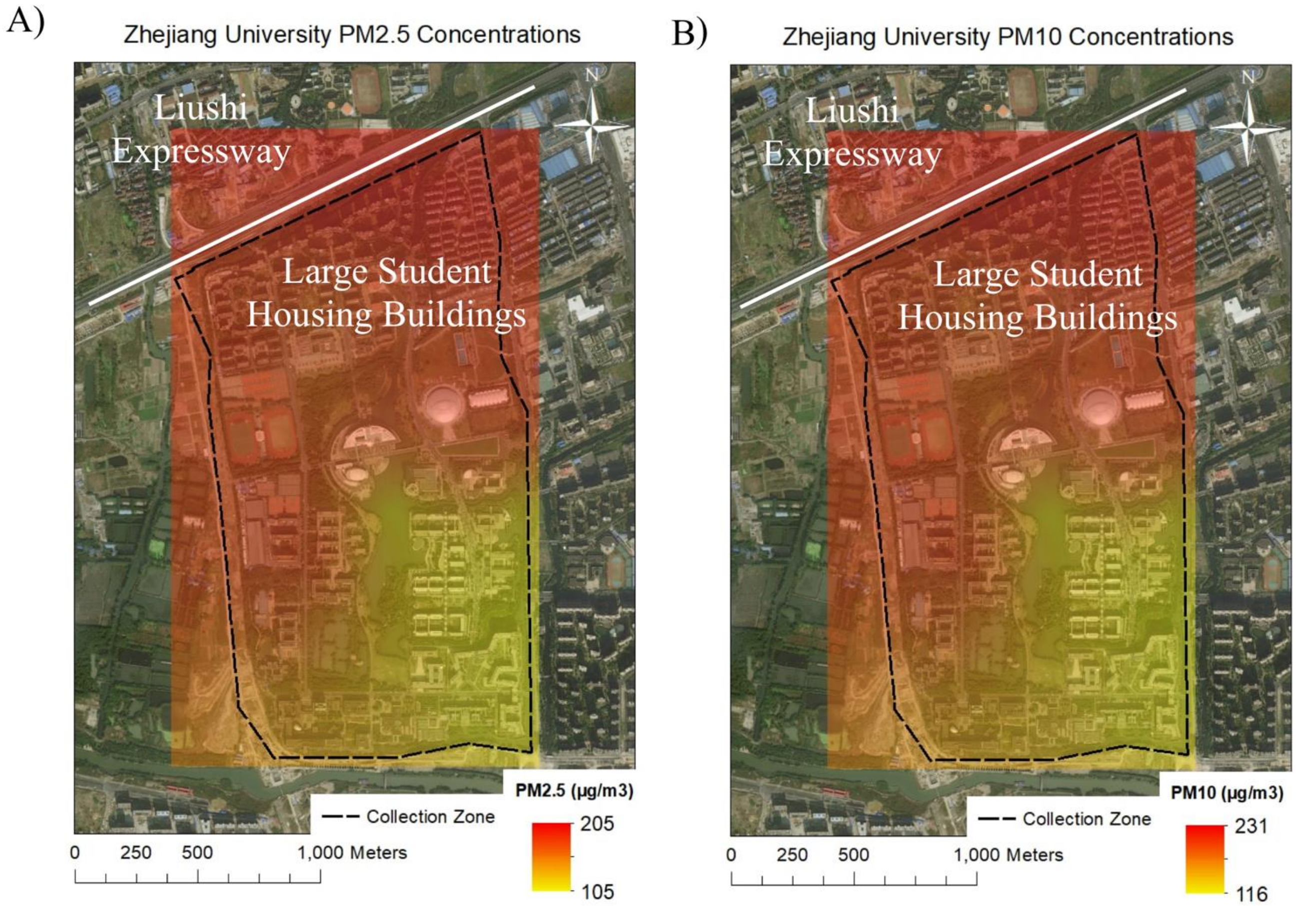

Figure 4.2: (A) PM2.5 and (B) PM10 concentration distributions for the Zhejiang University Zijingang Campus. Data collected November 14, 2017, Map created December 4, 2017.

4.1.2 Proximity to Pollutant Sources

We found that PM2.5 and PM10 had higher concentrations close to sources of pollutants. This pattern was present in multiple parks we studied in this research. Construction areas display a high correlation with areas of high particulate matter concentrations. This was observed in West Lake, Xixi National Wetland Park, and Jiayuan Park as seen in Figures 4.3 to 4.5. Construction areas are highlighted on the maps in in the figures, and a decreasing concentration gradient can be seen emanating from these areas.

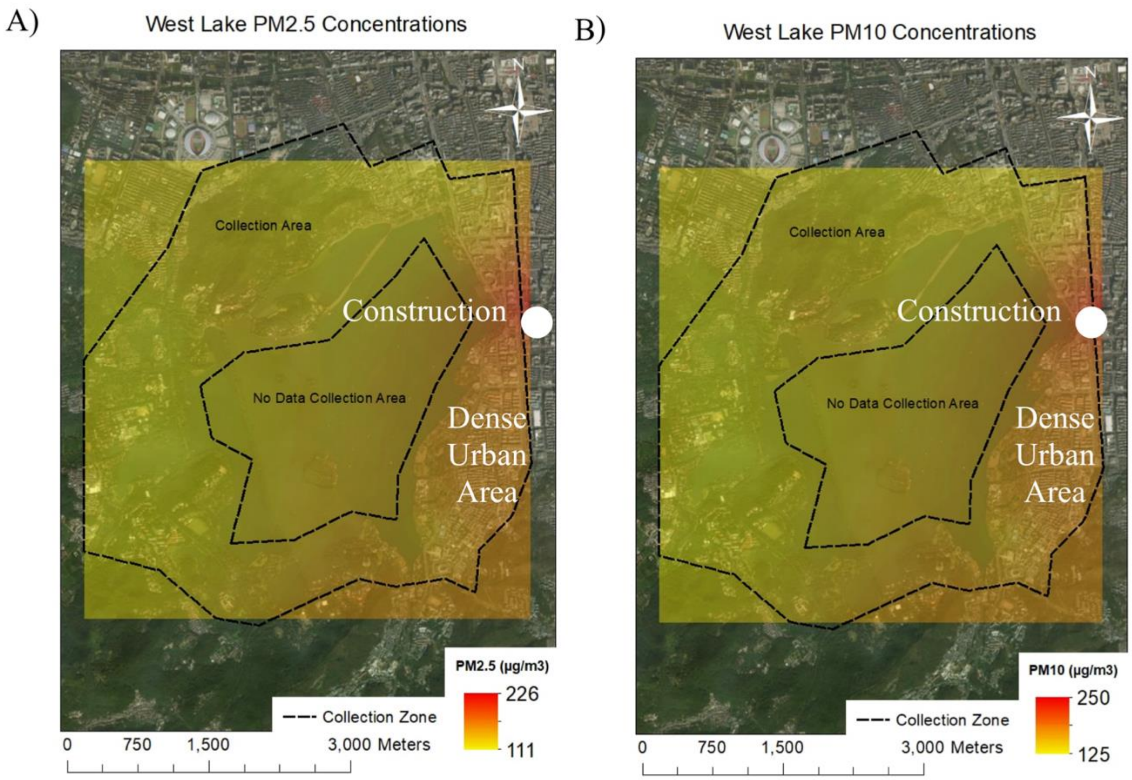

Figure 4.3: (A) PM2.5 and (B) PM10 concentration distributions for West Lake. Data collected November 29, 2017, Map created December 4, 2017.

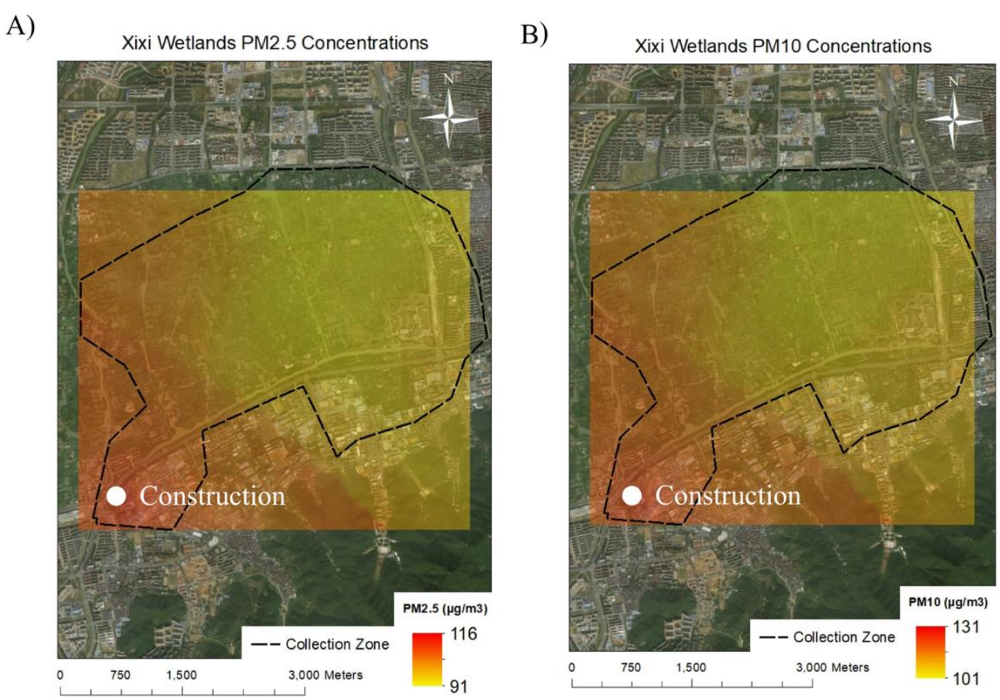

Figure 4.4: (A) PM2.5 and (B) PM10 concentration distributions for Xixi National Wetland Park. Data collected December 1, 2017, Map created December 4, 2017.

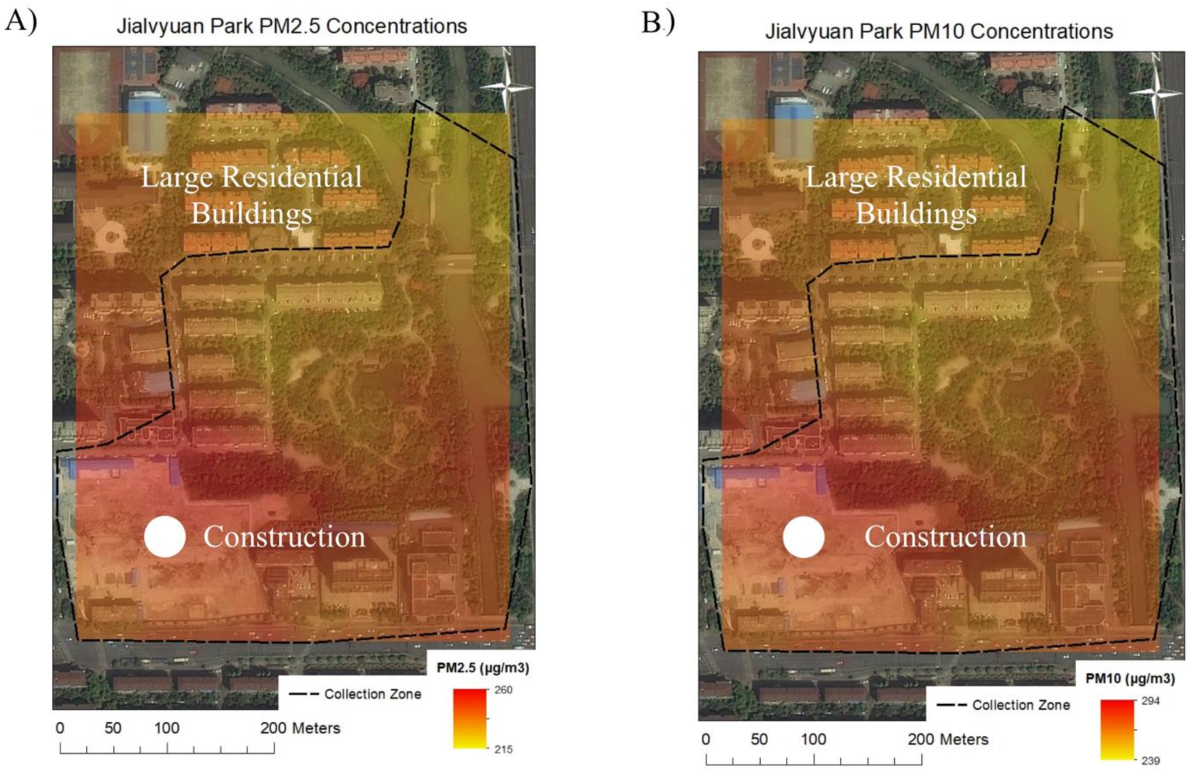

Figure 4.5: (A) PM2.5 and (B) PM10 concentration distributions for Jiayuan Park. Data collected November 14, 2017, Map created December 4, 2017.

A similar pattern was seen around other sources of pollutants. Around Shu Yuan Park, high concentrations of pollutants were found surrounding a gas station located northwest of the park, highlighted in Figure 4.6. This is an area frequented by vehicles and may experience higher emission rates from idling cars and trucks. The high concentrations in this area gradually decreased in the surrounding area, yet remained high within the park due to the canopy effect previously described. Similarly, we observed high concentrations of pollutants near major highways, roads, and dense urban areas. Surrounding the Zhejiang University Zijingang Campus, the Luishi Expressway exhibited high levels of pollution, with a decreasing gradient moving away from the road. This can be seen with several roadways surrounding parks, in West Lake, Jialvyuan Park, and the Wushan Scenic Area in Figures 4.3, 4.5, and 4.7, respectively.

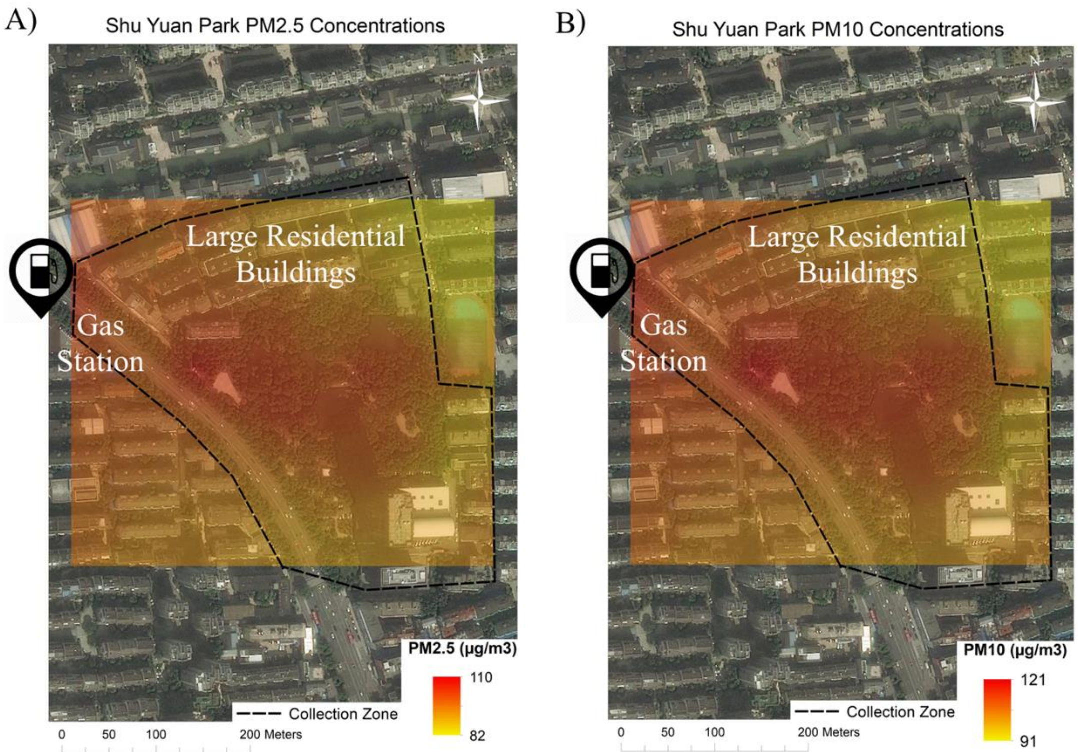

Figure 4.6: (A) PM2.5 and (B) PM10 concentration distributions for Shu Yuan Park. Data collected November 13, 2017, Map created December 4, 2017.

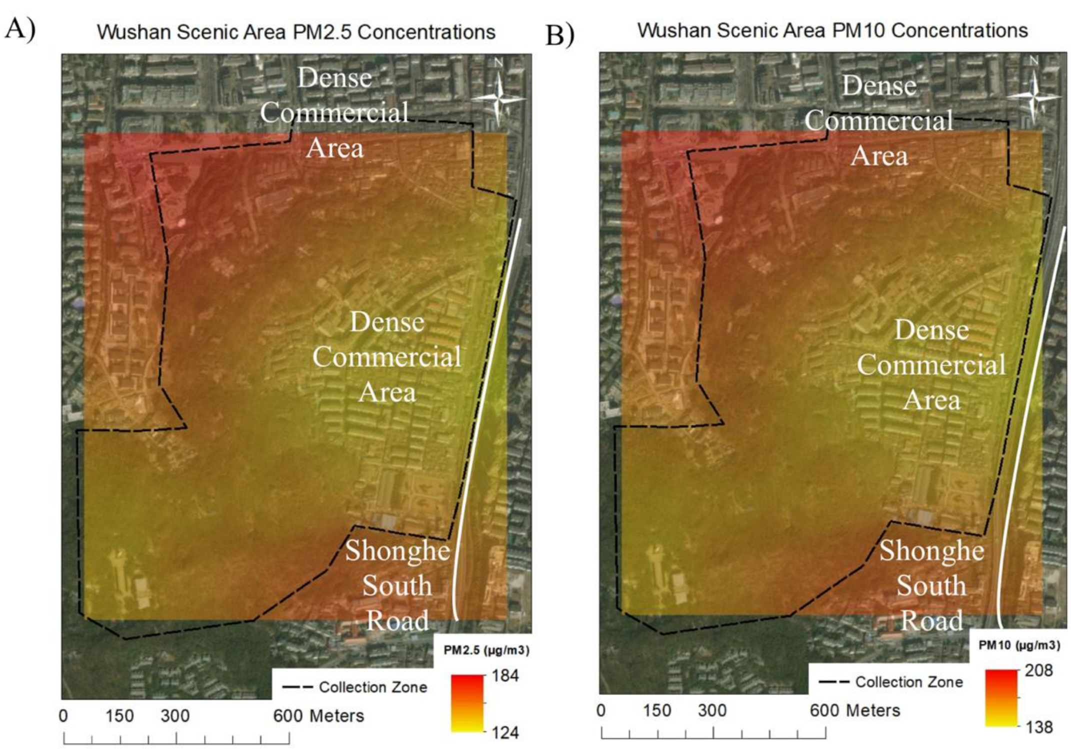

Figure 4.7: (A) PM2.5 and (B) PM10 Concentration distributions for the Wushan Scenic Area. Data collected November 15, 2017, Map created December 4, 2017.

Localized reductions compared to surrounding areas were present in areas that had larger distances from pollution sources, namely the Xixi National Wetland Park, West Lake, and Jialvyuan Park. It is interesting to note the concentration differences within each of these parks. In order of increasing park size the ranges of pollution concentration measured for Jilvyuan Park, West Lake, and Xixi National Wetland Park were 48 $\mu g/m^3$, 114 $\mu g/m^3$, and 25 $\mu g/m^3$ respectively. From this data, we cannot conclude a correlation between the magnitude of reductions and park size alone. We can, however, state that concentrations are lower in green spaces that are located at longer distances from high-emission areas. These patterns can be explained by the nature of gas movements. As gases expand and move away from their origins, their concentrations continuously decrease at changing rates dependent upon the structure of the surrounding area. Drawing from the conclusions made on landscape influence in 4.1.1, buildings and infrastructure can prevent pollutants from dissipating homogeneously from their sources. Based on these results, we conclude that particulate matter concentrations and air quality improves if distances from areas with high emissions are increased.

4.1.3 Canopy Coverage

In numerous parks, we observed pollutant concentrations that vary with canopy structures, as seen in Appendix J. The density of canopy vegetation over parks was proportional to the PM2.5 and PM10 seen in the area. Areas with higher canopy density correlated to areas with higher particulate matter concentrations. This can be seen in Shu Yuan Park and the Liuheta Culture Park in Figures 4.8 to 4.9. In each of these parks, areas of high particulate matter concentrations overlapped with areas classified as having a high canopy class composed of dense vegetation.

Shu Yuan Park exhibits this pattern in Figure 4.8. The center of the park has dense vegetation with a moderate to high canopy class. This coincides with high pollution concentrations found within the park. We found high concentrations near the entrance to the park along Moganshan Road, which then decreased slightly and remained constant throughout the densely wooded area.

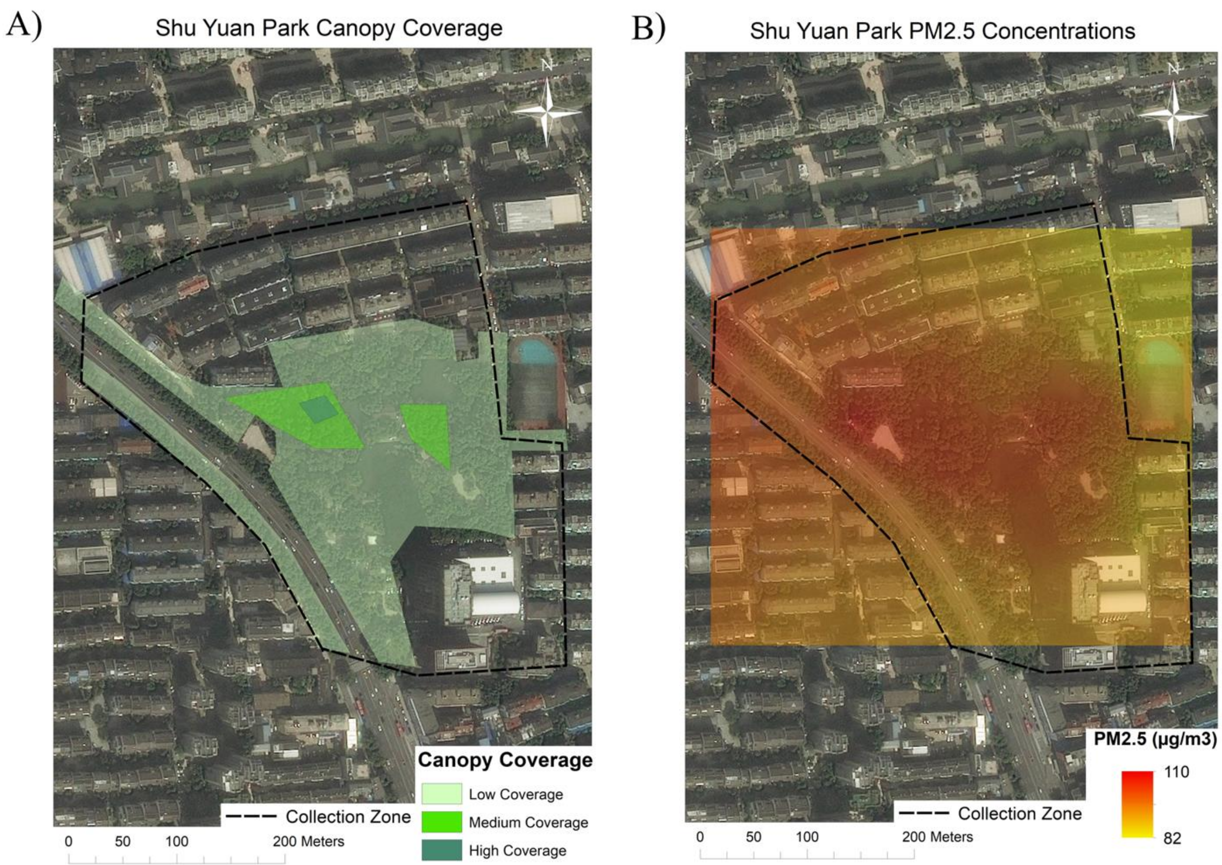

Figure 4.8: (A) Vegetation canopy and (B) PM2.5 concentration distributions for Shu Yuan Park. Data collected November 13, 2017, Map created December 4, 2017.

Similarly, this pattern was present at the Liuheta Culture Park as seen in Figure 4.9. In the north of the park, we found large areas of dense forest, which we classified as having a high canopy class. This region overlapped with areas of high particulate matter concentrations. This pattern was observed next to high pollutant concentrations near a roadway, an area which acted as a source of particulate matter. The area along the roadway, although having little to no canopy, also had high particulate matter concentrations. We believe this was due to the nearby pollution source.

