Understanding Open Spaces in an Arid City

by

Won Kyung Kim

A Dissertation Presented in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

Approved October 2011 by the
Graduate Supervisory Committee:

Elizabeth Wentz, Co-Chair
Soe Myint, Co-Chair
Anthony Brazel
Subhrajit Guhathakurta

ARIZONA STATE UNIVERSITY

December 2011

ABSTRACT

This doctoral dissertation research aims to develop a comprehensive definition of urban open spaces and to determine the extent of environmental, social and economic impacts of open spaces on cities and the people living there. The approach I take to define urban open space is to apply fuzzy set theory to conceptualize the physical characteristics of open spaces. In addition, a 'W-green index' is developed to quantify the scope of greenness in urban open spaces. Finally, I characterize the environmental impact of open spaces' greenness on the surface temperature, explore the social benefits through observing recreation and relaxation, and identify the relationship between housing price and open space be creating a hedonic model on nearby housing to quantify the economic impact.

Fuzzy open space mapping helps to investigate the landscape characteristics of existing-recognized open spaces as well as other areas that can serve as open spaces. Research findings indicated that two fuzzy open space values are effective to the variability in different land-use types and between arid and humid cities. W-Green index quantifies the greenness for various types of open spaces. Most parks in Tempe, Arizona are grass-dominant with higher W-Green index, while natural landscapes are shrub-dominant with lower index. W-Green index has the advantage to explain vegetation composition and structural characteristics in open spaces. The outputs of comprehensive analyses show that the different

qualities and types of open spaces, including size, greenness, equipment (facility), and surrounding areas, have different patterns in the reduction of surface temperature and the number of physical activities. The variance in housing prices through the distance to park was, however, not clear in this research.

This dissertation project provides better insight into how to describe, plan, and prioritize the functions and types of urban open spaces need for sustainable living. This project builds a comprehensive framework for analyzing urban open spaces in an arid city. This dissertation helps expand the view for urban environment and play a key role in establishing a strategy and finding decision-makings.

ACKNOWLEDGEMENTS

Through the writing of this dissertation, a deep appreciation for the support from committee members, colleagues, and family was developed. I would like to recognize and thank my advisors, Dr. Elizabeth Wentz and Dr. Soe Myint for their support and for generously sharing their expertise and guidance. The encouragement and inspiration of Dr. Wentz as my mentor has been invaluable throughout my time in the graduate program. I would also like to thank Dr. Myint for his expert advice and assistance for my research. Many thanks go to my other committee members, Dr. Anthony Brazel and Dr. Subhrajit Guhathakurta for their insight and advice they provided me.

This dissertation was undertaken with the continual support of my family and friends. My parents and parents-in-law have shown encouragement, love, and support throughout my academic pursuits. Thank you all my family members, Kyung-Ahn, Hyun-Myung, Sun-Young, So-Young, Moo-Sung, Sang-Yeob, Jin-Woo, and Seung-Hyun. I would also like to thank my friends, Min Hyung, Jong-Geun, Nayoung, Myunghwa, and Darren for their support.

Finally, I truly would like to acknowledge my wife, Min Jo, to whom I owe my undying love and support. Her continued love, support, and patience assisted me in the completion of this goal.

TABLE OF CONTENTS

CHAPTER Page

CHAPTER Page

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

Figure Page

Figure		Page

CHAPTER 1

INTRODUCTION

1.1 Sustainability and Urban Open Space

Urban open space plays a key role in promoting and maintaining sustainable cities. Sustainable development in cities is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations 1987). The core of sustainable development is the intersection of three dimensions, environmental, social and economic sustainability (Figure 1-1). Urban open space provides environmental, social and economic benefits to cities and their residents to advance sustainability and improve the quality of life. Understanding the key functions of urban open spaces is an important part to improve their effectiveness both for better development and management of open spaces. To explore the roles of urban open space, the delineation of open space in cities needs to be examined and clarified in terms of its physical characteristics.

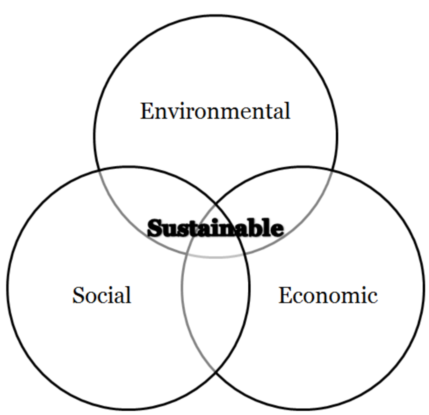


Figure 1-1. Intersection of the environmental, social and economic pillars of sustainability (adapted from Adams 2006)

1.2 Urban Open Space Typology

Urban open space is a term used to define regions of 'vacant lots', 'natural landscapes' and 'public green space' in cities, and the definition of urban open space has evolved in time embracing various types of urban open and green elements. Open space was initially defined as the area that was not built in cities. Lynch (1972) proposed a definition of open space in terms of both form and function: "It is an outdoor area which is open to the freely chosen and spontaneous activity, movement, or visual exploration of a significant number of city people." Thus, urban open space was defined as publicly accessible open lands such as parks, plazas, streets, and community gardens (Lynch 1972; Carr et al. 1992). Currently, the concept of 'open space' in urban setting is not limited to the natural preserves, undeveloped lands, and urban forest but also to urban parks, sports complexes, and non-park and non-natural places. Urban open spaces should be treated as a public good for urban residents, and they should be characterized with their physical elements and social factors (Zhu and Blumberg 2004).

There are several terms associated with urban open space, and the most common of these terms include public space, green space, and open space. Public space is open to and shared by all people and is often provided and managed by government institutions (Madanipour 1996). Green space is defined as an area covered by 'green' elements and vegetation. Green space, however, is sometimes used more broadly including urban parks, forest, vegetation, and open space. This term, green space, has been mainly used in research focusing more on an environmentally beneficial role than social and economic issues. Finally, many descriptions and definitions of open space in a city can be found, and I introduce three major concepts for urban open space. In addition, open space can be defined as being dominated by a 'natural' environment in contrast to the built environment (Maruani and Amit-Cohen 2007). Second, open space is a space that is legally designated and created by humans within urban areas for community use, including public parks, sports complex and fields, and town squares. Finally, urban open space can include all these concepts of green and public spaces as well as natural landscapes.

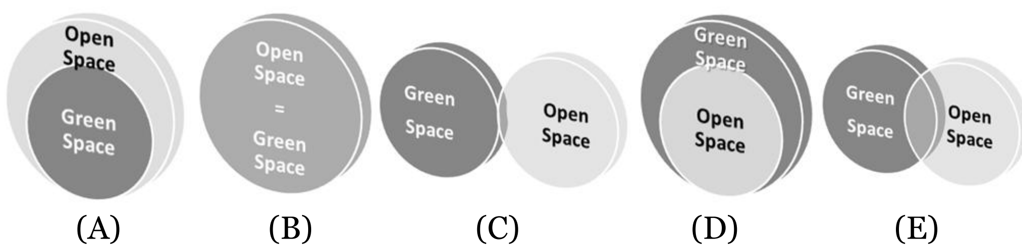


Figure 1-2. Terminology relationship between open and green spaces

The terms 'green space' and 'open space' are frequently used interchangeably (James et al. 2009). Recognizing the relationship between open space and green space will be helpful to establish the proper definition of urban open space (Figure 1-2). Compared two concepts of open space and green space in cities, there can be five relationships between them. Urban green space often has been used as a part of a more general open space in a number of planning and policies (Figure 1-2 A). As an extensive concept of open space, it includes all parks, public plazas, vacant areas, and natural landscapes. Open space has been sometimes employed for urban green space as same properties (Figure 1-2 B), while it may only mean vacant and undeveloped areas (Figure 1-2 C). As a broader concept of green space, green space can include residential green cover which is not open to public and privately owned (Figure 1-D). My assumption of ideal relationship is that there is an intersection between open space and green space even though one of them might be larger than the other (Figure 1-E). In this research, I use the term, urban open space, which can not only cover the extent of public and green spaces but also include the spaces with small amount of vegetation covers and greenness.

1.3 Open Spaces in Cities

Urban open space provides a range of tangible environmental benefits, such as mitigating urban heat island (UHI) as well as air and water pollution (Chen and Wong 2006; Cavanagh, Zawar-Reza, and Wilson 2009), and improving biodiversity (Tzoulas and James 2004). It also provides social and economic benefits to the residents, such as providing opportunities for recreation (Sugiyama and Ward Thompson 2008) and fostering cohesive neighborhoods (Austin 2004) as well as stabilizing and increasing housing prices and property values (Geoghegan 2002).

The physical characteristics of urban open spaces should be considered in understanding their roles on urban environment. Open spaces in arid and humid cities have different landscapes and roles. In arid and semi-arid regions where greenness requires irrigation, the greenness of open spaces varies substantially in its quality and extent. Most natural arid open spaces are composed of shrubs with a small number of trees and little or no turf. The source of greenness in other open spaces in arid areas is irrigated vegetation cover of turf grass, shrubs, and larger trees. In contrast, open spaces in humid cities can be recognized as green spaces in the same manner. This indicates that all arid urban open spaces do not have same influences and benefits on cities and people, and it should be identified the differences for the impacts of open spaces between arid and humid cities. To better understand urban open spaces in an arid city, it is necessary to have a comprehensive definition and flexible methodology to characterize open spaces in cities.

Therefore, my research questions are “What is urban open space?” and “Do urban open spaces in arid cities provide same environmental, social and economic benefits with those in humid cities?” The remainder of this dissertation outlines my research analyses to answer these questions. I begin with a literature review covering open spaces’ functions and benefits on people and cities, research methods for assessing open spaces, and planning models for urban open space design and management. The following chapters are three major research studies and outputs, which are 1) Fuzzy set based theoretical framework for urban open space mapping, 2) Developing a W-Green index for characterizing urban parks and open spaces in an arid city, and 3) Urban open spaces for urban environment and residents: a comprehensive approach. Finally, the chapter six presents the conclusions, significance of the dissertation, and future directions.

CHAPTER 2

LITERATURE REVIEW

The literature review first identifies the beneficial roles and potential disadvantages of urban open spaces. Based on these functions of open spaces, many studies have focused on examining urban planning strategy models to design and manage urban open spaces. Finally, this review also provides a theoretical base for measuring the quality and quantity of urban open spaces through urban remote sensing.

2.1 Urban Open Space Functions and Benefits

2.1.1 Environmental Benefits

Many studies have revealed that open space plays a key role in improving urban environmental quality (Pauleit 2003; Song 2005; Faryadi and Taheri 2006). Urban open spaces directly benefit the urban environment through reducing temperature (Chen and Wong 2006), ameliorating air pollution, and preserving biodiversity in cities. Several studies showed that more open and green space in urban area is positively related to mitigating the urban heat island (UHI) effect (Ca, Asaeda, and Abu 1998; Oh and Hong, 2005). Ca, Asaeda, and Abu (1998) measured temperatures on grounds to determine the cooling influence of urban open spaces, and air temperature measured at 1.2m above the grass land was more than 2 °C lower than those measured above hard impervious surfaces. Chen and Wong (2006) showed that the cooling impacts of urban open spaces were reflected through not only the lower temperatures in urban open spaces but also the lower temperatures in surrounding areas. The temperature difference caused by open spaces may reduce cooling requirements in surrounding buildings, and 10% reduction of the cooling load was observed in their simulation. In addition, Yin et al. (2007) performed correlation analysis between the vegetation status and the total suspended particles (TSP) removal percentage and proved that vegetation in urban open spaces greatly contributes to reduce TSP pollution.

2.1.2 Social Benefits

The social beneficial roles of open spaces are mainly to provide the opportunity of social activity and recreation and to improve human health both physically and psychologically. It is difficult to value social benefits from urban open spaces, but providing open spaces to people has the potential to improve quality of life (Groenewegen et al. 2006). Urban open spaces play a social integrative role for various social groups (Gernmann-Chiari and Seeland 2004). For example, Seeland, Dübendorfer, and Hansmann (2009) showed that urban open spaces provided the opportunity for children and youth to make friends and contact, and the patterns of socializing in open spaces were different depending on age, school level, and gender. Thus, the social benefits of urban open spaces are differently influenced to people depending on age and activity levels. Different age groups have different reasons to visit urban open spaces and perform different activities (Chiesura 2004). Hume et al. (2005) showed that children living near urban open spaces are more likely to be physically active. Kweon, Sullivan, and Wiley (1998) subsequently investigated the relationship between older adults' exposure to nearby green common spaces and their level of social integration and attachment to local community. They found the modest relationships between the use of green outdoor common space and the strength of neighborhood social ties and sense of community for older adult residents of inner-city neighborhoods.

The impact of open spaces on the well-being of urban citizens is also one of main research topics in open space's social benefits. Sanesi and Chiarello (2006) investigated the perception of open spaces within the city through qualitative methods. They showed people perceived open spaces as a life quality enhancer and patterns in the use of open spaces are related to age, marital status and area of residence. Some studies have provided strong evidences to show the positive effect of open spaces on recovery from stress and fatigue (Hartig et al. 2003; Kaplan and Kaplan 1989). Overall, these studies showed the importance of open space for human health as well as social activity and connection in urban area.

2.1.3 Economic Influences

Even though it is difficult to quantify the economic or market values of open spaces, research has been performed exploring the relationship between house price and urban open space. Economic approaches used to estimate value of open spaces include hedonic pricing, willingness to pay, travel cost and tree valuation. Many researchers have examined whether open space provides benefits to its neighboring housing and communities using hedonic price models (Geoghegan 2002; Sander and Polasky 2009). As I shown in previous sections, urban open space provides many environmental and social services that contribute to the quality of life in cities, and these benefits are connected to its economic impacts. Thus, open spaces enhance the economy and quality of life in cities by improving urban environmental quality as well as providing recreational opportunities (Poudyal et al. 2009a).

Previous research has shown that housing price increase with the proximity to open space (Sander and Polasky 2009) and the size of urban parks (Tyrväinen 1997). Many studies have confirmed the positive benefits of open space and indicated that proximity to public parks, golf courses, and natural resources raise housing values considerably (Correll, Lillydahl and Singell 1978; Frech and Lafferty 1984; Do and Grudnitski 1995; Bolitzer and Netusil 2000). Tyrväinen (1997) found that increasing portion of total forested area in the housing district had a positive influence on apartment price, but the effect of small parks was not clear. In contrast, Anderson and West (2006) did not show that the size of urban parks or green areas had a significant amenity effect. There also have been studies that estimate the willingness to pay for open space using the contingent valuation method (Breffle, Morey, and Lodder 1998). They showed that protection and restoration of forest ecosystems is an economic good that people are willing to support. The higher price paid by customers for houses that have urban open spaces compared with those without open spaces directly reflects the market value of the open spaces (Altunkasa and Uslu 2004).

Additionally, the valuation of open space with regard to its spatial configuration has become a matter of interest. The valuation of open space composition focuses on the comparison of amenity values among different types of open and green spaces. For instance, Anderson and Cordell (1988) found that a hardwood landscape is valued slightly more than a pinewood landscape. Recent literature also focused on the aesthetic value of land-use diversity and landscape quality in the surroundings (Geoghegan et al. 1997; Acharya and Bennett 2001; Kestens et al. 2004).

2.1.4 Efforts to Integrate the Benefits of Open Spaces

The demand for a comprehensive understanding of the roles of urban open spaces has been increased recently. Benefits of Urban Green Space (BUGS), which is a research project in European Union (EU), has tried to develop a methodology to evaluate the influences of open spaces on environmental quality and social well-being (De Ridder et al. 2004). Bell, Montarzino, and Travlou (2007) also organized research information and priorities for urban open spaces, and they showed the current steps of open space research and identified the priorities for further research topics. James et al. (2009) recognized the lack of research framework and tools for an understanding of the multiple functions of urban open spaces, and they suggested an integrating framework for a research agenda for urban open spaces, which are five research themes of physicality, experience, valuation, management and governance of open spaces.

2.1.5 Potential Disadvantages of Urban Open Spaces

Although the disadvantages of urban open spaces are not the focus of most research, some are identified and described. Some researchers suggested that city parks created boundaries between neighborhoods (Gobster 1998). Those parks might function as barriers between neighborhoods and discourage passage between them (Solecki and Welch 1995). These are referred to boundary parks, which are located between different neighborhoods. An excellent example was New York City's Morningside Park. This park in northern Manhattan separated a poor minority neighborhood of West Harlem from the predominantly white, middle-class neighborhood of Morningside Heights (Schaffer and Smith 1986). As another effect, low crime parks can serves as better amenities but high-crime parks may have the potential to negatively affect their surrounding neighborhoods (Troy and Grove 2008). Only in the case of proximity to heavily used recreational areas has open space been shown to reduce housing values, because of congestion and noise (Weicher and Zerbst 1973). It is necessary to carefully interpret the spatial organization of urban open spaces and the socioeconomic characteristics of adjacent populations.

2.2 Urban Open Space Planning Models

The necessity of open spaces in urban areas has been recognized, and planning of open spaces became in a key part of urban and land-use planning. Urban open space planning approaches and strategies vary with its regional and national policy as well as environmental and socioeconomic characteristics. There is no general agreement on the desirable planning criteria as to how much urban open space is needed, where they should be located, or how they should be used (Maruani and Amit-Cohen 2007). Originally, the purpose of urban open space was to provide recreational areas within the city center for urban residents (Schuyler, 1986). The view of urban planning for open spaces has been extended from an aesthetic view and social impacts related to recreation, health and psychology to environmental and ecological functions.

Urban open space planning can have different purposes with demand and supply aspects. From the demand approach, open spaces should be considered to fulfill the urban population's needs, so they should be focused on attributes of size, demographic variables, and residential distribution (Maruani and Amit-Cohen 2007). On the other hand, a supply approach aims at conservation of high-quality natural and landscape values. Table 2-1 shows the differences between two approaches.

Table 2-1. Approaches to Open Space Planning

Planning Aspects	Examples of Guiding Planning Principles	
	Demand Approach	Supply Approach
Site Selection	• Proximity to users • Accessibility • Visibility • Relation to other open spaces	• Presence of high-quality natural values • Uniqueness of natural values • Sensitivity or vulnerability of natural values • Visual quality • Integrity of ecosystem • Vital ecological processes
Quantitative Measures	• Size of each open space unit • Total amount of open spaces	• Preferably defined by natural features or ecosystem boundaries
Types of Activities	• A variety of recreational activities • Activities fit for different groups • Suitability to special needs and preferences	• Limited outdoor recreation • Activities compatible with conservation goals
Site Design	• Design for intensive use • High maintenance • Wide selection of facilities	• Minimal intervention • Limited access • Few facilities • Low maintenance

Source: Maruani and Amit-Cohen 2007

As mentioned in previous sections, urban open space provides a wide range of impacts on cities and people. To understand the multifunctional use and the full potential of urban open spaces, it is essential to obtain reliable data and to examine with appropriate methodologies. The selection of proper indicators and measurements is a key issue to evaluate urban open spaces (Van Herzele and Wiedemann

2003). Remote sensing has been developed as an important data source and tool for assessment and monitoring of urban open spaces, urban green elements, vegetation covers, and desertification (Ostir et al. 2003).

2.3 Measuring and Characterizing Urban Green of Open Spaces

I investigated why open spaces are important and how they can be examined in previous sections. A remote sensing provides a useful tool not only to identify the quality and quantity of open spaces but also to evaluate their functions in a more consistent way.