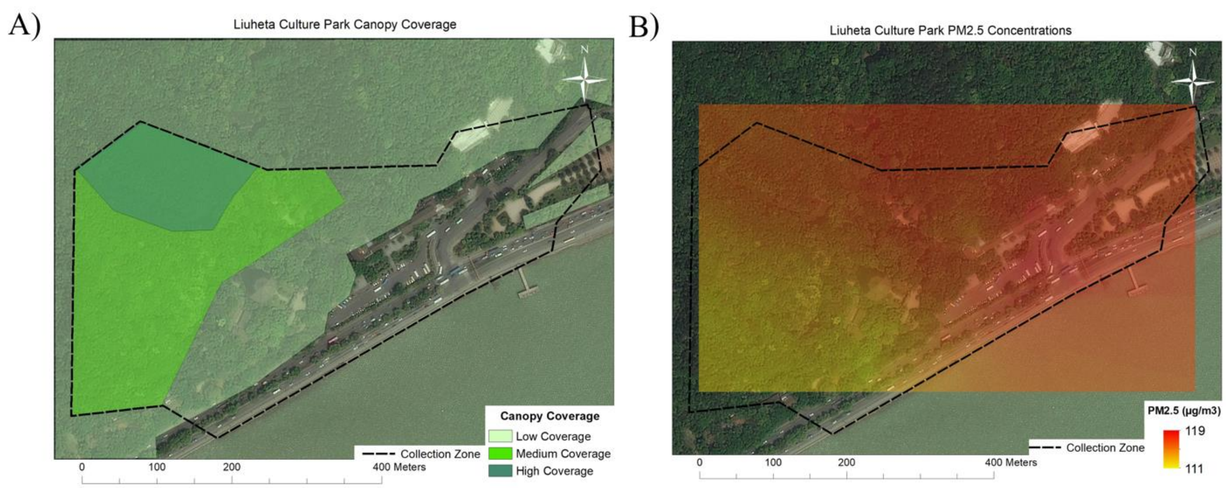

Figure 4.9: (A) Vegetation canopy and (B) PM2.5 concentration distributions for Liuheta Culture Park. Data collected November 20, 2017, Map created December 4, 2017.

In these two parks, we hypothesize that the large canopies of tree cover prevent upward air flow and thus upward pollution movement, thereby trapping pollutants. While the plants can filter some of the pollutants that get trapped in parks, the amount that remains is inhibited from moving out of the park by the umbrella effect. Because of this, parks with dense vegetation and high canopy coverage act as sinks and retain pollutants that are brought in from outside areas.

In contrast, we saw how this effect did not occur in areas with a low-density canopy. Wanxiang Park had a consistently low-density canopy throughout the park and thereby did not prevent pollutants from leaving into the outside environment as seen in Figure 4.10. While a dense band of particulate matter was found in the center of the park, this band continued out into the surrounding streets; this is most likely due to the particulate matter escaping the low density canopy.

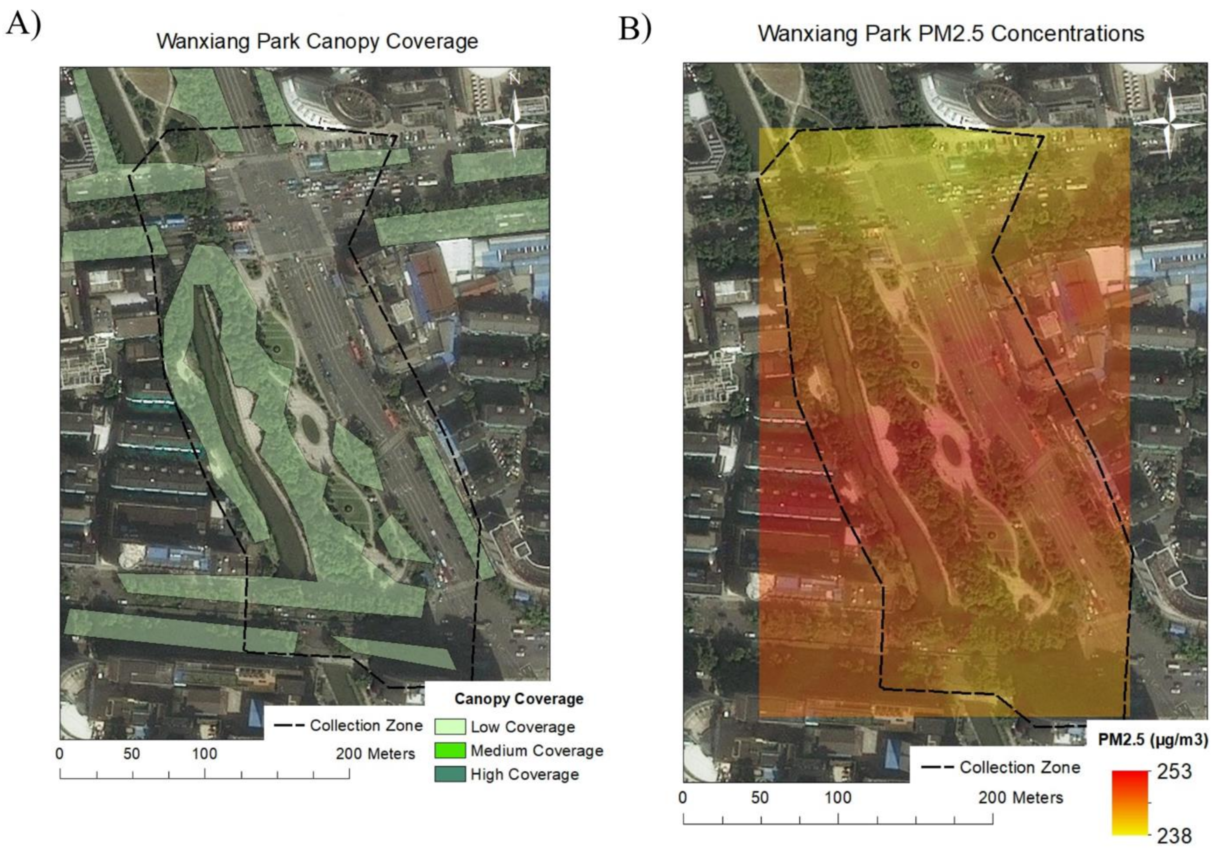

Figure 4.10: (A) Vegetation canopy and (B) PM2.5 concentration distributions for Wanxiang Park. Data collected November 14, 2017, Map created December 4, 2017.

4.1.4 Pattern Influences

The infrastructure, proximity to pollutant sources, and canopy coverage patterns each created a combined influence on the parks we studied in this research. We believe the proximity to sources of pollution has the largest influence on pollutant distributions, followed by city infrastructure layout and canopy density.

In each park, the pollutant concentrations are highest near sources of pollution. This is particularly evident in Jialvyuan Park, the Wushan Scenic Area, West Lake, Shu Yuan Park, Liuheta Culture Park, and Zhejiang University Zijingang Campus. Each of these parks had major pollution sources nearby, such as roadways, construction sites, and gas stations. From these sources, the particulate matter dispersed according to nearby infrastructure and landscape features. The presence of tall or large buildings would inhibit the flow of pollutants by acting as a wall, trapping them in a densely concentrated area. Where large buildings or other major pieces of infrastructure were not present, vegetation layout and density would control particulate distribution. After being influenced by those two, the density of the canopy within a park would further determine the distribution of pollution concentrations.

The combination of these patterns can be best seen at Shu Yuan Park, shown in Figure 4.11. The gas station in the northwest of the park acted as a source of pollutants, which were then blocked by buildings straddling the road and funneled down the road by the cars passing by. Finally, the particulate matter that entered the park was trapped in high concentrations due to the presence of dense canopy cover.

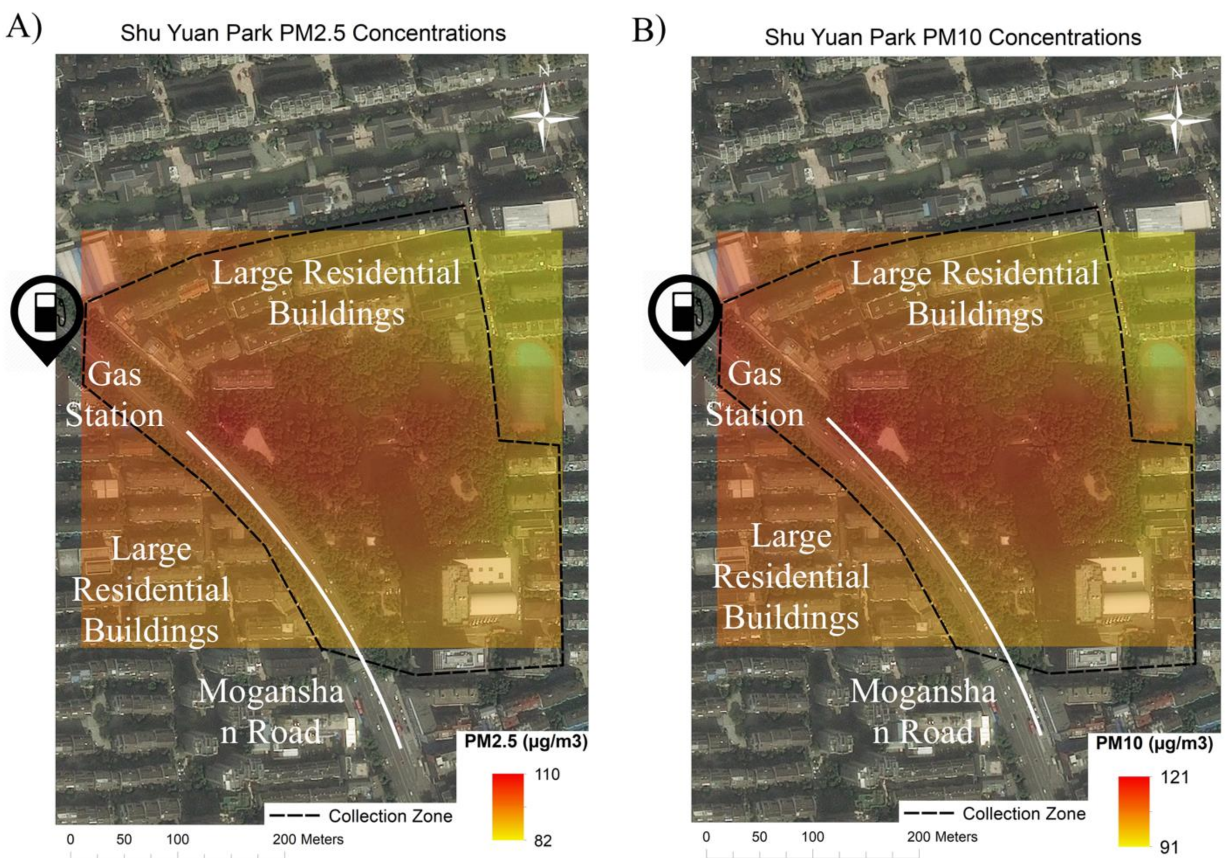

Figure 4.11: (A) Vegetation canopy and (B) PM2.5 concentration distributions for Shuyan Park. Data collected November 13, 2017, Map created December 4, 2017.

4.2 Social Implications

A survey conducted near West Lake revealed several opinions about the green spaces in Hangzhou. In conjunction with observations made in the eight green spaces we studied, we found ways in which parks in the city meet and do not meet the expectations and desires of citizens. Full survey results can be seen Appendix K.

4.2.1 Respondents

The respondents were primarily 19-35 year old females, with the majority of respondents visiting parks 1-3 times a week with friends, family, and by themselves. Demographics can be seen in Figures 4.12 to 4.15.

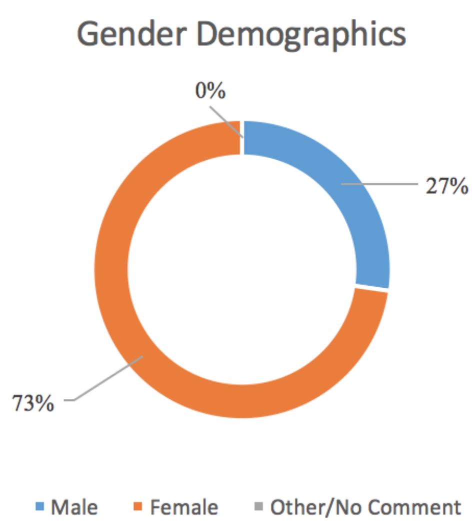

Figure 4.12: Gender demographics of survey respondents. December 4, 2017.

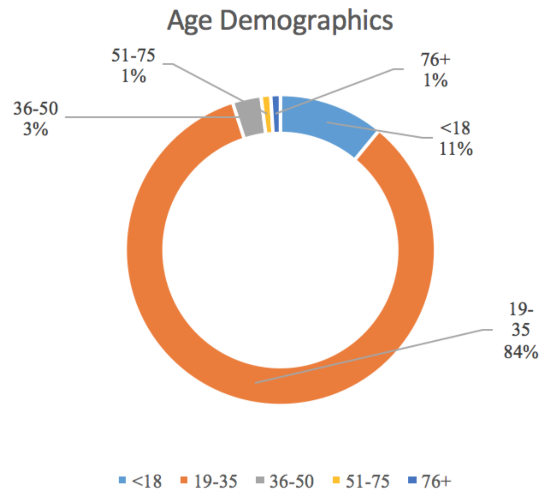

Figure 4.13: Age demographics of survey respondents. December 4, 2017.

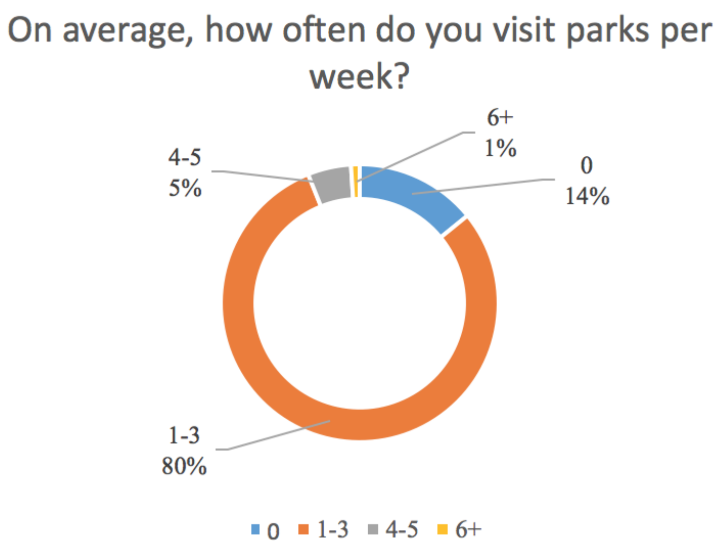

Figure 4.14: Visitation frequency demographics of survey respondents. December 4, 2017.

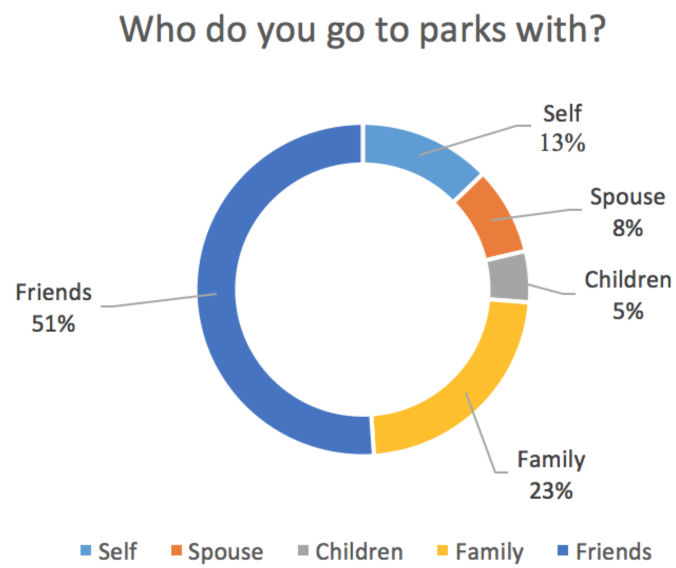

Figure 4.15: Visitation demographics of survey respondents. December 4, 2017.

4.2.2 Park Satisfaction

Our survey results showed that the primary reason citizens go to parks is for rest and relaxation, agreeing with previous findings discussed in Section 2.4.3. When asked about park function, 35.68% of respondents stated they used parks for rest and relaxation purposes, 35.14% for connecting with nature, and 12.97% for both recreation and for exercise. When subsequently asked if parks in Hangzhou fulfill their purpose for visiting, 71.7% of respondents were satisfied or very satisfied, as seen in Figure 4.16. This indicated that Hangzhou's parks are effective at meeting the goals of citizens. This was confirmed by the overall satisfaction citizens felt toward parks, with 83.8% of respondents being satisfied or very satisfied with the green spaces in the city, as seen in Figure 4.17. These responses showed that the parks in Hangzhou are designed well and with the intentions of citizens in mind.

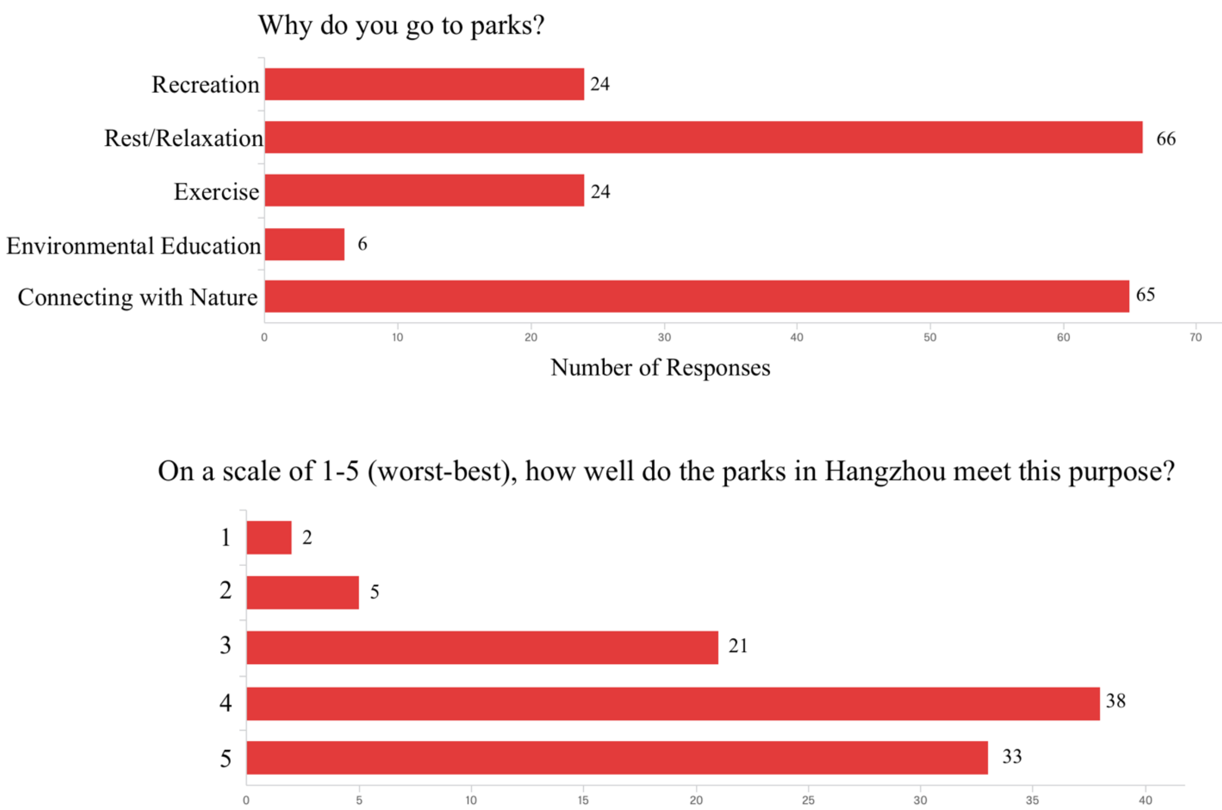

Figure 4.16: Purpose and satisfaction of park visitation. December 4, 2017.

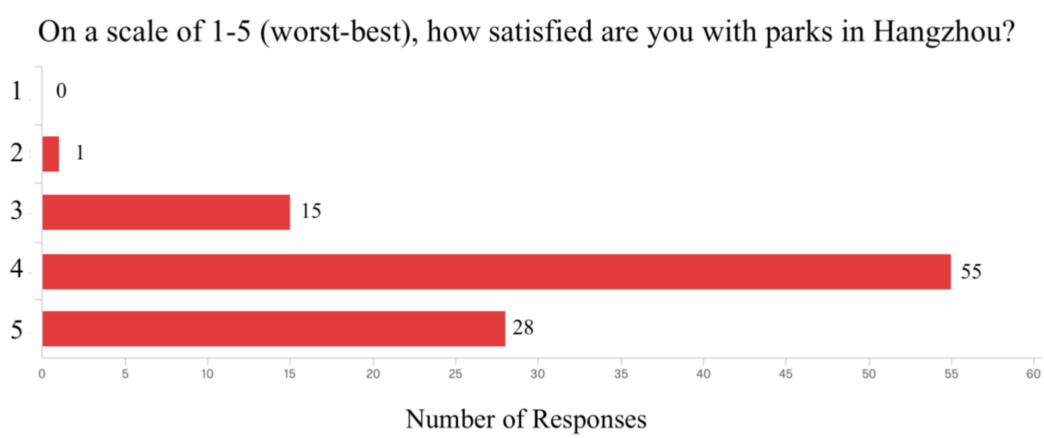

Figure 4.17: Overall park satisfaction. December 4, 2017.

In addition to overall feelings toward parks, we assessed the specific desires of citizens. On average, respondents ranked open grass areas as the most desired park feature, followed by benches, restrooms, and pergolas, with restaurants being the least desired, as shown in Figure 4.18. To compare with the observations we made in Appendix L, very few parks had sections of open grass — most parks we investigated had more area covered by trees, shrubs, and other vegetation. Many benches were located throughout the parks, and at least one public restroom was present in each park. By a margin of 19 responses, open grasses were selected as being the best feature in Hangzhou's parks, despite our observations that there were few grassy areas. By contrast, restrooms were selected as the worst feature in Hangzhou's parks, despite the presence of restrooms in all the parks we studied. This may be a result of poor quality despite the quantity of public restrooms.

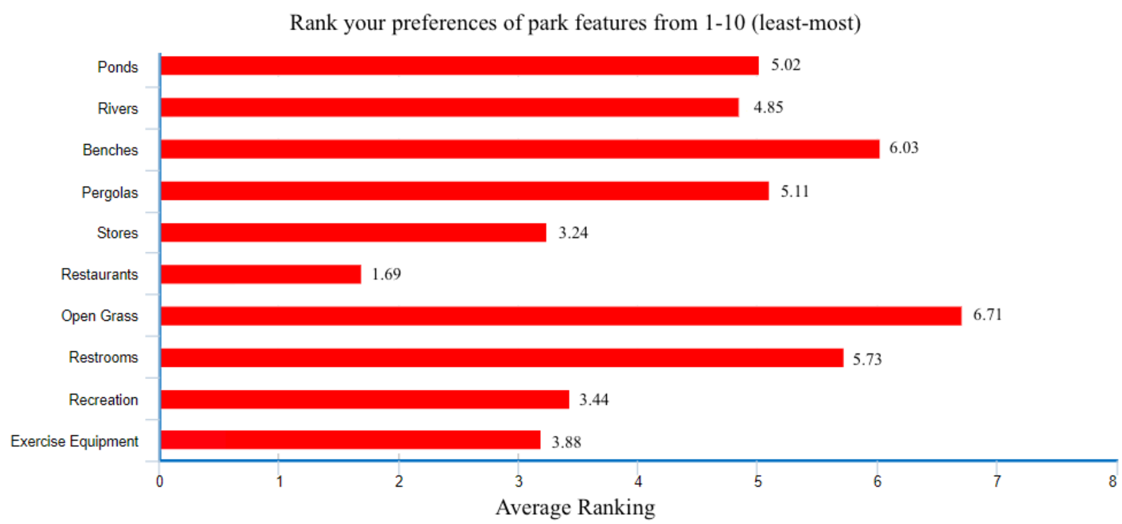

Figure 4.18: Preferred park features. December 4, 2017.

4.2.3 Environmental Opinions

An interesting connection can be drawn between the social approval of parks and their environmental impacts. A combined 78.57% of respondents believed that parks improve air quality well or very well. Of the remaining 21.43% of respondents, 18.37% were neutral on the topic and only a combined 3.06% believed parks do not improve air quality well. This widespread belief does not agree with the findings of our particulate matter concentration measurements.