2.3.1 Urban Remote Sensing

A growing number of studies have focused on remotely sensed image analysis techniques to measure vegetation cover and greenness for urban open space. Urban remote sensing has been used successfully in land cover classification and monitoring urban environment over a range of spatial and temporal scales (Geerken and Ilaiwi 2004, Symeonakis and Drake 2004). It can provide calibrated, quantitative, repeatable and cost effective information for large areas and can be related empirically to field data (Graetz 1987; Pickup 1989; Tueller 1989). Many classification methods have been used to extract the information of urban elements including per-pixel analysis, sub-pixel classification, and object-orient approach. The spatial resolution of satellite sensors has been improved to be appropriate for urban environment applications (Mathieu et al., 2007).

Traditional pixel-based classification methods classify individual pixels by using only the spectral content of the images. But urban environments consist of a mosaic of small-scale features with different materials (Hofmann, 2001). Sub-pixel analysis is capable of generating fractional amount of spatially mixed spectral signatures from different land cover feature, so it is more suitable for medium resolution satellite images, such as Landsat Thematic Mapper (TM) (Myint and Okin 2009). Object-based image analysis recognizes that important meaningful information is represented in image objects and their mutual relations (Myint et al. 2008), and these techniques have showed potential to improve the automatic extraction of information from high-resolution satellite images (Benz et al. 2004; Tansey et al. 2009).

2.3.2 Vegetation Index

Different methods to calculate vegetation indices had been attempted including ratio vegetation index (RVI), normalized difference vegetation index (NDVI), perpendicular vegetation index (PVI), and tasseled cap greenness. Green vegetation absorbs a substantial proportion of radiation in the range of visible red light but reflects most of the near-infrared energy during the process of photosynthesis. Based on this difference the first vegetation index was developed by combining near-infrared and red spectral reflectances into a ratio as a measure of above-ground biomass or vegetation vigor (Jordan 1969). These vegetation indices have been attempted and applied to urban environmental research, and the NDVI is the most commonly used to understand vegetation cover among them.

Fung and Siu (2001) analyzed the spatial patterns of the magnitude and variability of 'greenness' based on five variables: 1) percentage of area covered by vegetation, 2) mean NDVI, 3) standard deviation of NDVI, 4) entropy of NDVI, and 5) percentage of woodland. They used these variables to explain changes of open spaces in the urban environment of Hong Kong and proved that satellite data provide an important source of information for better planning in urban/suburban development. However, green vegetation is often intermixed and difficult to differentiate in arid regions (Laliberte, Fredrickson, and Rango 2007). In order to consider the effect of background soils, soil adjusted vegetation index were developed by Huete (1988), and there have been continuing attempts to have a better index, such as transformed soil adjusted vegetation index (TSAVI) and modified soil adjusted vegetation index (MSAVI).

2.4 Research Needs

A motivation for this research is the desire to provide comparable information for the delineation and benefits of urban open space in an arid environment. The growing demand for a high quality of life has coincided with a deep concern for the availability and quality of urban open space in spite of ambiguous delineation. Although the background for development and management of urban open spaces are different depending on cities and countries, most studies have proved that urban open spaces are an important for urban environment and the quality of life.

Literature also shows that different types of urban open spaces have different functions and provide different benefits. There is, however, no standard definition of urban open space that could be applied to various academic fields. Definitions vary with regions and cities and are often evaluated with different parameters. In addition, research articles and planning policies and documents defined urban open space and categorized types of open space differently according to its location, purpose, and function. Understanding diverse types and roles of different open spaces perform helps planners to recognize and understand how to develop and manage urban open spaces. Therefore, it is necessary to have reliable definitions and approaches to the valuation of urban open spaces in order to have better understanding urban open spaces, especially in desert cities.

Desert cities, such as Phoenix metropolitan area, have less prominent vegetation cover than non-arid regions do (Wentz et al. 2006). Some open spaces may be undisturbed forest or scrubland, or they may not include recreation facilities and trails. The reason for a new approach to define urban open space is that it might be a problem in arid cities to consider both open space and green space as same properties because the impacts of urban open space might be different between arid and non-arid environments. Recognizing the difference of arid urban open spaces may lead the possibility that urban open spaces in arid cities may have some limitation for cities and people to provide their functions. For example, parks which formed the majority of shrubs may have no effect of the mitigation of UHI and no aesthetic value, but people may use trails for hiking and horse-riding. People may prefer not to use urban parks and visit natural landscapes in the hot summer because it is too hot to be there. There may be different influences on environmental quality between grass-dominant and tree-dominant spaces. Therefore, environmental situations in arid cities require a different emphasis analytically with humid climate cities. Though many previous studies have highlighted the contributions of urban open spaces from ecological, social, and economic perspectives, it should be confirmed whether urban open spaces in desert cities provide same environmental, social and economic benefits.

In addition, urban open space planning models have only focused on the quantity and social functions of urban open spaces. Strategies and models for urban open space should have a comprehensive picture to cover various roles and regional characteristics. Urban planners and designers must understand what constitutes the ‘quality’ of urban open space in desert cities and how it can be achieved. To better understand urban open space in an arid city, it is necessary to identify the benefits of arid open spaces correctly and to find the connections in those functions.

CHAPTER 3

DEVELOPING A W-GREEN INDEX FOR CHARACTERIZING URBAN PARKS AND OPEN SPACES IN AN ARID CITY

3.1 Introduction

Green-vegetated open space provides environmental, social, and economic benefits to people and cities (Tyrväinen 1997, Groenewegen et al. 2006, Barbosa et al. 2007, James et al. 2009). 'Green' is becoming a keyword in everyday life with the demand for green and sustainable environment in cities. 'Green' vegetation is important in a climate role due to its role in hydrologic cycle (Montandon and Small 2008). These benefits include mitigating urban heat islands (UHI), reducing air and water pollution, enhancing biodiversity, increasing recreation opportunity, and stabilizing and increasing property values (Geoghegan 2002; Austin 2004; Tzoulas and James 2004; Chen and Wong 2006; Sugiyama and Ward Thompson 2008; Cavanagh, Zawar-Reza, and Wilson 2009). However, most studies on urban open spaces are based on humid cities where open spaces are also "green" spaces with dense vegetation.

Arid city open spaces have a wide range of "greenness" ranging from native desert with spare vegetation to irrigated land with dense vegetation. In arid and semi-arid regions where greenness requires irrigation, the greenness of open space varies substantially in its quality and extent as well as the cost and benefits to the residents and environment. Green vegetation is often intermixed and difficult to differentiate from bare soil and non-green shrubs in arid regions (Laliberte, Fredrickson, and Rango 2007). Most natural open spaces are composed of shrubs with a small number of trees and little or no turf, for example, South Mountain in Phoenix is mostly covered by shrubs. The sources of greenness in other open spaces are irrigated vegetation cover of turf grass, more shrubs, and larger trees. Urban parks and educational facilities have main places for greenness. This means that all arid urban open spaces might not have the same influences and benefits on cities and people, and it should be confirmed that the impacts of open spaces are truly influenced on arid cities.

Thus, the selection of proper indicators and measurements is a key issue in evaluating urban open spaces (Van Herzele and Wiedemann 2003), and the plans of urban open spaces are important for maintaining sustainable cities (Wu and Plantinga 2003). These can be achieved with a methodologically sound assessment that identifies the characteristics and qualities of urban open spaces. Landscape indices and vegetation indices for the assessment of urban open space have been developed to explain the spatial structure and patterns of ecological landscape in urban open space and to quantify vegetation fraction using remote sensing data, respectively. However, these indices are limited to by their need to consider the different characteristics of climate conditions and different composition of vegetation in urban open spaces.

This paper introduces W-Green index as a newly designed methodological approach to quantify vegetation in urban open spaces. The W-Green index allows us to examine compositional structure of vegetation in urban open spaces in arid cities.

In this study, I develop three green indices (simple green index, weighted green index 1, and weighted green index 2) with density and height of vegetation in urban open spaces and then finally an advanced W-Green index. To verify the motivation of the study, I investigated the characteristics of urban open spaces and the roles of vegetation in urban open spaces in Section 2. The conceptual framework, data, and model for W-Green index are described in Section 3. In Section 4, I test W-Green index and apply to urban open spaces in Tempe, Arizona. To confirm the validity of W-Green index, I also compare it with a vegetation index, which is widely used and produced by remote sensing data. Finally, I discuss research methods and outputs and make a conclusion for this study.

3.2 The Characteristics and Benefits of Urban Open Space

Existing urban open space research has examined environmental, social, economic, and management and maintenance of urban open spaces (Bell, Montarzino, and Travlou 2007). First, many studies have focused on specific types of urban open spaces such as urban forests, parks, wetlands, and golf courses (Dwyer et al. 1992). Tyrväinen and Miettinen (2000) examined residents' valuations attached to urban forests, and they showed the negative relation between the distance to the nearest forests and housing price. Chen and Wong (2006) proved the cooling effects of city green parks at vegetated areas and the surrounding built environments. Shutes et al. (1997) represented the pollution removal performance of wetlands for urban runoff treatment. Second, many existing studies have also examined the characteristics of urban open spaces with remote sensing classification and vegetation indices (Kong and Nakagoshi 2006). Fung and Siu (2001) used normalized vegetation index (NDVI), which is widely used for vegetation research, to examine the changes of spatial patterns for urban open spaces in Hong Kong, and they showed the continuous loss of open spaces due to urban development and hill fire.