4.2.4 Maintenance Equity

Maintenance plays an important role in the social approval of parks (see Section 2.2.3). Green spaces must be kept up in order to remain attractive to the public. At all of the parks we visited, maintenance crews were working, performing a variety of tasks ranging from raking leaves to picking up litter, as seen in Appendix M. Every park we analyzed was clean and showed evidence of continuous maintenance. We also observed maintenance equity between all of the parks we visited. Each park had a similar level of maintenance upkeep despite their different qualities. This is different from how parks in the United States work, where routine maintenance is based on property tax and on donations from the local residents. The current Chinese strategy is to focus government funds on needy areas and to allow the wealthy to develop and maintain their own local parks (see Section 2.4.4). Larger parks like West Lake or Xixi Wetlands generate enough tourism that they manage to pay for themselves as well as other green spaces. Many other parks, such as the Zhejiang University Campus, are owned and maintained by a large institution. This allows for the smaller parks to fall into one of two equity categories: government-funded park or club/community based park. This is why we saw perfect equity in the maintenance of the parks, regardless of size, location, or surroundings. Hangzhou residents are currently very satisfied with the city's urban green spaces and are willing to have their taxes increased to preserve the spaces' high quality (see Section 2.4.3).

4.3 Hangzhou's Pollution

While we observed trends in particulate matter movements, we did not see significant pollution reductions in the parks in Hangzhou. The pollution levels we recorded in Hangzhou were unhealthy according to international standards, reaching up to 8 times the accepted concentrations. The minimum particulate matter concentration we observed was 71 $\mu g/m^3$ at Shu Yuan Park, with other measured concentrations going up to 280 $\mu g/m^3$. Concentrations this high can lead to adverse health effects, and the fact that these concentrations are consistent is highly concerning (see Section 2.2.2). See Appendix N for standardized particulate matter concentration graphics. These graphics show, overall, how high the pollution is in Hangzhou. While we observed only minimal localized improvements in pollution concentrations as discussed in Section 4.1, any pollution reductions parks might create are insignificant compared to the larger pollution problem. China's coal based economy creates large amounts of pollution everyday that is felt in cities around the country. Small urban parks and vegetation cannot mitigate such high pollution concentrations and do not provide substantial benefits to the environment and air quality.

This suggests that parks primarily serve the social and mental health of urban residents. Despite the lack of positive environmental effects, parks provide benefits of more importance to visitors than pollution reduction. They serve as areas of rest and relaxation to serve as havens to park goers from tense urban lifestyles. Citizens in Hangzhou are overwhelmingly satisfied with the parks in the city and find happiness when using them. Parks remain important landmarks in cities for this reason.

4.4 Limitations

Given the complexity of our topic of interest and our time constraints, there were many potential sources of error in our data collection. First, our handheld device was not intended for professional field research. Using this detector may have resulted in inaccurate particulate matter readings. Second, our data collection only occurred during the autumn season. The local and regional climate and wind patterns change from month to month and have been shown to affect particulate matter concentrations as discussed in Section 2.2.2. Changing wind directions each season can bring pollution into Hangzhou from other cities, with northerly winds in the autumn and winter carrying pollutants from Beijing. Similarly, low humidity, temperatures, and rainfall in the autumn and winter months allows pollution concentrations to increase. Third, due to restrictions in our data collection time frame, we were not able to make observations on meteorologically similar days. Similarly, we could not collect all the data within each park simultaneously. This may have led to variations over time during data collection. Fourth, the resolution of data collection point distributions in each park varied based on the size of the green space. The distances between each data point were not consistent and therefore may not provide a clear comparison between parks.

Surveys also had potential sources of error. We used a convenience sampling method for surveying, which does not consider selecting subjects that are representative of the entire Hangzhou population. Random sampling could provide a more accurate representation of the opinions of citizens in Hangzhou. We also did not reach the number of survey responses that would make our study statistically significant. Limited results makes the claims we make from survey results less persuasive. This also resulted in uneven demographics with 75% female and 25% male respondents. This could have changed patterns we saw in our responses. The bulk of our surveys were distributed in the areas surrounding green spaces. This may have led to different results than if the surveys were conducted exclusively inside the parks. In addition, we only conducted surveys in a relatively wealthy section of Hangzhou. We felt error from this would be somewhat mitigated by the amount of people in the West Lake area who are only visiting there and do not live there, but it is still a possible source of error. We present possible ways to address these sources of error in Section 5.2.

4.5 Summary

Throughout this chapter we have identified and discussed a number of significant results. We identified three prominent particulate matter patterns involving the infrastructure surrounding and within green spaces, the proximity of the green spaces to pollutant sources, and the green spaces' vegetation canopy. Particulate matter patterns are not definitive for each of these categories, as there are many other factors influencing pollutant concentration; patterns can also be influenced by a mixture of the aforementioned factors. Of the categories we investigated, we believe that proximity to pollutant sources is the most influential. Finally, through our survey we noticed that a large proportion of Hangzhou citizens visit parks to rest, relax and to connect with nature. In Hangzhou, a large majority of citizens find that their purposes for going to parks are satisfied, as a result they feel happy at the parks. We will present recommendations for further analyzing pollutant concentration patterns and ways in which the city of Hangzhou can improve the social efficacy of green spaces in the next chapter.

5.0 Conclusions and Recommendations

In this chapter, we present our conclusions on the efficacy of green spaces related to environmental and social improvements in Hangzhou, China. To address these conclusions, we make recommendations on future areas of study and ways in which green space planning can be improved. These recommendations should help city planners design green spaces that are beneficial to the environment and society.

5.1 Conclusions

We reached several conclusions on green spaces through our research conducted for this project. Both environmental effects and public approval of green spaces are described below. Our conclusions and recommendations are based on the results we presented in Chapter 4.

5.1.1 Environmental Effects of Green Spaces

We reached the following three conclusions on green spaces from our research.

1. **Green spaces do not conclusively improve air pollution in urban areas.**

We observed varying levels of PM2.5 and PM10 concentrations in eight green spaces in Hangzhou. We did not identify a common characteristic of reduced pollutant concentrations in green spaces when compared to the surrounding environment. The green spaces, regardless of size, cannot clean the high amounts of pollution in the air at a fast enough rate that would show a significant difference among pollution levels around the park. The green space does help to clean the air of some pollutants, but mainly helps to trap and settle the pollutants from the air, allowing them to be carried away by groundwater.

2. **Proximity to pollution sources, infrastructure design, and canopy density affects pollution levels in and around green spaces.**

Data patterns revealed that the proximity of parks and green spaces to pollution sources was the largest contributing factor to geographic pollutant concentration differences. Increasing distance from pollution sources reduces particulate matter concentrations. Similarly, the design of infrastructure and the surrounding urban landscape changes how pollutants interact with green spaces. Roadways and large buildings influence air flow patterns and have the potential to direct pollutants both toward and away from green spaces. Finally, vegetation that creates relatively closed canopies over green spaces traps pollutants and prevents them from dissipating out of green spaces.

3. **Many factors influence pollution movements.**

Each of the factors identified by the results of this research contributes to the determination of pollution concentrations in green spaces. No single factor can be considered in the study of particulate matter distributions, and more research is needed to address the contributions of other factors.

5.1.2 Public's Approval of Green Spaces

We reached the following four conclusions on the public's approval of green spaces based on our research.

1. **People prefer open grass in parks.**

Through our survey, we determined that open grass was the most desired feature in parks, while restaurants were the least desired feature. Open grass was also ranked as the best feature in parks with almost a quarter of respondents listing it as such.

2. **Restrooms need an improvement.**

We gathered that restrooms are the worst feature in parks from our survey. We believe this is an issue of amenity quality. Public restrooms tend not to be the cleanest areas; this can give them a negative connotation and take away from the overall park visitor experience. No matter if our hypothesis is correct or incorrect, the public restrooms need improvement according to citizens of Hangzhou.

3. **People are satisfied with Hangzhou's parks.**

Citizens of Hangzhou are satisfied with their local parks. About 98.99% of the citizens that took our survey claimed to be satisfied. Specifically, 71.71% of respondents claimed to be satisfied with how well their reason for visiting was met.

4. **Resource allocation is adequately distributed between parks in Hangzhou.**

Our observations showed that Hangzhou's parks do not face disproportionate funding in accordance with their size, location, or visitation rates. Each park was well maintained, suggesting the economic structure discussed in Section 2.2.5 sufficiently cares for parks in Hangzhou. The contrast between this structure and that of Western countries shows that resource usage in other countries may be improved by adopting some policies in the Chinese model.

5. **Parks primarily provide social, rather than environmental benefits.**

The social benefits of parks and green spaces outweigh environmental benefits. As discussed in Section 5.1.1, green spaces do not definitively show localized pollution reductions compared to surrounding urban areas. Additionally, any improvements they may make are insignificant given the high pollution concentrations throughout the city. In contrast, parks are capable of providing areas of rest and relaxation for city residents. The satisfaction and happiness derived in these areas benefit Hangzhou’s residents and make them an important component of city infrastructure.

5.2 Recommendations

Based on the conclusions of our research, we can make several recommendations toward the improvement of green spaces in Hangzhou.

5.2.1 Ways to Increase Green Space Efficacy

- **Consider spatial layout of green spaces.**

City planners must carefully consider all factors of airflow and pollutant movements when designing green spaces. Instead of assuming that any type of green space or vegetation will improve pollution levels in the city, as discussed in Section 2.2.2, thoughtful manipulation of these factors can create green spaces that provide a clean environment for visitors.

- **Research source-sink theory applicability.**

Through our literature review we came across the source-sink concept (as elaborated on in Section 2.2.2). Although we were not able to make a full conclusion in regards to source-sink, some of our data suggest that it would be a fruitful avenue to explore. We recommend that a study be carried out that studies the possibility of parks behaving as sinks for pollution as well as the implications of this. The idea that parks could have worse air quality than their surrounding areas is an unintuitive and strange one, but it is a definite possibility, and we believe it is an important possibility to study.

- **Conduct further research into the multiscalar factors influencing particulate distribution.**

The scope of our research was limited and did not consider all factors that may affect particulate matter distribution. Further research is required to fully understand what factors influence pollution movement through urban green spaces. Potential areas of further research include the effects of meteorological conditions and differences in elevation. While this study was limited to eight parks in Hangzhou, additional studies can consider other green spaces in the city and collect particulate matter concentration data on a larger, city-wide scale to create a clear and defined picture of pollution distributions. In addition, it is important to take into account that pollution trends are not isolated to a city's bounds. They can be influenced by regional, national, or even international air quality conditions.

5.2.2 Ways to Increase Public Approval of Green Spaces

- **Focus on addressing citizen's green space preferences.**

Park satisfaction can be addressed or improved by catering to the preferences of their users. As concluded from our survey and discussed in Section 4.2.2, citizens in Hangzhou prefer open grassy areas over other amenities in parks, and use parks for rest and relaxation. Since we have concluded that dense trees do not conclusively decrease pollution in urban parks and have the potential to trap particulate matter, we suggest that urban planners turn their attention away from these vegetation structures. By focusing on developing open grassy areas, the benefits can be two fold. First, pollutants will not be trapped in dense canopy coverage thereby increasing pollution concentrations in the park. Second, park goers will have access to areas that satisfy their preferences and provide more areas for rest and relaxation.

Open grass is not the only thing that should be maintained, of course. Amenities such as restrooms, benches, and exercise equipment, among others, are also used by park visitors and should meet their needs. These strategies should effectively increase approval ratings of green space, more specifically parks. Restaurants, however, were not very attractive to visitors. We noticed that there were plenty of restaurants near parks; this can eliminate the need for them inside parks. For future green space developments, it may be beneficial to focus less on adding restaurants and rely more on people bringing their own food into the park. If the latter is an issue of concern, small snack stations could be introduced.

- **Confirm satisfaction levels city-wide.**

Hangzhou is doing an excellent job with the public approval of green spaces, as 99% of our survey respondents declared they were satisfied with the parks in Hangzhou. However, since our survey was conducted only in the West Lake area, one of Hangzhou's main tourist attractions, more surveying should be done to get a feel for satisfaction levels of other less popular areas. Consistent results throughout the city can support our results or reveal areas in the city that need more attention.

Despite the limitations of our research, we believe that this project has made an important contribution to showing that green spaces are not the be-all and end-all solution to China's pollution epidemic. Having a select amount of parks in an industrializing city like Hangzhou will only improve the air quality so much, and city planners should not be misled into thinking that pollution levels will be drastically reduced by creating new parks around the city. However, we have found that green spaces are still very useful in other ways. Namely, they help reduce people's stress and allow them to reconnect with nature. They also provide areas for people to easily socialize. Green spaces are very important areas to invest in when planning cities.

However, planners need to know what green spaces are good at so that they can plan them to be efficacious.

References

Alawadhi, S., Aldama-Nalda, A., Chourabi, H., Gil-Garcia, J., Leung, S., Mellouli, S., & Walker, S. (2012). Building understanding of smart city initiatives. *Lecture Notes in Computer Science,* 7443, 40-53.

Albino, V., Berardi, U., & Dangelico, R. M. (2015). Smart cities: Definitions, dimensions, performance, and initiatives. *Journal of Urban Technology*, *22*(1), 3-21.

Batagan, L. (2011). Indicators for economic and social development of future smart city. *Journal of Applied Quantitative Methods*, *6*, 27+.

Beyer, K. M., Kaltenbach, A., Szabo, A., Bogar, S., Nieto, F. J., & Malecki, K. M. (2014). Exposure to neighborhood green space and mental health: Evidence from the survey of the health of Wisconsin. *International Journal of Environmental Research and Public Health, 11*(3), 3453-3472.

Bosch, P., & Rovers, V. (2017). *CityKeys: Key performance indicators* [PowerPoint slides]. Retrieved from http://espresso.espresso-project.eu/wp-content/uploads/2017/03/CITYKeys-Webinar.pdf

Bureau of Indian Standards (BIS) (2016a). Encyclopædia Britannica Inc.

Bureau of Indian Standards. (2016b). Smart cities – indicators - lCS 13.020.20. New Delhi, India: Bureau of Indian Standards.

Chen, B., Adimo, O. A., & Bao, Z. (2009). Assessment of aesthetic quality and multiple functions of urban green space from the users' perspective: The case of Hangzhou Flower Garden, China. *Landscape and Urban Planning*, *93*(1), 76-82.

Chen, B., Bao, Z., & Zhu, Z. (2006). Assessing the willingness of the public to pay to conserve urban green space: The Hangzhou City, China, case. *Journal of Environmental Health*, *69*(5), 26.

CITYKeys. (2017). CITYKeys. Retrieved from http://www.citykeys-project.eu/

Dameri, R. (2013). Searching for smart city definition: A comprehensive proposal. *International Journal of Computers & Technology, 11*(5), 2544-2551.

ESRI. (2009). World imagery. Retrieved from https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9

Fan, S., Li, X., Han, J., Cao, Y., & Dong, L. (2017). Field assessment of the impacts of landscape structure on different-sized airborne particles in residential areas of Beijing, China. *Atmospheric Environment*, *166*, 192-203.

Farkas, G., & Safari Books Online. (2017). *Practical GIS*. Birmingham: Packt Publishing, Limited.

Frantz, K., Webster, C., & Glasze, G. (2002). The global spread of gated communities. Environment and Planning B: Planning and Design, 29(3), 315-320.

Fatichi, S., Leuzinger, S., & Körner, C. (2014). Moving beyond photosynthesis: From carbon source to sink-driven vegetation modeling. New Phytologist, 201(4), 1086-1095.

Gallagher, J. (2015). Greener but not cleaner? How trees can worsen urban air pollution. Retrieved from https://theconversation.com/greener-but-not-cleaner-how-trees-can-worsen-urban-air-pollution-44856

Greco, I., & Cresta, A. (2015). A smart planning for smart city: The concept of smart city as an opportunity to re-think the planning models of the contemporary city. *Computational science and its applications -- ICCSA 2015: 15th international conference, Banff, AB, Canada, June 22-25, 2015, proceedings, part II* (pp. 563-576). Cham, Switzerland: Springer International Publishing.

Green Business Certification Inc. (2017). The sustainable SITES initiative. Retrieved from http://www.sustainablesites.org/about

Groenewegen, P. P., Berg, Agnes E., Van Den, Vries, S. d., & Verheij, R. A. (2006). Vitamin G: Effects of green space on health, well-being, and social safety. *BMC Public Health, 6*(1), 149.

Gromke, C. (2011). A vegetation modeling concept for building and environmental aerodynamics wind tunnel tests and its application in pollutant dispersion studies. *Environmental Pollution, 159*(8), 2094-2099.

Gromke, C., & Ruck, B. (2012). Pollutant concentrations in street canyons of different aspect ratio with avenues of trees for various wind directions. *Boundary-Layer Meteorology, 144*(1), 41-64.

Hall, R., Bowerman, B., Taylor, J., Todosow, H., & Von Wimmersperg, U. (2000, Sep. 28). The vision of a smart city. *Second International Life Extension Technology Workshop.*

Retrieved from https://digital.library.unt.edu/ark:/67531/metadc717101/m2/1/high_res_d/773961.pdf

Han, H., Ma, Q., & Li, Y. (2017). Urban growth boundaries of the Hangzhou metropolitan area based on ecosystem service. *International Review for Spatial Planning and Sustainable Development*, *5*(2), 4-16.

Hangzhou Planning Bureau. (2010). Hangzhou planning bureau overall master plan. Retrieved from http://www.hzplanning.gov.cn/index.aspx?tabid=e8227e40-45c1-40e6-a962-4ba63207add7

Hangzhou Planning Bureau. (2015). Urban green system. Retrieved from http://www.hzplanning.gov.cn/index.aspx?tabid=34777527-b79c-4543-86c7-f21c5a5111d7

Hardoy, J., Mitlin, D., & Satterthwaite, D. (1992). *Environmental problems in third world cities* (3rd ed.). London, England: London England Earthscan Publications.

Harrison, C., Eckman, B., Hamilton, R., Hartswick, P., Kalagnanam, J., Paraszczak, J., & Williams, P. (2010). Foundations for smarter cities. *IBM Journal of Research and Development, 54*(4), 1-16.

Harrison, C., & Donnelly, I. A. (2011). *A theory of smart cities.* Hull, UK: The University of Hull.

Hinsbergh, G. (2017). China's top 10 largest cities. Retrieved from https://www.chinahighlights.com/travelguide/top-large-cities.htm

Hollands, R. G. (2008). Will the real smart city please stand up? *City*, *12*(3), 303-320.

IEEE. (2017). Smart cities: About. Retrieved from https://smartcities.ieee.org/about.html

Ishida, T. (2002, Jul). Digital city Kyoto. *Communications of the ACM,* 76-81.

Janssen, N. A., Hoek, G., Simic-Lawson, M., Fischer, P., Van Bree, L., Ten Brink, H., . . . & Brunekreef, B. (2011). Black carbon as an additional indicator of the adverse health effects of airborne particles compared with PM10 and PM2. 5. *Environmental Health Perspectives, 119*(12), 1691.

Maas, J., Verheij, R., Groenewegen, P., Vries, S., & Spreeuwenberg, P. (2006). Green space, urbanity, and health: How strong is the relation? *Journal of Epidemiology and Community Health, 60*(7), 587-592.

Karayannis, G. (2014). Dissecting ISO 37120: Why this new smart city standard is good news for cities. Retrieved from http://smartcitiescouncil.com/article/dissecting-iso-37120-why-new-smart-city-standard-good-news-cities

Landa, A. (2017). Why do we need smart cities? Retrieved from http://usgbcma.org/blog/why-do-we-need-smart-cities

Li, L., Lu, D., & Kang, W. (2016). Examining urban impervious surface distribution and its dynamic change in Hangzhou metropolis. *Remote Sensing, 8*(3), 265.

Liu, L., Zhou, L., Vaughn, B., Miller, J., Brand, W., Rothe, M., & Xia, L. (2014). Background variations of atmospheric CO2 and carbon-stable isotopes at Waliguan and Shangdianzi stations in China. Journal of Geophysical Research: Atmospheres, 119(9), 5602-5612.

Lombardi, P., Giordano, S., Farouh, H., & Yousef, W. (2012). Modelling the smart city performance. *Innovation: The European Journal of Social Science Research, 25*(2), 137-149.

MacKenzie, R. (2015). Do trees really help clear the air in our cities? *The Epoch Times.* Retrieved from https://search.proquest.com/docview/1768310972

McDonald, A. G., Bealey, W. J., Fowler, D., Dragosits, U., Skiba, U., Smith, R. I., . . . & Nemitz, E. (2007). Quantifying the effect of urban tree planting on concentrations and depositions of PM10 in two UK conurbations. *Atmospheric Environment, 41*(38), 8455-8467.

McPherson, E. G. & Rowntree, R. A. (1993). Energy conservation potential of urban tree planting. *Journal of Arboriculture, 19*(6), 321.

Nowak, D., Hoehn, R., Crane, D., & Stevens, J. (2010). *Assessing urban forest effects and values: Chicago's urban forest*. Newtown Square, PA: USDA Forest Service.

Nowak, D. (2017). The effects of urban trees on air quality. Retrieved from https://www.nrs.fs.fed.us/units/urban/local-resources/downloads/Tree_Air_Qual.pdf

Nowak, D. & Crane, D. E. (2002). Carbon storage and sequestration by urban trees in the USA. *Environmental Pollution, 116*(3), 381-389.

Nowak, D., Crane, D. E., & Stevens, J. C. (2006). Air pollution removal by urban trees and shrubs in the United States. *Urban Forestry & Urban Greening, 4*(3), 115-123.

Pandis, S. N., Skyllakou, K., Florou, K., Kostenidou, E., Kaltsonoudis, C., Hasa, E., & Presto, A. A. (2016). Urban particulate matter pollution: A tale of five cities. *Faraday Discussions, 189*(0), 277-290.

Parliamentary Office of Science and Technology. (2016). Green spaces and health. POSTnote, 538, 1-5.

Pataki, D. E., Carreiro, M. M., Cherrier, J., Grulke, N. E., Jennings, V., Pincetl, S., . . . & Zipperer, W. C. (2011). Coupling biogeochemical cycles in urban environments: Ecosystem services, green solutions, and misconceptions. *Frontiers in Ecology and the Environment, 9*(1), 27-36.

SOACU. (2017). Hangzhou Dianzi University. Retrieved from http://www.soacuni.com/InfoHZDU.php

Song, H., Thisse, J., & Zhu, X. (2012). Urbanization and/or rural industrialization in China. *Regional Science and Urban Economics, 42*(1-2), 126-134.

Thompson, C. W., Roe, J., Aspinall, P., Mitchell, R., Clow, A., & Miller, D. (2012). More green space is linked to less stress in deprived communities: Evidence from salivary cortisol patterns. *Landscape and Urban Planning, 105*(3), 221-229.

Tyagi, A., & Singh, P. (2013). Applying kriging approach on pollution data using GIS software. *International Journal of Environmental Engineering and Management, 4*(3), 185-190.

U.S. Green Building Council. (2017a). *LEED v4 for neighborhood development.* Retrieved from https://www.usgbc.org/sites/default/files/LEED%20v4%20ND_07.8.17_current.pdf

United Nations. (2015). *World urbanization prospects: The 2014 revision.* New York, NY: United Nations.

United States Environmental Protection Agency. (2016). Particulate matter (PM) basics. Retrieved from https://www.epa.gov/pm-pollution/particulate-matter-pm-basics#PM

Van Den Berg, A., Maas, J., Verheij, R., & Groenewegen, P. (2010). Green space as a buffer between stressful life events and health. *Social Science & Medicine, 70*(8), 1203-1210.

Venkateswarlu, B., & Visperas, R. (1987). Source-sink relationships in crop plants. Manila, Philippines: International Rice Research Institute.

Vos, P., Maiheu, B., Vankerkom, J., & Janssen, S. (2013). Improving local air quality in cities: To tree or not to tree? *Environmental Pollution, 183,* 113-122.

Walsh, M. (2015). Rising car use and smog sullies China's most photogenic city. Retrieved from http://scholar.aci.info/view/1465c41dcbb5c0c0128/14c4924fa33000f0021

Wang, J., & Ogawa, S. (2015). Effects of meteorological conditions on PM2.5 concentrations in Nagasaki, Japan. International Journal of Environmental Research and Public Health, 12(8), 9089-9101.

Wania, A., Bruse, M., Blond, N., & Weber, C. (2012). Analyzing the influence of different street vegetation on traffic-induced particle dispersion using microscale simulations. *Journal of Environmental Management, 94*(1), 91-101.

WCCD. (2017a). *WCCD city data for United Nations sustainable development goals* [PowerPoint slides]. Retrieved from http://www.dataforcities.org/publications/

Wolch, J. R., Byrne, J., & Newell, J. P. (2014). Urban green space, public health, and environmental justice: The challenge of making cities 'Just green enough'. *Landscape and Urban Planning*, *125*, 234-244.

World Health Organization. (2006). *WHO air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide: Global update 2005 : Summary of risk assessment*. Geneva, Switzerland: World Health Organization.

World Health Organization Regional Office for Europe. (2016). *Urban green spaces and health.* Copenhagen: World Health Organization.

Wu, J., Xie, W., Li, W., & Li, J. (2015). Effects of urban landscape pattern on PM2. 5 pollution—a Beijing case study. *PloS One, 10*(11), e0142449.

Wu, Y., Fan, P., Li, B., Ouyang, Z., Liu, Y., & You, H. (2017). The effectiveness of planning control on urban growth: Evidence from Hangzhou, China. *Sustainability, 9*(5), 855.

Xiao, Y., Lu, Y., Guo, Y., & Yuan, Y. (2017). Estimating the willingness to pay for green space services in Shanghai: Implications for social equity in urban China. Urban Forestry & Urban Greening, 26, 95-103.

Xiao, Y., Wang, Z., Li, Z., & Tang, Z. (2017). An assessment of urban park access in Shanghai – implications for the social equity in urban China. Landscape and Urban Planning, 157, 383-393.

Yang, X., Yue, W., Xu, H., Wu, J., & He, Y. (2014). Environmental consequences of rapid urbanization in Zhejiang province, East China. *International Journal of Environmental Research and Public Health, 11*(7), 7045-7059.

Zhejiang Provincial Government. (2012). Hangzhou Dianzi University. Retrieved from http://english.zj.gov.cn/art/2012/5/30/art_11122_164346.html

Appendix A: Sponsor Description

Hangzhou Dianzi University strives to develop students with quality talents and innovative skills (Zhejiang, 2012). Their focus on scientific and technological research is exemplified in their numerous research projects and prominence in the local scientific community. The school is widely known in China as “The Cradle of Entrepreneurs” for their engineering, scientific, and business focused curriculum. HDU was founded in 1956 with the original name of Hangzhou Institute of Electrical Engineering, and today 2,200 faculty and staff teach 28,000 full time students. It is a non-profit, public institution (SOACU, 2017).

The university offers courses and programs for higher education degrees, including bachelors, masters, and doctorates (SOACU, 2017). HDU has numerous areas of concentration with a particular focus in the science and engineering disciplines.

Since 2000, Hangzhou Dianzi University has been managed by the Provincial Government, under the Ministry of Industrial and Information Technology (SOACU, 2017). Below government leadership, the head of Hangzhou Dianzi University is President Xue Anke.

The Zhejiang Smart City Research Center of HDU, founded in 2013 and dedicated to the research and practices of smart cities (L. Huang, personal communication, September 11, 2017). The center puts a primary focus on smart urban planning, smart health, smart water affairs, smart education, and smart artificial intelligence. Dr. Lu Huang is the head of the smart city planning and assessment division.

Appendix B: Smart City Definitions

Table B.1: Smart City Definitions

Definition	Source
Smart city as a high-tech intensive and advanced city that connects people, information and city elements using new technologies in order to create a sustainable, greener city, competitive and innovative commerce, and an increased life quality.	Bakıcı et al. (2012T. Bakıcı, E. Almirall, and J. Wareham, "A Smart City Initiative: The Case of Barcelona," *Journal of the Knowledge Economy* 2: 1 (2012) 1–14. [Google Scholar])
Being a smart city means using all available technology and resources in an intelligent and coordinated manner to develop urban centers that are at once integrated, habitable, and sustainable.	Barrionuevo et al. (2012J.M. Barrionuevo, P. Berrone, and J.E. Ricart, "Smart Cities, Sustainable Progress," *IESE Insight* 14 (2012) 50–57.[Crossref], [Google Scholar])
A city is smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance.	Caragliu et al. (2011A. Caragliu, C. Del Bo, and P. Nijkamp, "Smart Cities in Europe," *Journal of Urban Technology* 18: 2 (2011) 65–82. doi: 10.1080/10630732.2011.601117[Taylor & Francis Online], [Web of Science ®], [Google Scholar])
Smart cities will take advantage of communications and sensor capabilities sewn into the cities' infrastructures to optimize electrical, transportation, and other logistical operations supporting daily life, thereby improving the quality of life for everyone.	Chen (2010T.M. Chen, "Smart Grids, Smart Cities Need Better Networks [Editor's Note]," *IEEE Network* 24: 2 (2010) 2–3. doi: 10.1109/MNET.2010.5430136[Crossref], [Web of Science ®], [Google Scholar])
Two main streams of research ideas: 1) smart cities should do everything related to governance and economy using new thinking paradigms and 2) smart cities are all about networks of sensors, smart devices, real-time data, and ICT integration in every aspect of human life.	Cretu (2012G.L. Cretu, "Smart Cities Design Using Event-driven Paradigm and Semantic Web," *Informatica Economica* 16: 4 (2012) 57–67. [Google Scholar])
Smart community – a community which makes a conscious decision to aggressively deploy technology as a catalyst to solving its social and business needs – will undoubtedly focus on building its high-speed broadband infrastructures, but the real opportunity is in rebuilding and renewing a sense of place, and in the process a sense of civic pride. […] Smart communities are not, at their core, exercises in the deployment and use of technology, but in the promotion of economic development, job growth, and an increased quality of life. In other words, technological propagation of smart communities isn't an end in itself, but only a means to reinventing cities for a new economy and society with clear and compelling community benefit.	Eger (2009J.M. Eger, "Smart Growth, Smart Cities, and the Crisis at the Pump A Worldwide Phenomenon," *I-Ways* 32: 1 (2009) 47–53. [Google Scholar])
A smart city is based on intelligent exchanges of information that flow between its many different subsystems. This flow of information is analyzed and translated into citizen and commercial services. The city will act on this information flow to make its wider ecosystem more resource-efficient and sustainable. The information exchange is based on a smart governance operating framework designed to make cities sustainable.	Gartner (2011)
A city well performing in a forward-looking way in economy, people, governance, mobility, environment, and living, built on the smart combination of endowments and activities of self-decisive, independent and aware citizens. Smart city generally refers to the search and identification of intelligent solutions which allow modern cities to enhance the quality of the services provided to citizens.	Giffinger et al. (2007R. Giffinger, C. Fertner, H. Kramar, R.Kalasek, N. Pichler-Milanović, and E.Meijers, *Smart Cities: Ranking of European Medium-sized Cities* (Vienna: Centre of Regional Science, 2007). [Google Scholar])
A smart city, according to ICLEI, is a city that is prepared to provide conditions for a healthy and happy community under the challenging conditions that global, environmental, economic and social trends may bring.	Guan (2012L. Guan, "Smart Steps To A Battery City," *Government News* 32: 2 (2012) 24–27. [Google Scholar])
A city that monitors and integrates conditions of all of its critical infrastructures, including roads, bridges, tunnels, rails, subways, airports, seaports, communications, water, power, even major buildings, can better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizens.	Hall (2000R.E. Hall, "The Vision of a Smart City." Proc. of the 2nd International Life Extension Technology Workshop, Paris, France, 2000. [Google Scholar])
A city connecting the physical infrastructure, the IT infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city.	Harrison et al. (2010C. Harrison, B. Eckman, R. Hamilton, P.Hartswick, J. Kalagnanam, J. Paraszczak, and P. Williams, "Foundations for Smarter Cities," *IBM Journal of Research and Development* 54: 4 (2010) 1–16. doi: 10.1147/JRD.2010.2048257[Crossref], [Web of

	Science ®], [Google Scholar])
(Smart) cities as territories with high capacity for learning and innovation, which is built-in the creativity of their population, their institutions of knowledge creation, and their digital infrastructure for communication and knowledge management.	Komninos (2011N. Komninos, "Intelligent Cities: Variable Geometries of Spatial Intelligence," *Intelligent Buildings International* 3: 3 (2011) 172–188. doi: 10.1080/17508975.2011.579339[Taylor & Francis Online], [Google Scholar])
Smart cities are the result of knowledge-intensive and creative strategies aiming at enhancing the socio-economic, ecological, logistic and competitive performance of cities. Such smart cities are based on a promising mix of human capital (e.g. skilled labor force), infrastructural capital (e.g. high-tech communication facilities), social capital (e.g. intense and open network linkages) and entrepreneurial capital (e.g. creative and risk-taking business activities).	Kourtit and Nijkamp (2012K. Kourtit, and P. Nijkamp, "Smart Cities in the Innovation Age," *Innovation: The European Journal of Social Science Research* 25: 2 (2012) 93–95.[Taylor & Francis Online], [Web of Science ®], [Google Scholar])
Smart cities have high productivity as they have a relatively high share of highly educated people, knowledge-intensive jobs, output-oriented planning systems, creative activities and sustainability-oriented initiatives.	Kourtit et al. (2012K. Kourtit, and P. Nijkamp, "Smart Cities in the Innovation Age," *Innovation: The European Journal of Social Science Research* 25: 2 (2012) 93–95.[Taylor & Francis Online], [Web of Science ®], [Google Scholar])
Smart city [refers to] a local entity - a district, city, region or small country -which takes a holistic approach to employ[ing] information technologies with real-time analysis that encourages sustainable economic development.	IDA (2012IDA Singapore, "iN2015 Masterplan" (2012) <http://www.ida.gov.sg/~/media/Files/Infocomm%20Landscape/iN2015/Reports/realisingthevisionin2015.pdf> [Google Scholar])
A community of average technology size, interconnected and sustainable, comfortable, attractive and secure.	Lazaroiu and Roscia (2012G.C. Lazaroiu, and M. Roscia, "Definition Methodology for the Smart Cities Model," *Energy* 47: 1 (2012) 326–332. doi: 10.1016/j.energy.2012.09.028[Crossref], [Web of Science ®], [Google Scholar])
The application of information and communications technology (ICT) with their effects on human capital/education, social and relational capital, and environmental issues is often indicated by the notion of smart city.	Lombardi et al. (2012P. Lombardi, S. Giordano, H. Farouh, and W. Yousef, "Modelling the Smart City Performance," *Innovation: The European Journal of Social Science Research* 25: 2 (2012) 137–149.[Taylor & Francis Online], [Web of Science ®], [Google Scholar])
A smart city infuses information into its physical infrastructure to improve conveniences, facilitate mobility, add efficiencies, conserve energy, improve the quality of air and water, identify problems and fix them quickly, recover rapidly from disasters, collect data to make better decisions, deploy resources effectively, and share data to enable collaboration across entities and domains.	Nam and Pardo (2011T. Nam, and T.A. Pardo, "Conceptualizing Smart City with Dimensions of Technology, People, and Institutions," Proc. 12th Conference on Digital Government Research, College Park, MD, June 12–15, 2011. [Google Scholar])
Creative or smart city experiments […] aimed at nurturing a creative economy through investment in quality of life which in turn attracts knowledge workers to live and work in smart cities. The nexus of competitive advantage has […] shifted to those regions that can generate, retain, and attract the best talent.	Thite (2011M. Thite, "Smart Cities: Implications of Urban Planning for Human Resource Development," *Human Resource Development International* 14: 5 (2011) 623–631. doi: 10.1080/13678868.2011.618349[Taylor & Francis Online], [Google Scholar])
Smart cities of the future will need sustainable urban development policies where all residents, including the poor, can live well and the attraction of the towns and cities is preserved. […] Smart cities are cities that have a high quality of life; those that pursue sustainable economic development through investments in human and social capital, and traditional and modern communications infrastructure (transport and information communication technology); and manage natural resources through participatory policies. Smart cities should also be sustainable, converging economic, social, and environmental goals.	Thuzar (2011M. Thuzar, "Urbanization in SouthEast Asia: Developing Smart Cities for the Future?," *Regional Outlook* (2011) 96–100. [Google Scholar])
A smart city is understood as a certain intellectual ability that addresses several innovative socio-technical and socio-economic aspects of growth. These aspects lead to smart city conceptions as "green" referring to urban infrastructure for environment protection and reduction of CO_2 emission, "interconnected" related to revolution of broadband economy, "intelligent" declaring the capacity to produce added value information from the processing of city's real-time data from sensors and activators, whereas the terms "innovating", "knowledge" cities interchangeably refer to the city's ability to raise innovation based on knowledgeable and creative human capital.	Zygiaris (2013S. Zygiaris, "Smart City Reference Model: Assisting Planners to Conceptualize the Building of Smart City Innovation Ecosystems," *Journal of the Knowledge Economy* 4: 2 (2013) 217–231. doi: 10.1007/s13132-012-0089-4[Crossref], [Google Scholar])
The use of Smart Computing technologies to make the critical infrastructure components and services of a city—which include city administration, education, healthcare, public safety, real	Washburn et al. (2010D. Washburn, U. Sindhu, S. Balaouras, R.A.Dines, N.M. Hayes, and L.E.

estate, transportation, and utilities—more intelligent, interconnected, and efficient.	Nelson, *Helping CIOs Understand "Smart City" Initiatives: Defining the Smart City, Its Drivers, and the Role of the CIO*(Cambridge, MA: Forrester Research, 2010). [Google Scholar])
Smart Cities initiatives try to improve urban performance by using data, information and information technologies (IT) to provide more efficient services to citizens, to monitor and optimize existing infrastructure, to increase collaboration among different economic actors, and to encourage innovative business models in both the private and public sectors.	Marsal-Llacuna et al. (2014M.L. Marsal-Llacuna, J. Colomer-Llinàs, and J. Meléndez-Frigola, "Lessons in urban monitoring taken from sustainable and livable cities to better address the Smart Cities initiative, Technological Forecasting and Social Change" (2014). [Google Scholar])

(Albino, Berardi, & Dangelico, 2015)

Appendix C: Proposed Indicator System

Table C.1: Proposed Indicator System

Indicator Type	ID	Indicator	Definition	Source	Rationale for Choosing
Environmental	1	Fine Particulate Matter (PM2.5) Concentration	Total mass of collected particles 2.5 microns or less in diameter divided by the volume of air sampled.	BIS, CITYkeys	PM2.5 is a direct environmental quality
	2	Particulate Matter (PM10) Concentration	Total mass of collected particles 10 microns or less in diameter divided by the volume of air sampled.	BIS, CITYkeys	PM10 is a direct environmental quality
	3	Canopy Classification	Height to which the green canopy is present. This is influenced by vegetation structure.	Self Generated	Canopy class has been shown to affect PM measurements
Social	4	Existence of Green Space Maintenance	Yes/No, observations on notable characteristics	Self Generated	Influences visitation rates and satisfaction of visitors
	5	Presence of Amenities	Observations on notable amenities	Self Generated	Influences visitation rates and satisfaction of visitors
	6	Public Approval Rating	Average public ranking of park usage 1-5	Self Generated	Direct measurement of how satisfied visitors are with the park

Appendix D: Park Sampling Methods

Wanxiang Park

Wanxiang Park is approximately 0.01 km^2 in size and is located along the Guxin River. Figure D.1 shows the hexagonal overlay of the park, depicting the centers of the each hexagon, where data were collected, and their corresponding identifications. Each hexagon on the map overlay has a 20 meter long side-length, and 58 data points were accessible and collected. Hexagonal center points that were located within the boundaries of the park were collected, and data around the urban perimeter of the park were collected on Wuling Road, Huancheng North Road, Tiyuchang Road, and the opposite side of the Guxin River.

Figure D.1: Hexagonal Overlay of Wanxiang Park. November 10, 2017.

Jialvuyan Park

Jialvyuan Park is approximately 0.03 km^2 and is located adjacent to the Gudang Residential District. Figure D.2 shows the hexagonal overlay of the park, depicting the centers of the each hexagon, where data were collected, and their corresponding identifications. The hexagons on the map overlay have a 30 meter long side-length, and 55 data points were collected. Data points for hexagonal centers within the borders of the park were collected, along with the urbanized surrounding perimeter on Wensan Road, Yile Road, Jialv Cross Road, Huaxing Road, and Gucui Road.

Figure D.2: Hexagonal Overlay of Jialvyuan Park. November 10, 2017.

Shu Yuan Park

Shu Yuan Park is approximately 0.04 km^2 and is located adjacent to the Hushu Residential District. Figure D.3 shows the hexagonal overlay of the park, depicting the centers of the each hexagon, where data were collected, and their corresponding identifications. Each hexagon on the map overlay has a 30 meter long side length, and 47 data points were collected at this location. Hexagons within the park borders were recorded, along with urban data on the perimeter on Moganshan Road, Caoying Alley, Zhongya Long Road, and Shuangdang Road.

Figure D.3: Hexagonal Overlay of Shu Yuan Park. November 10, 2017.

Liuheta Culture Park

The Liuheta Culture Park is approximately 0.13 km^2 in size and is located along the Qiantang River. Figure D.4 shows the hexagonal overlay of the park. Each hexagon on the map overlay has a 50 meter long side-length, and 28 data points were accessible and collected. Hexagonal center points that were located within the boundaries of the park were collected in addition to urban data along the southern perimeter of the park on Zhijiang Road. Data for hexagonal center points along the northern, eastern, and western sides of the park were not collected, as they were located within other green spaces surrounding the Liuheta Culture Park, such as the Duhuang Mountain, Erlong Mountain, and Nine Creeks Meandering Through a Misty Forest.

Figure D.4: Hexagonal Overlay of the Liuheta Culture Park. November 10, 2017.

Wushan Scenic Area

The Wushan Scenic Area has an area of approximately 0.71 km^2 and is surrounded by roadways and elevated highways. Figure D.5 shows the hexagonal overlay of the park, depicting the centers of the each hexagon, where data were collected, and their corresponding identifications. Each hexagon on the map overlay has a 75 meter long side-length, and 55 data points were accessible and used to collect information.

Figure D.5: Hexagonal Overlay of Wushan Scenic Area. November 10, 2017.

Zhejiang University Zijingang Campus

The Zhejiang University Zijingang Campus is approximately 1.4 km^2 in size and is located adjacent to the Zijingcheng Creative Industrial Park. Figure D.6 shows the hexagonal overlay of the park, depicting the locations at which data was collected. The hexagons on the overlay have a 200 meter long side-length, and 35 data points. Data in the urbanized surroundings were taken on Shixiang West Road, Zijinghua North Road, and Yuhangtang Road.

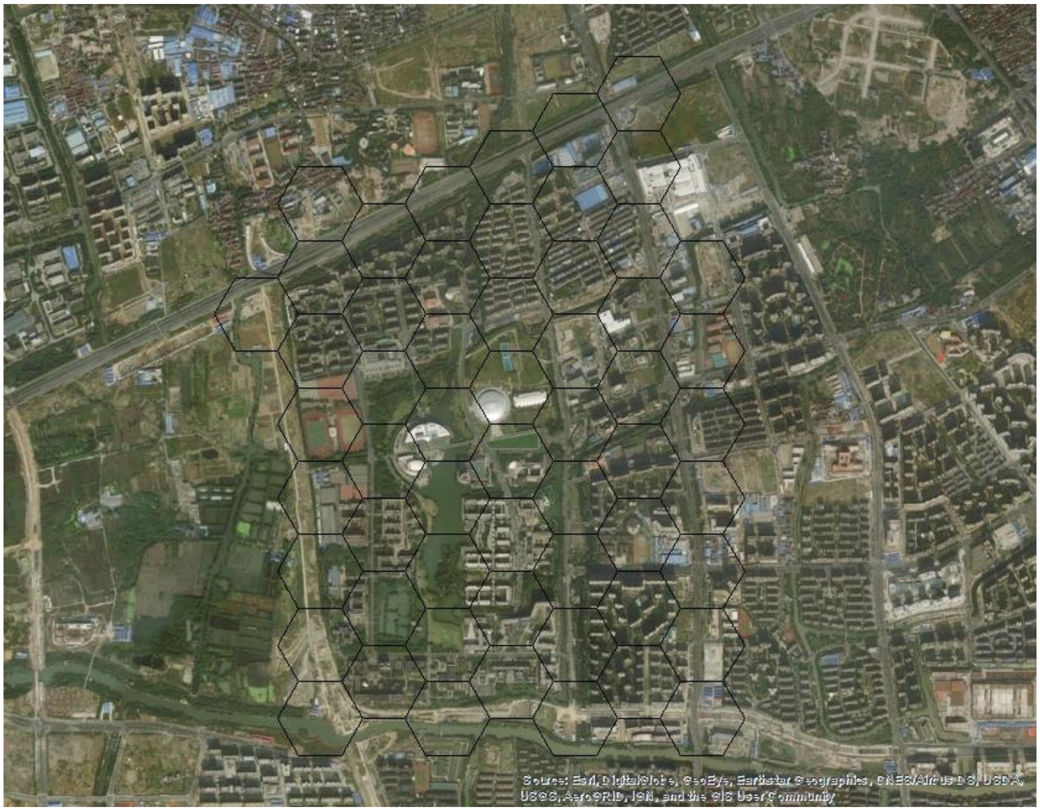

Figure D.6: Hexagonal Overlay of the Zhejiang University Zijingang Campus. November 10, 2017.

West Lake

West Lake is approximately 10.7 km^2 in size and is located in the southwest region of the Xihu District. Figure D.7 shows the hexagonal overlay of the park. Each hexagon on the overlay has a 350 meter long side-length, and 32 data points were accessible and collected. Data was collected within the park on the perimeter of the lake and along Yan'an Road and Nanshan Road.

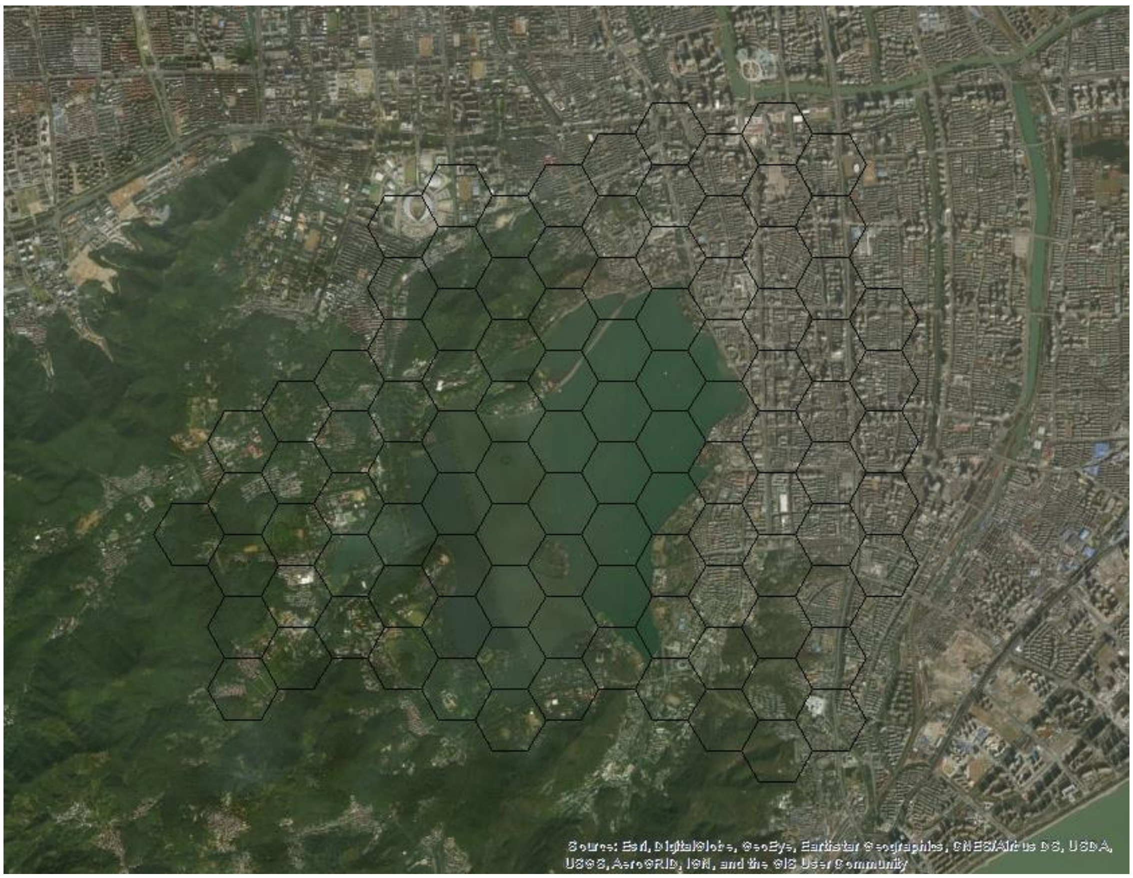

Figure D.7: Hexagonal Overlay of the West Lake. November 10, 2017.