The characteristics and design of urban open spaces determine their influences on the quality of urban environments as well as the visiting pattern of people (Bruse 2007). For example, Chudnovsky, Ben-Dor, and Saaroni (2004) showed that grass area was found to be cooler than other vegetation by about 4°C in surface temperature during night-time. Ca, Asaeda, and Abu (1998) also found the cooling influence of grassland on air temperature, and the air temperature on the grassland was lower than that on the impervious surface. Trees also can mitigate urban surfaces and air temperature through heat-absorption, evapotranspiration, and shading (Chang, Li, and Chang 2007). One urban park covered with broadleaf trees in Kumamoto, Japan, had a maximum cooling effect of 3°C during the day (Saito et al. 1990/1991). People visit urban open spaces to enjoy the weather and fresh air, and distance to urban open spaces is not a limiting factor for visiting (Schipperijn et al. 2010). The quality and accessibility of urban open spaces have the positive relation with walking time (Sugiyama and Ward Thompson 2008). Recent research has interests in structure and design of urban open spaces. Chen, Adimo, and Bao (2009) evaluated aesthetic quality of urban open spaces and showed that people had expectation of auditory, visual quality and recreational needs from urban open spaces. Goličnik and Ward Thompson (2010) described patterns of uses in urban open spaces through behaviour mapping and emphasized the relationship between environmental design and use of open space. In addition, better design and management of urban open spaces enhance their ecological integrity (LaPaix and Freedman 2010).

3.3 W-Green Index

A motivation for this research is to provide comparable information for the characteristics of urban open space in an arid environment. Understanding diverse types and roles of different open spaces helps urban planners to recognize and understand how to develop and manage them. To achieve this understanding, I designed a "W-Green Index," which can be used to characterize different kinds of urban open spaces and different statuses of vegetation in open spaces. The W-Green index is produced based on the density and height of urban green in open spaces

(Figure 3-1). The goal of this research is to measure and characterize vegetation cover and greenness of urban open spaces. As a newly designed measurement for urban open spaces, the green index will be a useful tool to quantify the greenness and openness of open spaces in an arid city and to understand their functionality and quality. There are four steps to produce the green index: 1) constructing data input with remotely sensed data and techniques, 2) conducing ground surveys for data input and correction, 3) producing density and height values for vegetation in open spaces, and 4) calculating simple and weighted green index values. To have a better understanding of W-Green index, I introduce an open space category that shows representative open spaces for nine levels of W-green index (Figure 3-2). This categorization is also used to produce weight values to density and height for weighted green indices.

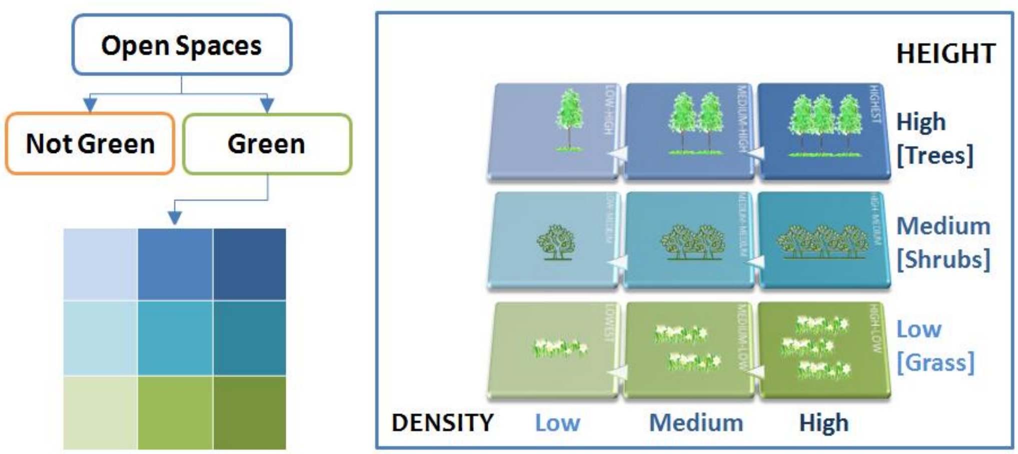


Figure 3-1. The conceptual diagram for W-Green index

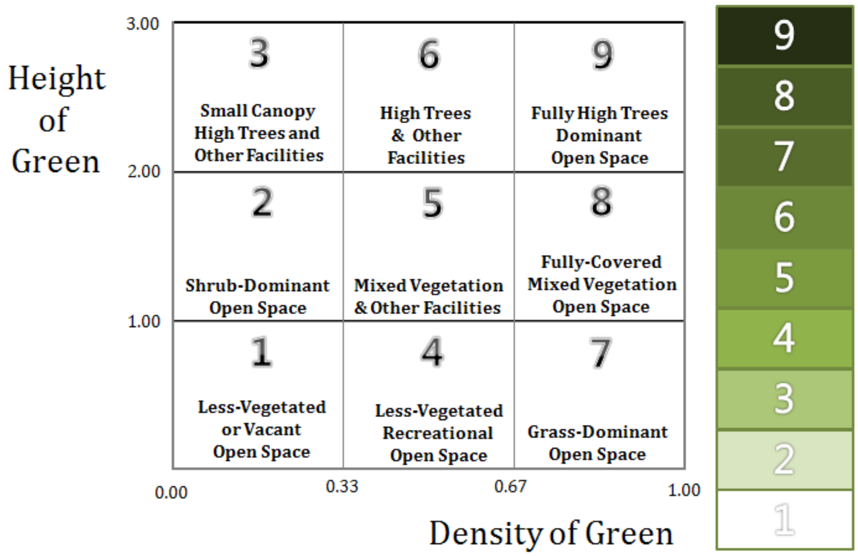


Figure 3-2. The categorization of open spaces with W-Green index

3.3.1 W-Green Index Derivation

To produce W-Green index, I calculate a simple green index and two weighted green indices based on density and height of urban green in open spaces. Density of vegetation in open spaces was produced from corrected classification maps, and height of vegetation was estimated from the number of categorized trees and shrubs. The sum of canopy areas of tree and shrub and grassland area divided by total open space area gives simple density values of open spaces. This is a simple green index (SGI) in equation 3-1. For the two weighted green indices (WGI1 and WGI2), I assigned weights to density and height values for tree, shrub, and grass in equations 3-2 and 3-3. Finally, W-Green index is produced by combining these two weight values with the consideration of height and density of vegetation in open spaces in equation 3-4.

$$\text{SGI}=\frac{\text{AT}+\text{AS}+\text{AG}}{\text{AO}} \tag{3-1}$$

$$\text{WGI 1}=\frac{(\text{AT}\times(1+\omega1)+\text{AS}\times(1+\omega2)+\text{AG}\times(1+\omega3)}{\text{AO}} \tag{3-2}$$

$$\text{WGI 2}=\frac{\text{AT}\times\text{H1}+\text{AS}\times\text{H2}+\text{AG}}{\text{AO}} \tag{3-3}$$

$$\text{W-Green Index}=\frac{\text{AT}\times(1+\omega1)\times\text{H1}+\text{AS}\times(1+\omega2)\times\text{H2}+\text{AG}\times(1+\omega3)}{\text{AO}} \tag{3-4}$$

where AT is area of trees, AS is area of shrubs, AG is area of grassland, AO is total open space area, ω is a weight value for each type of vegetation ($\omega1+\omega2+\omega3 = 1.00$), and H is height level indicators of tree and shrub. These weighted values are decided with the conceptual diagram of green index level (Figure 3-2). To categorize the level of the green index, we set the rules for density and height as follows: For the density of green, 1) the level of low density of green covers no more than 20 percent of vegetation-covered open spaces, 2) medium density of green includes at least 20 percent and less than 70 percent of vegetation-covered open spaces, and 3) high density of green covers more than 70 percent of vegetation-covered open spaces. For the height of green, 1) the level of low height of green includes open spaces with less than 1 m of mean vegetation height, 2) medium height of green covers open spaces with more than 1 m and less than 2 m of mean vegetation height, and 3) high height of green includes open spaces with more than 3 m of mean vegetation height. Based on this categorization, I set ω1 to 0.5, ω2 to 0.2, and ω3 to 0.3 for density weights.

H1 and H2 are calculated with total estimated heights of open spaces and the ratio between tree and shrub areas in equations 3-5 and 3-6.

$$H1=\sqrt{\frac{ETH}{NT}\times\frac{AT}{AO}} \tag{3-5}$$

$$H2=\sqrt{\frac{ESH}{NS}\times\frac{AS}{AO}} \tag{3-6}$$

where H1 is a height level indicator for tree, H2 is a height level indicator for shrubs, ETH is an estimated total tree height, NT is the number of trees, ESH is an estimated total shrub height, and NS is the number of shrubs.

3.3.2 Data Inputs for W-Green Index

Primary data sources used for the W-Green index include satellite images to extract vegetation cover information of urban open spaces with ground surveys. High resolution satellite images are required to identify the information for vegetation, such as the areas of tree, shrub, and grassland and location of trees and shrubs. However, high-resolution satellite images, for example Quickbird and IKONOS, are expensive to acquire to use, and these can be replaced by Google Earth to extract the vegetation information. Field survey also needs to distinguish shrubs from trees and to assign the levels of tree and shrub height (Figure 3-3). Collecting height data for trees and shrubs in open spaces is not measuring exact height of trees and shrubs but categorizing (the number of each category: range mean 1 m, 2 m, 3 m, 5 m, 7 m, 10 m, 12 m, and 15 m). Assigned height levels of each tree and shrub are calculated to estimate total height of each open space or each grid unit. In addition, parcel data or square grids are served as the units for data collection and representation of W-Green index.

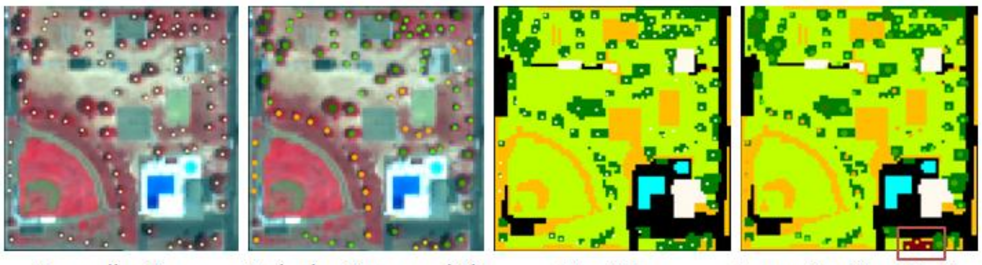


Figure 3-3. Data input and correction through field surveys

3.3.3 W-Green Index Example

Assume that there are open spaces whose sizes are 2,500 m^2. I have three different scenarios of vegetation types in open spaces (Figure 3-4). The first open space is covered by twenty-five trees which are 7 m high and have 80 m^2 of canopy size. The second open space is covered by one hundred shrubs which are 1.5 m high and have 20 m^2 of canopy size. Finally, 80 percent (2,000 m^2) of the third open space is covered by grass. The values of SGI, WGI1, H, WGI2, and W-Green index are in Table 3-1. Based on outputs of three scenarios, vegetation-covered area is the same for all scenarios even though they have different vegetation compositions. WGI1 gives more values to greener vegetation, so trees (Scenario 1) and grasslands (Scenario 3) have higher WGI1 values than shrubs (Scenario 2).