Xixi National Wetland Park

The Xixi National Wetland Park is approximately 11.5 km^2 in size and is located northwest of West Lake. Figure D.8 shows the hexagonal overlay of the park. Each hexagon on the overlay has a 400 meter long side-length, and 32 data points were accessible and collected. Data was collected within the park and along Zijingang Road, Tianmushan Road, Wushang Avenue, and Changshen Expressway.

Figure D.8: Hexagonal Overlay of the Xixi National Wetland Park. November 10, 2017.

Appendix E: Green Space Survey - English Version

1) What is your favorite park in Hangzhou?

2) What is your least favorite park in Hangzhou?

3) With 1 being the least desired and 5 being the most desired, rank what criteria you like in parks.

Ponds ___
Rivers ___
Benches ___
Pergalas ___
Stores ___
Restaurants ___
Open grass ___
Restrooms ___
Recreation ___

4) Why do you go to parks? (select the one(s) that fits best for you)

Recreation   Rest/Relaxation   Exercise   Environmental Education   Connecting with Nature

5) Who do you go with? (select the one(s) that fit(s) best for you)

Self   Spouse   Children   Family   Friends

6) On a scale of 1-5, how well are parks in Hangzhou maintained?

Not Well   1   2   3   4   5   Well

7) On average, how often do you visit parks per week? (Select the one that fits best for you)

0   1-3   4-5   6+

8) When do you go to parks on average?

A) Time of Day: Morning Afternoon Evening

B) Type of Day: Weekdays Weekends

9) Your Age Category (circle one)

<18 19-35 36-50

51-75 75+

10) Gender (circle one) Male Female Other/No comment

Appendix F: Green Space Survey - Chinese Version

绿地调查

您好！我们是来自美国伍斯特理工学院的学生，这项调查旨在确定杭州公园的改善方式，以满足市民的需要。所有答复都将是匿名的。在此，我们衷心感谢您的大力支持！

1.在杭州，您最喜欢的公园是哪个？

2.在杭州，您最不喜欢的公园是哪个？

3.排名公園的不同部分。

池塘	___
河流	___
长凳	___
凉亭	___
商店	___
饭店	___
空旷的草地	___
厕所	___
娱乐	___

4.您为什么去公园？（可以多选）

A.娱乐

B.休息/放松

C.锻炼

D.环境教育

E.感受自然

5.您一般和谁一起去公园？（可以多选）

A. 自己

B. 配偶

C. 孩子

D. 家人

E. 朋友

6. 请您对杭州的公园满意程度打分

不满意 1 2 3 4 5 满意

7.在1到5的範圍內，杭州的公園有多好？

8.一般您每周去公园几次？

A.0
B.1-3
C.4-5
D.6+

9. 您一般什么时候去公园？

①一天中什么时候去:

A. 早上

B. 下午

C. 晚上

②一周中什么时候去:

A. 工作日

B. 周末

10.您的年龄范围

A. <18

B. 19-35

C. 36-50

D.51-74

E.75+

11. 性别

A. 男

B. 女

C.其他/无可奉告

再次感谢您抽出宝贵的时间填写我们的这份问卷！

Appendix G: Updated Green Space Survey - English Version

Hello! We are students from Worcester Polytechnic Institute in the United States. This Survey is to determine ways parks can be improved to accommodate citizens wants. Please answer the following questions. All responses will be anonymous.

1) Rank the features you want in parks, with 1 being the highest and 10 being the lowest.

Ponds	___	Rivers	___
Benches	___	Pergolas	___
Stores	___	Restaurants	___
Open grass	___	Restrooms	___
Recreation	___	Exercise Equipment	___

2) What is the <u>best</u> feature of parks in Hangzhou? (Circle)

Ponds Rivers Benches Pergaląs Stores
Restaurants Open grass Restrooms Recreation Exercise Equipment

3) What is the <u>worst</u> feature of parks in Hangzhou? (Circle)

Ponds Rivers Benches Pergaląs Stores
Restaurants Open grass Restrooms Recreation Exercise Equipment

4a) Why do you go to parks? (Select the one(s) that fits best for you)

Recreation Rest/Relaxation Exercise Environmental Education Connecting with Nature

4b) On a scale of 1-5, how well do the parks in Hangzhou meet this purpose?

Not satisfied 1 2 3 4 5 Satisfied

5) On a scale of 1-5, how satisfied are you with parks in Hangzhou?

Not Satisfied 1 2 3 4 5 Satisfied

6) Are you happy when you go to parks?

Yes No

7) On a scale of 1-5, how well do you think parks improve the air quality?

Not Well 1 2 3 4 5 Well

8) Who do you go with? (select the one(s) that fit(s) best for you)

Self Spouse Children Family Friends

9) On average, how often do you visit parks per week? (Select the one that fits best for you)

0 1-3 4-5 6+

10) Your Age Category (Circle one)

<18 19-35 36-50 51-75 76+

11) Gender (Circle one)

Male Female Other/No comment

Thanks for taking the time to fill in our questionnaire!

Appendix H: Updated Green Space Survey - Chinese Version

绿地调查

您好！我们是美国伍斯特理工的学生。这项调查旨在确定公园的改善方式，以满足市民的需要。请回答下面的问题（圈出所选答案）。所有的回答都将是匿名的。

1)**您希望公园里应该有的事物（从最希望有的到最不希望有的，按1-10排序）**

池塘___ 河流___ 长凳___ 凉亭___ 商店___ 饭店___

空旷草地___ 厕所___ 娱乐___ 运动器材___

2)**您认为下边哪个因素杭州的公园是做的最好的？**

A.池塘 B.河流 C.长凳 D.凉亭

E.商店 F.饭店 G.空旷的草地 H.厕所

I.娱乐 J.运动器材

3)您认为下边哪个因素杭州的公园是做的最差的？

A.池塘 B.河流 C.长凳

D.凉亭 E.商店 F.饭店

G.空旷的草地 H.厕所 I.娱乐 J.运动器材

4a) 您为什么去公园？（可多选）

A.娱乐 B.休息 C.锻炼 D.环境教育 E. 感受自然

4b) 杭州的公园能满足您去公园的目的（上题所选）吗？

不满足 1 2 3 4 5 满足

5) 请您对杭州公园的满意程度打分。

不满意 1 2 3 4 5 满意

6)您去公园时开心吗？

A.是　　　B.不是

7)您认为公园对改善空气质量的影响有多大？

影响不大 1　2　3　4　5 影响大

8)您和谁一起去公园（可多选）

A.自己　　B.配偶　　C.孩子　D.家人　E.朋友

9)您每周平均去几次公园？

A.0　B.1-3　C.4-5　D.6+

10)您的年龄？

A.<18　B.19-35　C.36-50　D.51-75　E.76+

11)性别

A.男性　B.女性　C.无可奉告

感谢您花时间填写我们的问卷！

Appendix I: PM2.5 and PM10 Concentration Maps

Wanxiang Park

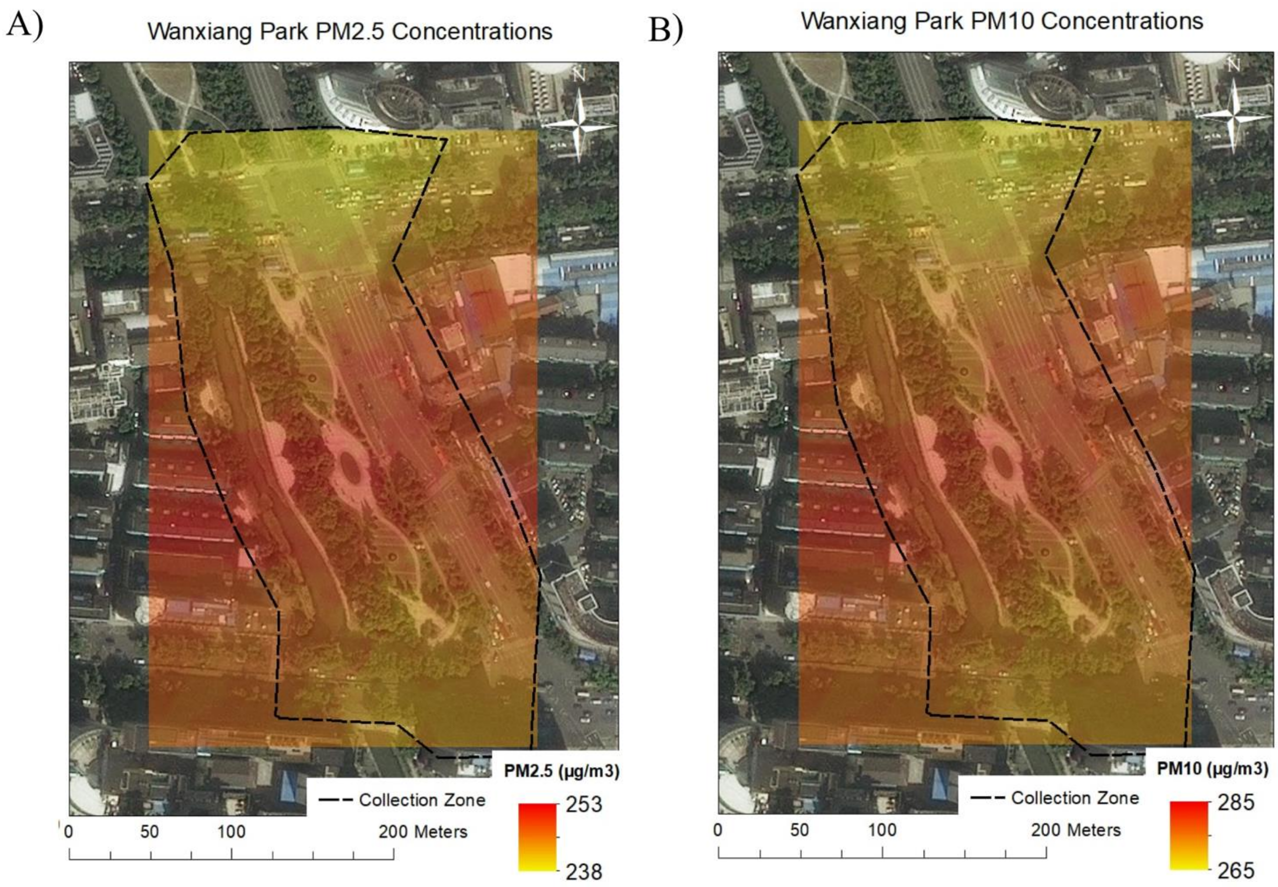

Figure I.1: (A) PM2.5 and (B) PM10 concentration distributions in and around Wanxiang Park. Data collected November 14, 2017, Map created December 4, 2017.

Jialvyuan Park

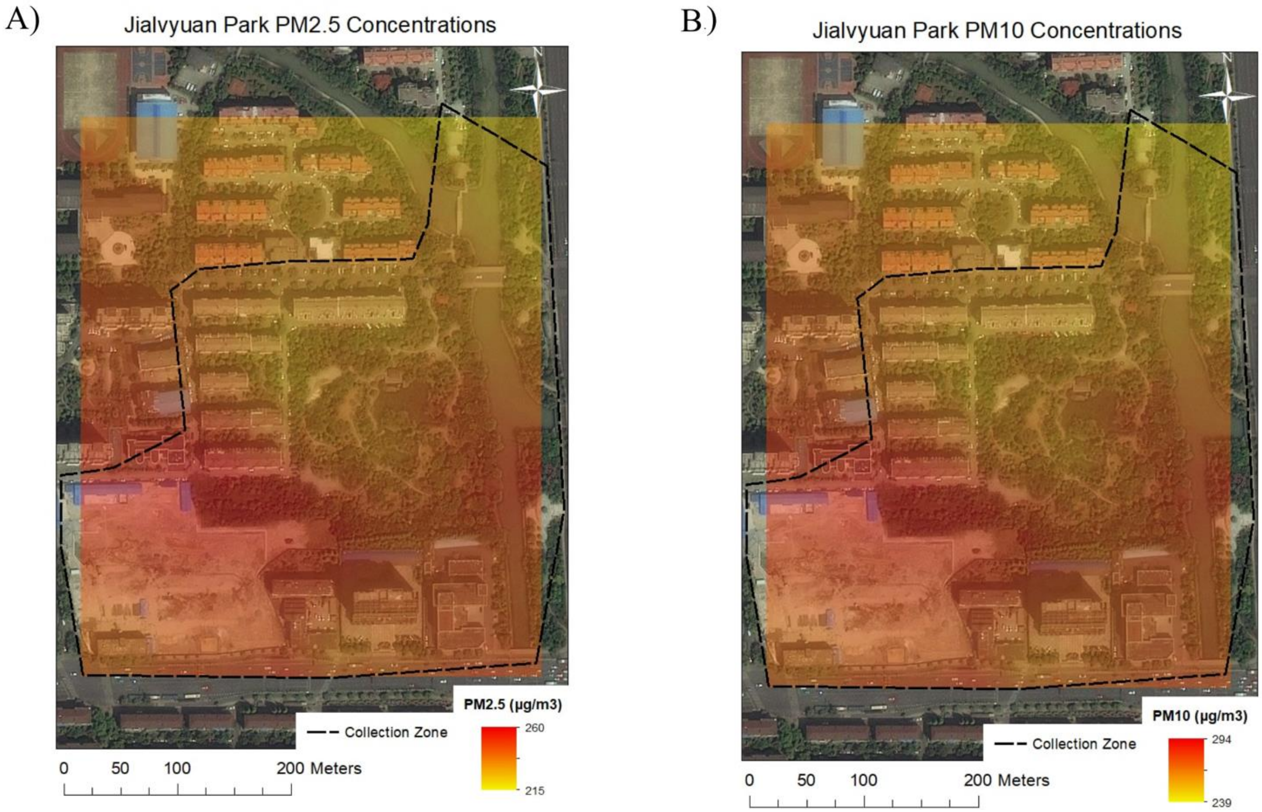

Figure I.2: (A) PM2.5 and (B) PM10 concentration distributions in and around Jialvyuan Park. Data collected November 14, 2017, Map created December 4, 2017.

Shu Yuan Park

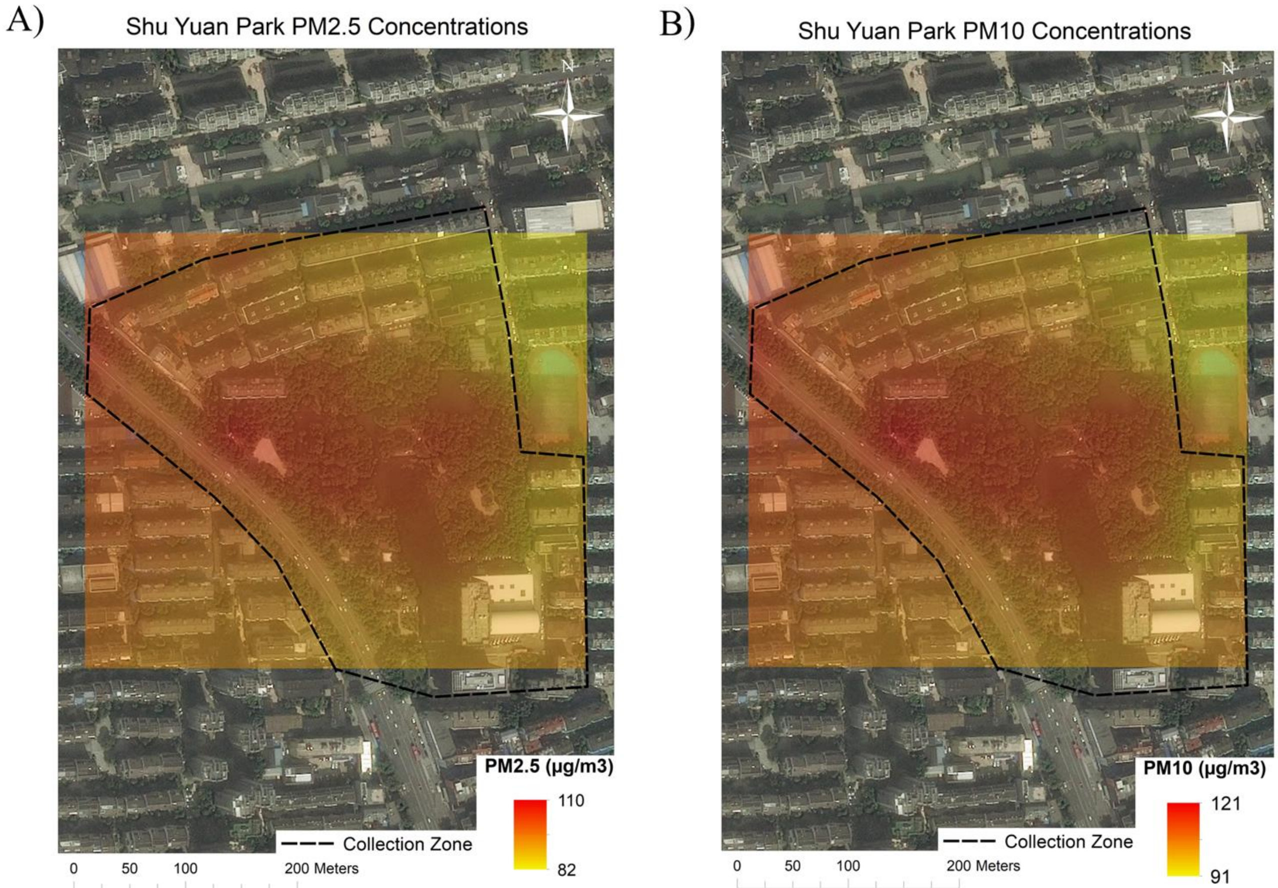

Figure I.3: (A) PM2.5 and (B) PM10 concentration distributions in and around Shu Yuan Park. Data collected November 13, 2017, Map created December 4, 2017.

Liuheta Culture Park

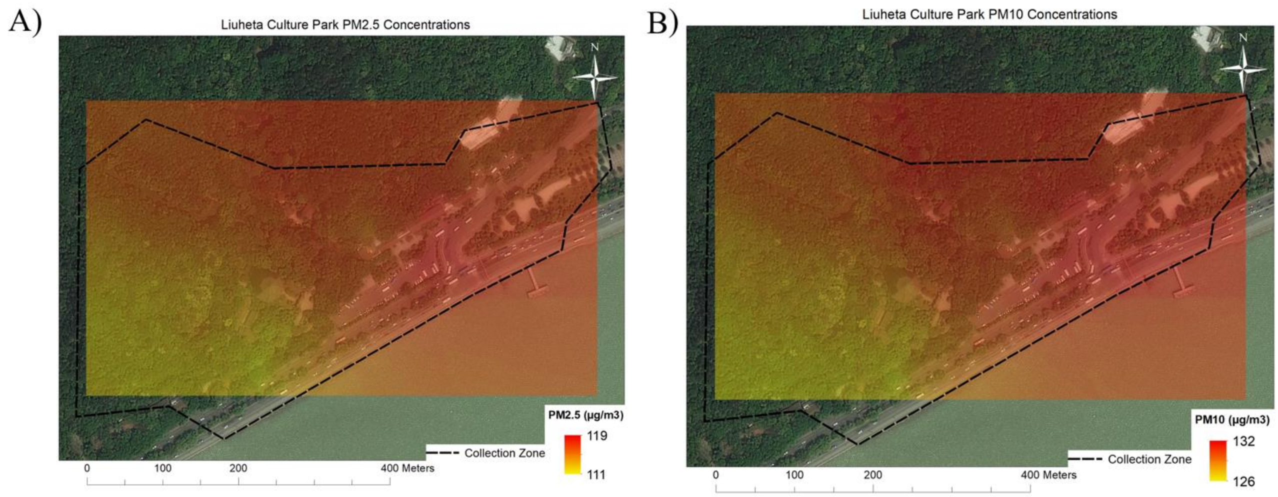

Figure I.4: (A) PM2.5 and (B) PM10 concentration distributions in and around Liuheta Culture Park. Data collected November 20, 2017, Map created December 4, 2017.

Wushan Scenic Area

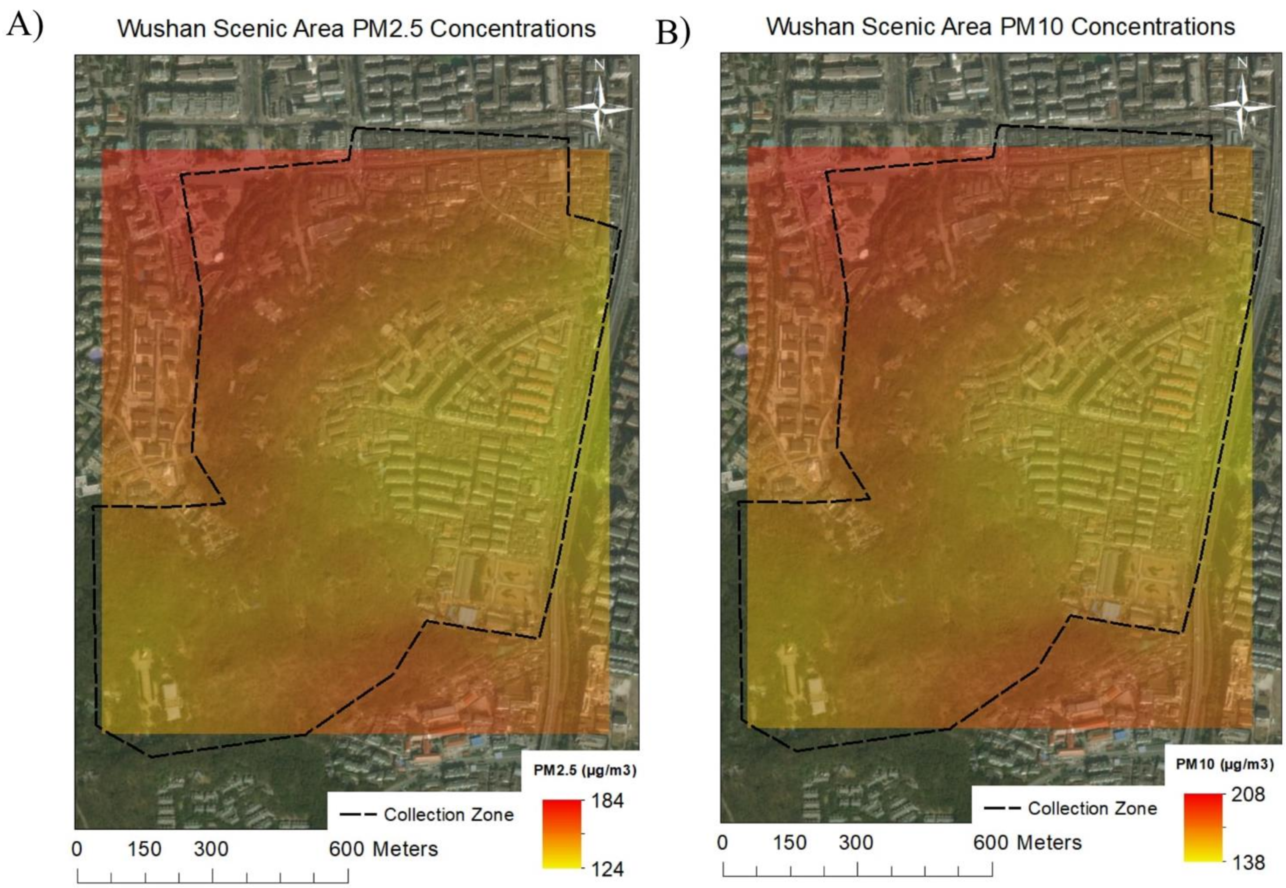

Figure I.5: (A) PM2.5 and (B) PM10 Concentration Distributions in and Around Wushan Scenic Area. Data collected November 15, 2017, Map created December 4, 2017.

Zhejiang University Zijingang Campus

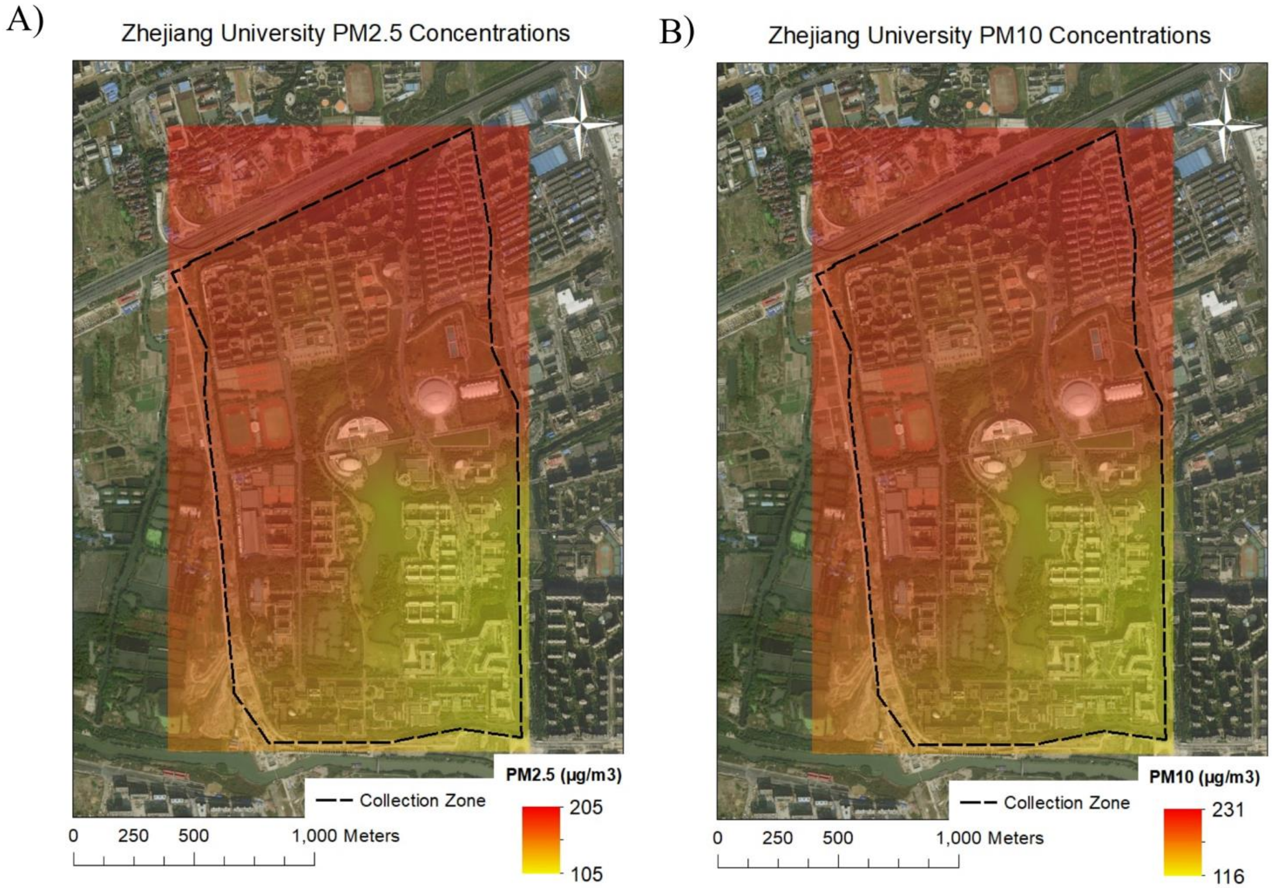

Figure I.6: (A) PM2.5 and (B) PM10 concentration distributions in and around Zhejiang University Zijingang Campus. Data collected November 14, 2017, Map created December 4, 2017.

West Lake

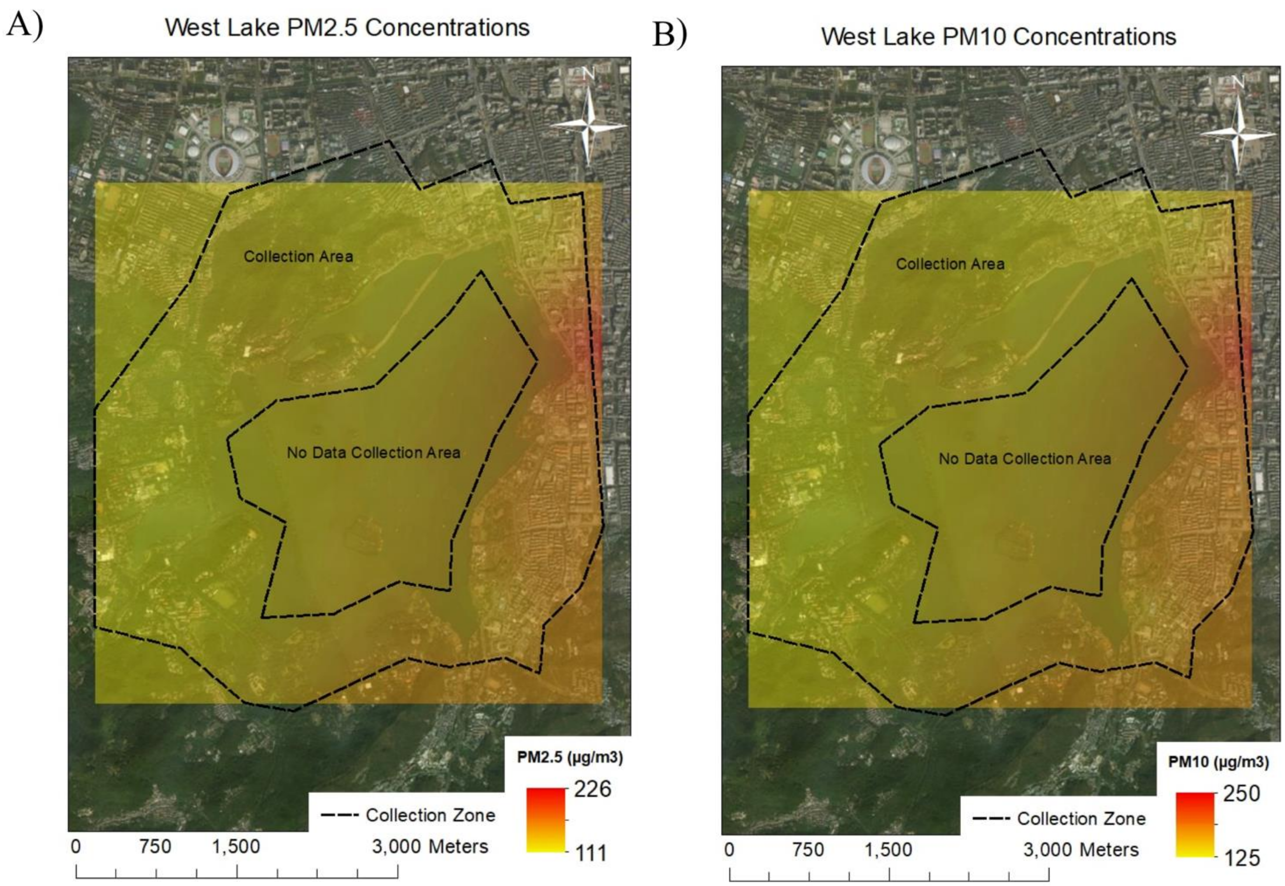

Figure I.7: (A) PM2.5 and (B) PM10 concentration distributions in and around West Lake. Data collected November 29, 2017, Map created December 4, 2017.

Xixi National Wetland Park

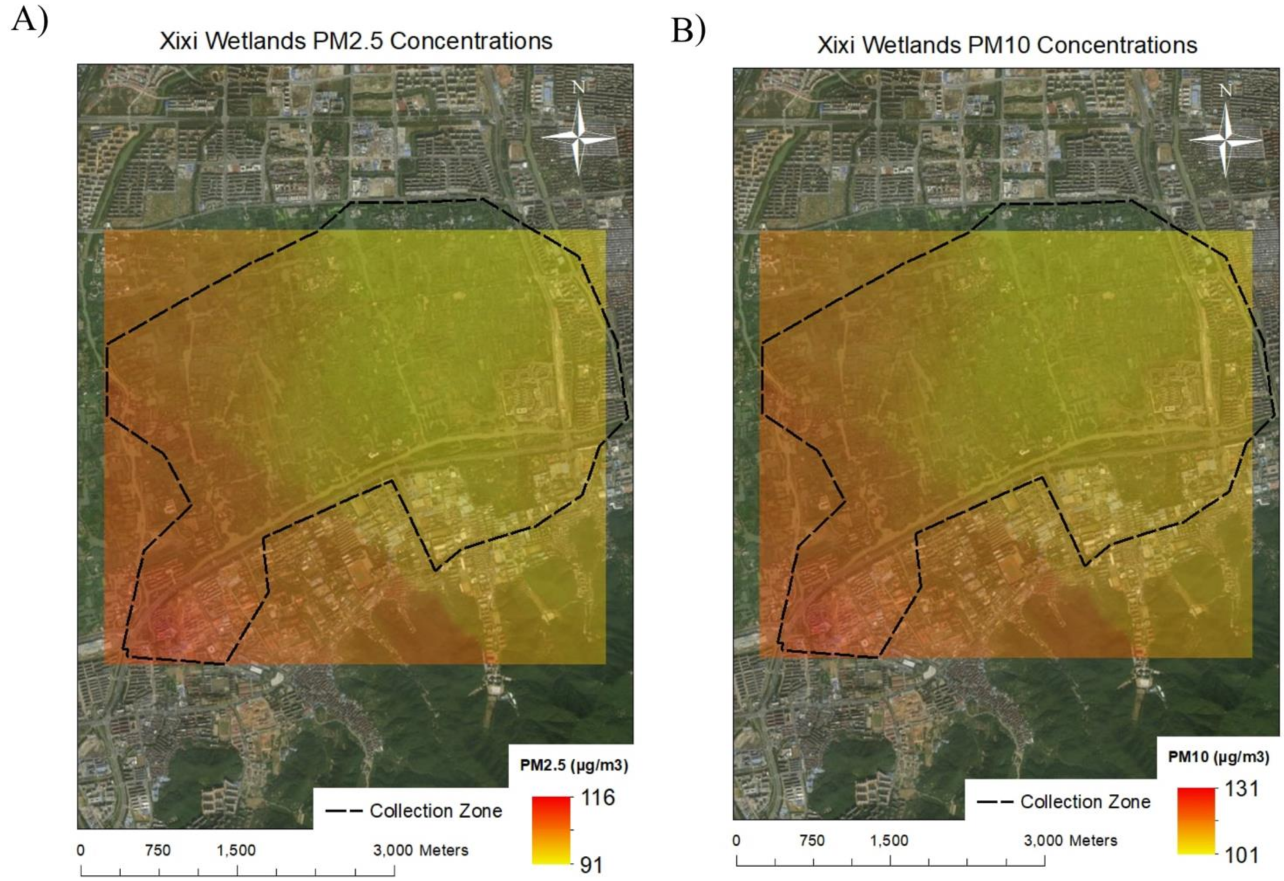

Figure I.8: (A) PM2.5 and (B) PM10 concentration distributions in and around Xixi National Wetland Park. Data collected December 1, 2017, Map created December 4, 2017.

Appendix J: Vegetation Canopy

Figure J.1: Vegetation canopy coverage at Wanxiang Park. Data collected November 14, 2017, Map created December 4, 2017.

Figure J.2: Vegetation canopy coverage at Jialvyuan Park. Data collected November 14, 2017, Map created December 4, 2017.

Figure J.3: Vegetation canopy coverage at Shu Yuan Park. Data collected November 13, 2017, Map created December 4, 2017.

Figure J.4: Vegetation canopy coverage at Liuheta Culture Park. Data collected November 20, 2017, Map created December 4, 2017.

Figure J.5: Vegetation canopy coverage at Wushan Scenic Area. Data collected November 15, 2017, Map created December 4, 2017.

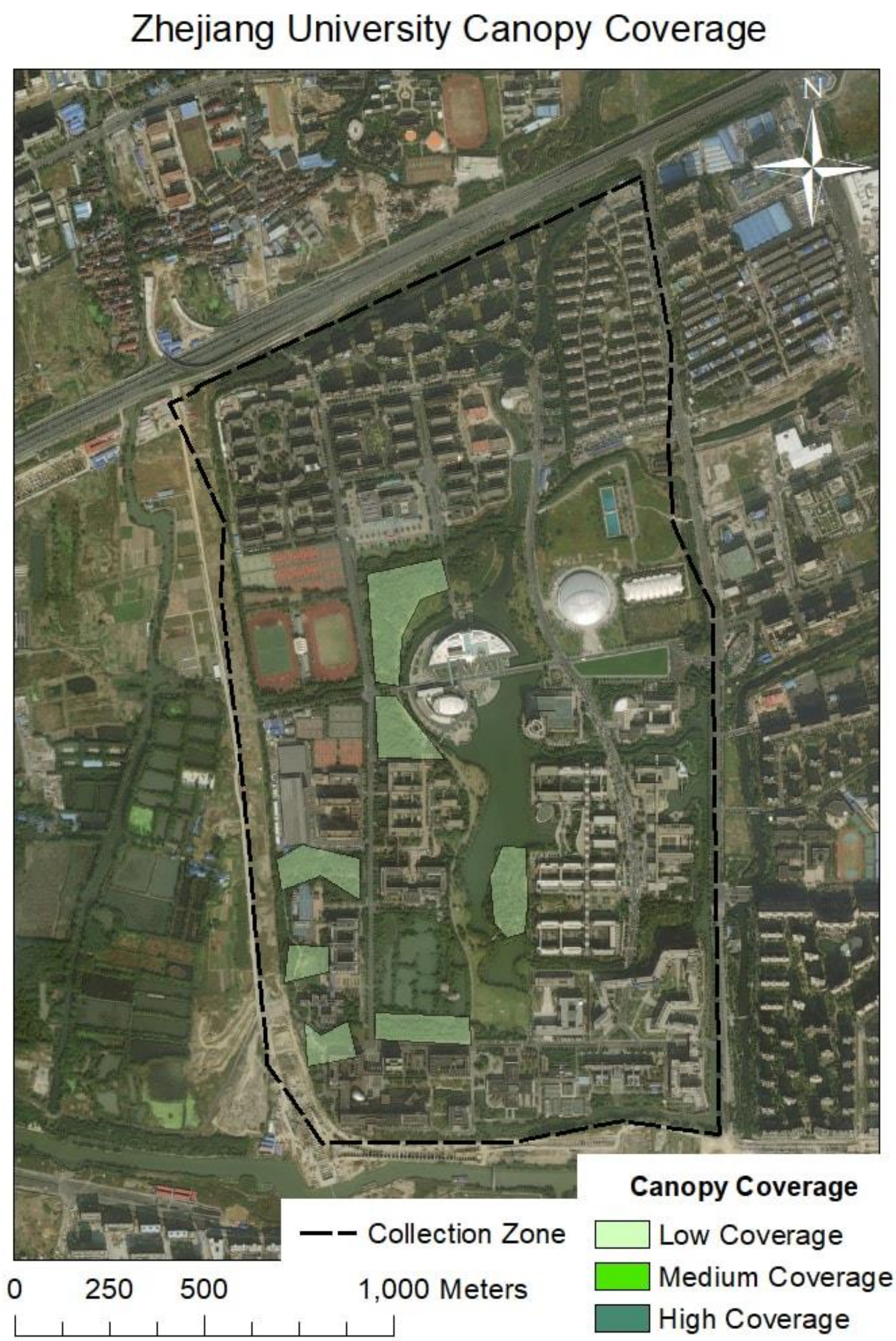

Figure J.6: Vegetation canopy coverage at Zhejiang University Zijingang Campus. Data collected November 14, 2017, Map created December 4, 2017.

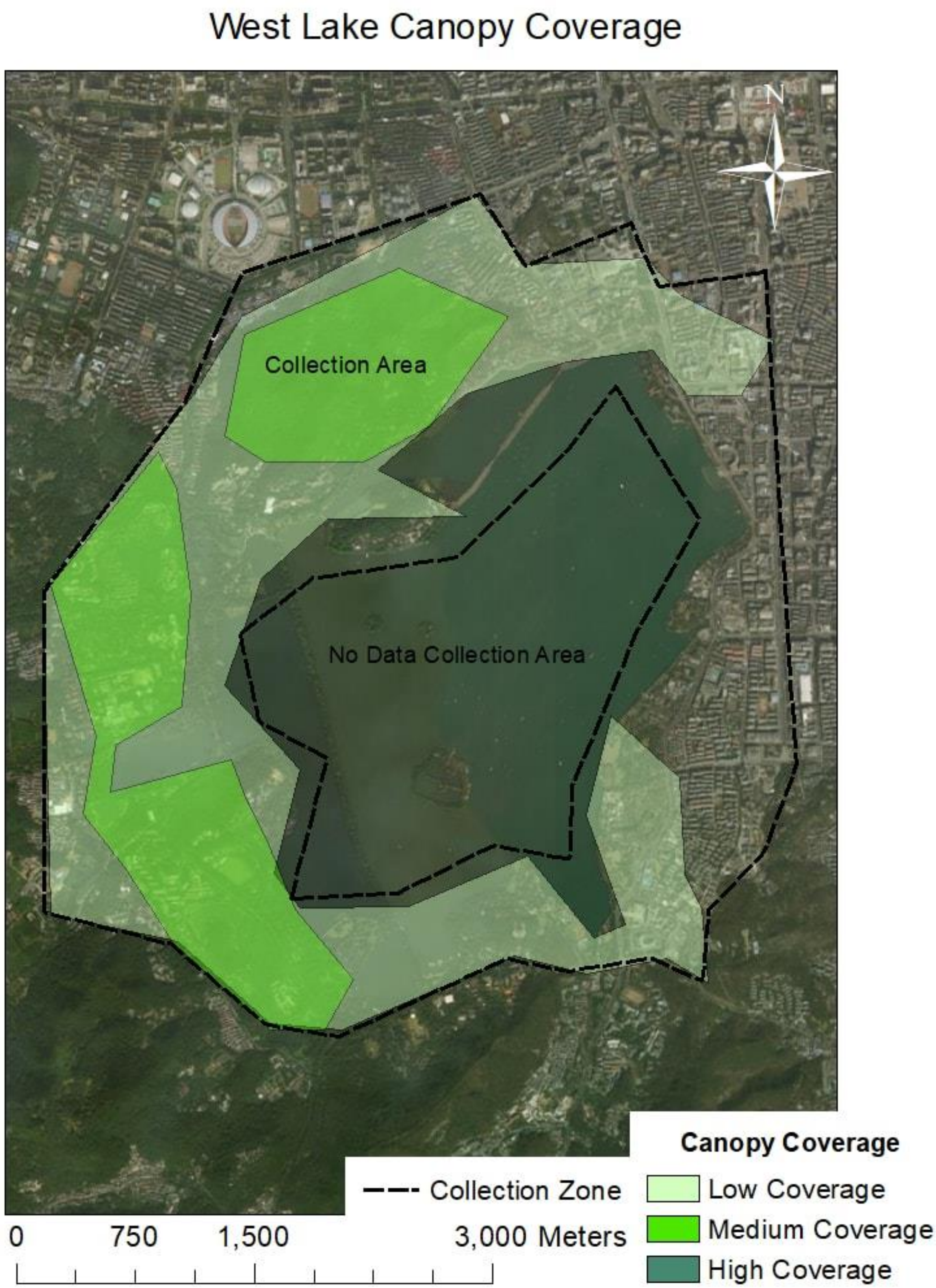

Figure J.7: Vegetation canopy coverage at West Lake. Data collected November 29, 2017, Map created December 4, 2017.

Figure J.8: Vegetation canopy coverage at Xixi National Wetland Park. Data collected December 1, 2017, Map created December 4, 2017.

Appendix K: Survey Results

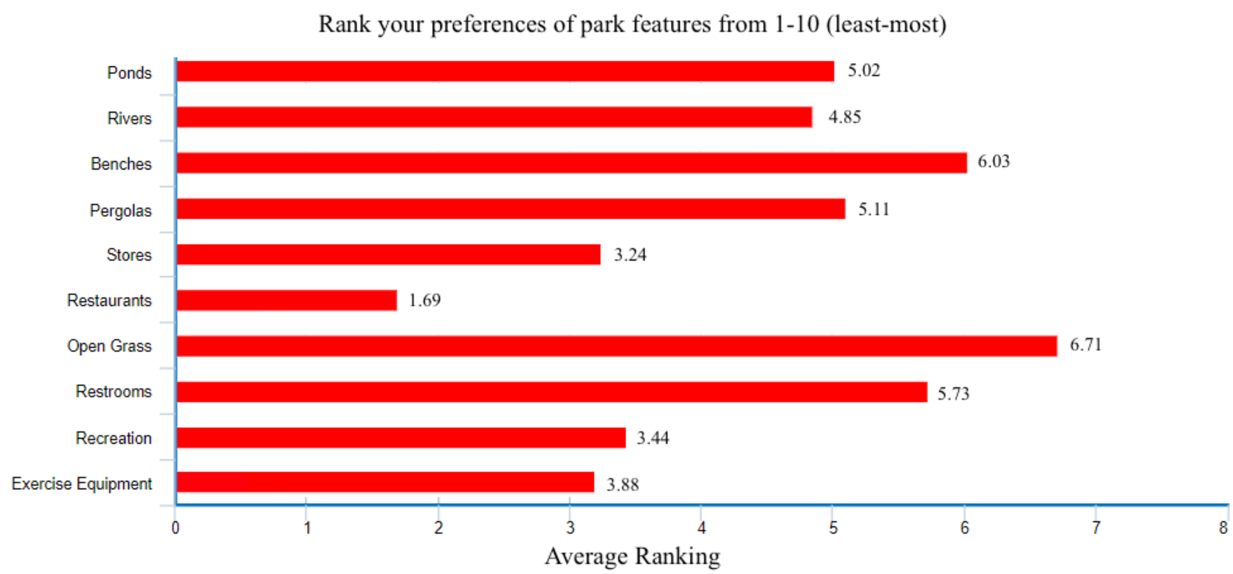

Figure K.1: Survey responses to Question 1. December, 4, 2017.

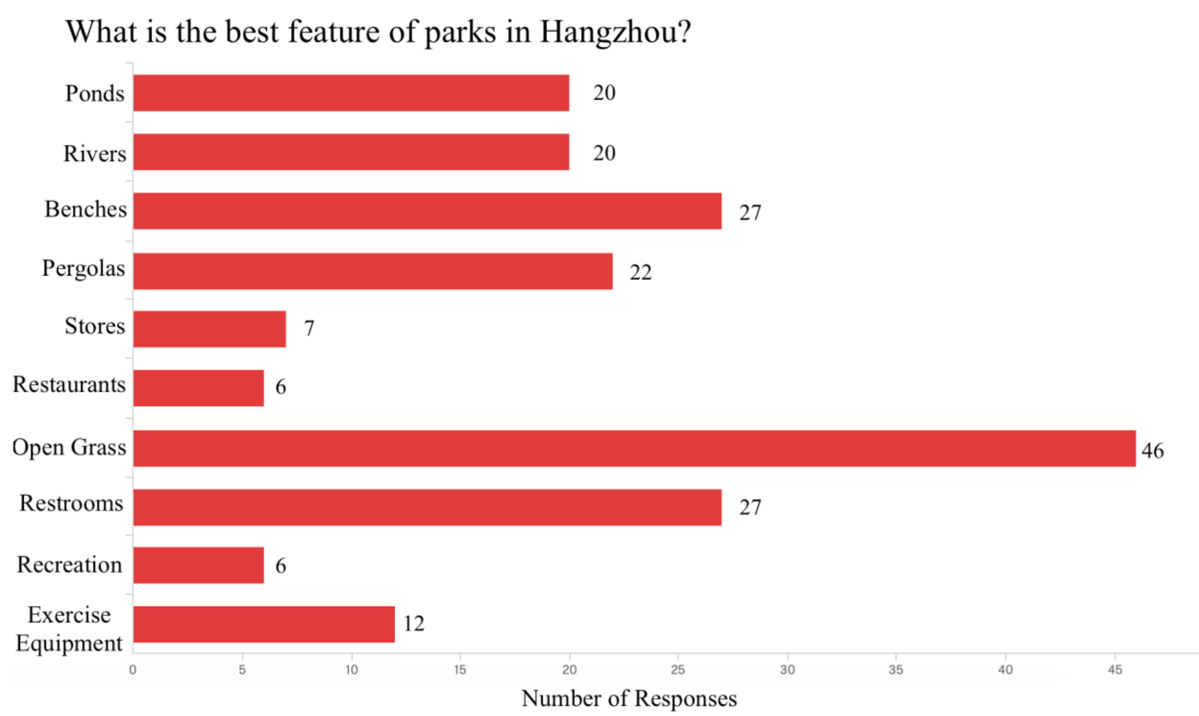

Figure K.2: Survey responses to Question 2. December 4, 2017.