Higher vegetation features are assigned more values for WGI2, and therefore WGI2 values of trees and shrubs are higher than those of grasslands.

Table 3-1. SGI, WGI, H, WGI2, and W-Green index for scenarios

	SGI	WGI1	H = H1+H2	WGI2	W-Green Index
Scenario 1	0.800	1.200	2.366	1.893	2.840
Scenario 2	0.800	0.960	0.876	1.095	1.051
Scenario 3	0.800	1.040	0.000	0.800	1.040

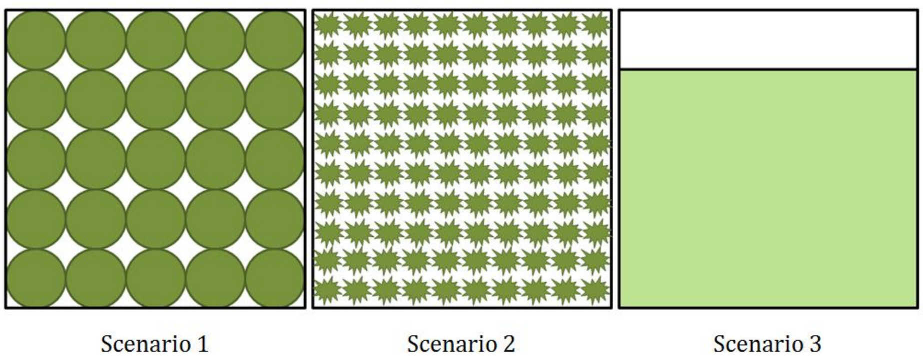


Figure 3-4. Three representative examples for W-Green index

3.4 Case Study: Analysis and Comparison

3.4.1 Study Area

To test and validate the W-Green index, I empirically applied the index for selected urban open spaces in the city of Tempe, Arizona. Tempe is located in East Valley of the Phoenix metropolitan area (Figure 3-5). The population of Tempe was 174,255 in 2009, and it has increased 9.9 percent since 2000. The climate of this city is typically hot and dry, with an average annual maximum temperature of 86°F and annual average rainfall

237.7 mm. According to City of Tempe 2007 Community Attitude Survey, Tempe's residents were generally satisfied with the quality of city parks, and parks and recreation services were the most important for the city to emphasize over the next year (City of Tempe 2008). Based on Tempe General Plan 2030, Tempe plans to have at least 15.38 acres of open space per 1,000 residents in 2030 (City of Tempe 2003). This indicates that it is important to understand the status of existing open spaces and the impact of new open spaces' development in Tempe. In addition, many existing studies on the Phoenix metropolitan area have examined urban physical environment such as urban climate and ecosystem. Urban heat island is one of the most examined topics along with its impact on urban environment (Guhathakurta and Gober 2007). With the growth of population and severely hot weather, urban open spaces may help to create a more comfortable living environment for residents.

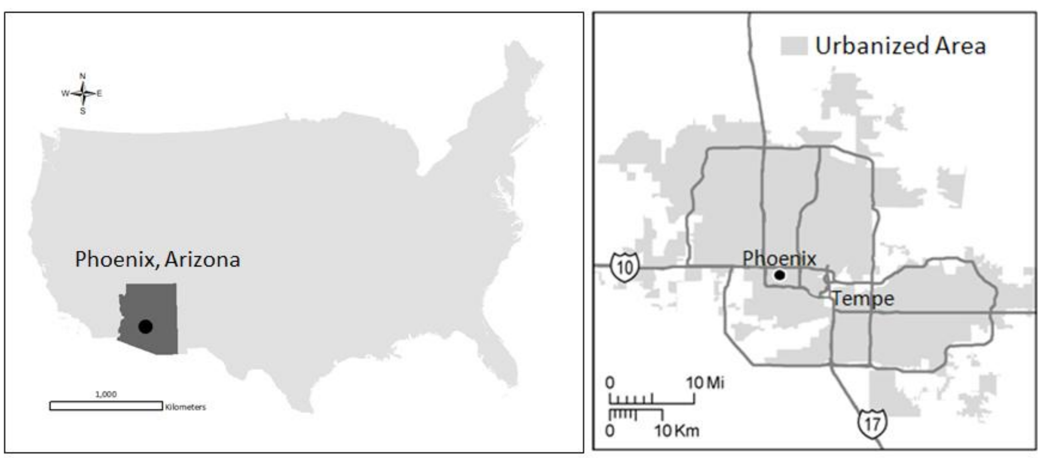


Figure 3-5. The case study area, the City of Tempe, Arizona

Given the climate and physical characteristics of desert cities, such as Phoenix, W-Green index is evaluated to investigate the availability to differentiate more vegetation-covered open spaces from less ones, and this index is compared with NDVI to investigate W-Green index's application for urban open spaces in an arid city. In this research, the W-Green index is mapped for twenty sample open spaces in Tempe, and they are selected under the consideration of their locations and types. Table 3-2 shows general characteristics of these sites to produce the index in Tempe.

Table 3-2. General information of twenty sample sites in Tempe

ID	Name	Site Description	Zip Code	Acreage
CP1	Dailey Park	Community Park	85281	17.0
CP2	Tempe Beach Park	Community Park	85281	25.0
CP3	Clark Park	Community Park	85281	10.0
NP1	Celaya Park	Neighborhood Park	85283	5.5
NP2	Indian Bend Park	Neighborhood Park	85281	8.0
NP3	Moeur Park	Neighborhood Park	85281	10.0
NP4	Corbell Park	Neighborhood Park	85283	11.0
NP5	Hudson Park	Neighborhood Park	85281	3.0
NP6	Goodwin Park	Neighborhood Park	85284	5.0
NP7	Stroud Park	Neighborhood Park	85283	5.6
NP8	Alegre Park	Neighborhood Park	85281	3.0
SNP1	Arredondo Park	School & Neighborhood Park	85282	4.0
SNP2	Scudder Park	School & Neighborhood Park	85283	4.0
SNP3	Redden Park	School & Neighborhood Park	85283	10.0
SNP4	Waggoner Park	School & Neighborhood Park	85284	8.0
SNP5	Cole Park	School & Neighborhood Park	85282	3.7
PG1	Benedict Sports Park	Playground	85282	20.0
ETC1	Twin Butte	Natural Landscape	85282	-
ETC2	Double Butte Cemetery	Other Open Space	85282	-
ETC3	Road Buffer in Tempe	Other Open Space	85281	-

3.4.2 Methods

To identify vegetation cover information in urban open spaces, Quickbird high-resolution satellite images, which was dated July 22, 2005, were interpreted using an object-oriented classification method in eCognition 8.0 and Erdas Imagine 9.3 software. Brightness, red, and near-infrared bands of Quickbird images were used to extract vegetation and to identify tree/shrub and grasslands. Additionally, mean values of NDVI were also produced to compare with the values of W-Green index. Parcel data produced in 2005 for the city of Tempe were acquired from the Maricopa County Assessor's Office.

3.4.3 Research Findings

First, I produced a graph of W-Green index values for open spaces in Tempe, and it shows the different characteristics with types of open spaces (Figure 3-6). Neighbourhood parks, which are usually located near residential communities, have relatively high values of W-Green index, and natural landscapes and other open spaces, such as Twin Butte preserves and road buffer open space, have low green index values. Goodwin Neighbourhood Park has the highest green index with a large area of grassland and many large trees throughout the park. Regional open spaces and community parks, such as Tempe Beach Park and Daley Park, have relatively lower values of W-Green index than neighbourhood parks with large parking lots and recreation facilities. When I compared the ratio of grassland, shrubs, and trees in open spaces, different types of urban open spaces have different characteristics of vegetation. Benedict Sports Park and Playground, which is a grass-dominant area, has a similar W-Green index to those of Redden Neighbourhood Park and Double Butte Cemetery. Double Butte Cemetery has more trees than the other two open spaces, and this can be recognized with the height of vegetation in open spaces.

To see the characteristics of each urban open space, the scatter plots are drawn based on W-green index values and the conceptual diagram of Figure 3-2 (Figure 3-7). Community Parks of Tempe Beach and Clark Park are classified into Level 2 of less vegetated recreational open spaces. Most neighbourhood parks are classified into Levels 5 and 6 of open spaces, which are mostly covered by grass and mixed vegetation. In the open spaces of this arid city, there is no open space that is categorized into W-Green index Level 3, 6, and 9.

The reasons for no open space in these levels include 1) there is no sample open space which has only high palm trees (Level 3), 2) this index has the potential to apply open spaces in humid cities as well as residential properties. Open spaces in humid cities can be classified into level 6 and 9. Residential properties in an arid city might have more possibility to be classified into level 3 than open spaces.

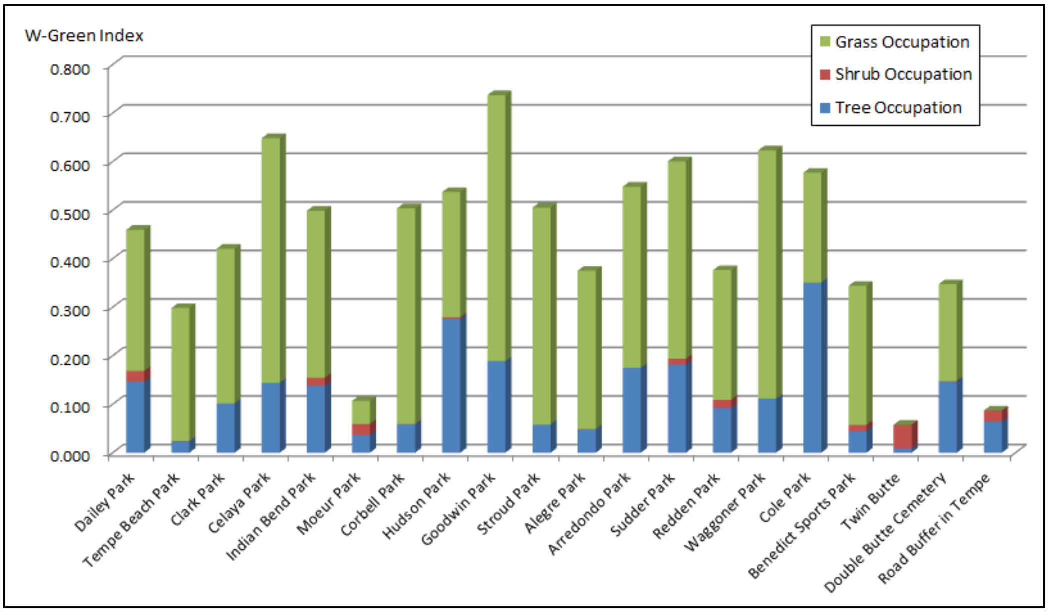


Figure 3-6. W-Green index for urban open spaces in Tempe

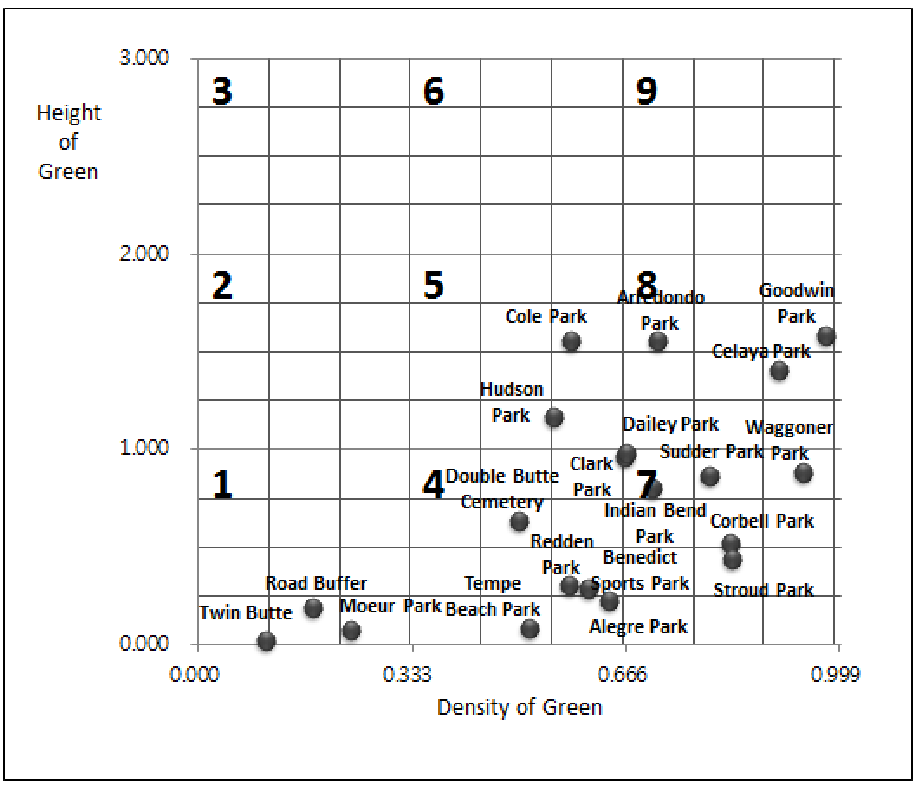


Figure 3-7. The categorization of open spaces with W-Green index

W-Green index can be mapped at various scales. To test W-Green index in a different scale, I created the maps of W-Green index on 150 m by 150 m grids for open spaces (Figure 3-8). Each grid has the green index value based on density and height of vegetation. This provides more interpretable outputs to identify the difference of greenness within open spaces. For example, Double Butte Cemetery is allocated in the medium level of green index, but west part of the cemetery has much greener and higher than other parts (Figure 3-9), and I could identify this difference in the 150 m green index map.

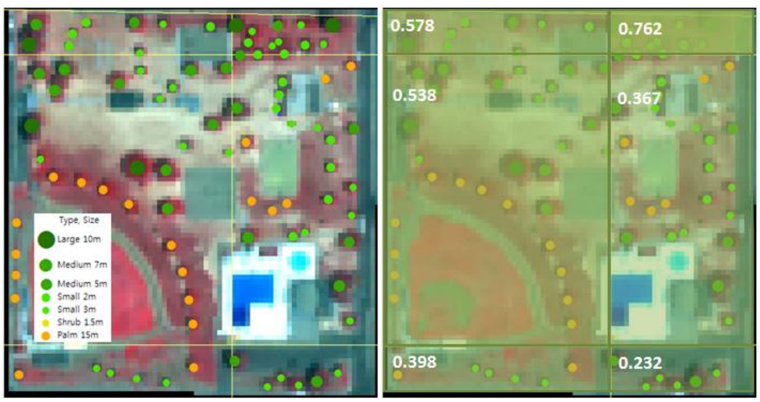


Figure 3-8. W-Green index on 150 m by 150 m grid map, Clark Park

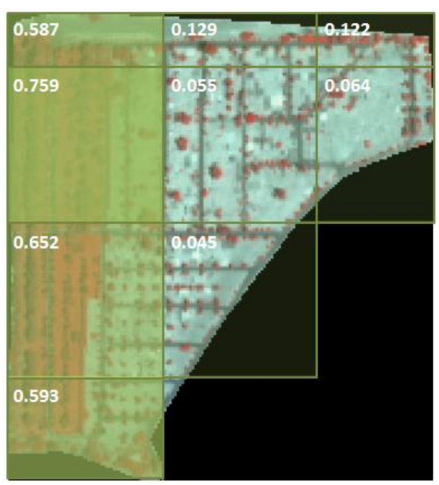


Figure 3-9. W-Green index on 150 m by 150 m grid map, Double Butte Cemetery in Tempe

For the comparison between W-Green index and NDVI, I selected four samples of 50 m by 50 m grids for grass-dominant, tree-dominant, shrub-dominant, and mixed-vegetation areas (Figure 3-10). They are extracted from the part of Arizona State University Soccer Stadium, Twin Butte cemetery, South Mountain, and Moeur Park, respectively. I also use twenty sample sites from Phoenix and Tempe. The values of the green index and NDVI are produced for four sample grids (Table 3-3). The grass-dominant area has the highest NDVI value, while the shrub-dominant area shows low NDVI value. Even though the part of Twin Butte Cemetery has many large trees and grasslands under trees, the soccer field has higher NDVI than this tree-dominant area. On the contrast, the W-green index of tree-dominant area is higher than those of other areas. W-Green index has higher weights on trees than grasslands and shrubs.

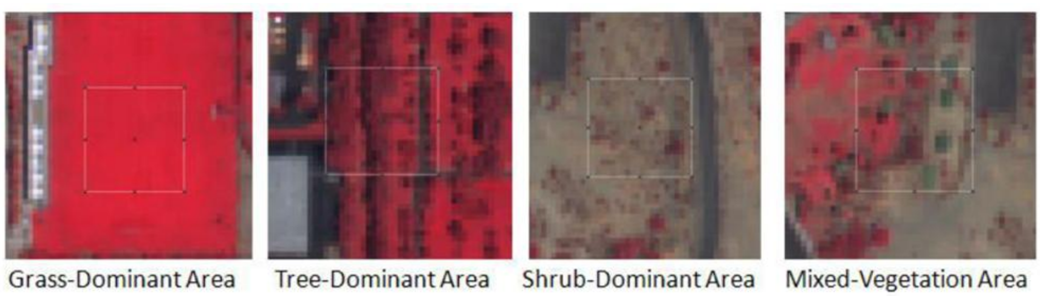


Figure 3-10. Sample grids for the comparison between W-Green index and NDVI

Table 3-3. The values of W-Green index and NDVI for sample grids

Sample Sites	W-Green Index	Mean NDVI
Grass-Dominant Area (Grass 100%)	0.810	0.617
Tree-Dominant Area (Tree 60% / Grass 25%)	1.525	0.402
Shrub-Dominant Area (Shrub 50%)	0.082	0.075
Mixed-Vegetation Area (Tree 18% / Grass 15% /Shrub 10%)	0.550	0.158

3.5 Discussion

The “W-Green Index” is developed to understand the characteristics of urban open spaces with the information of density and height for urban vegetation and forests through the analysis of high-resolution satellite images and ground survey. Urban open spaces with low vegetation cover should be understood with a different approach from previous concepts and methods. The Phoenix metropolitan area, which Tempe is part, has relatively low natural green vegetation with a hot and dry climatic characteristic. To solve this problem, a green index was designed and applied to urban open spaces in Tempe.

The W-Green index is designed under the consideration of height and density for urban forest and vegetation, and it is used to categorize urban open spaces in the arid city. Urban open space can be delineated in physical and functional views, and currently most regions have classified with its function. Different types of urban open spaces have clearly different types of vegetation cover and greenness, and those factors play a key role in determining the characteristics of urban open spaces. With this W-Green index, it is possible to explain the condition of greenness for urban open spaces in an arid environment and to apply for research which is related to the impacts of urban open space on cities and their residents. Our findings show how a new measurement of greenness of urban open spaces designed in this study allows for detailed and appropriate analyses for open space research in an arid city.