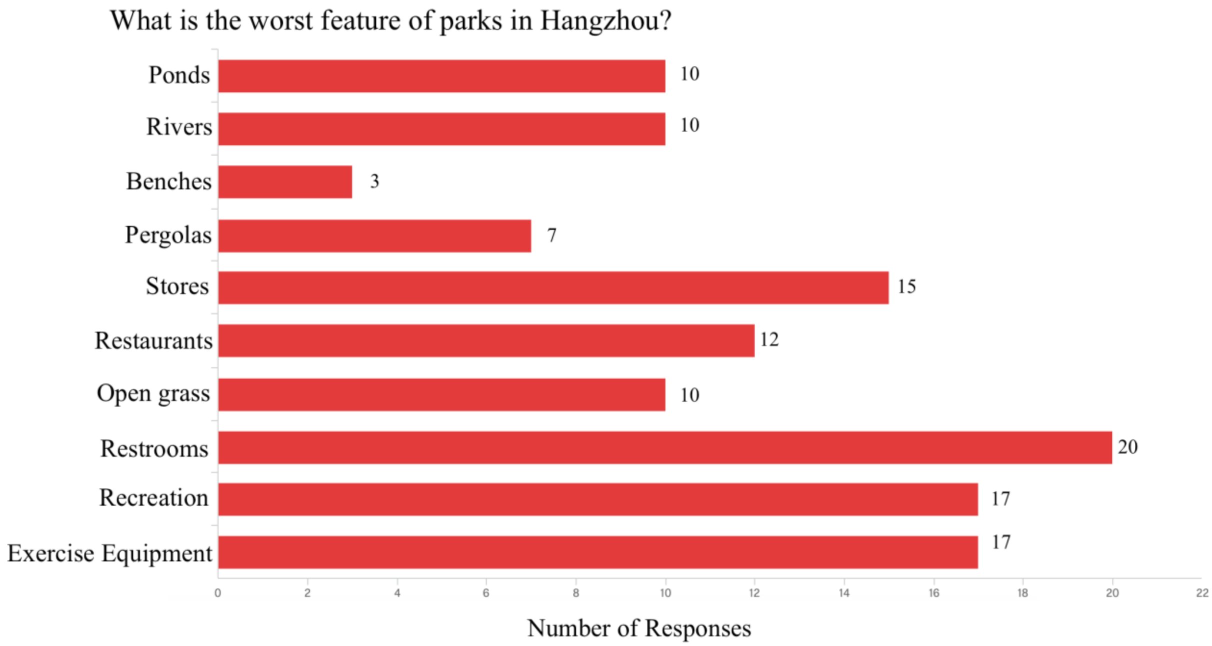

Figure K.3: Survey responses to Question 3. December 4, 2017.

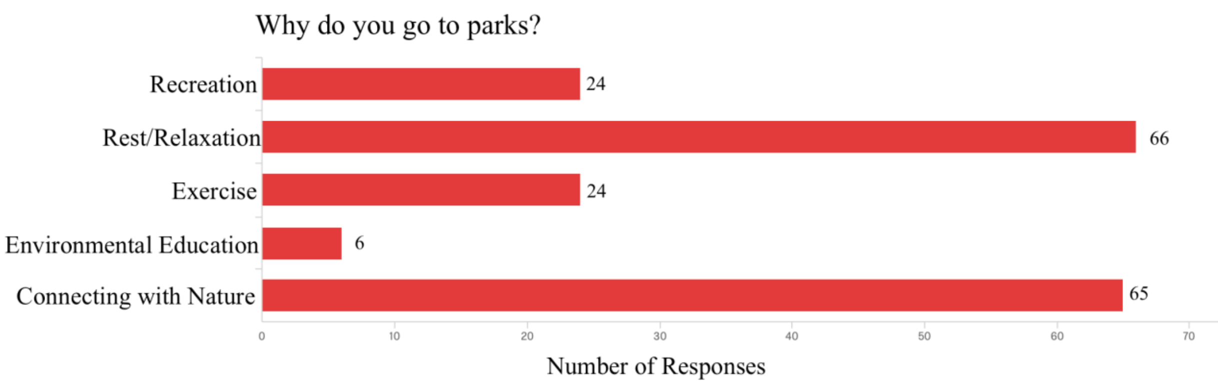

Figure K.4: Survey responses to Question 4a. December 4, 2017.

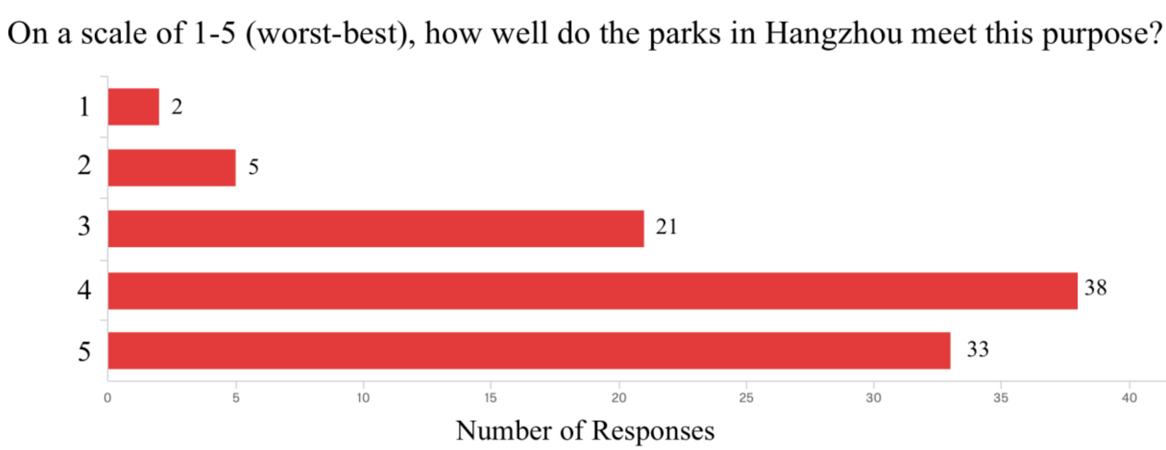

Figure K.5: Survey responses to Question 4b. December 4, 2017.

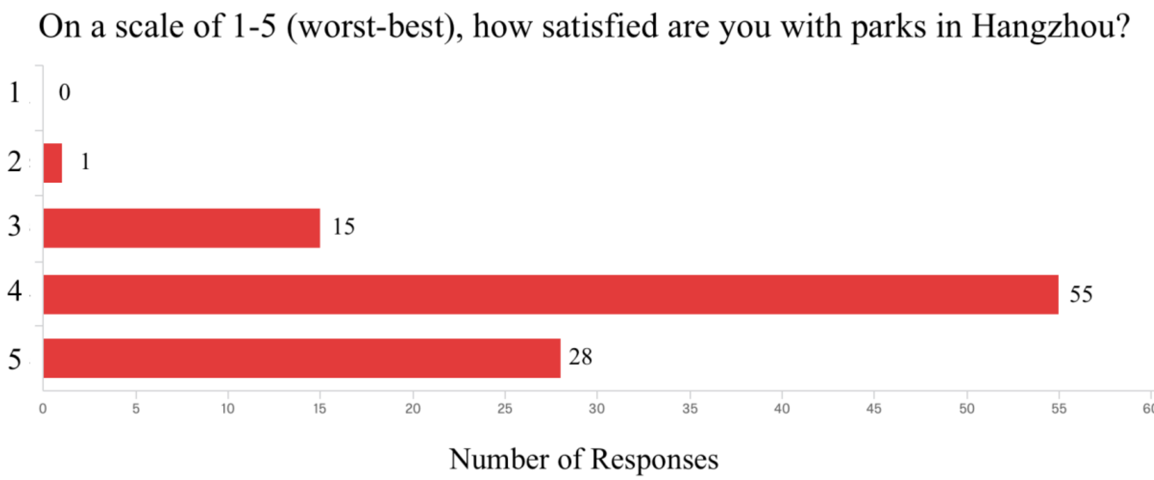

Figure K.6: Survey responses to Question 5. December, 4, 2017.

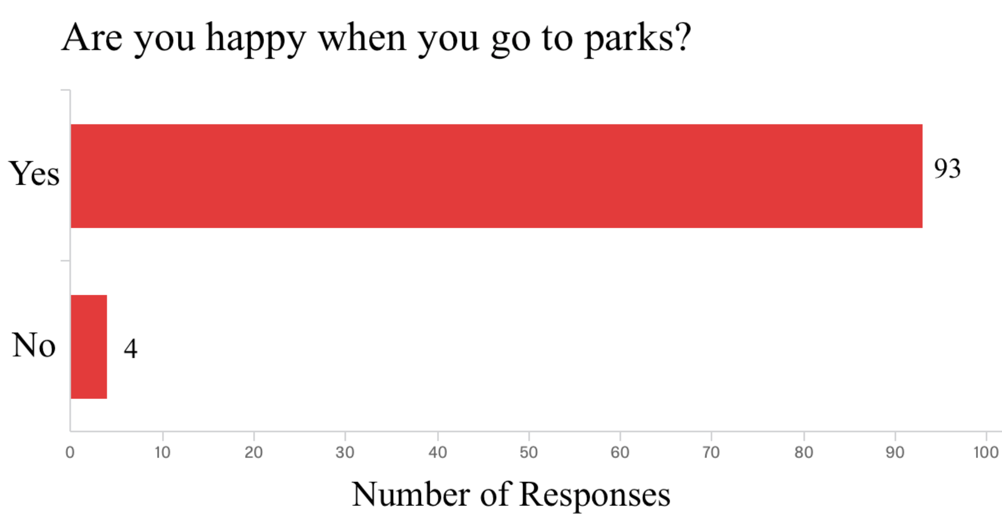

Figure K.7: Survey responses to Question 6. December, 4, 2017.

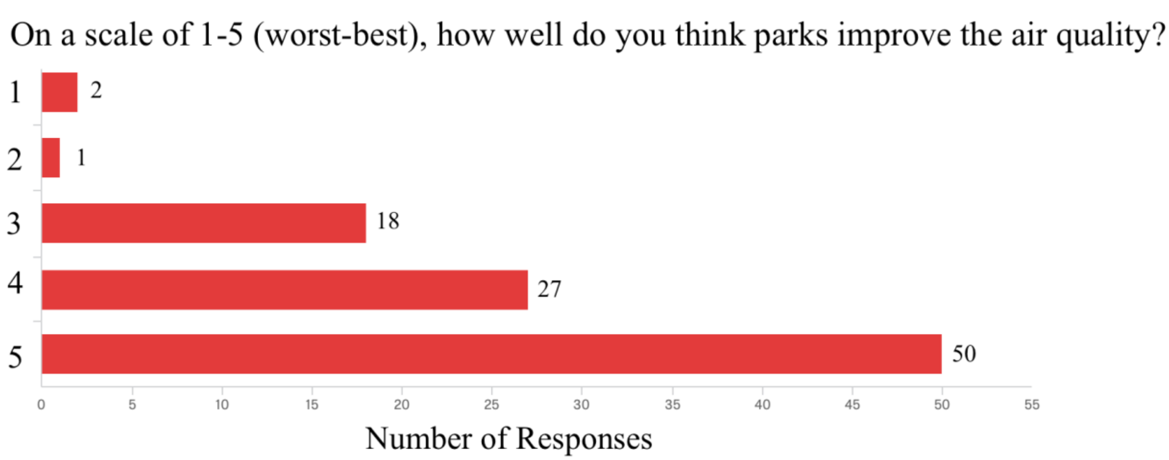

Figure K.8: Survey responses to Question 7. December 4, 2017.

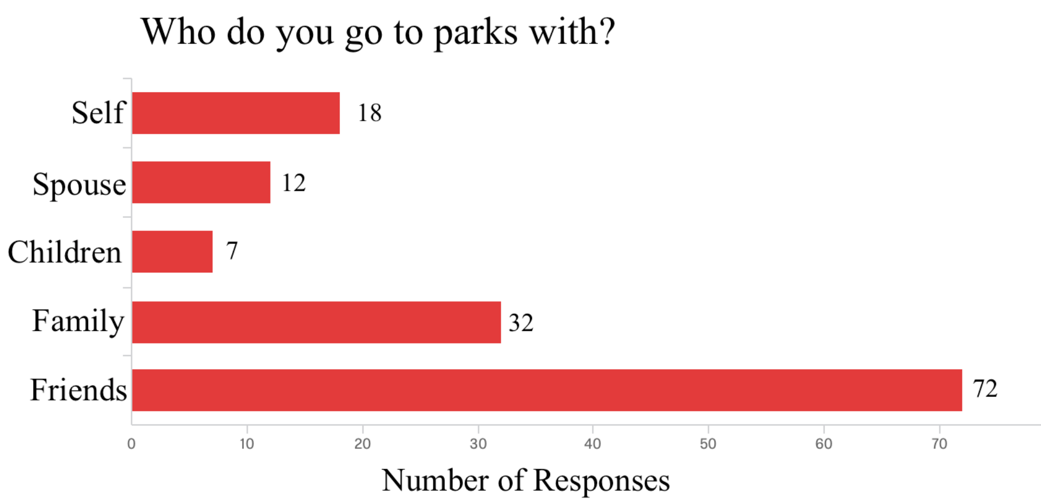

Figure K.9: Survey responses to Question 8. December 4, 2017.

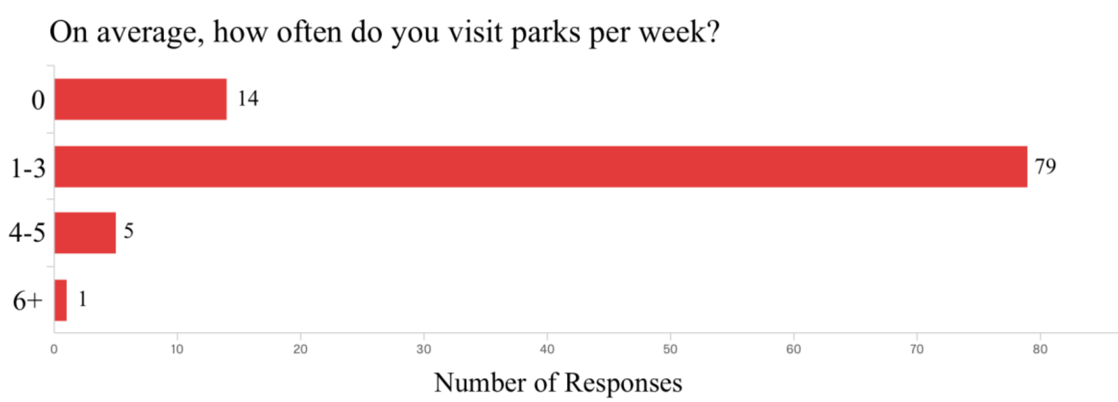

Figure K.10: Survey responses to Question 9. December 4, 2017.

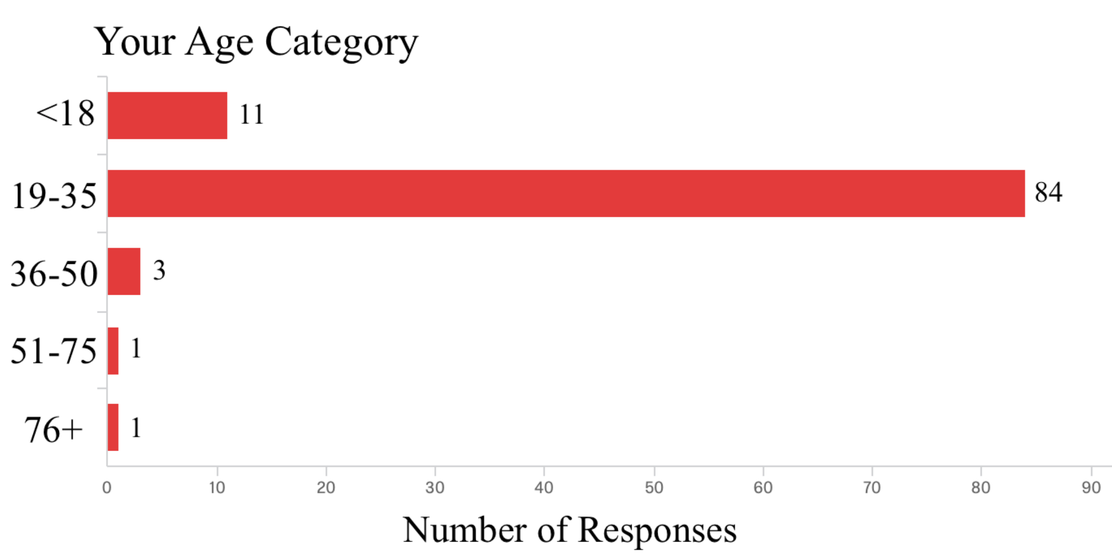

Figure K.11: Survey responses to Question 10. December 4, 2017.

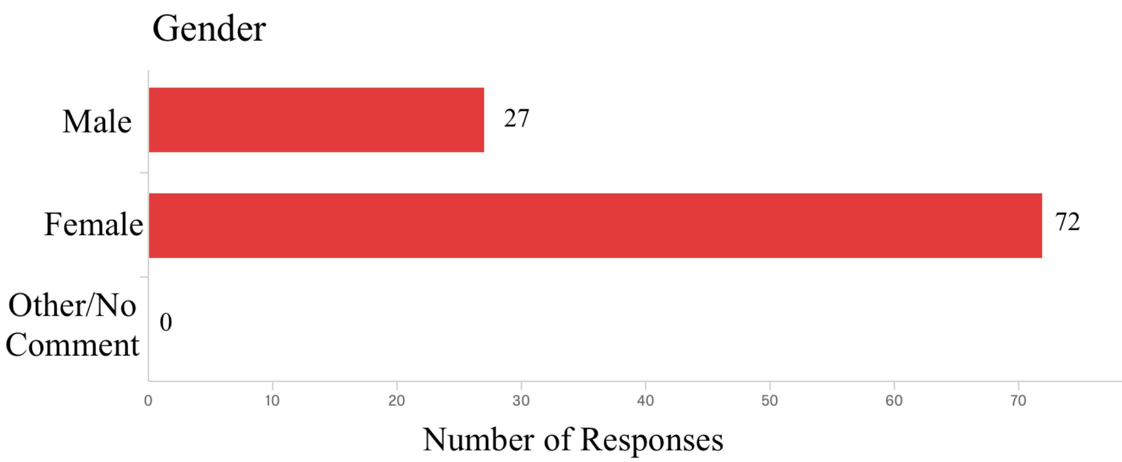

Figure K.12: Survey responses to Question 11. December 4, 2017.

Appendix L: Park Amenity Observations

Table L.1: Park Amenity Observations

Wanxiang Park	Jialvyuan Park	Shu Yuan Park	Liuheta Cultural Park
- Restrooms - Light posts - Broken center fountain - Benches - Card tables	- Restrooms - Fountains - Bridges - Security building - Pavilions - Benches - Statues - Walkway next to water - Exercise equipment - Light posts	- Bookshare station - Bridge - Pavilions - Benches - Small tea shop, closed - Card tables - Small pond with a fountain - One public restroom	- Restrooms - Benches - Stone paths and walkways, trails - Replications of famous pagodas - Light signage including maps of the park
Wushan Scenic Area	**Zhejiang University Zijingang Campus**	**West Lake**	**Xixi Wetlands**
- Restrooms - Museum - Pavilions - Card tables - Benches - Stone paths and walkways, trails - Minimal handrails or safety bars - Statues -Buddhist shrines throughout - Flat paved areas within forests - Caves - Signage, maps - Places to burn incense - Fire hydrants	- College campus facilities - Large open lawns - Ponds - Bridges - Pagodas - Maps and signage - Speakers on walkways - Monuments and statues - Help stations	- Bathrooms present - Numerous stores - Lake - Bridges - Pagodas - Maps and lots of signage - Music acts - Monuments and statues - Police areas	- Tourist Service Center - Restrooms - Shopping areas - Smoking areas - Coffee shops - Bar - Restaurants - Teahouse - Medical treatment area - Boat excursions - Walkways & bridges

Appendix M: Park Maintenance Observations

Table M.1: Park Maintenance Observations

Wanxiang Park	**Jialvyuan Park**	**Shu Yuan Park**	**Liuheta Cultural Park**
- Appeared well maintained with the exception of a broken fountain	- Appeared well maintained	- Workers were doing maintenance while there, cleaning up leaves from the walkways and water - Small unidentified buildings in the back of the park were undergoing construction to their exterior	- Appeared well-maintained
Wushan Scenic Area	**Zhejiang University Zijingang Campus**	**West Lake**	**Xixi Wetlands**
- Appeared well maintained, workers were seen cleaning trails and amenities, as well as raking leaves - Construction was happening near the northwestern side of the area	- Well maintained facilities and lawns - Presence of maintenance crews	- Well maintained facilities and vegetation - Workers were seen clearing trails and amenities - Water clean-up was also present	- Well maintained facilities and grounds

Appendix N: Full Scale PM2.5 Concentration Maps

The PM2.5 concentration maps shown below display the data for all parks on the same scale to show the overall pollution levels in parks in Hangzhou.

Wanxiang Park

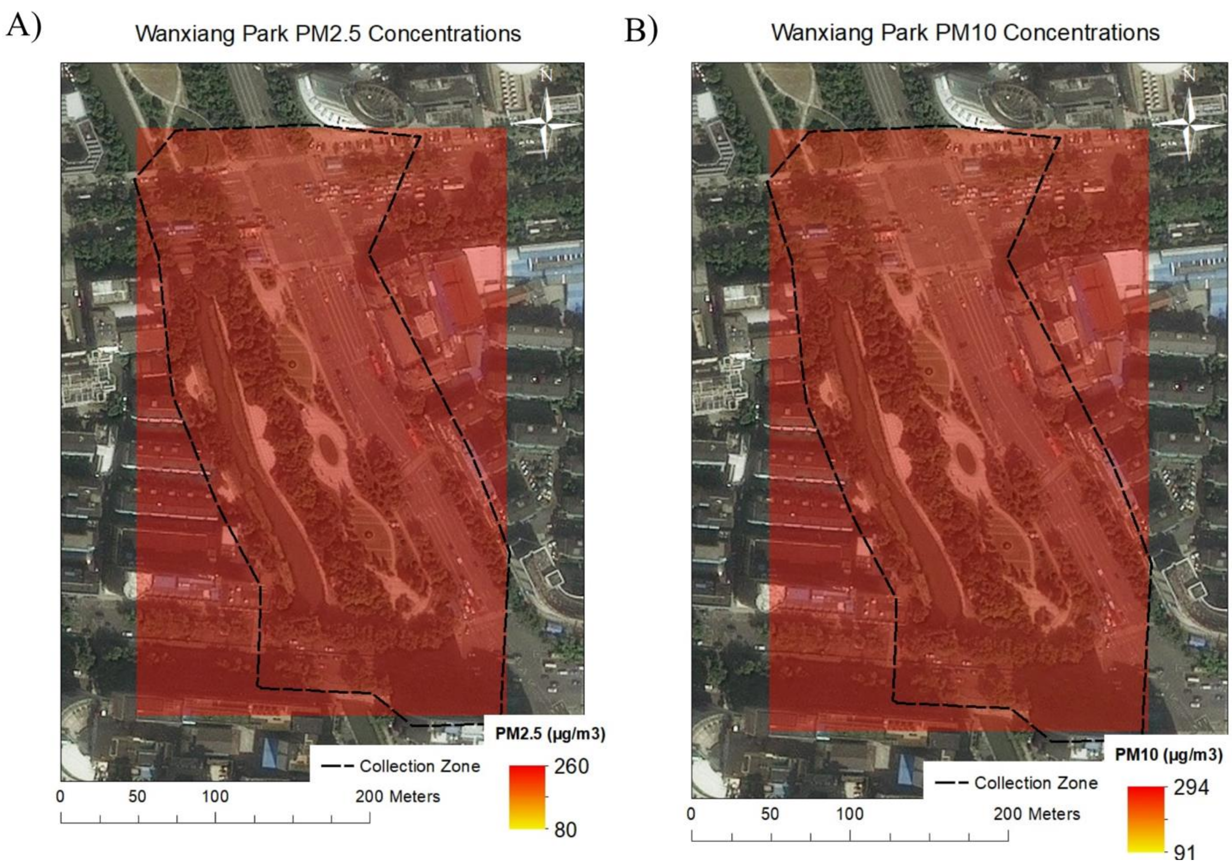

Figure N.1: (A) PM2.5 and (B) PM10 concentration distributions in and around Wanxiang Park with a standard scale. Data collected November 14, 2017, Map created December 4, 2017.