The limitation in the current research step is, however, that this W-Green index was designed and tested for only urban open spaces in an arid city. There are potential extensions for W-Green index with the consideration of water consumption and humid environment. To validate use for open spaces in humid cities, the weights should be re-examined to produce appropriate index values for both arid and humid cities. It is also necessary to consider independent information layers for vegetation elements. Grasslands or exposed soil can be overlaid under trees. This might cause underestimated grassland area and different thermal impact and water consumption in urban open spaces. In addition, examining the spatial structure of vegetation within open spaces can be a future research topic. For example, the same amount of trees might be different influences when they have different arrangements and clusters.

3.6 Chapter Conclusions

Spatial variability in vegetation cover in urban open space determines the influence and roles of open spaces on urban environment. This research provides an overview of the W-Green index to measure the greenness and openness of urban open spaces in an arid environment. To develop and advance to W-Green index, I produced simple green index and two weighted green index with density and height of urban green. Simple green index is to present the ratio of vegetation cover in open spaces. I have two options to assign higher weights for 1) greener vegetation and 2) higher vegetation. Small neighbourhood parks are relatively more covered by vegetation than other open spaces. As easily expected, most parks are grass-dominant, and natural landscapes are shrub-dominant. In addition, newly constructed parks consist of lower vegetation than old ones. Therefore, older small neighbourhood parks tend to have higher W-Green index than others.

To test the validity of W-Green index, I also compared it with NDVI. NDVI and other existing vegetation indices from remote sensing data have been widely used to identify greenness and vegetation conditions for urban features, but they have the limitations to explain structural characteristics of open spaces and to understand environmental and social benefits of open spaces in the arid city. The degree and strength of vegetation cover's greenness can be evaluated from NDVI and vegetation density, but it is difficult to understand what types of elements urban open spaces are composed of and how dense they are. Grass-dominant area has the highest NDVI value, while shrub-dominant area shows low NDVI value. Even though the part of Twin Butte Cemetery has many large trees and grasslands under trees, the soccer field has higher NDVI than this tree-dominant area. In contrast, the W-green index of the tree-dominant area is higher than those of other areas. W-Green index has higher weights on trees than grasslands and shrubs.

The W-Green index can be used not only to characterize urban open spaces but also to have other potential applications, such as urban heat island and water management research for urban open spaces. Different types and characteristics of urban open spaces have different roles and impacts for urban environment and people. In analysing the functions and influences of open spaces, it is required to consider both quality and quantity of open spaces. In particular, open spaces in desert cities have less vegetation than those in humid cities.

CHAPTER 4

FUZZY SET BASED THEORETICAL FRAMEWORK FOR URBAN OPEN SPACE MAPPING

4.1 Introduction

To better understand the quality and roles of urban open spaces, urban open space delineation needs to adapt to its physical characteristics of vegetation cover, design and configuration, and size. These factors influence the functions of urban open spaces, which are improving the environmental quality, providing the opportunity for recreation and relaxation, and increasing amenity values. Green-vegetated open spaces have significant amenity values for climate comfort (Gómez, Gil, and Jabaloyes 2004; Gill et al. 2007) and ecological intensity and diversity (Sandström, Angelstam, and Mikusliński 2006). The design and spatial configuration of open spaces are also closely related to people's behavior in providing opportunities for recreation (Tyrväinen, Mäklnen, and Schipperijn 2007) and social connection (Germann-Chiari and Seeland 2004). In addition, larger open spaces generally have more functions and different influences than small neighborhood parks in cities (Giles-Corti et al. 2005). Therefore, it is essential to emphasize the multifunctional use of urban open spaces and to obtain a comprehensive understanding of the characteristics and roles of urban open spaces.

First, vegetation cover in desert cities is representatively native shrub and irrigation-required grasslands and trees. Thus, arid city open spaces have different landscape characteristics than humid city open spaces, and this means that urban open spaces impact arid and humid cities differently. Secondly, open space is a broad concept that includes the attributes of both green and public spaces. Green space is strongly supported by the characteristic of its 'greenness', and public space is characterized by its 'publicness', which is defined as being publicly accessible to people. The reason we used the term *urban open space* in this research is to involve all those characteristics of 'greenness' as well as 'openness' and 'publicness,' and to cover spaces with various range of greenness, from sparse vegetation cover to forest. Finally, residential properties with a large lot may provide recreational opportunities and represent economic benefits to the people who live there. In addition, large houses fully covered by irrigated vegetation may have a cooling impact on surrounding areas. However, these potential facts cannot be considered in the binary definition of urban open space.

In this research, the first part (section 4.2 – 4.4) explains why fuzzy open space delineation is necessary and how to produce fuzzy membership values from the attributes of urban open spaces. The second part (section 4.5 – 4.8) describes how fuzzy open space mapping can contribute to urban environment research with case studies. Two case studies are implemented to test the applicability of fuzzy open space values. Urban open spaces in Phoenix, Arizona, are tested to identify the physical characteristics of arid city open spaces and to find the relationship between fuzzy open space delineation and surface temperature. Binary and fuzzy open space mapping approaches were compared in producing open space area and examining surface temperature mitigation. The other case study compares fuzzy open space values between the arid and humid cities of Phoenix, Arizona, and Tallahassee, Florida.

4.2 Background

4.2.1 Urban Open Space Delineation

Urban open space is often delineated with categories following classical set theory in which each open space in cities is assumed with a binary classification. This includes green or non-green space and public or private space, as well as single type of spaces, such as urban parks, golf courses, and vacant land. Classic set theory requires boundaries to be fixed or precise in defining and delineating urban open space. In existing urban open space typology, it is therefore difficult to consider the mixed physical and social characteristics of urban open spaces and other spaces' roles to serve urban environments.

The fundamental problem involved in defining urban open space arises from the following facts: 1) There is no standard definition for urban open space, and the term *urban open space* is often confused with other terms, like *green space* and *public space*; 2) In terms of the binary definition of open space, specific types of urban open spaces, such as parks, natural preserves, or golf courses, are only considered to examine the benefits of urban open spaces; and 3) Arid city open space varies with humid city open space in terms of greenness and function. Thus, uncertainties exist in the crisp object description of urban open spaces. This research solves the problem of uncertainties in categories with fuzzy open space delineation and mapping. The uncertainties arise from fuzziness and multiple criteria in delineating spatial objects. Most geographical features represented as spatial objects are considered to have indeterminate boundaries and fuzzy extent. Fuzzy set theory provides a set of tools for handling a variety of semantics for uncertainty and vagueness (Cross and Firat 2000). The factors of different types of urban open spaces in a crisp extent might be different from the membership degree of an object in a fuzzy set extent (Table 4-1). By applying fuzzy set in delineating and mapping urban open spaces, it is possible to consider different characteristics of spatial objects in terms of urban open spaces. This approach offers the opportunity to adapt the decision rules for this characterization to the local conditions of cities by adjusting the parameters based on local knowledge, such as climate conditions.

Table 4-1. The comparison of crisp and fuzzy sets for the factors of urban open space

Factors	Classical Crisp Set	Fuzzy Set
Greenness	Green / Not Green	Vegetation Cover Ratio
Imperviousness	Impervious / Pervious	Imperviousness Ratio
Brownness (Openness)	Soil-covered (Empty) / Covered by Certain Materials	Soil Cover Ratio / Covered Area Ratio

4.2.2 Theoretical Background for Fuzzy Open Space Delineation

The key idea of our new theoretical framework of fuzzy open space delineation and mapping is to represent spatial objects with fuzziness and multiple criteria. Fuzzy set theory has been applied in thematic representation (Wang and Hall 1996), multi-criteria decision (Jiang and Eastman 2000), and remote sensing classification (Wang 1990; Binaghi et al. 1997) to handle vague boundaries and uncertainty. In this research, fuzzy set theory is applied to define categories of 'open space' and to represent linguistic terms, such as 'green' and 'open'. Thus, fuzziness of both categories and attributes is the key issue for fuzzy open space mapping and delineation. Fuzzy open space mapping and delineation is based on category theory and fuzzy thematic representation. Fuzziness of category indicates that some categories of spatial objects are similar to each other than others (Hagen 2003). For example, open space and residential property may have similar landscape characteristics even though they are categorized into different land use types. The approach we take to define categories is to apply fuzzy set theory to conceptualize the functional and structural characteristics of urban open spaces. Physical attributes of urban open spaces, which are greenness, imperviousness, and brownness, are domains to define categories, and fuzzy open space is codomain (Figure 4-1).

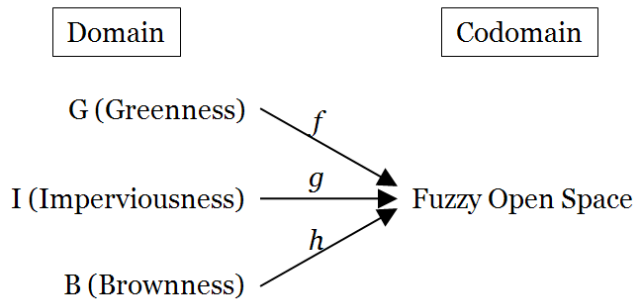


Figure 4-1. Domain and Codomain for Fuzzy Open Space Delineation

Membership function assigns to each element (spatial object) x of the universal set X a number A(x), in the closed unit interval [0,1], and this number is the degree of membership of x in the fuzzy set A. The next step is to delineate three parts and define the grad of fuzzy set membership function. Specifying a fuzzy set for the attributes of urban open spaces includes the following: *Greenness* is the most important factor in defining urban open spaces because it determines the types and characteristics of urban open spaces. For example, urban parks and golf courses contain plenty of green vegetation, and the vegetation of natural landscapes can vary widely depending on the region and the climate. Greenness has a positive effect on urban environments, so it has a direct positive impact in relation to the fuzzy membership rule. *Imperviousness* refers to the area of impervious surface and buildings that are mainly artificial structures covered by impenetrable materials. Impervious surfaces and buildings are generally not effective in improving urban environmental quality because they modify urban air and water resources. *Brownness* represents the ratio of soil-occupied area without impervious and vegetated surfaces. Vacant and undeveloped lands might have high values of brownness. Brownness for open spaces in arid cities is expected to be higher than that of humid cities. More brownness has the greater possibility of being an open space, but less brownness has a positive impact on the environmental and social aspects of an urban environment. *Size* is the factor that enhances the influence of the above three factors. Larger areas can have more of an impact on the characteristics of urban open space and vice versa. In addition, a given amount of open space might be better in a single unit than in several small patches because larger plots can provide more social carrying capacity and better environmental purification (Poudyal et al. 2009a). Therefore, size is used as a weight value to produce size-considered fuzzy open space value.