Jialvyuan Park

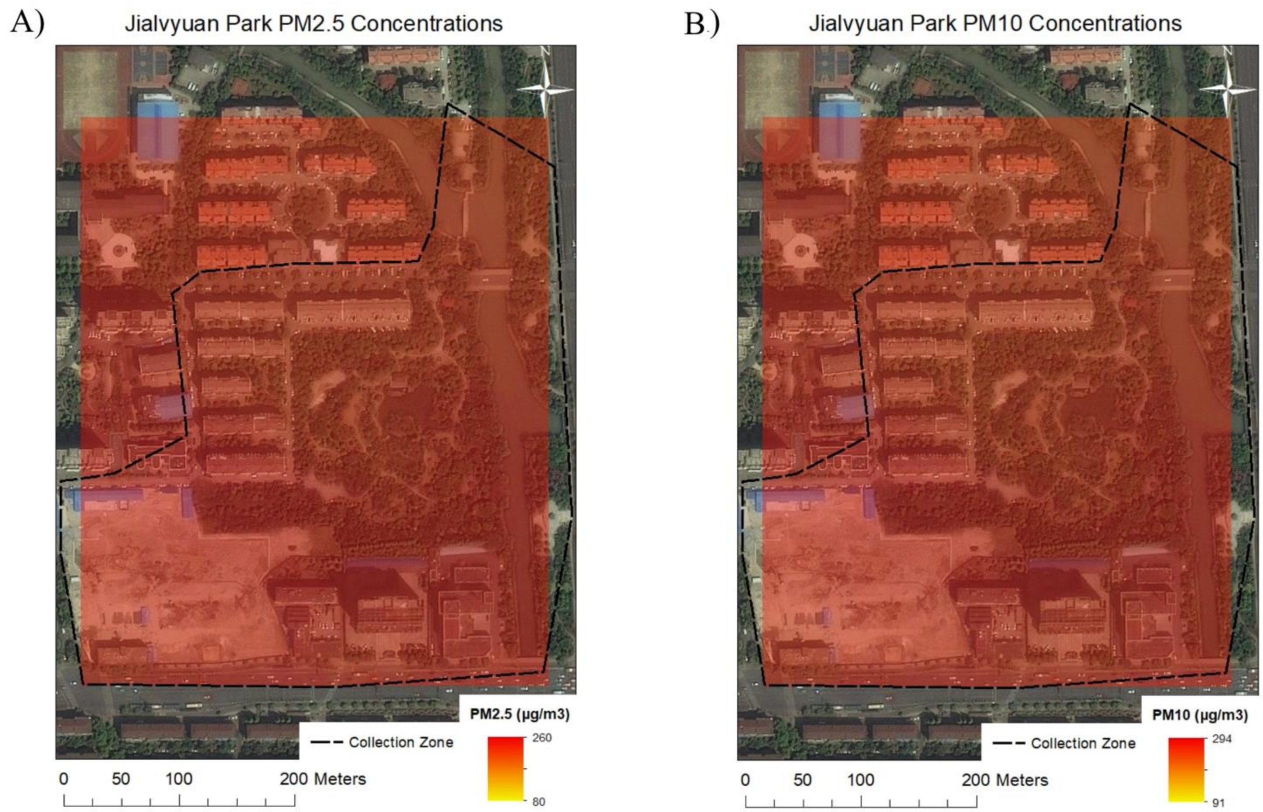

Figure N.2: (A) PM2.5 and (B) PM10 concentration distributions in and around Jialvyuan Park with a standard scale. Data collected November 14, 2017, Map created December 4, 2017.

Shu Yuan Park

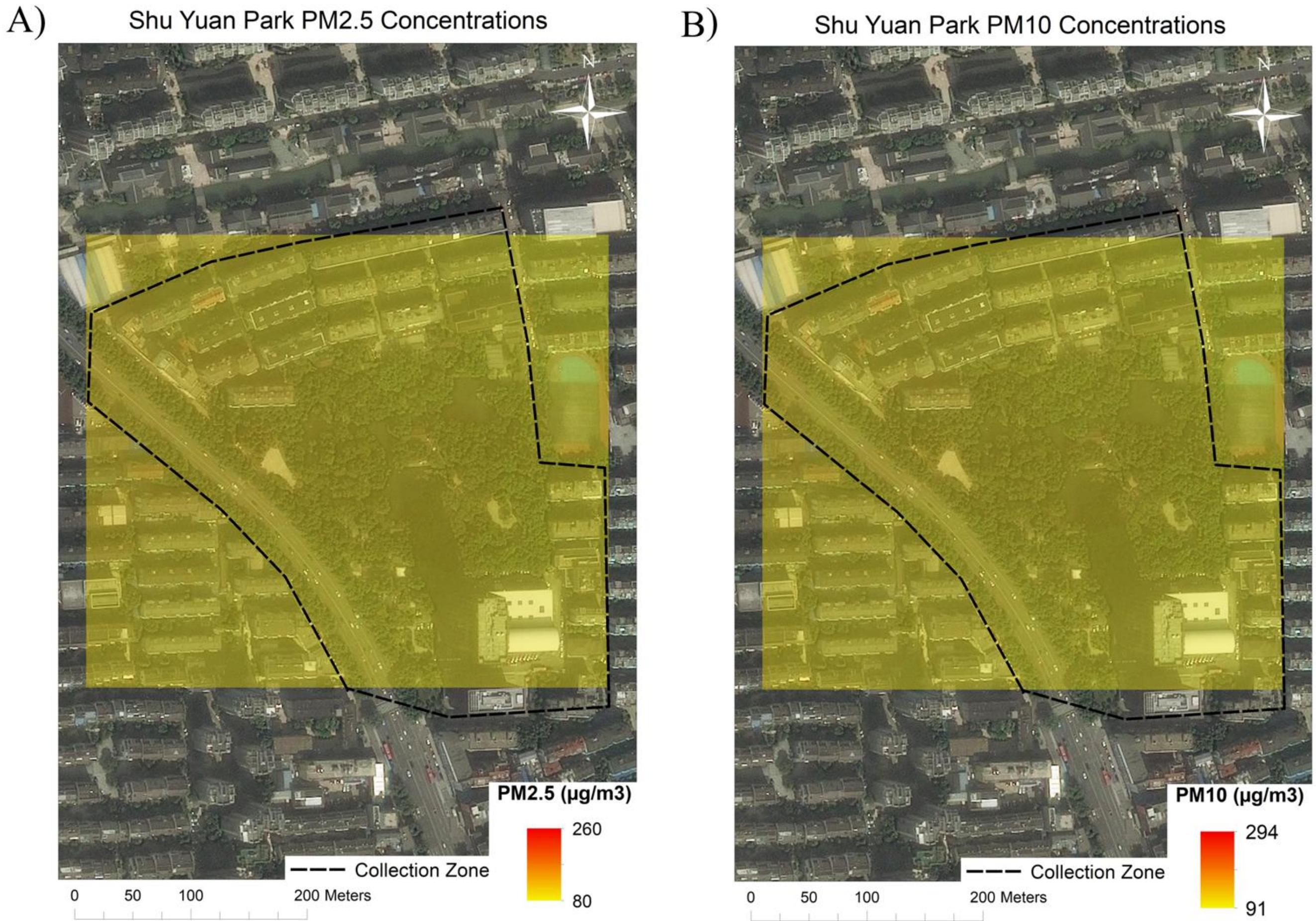

Figure N.3: (A) PM2.5 and (B) PM10 concentration distributions in and around Shu Yuan Park with a standard scale. Data collected November 13, 2017, Map created December 4, 2017.

Liuheta Culture Park

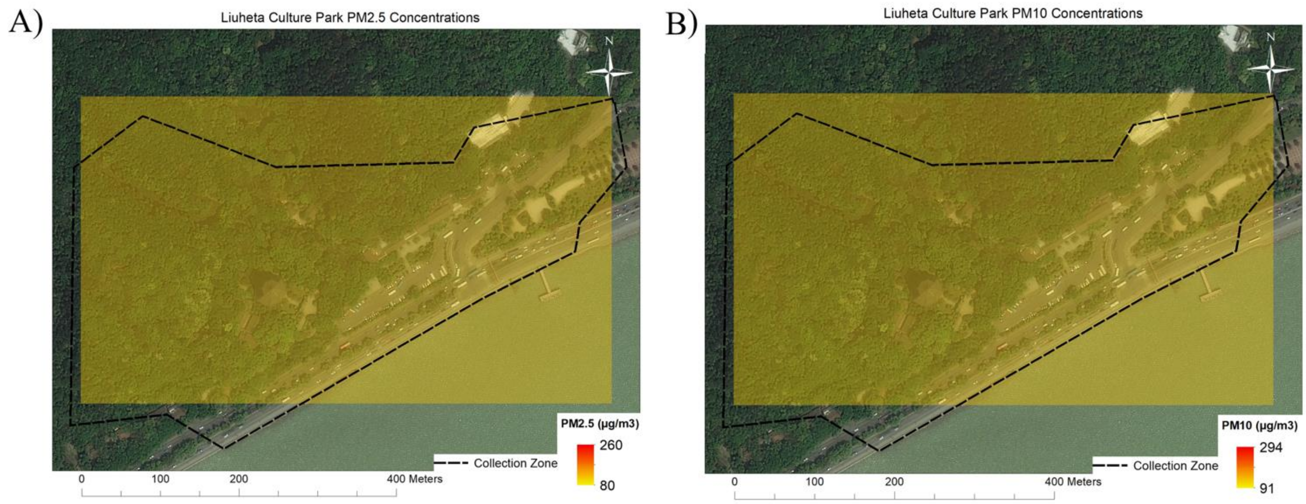

Figure N.4: (A) PM2.5 and (B) PM10 concentration distributions in and around Liuheta Culture Park with a standard scale. Data collected November 20, 2017, Map created December 4, 2017.

Wushan Scenic Area

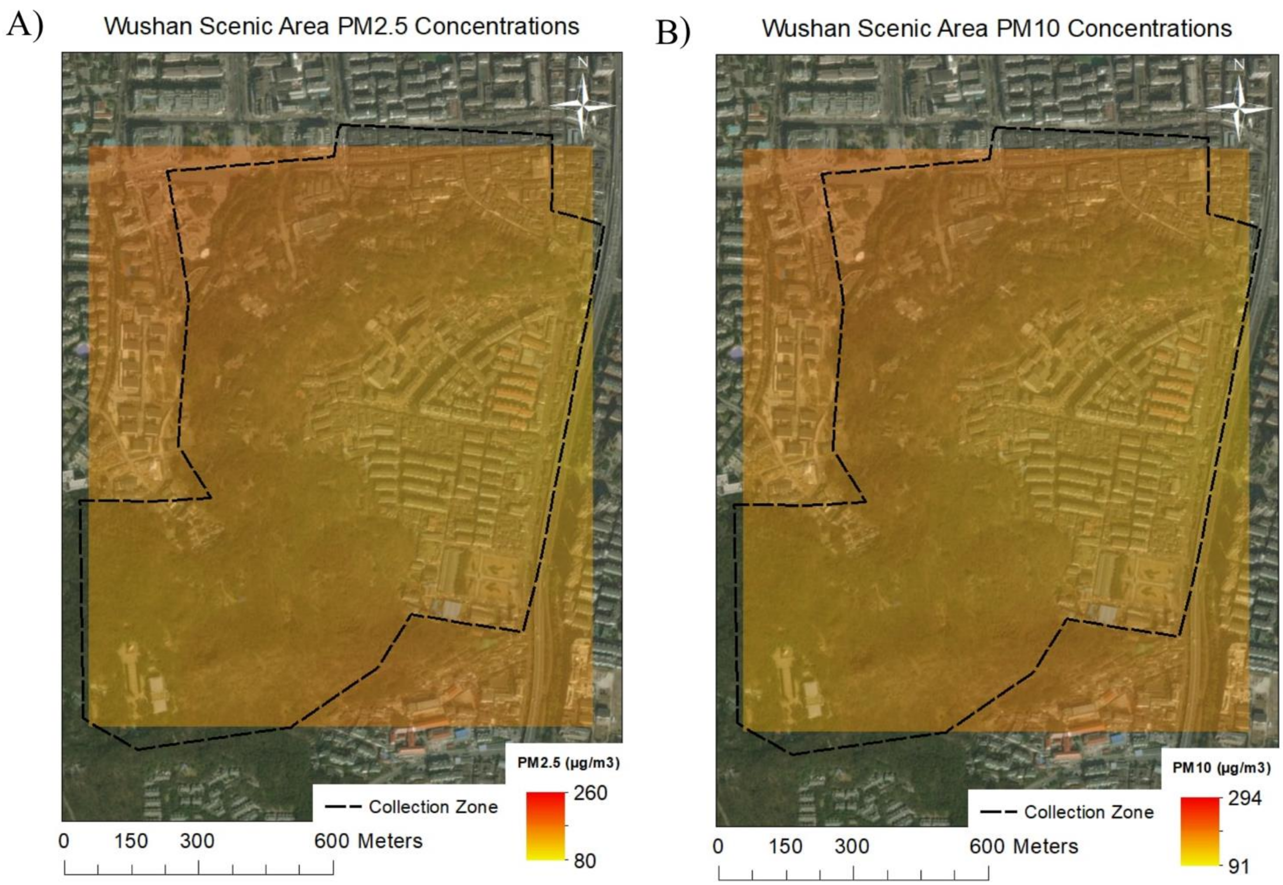

Figure N.5: (A) PM2.5 and (B) PM10 Concentration Distributions in and Around Wushan Scenic Area with a standard scale. Data collected November 15, 2017, Map created December 4, 2017.

Zhejiang University Zijingang Campus

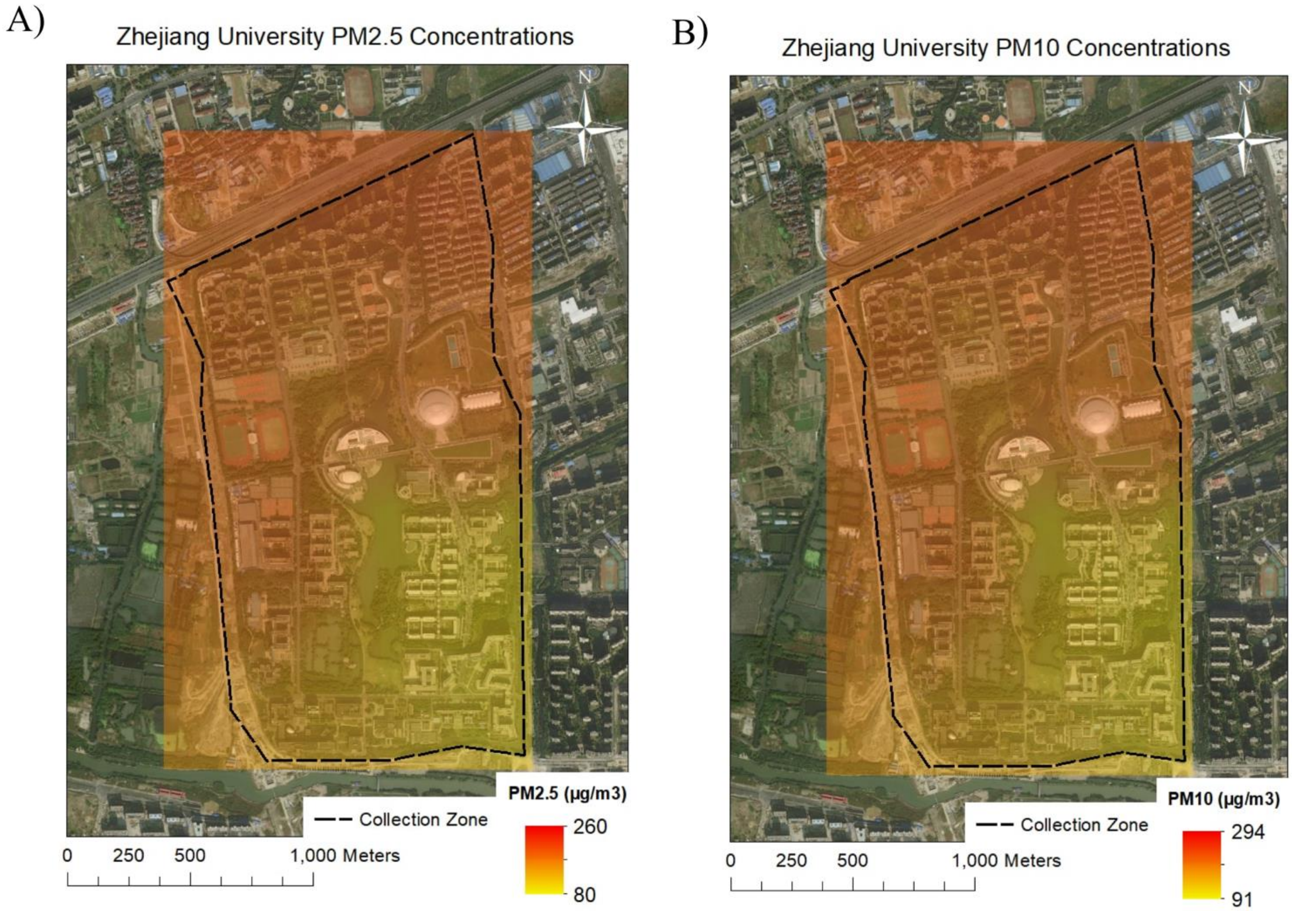

Figure N.6: (A) PM2.5 and (B) PM10 concentration distributions in and around Zhejiang University Zijingang Campus with a standard scale. Data collected November 14, 2017, Map created December 4, 2017.

West Lake

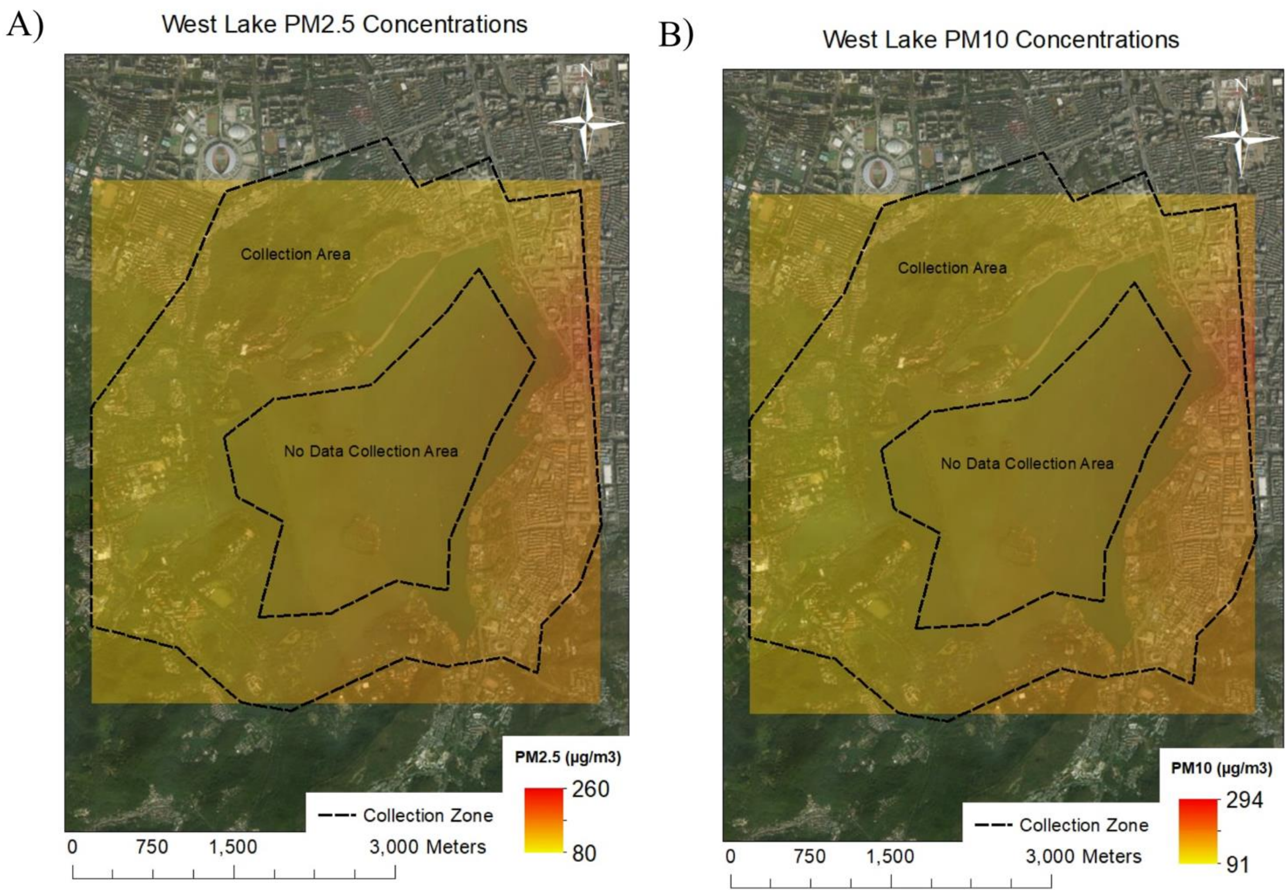

Figure N.7: (A) PM2.5 and (B) PM10 concentration distributions in and around West Lake with a standard scale.

Data collected November 29, 2017, Map created December 4, 2017.

Xixi National Wetland Park

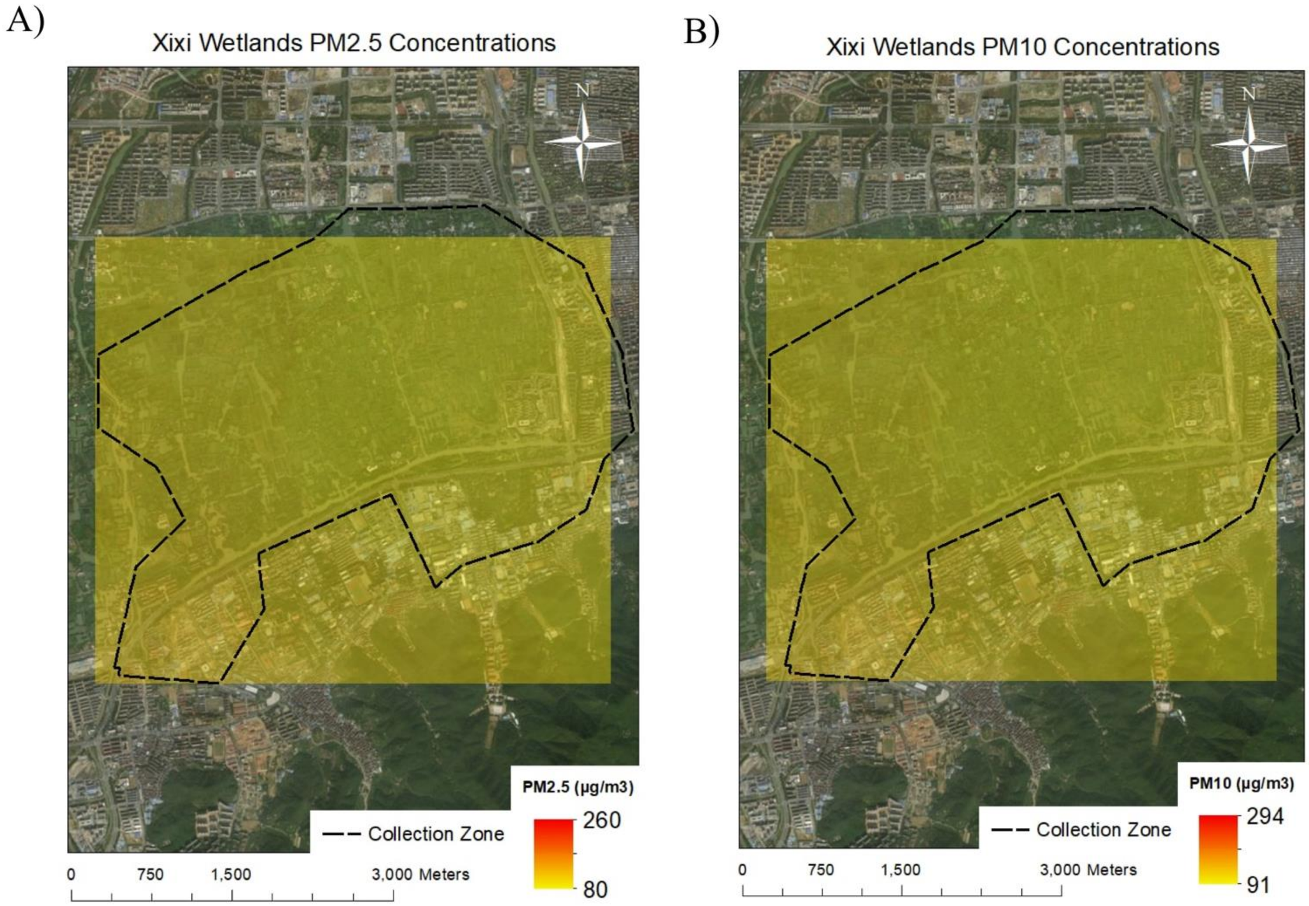

Figure N.8: (A) PM2.5 and (B) PM10 concentration distributions in and around Xixi National Wetland Park with a standard scale. Data collected December 1, 2017, Map created December 4, 2017.