This paper focuses on applying fuzzy set theory to define urban open space. We evaluate how this approach investigates urban open space and how it can contribute to examine the influence of open spaces on urban environments. When urban open spaces are classified with binary logic, open spaces can be classified as green or non-green land and built or non-built area, according to the characteristics of spatial objects (Figure 4-2 A). For example, the lands where green vegetation covers more than 50 percent of total area can be classified into green open space, and less-vegetation covered lands can be classified as non-green open spaces. A golf course that is mostly covered by grass can be classified as a green open space, but a natural landscape of desert cities with less-vegetation can be classified as a non-green space. The substitution of fuzzy sets allows consideration of the magnitude for the characteristics of urban open spaces by exhibiting partial membership in each of a number of sets (Figure 4-2 B).

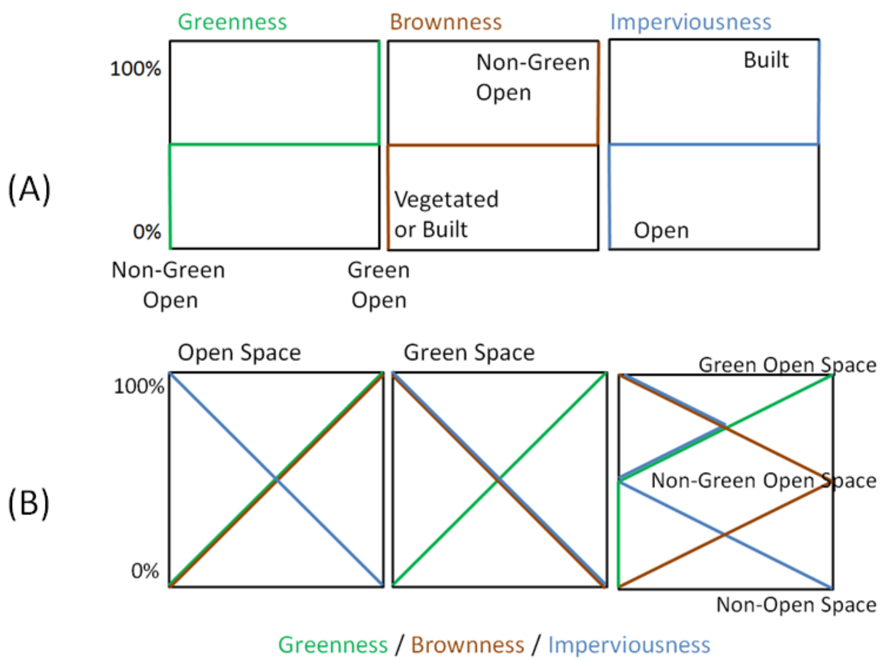


Figure 4-2. Binary (A) and fuzzy (B) rules for urban open space delineation

4.3 Fuzzy Open Space Delineation and Mapping

This research is based on two main ideas: 1) All spatial objects in urban areas can have the possibility to serve as open space, and 2) They have different roles according to their physical and social characteristics. Parcels, grids, blocks, and cities can be spatial objects for fuzzy open space value in accordance with research purpose and scale. For fuzzy open space delineation and mapping, we employ the criteria and factors of greenness, imperviousness, brownness, and size to define an urban open space. For example, in determining the roles and characteristics of urban open spaces, we can describe one specific spatial object as green vegetation covered land, good public service, a non-built area, and a large area. In terms of the greenness of an urban open space, it can be described as green, less-vegetated, full of trees, and grass-dominant. Thus, urban open space can be linguistically characterized with inexact meaning. A fuzzy set is, however, a set whose elements belong to the set only with a certain degree represented by the number in the interval [0, 1]. Fuzzy sets of greenness (G), imperviousness (I), and brownness (B) are determined by land cover attributes for spatial objects. The values of land cover area and ratio for spatial objects are converted to fuzzy membership values to produce fuzzy open space values. When different magnitudes for the factors of urban open spaces are permitted to exist in the attribute values for urban open spaces, such as greenness, the unit of urban spaces becomes a fuzzy object (Figure 4-3).

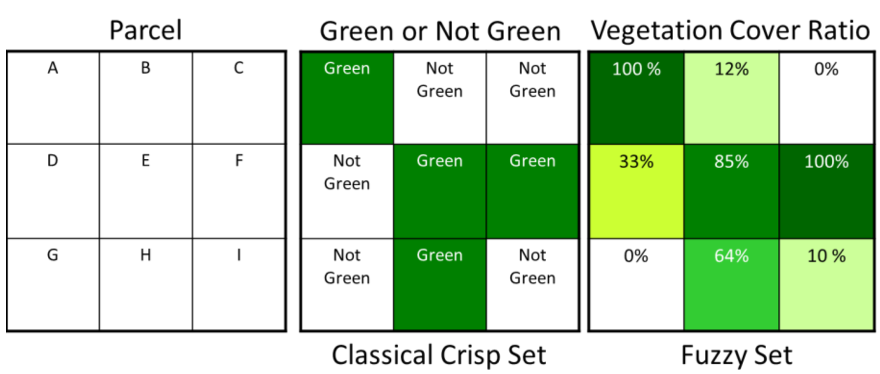


Figure 4-3. Graphical representation of membership functions for urban open space

Based on these rules, each spatial object is allowed to have a 'fuzzy membership' rather than a single-land-use label, and membership of each element is a matter of degree to which it meets the operating concept of the fuzzy set. The degree of membership expresses the degree of "compatibility" with the concept represented by the fuzzy set. To produce fuzzy membership values, different fuzzy logic rules are applied to greenness, imperviousness, and brownness. The membership degree is necessary for each value of attribute, but the meaning of the membership strength might be dependent with each other. For example, greenness and imperviousness in open spaces might be related to interpret the function of urban open spaces. Greener open spaces might have a positive impact in mitigating urban heat islands and attracting people both environmentally and socially, but imperviousness and brownness might be negative for those impacts of spatial objects, even though they have different influences on urban environmental quality.

4.4 Fuzzy Open Space Value (FOV) Derivation

Spatial objects in urban areas are mapped with the attributes of greenness, imperviousness, and brownness with or without the size. Based on the compositional and proportional values, each spatial object can be characterized for urban open spaces. The fuzzy membership values from those attributes are combined with fuzzy logics based on their contribution to open space characteristics. For example, large open and vegetated cover areas have high fuzzy membership values in an open space fuzzy set. We produced two fuzzy values of basic fuzzy open space value (BFV) and size-considered fuzzy open space value (SFV) based on Figure 4-4 (equation 4-1 and 4-2).

$$BFV= \left[G+\left(\frac{1-\sqrt{I}}{2}\right)+(B^2\times 0.8)\right] \quad (4\text{-}1)$$

G: Greenness Fuzzy Value
I: Imperviousness Fuzzy Value
B: Brownness Fuzzy Value

$$SFV= \left[(G+\left(\frac{1-\sqrt{I}}{2}\right)+(B^2\times 0.8))\times(1+\frac{(TA-IA)}{\alpha})\right] \quad (4\text{-}2)$$

TA: Total Area of a Spatial Object
IA: Impervious Surface Area of a Spatial Object
α: Area Adjustment Value (Determined by spatial object units)

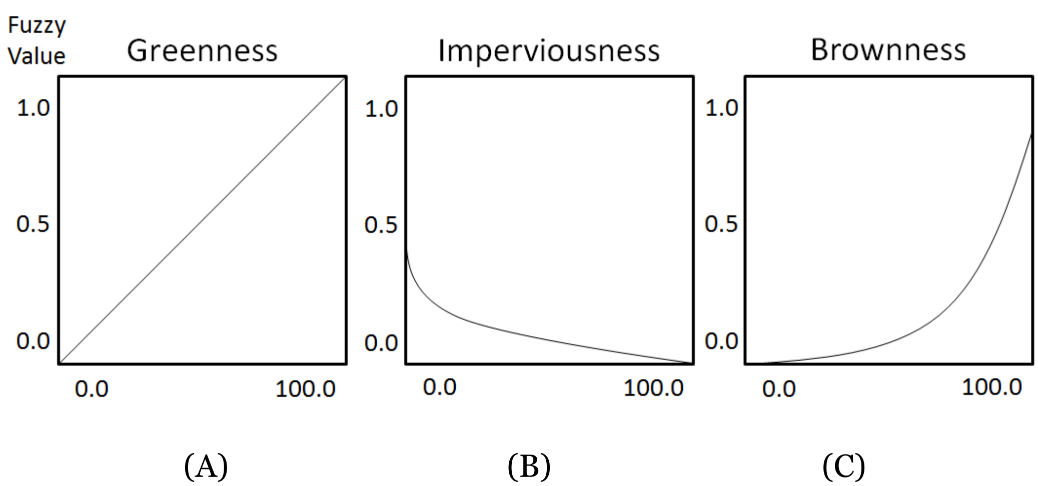


Figure 4-4. Fuzzy open space rules for greenness, imperviousness, and brownness

The fuzzy membership logics define how the possibility of membership varies continuously from 0 to 1 (Li and Yen 1995). The equations for BFV and SFV are formed based on fuzzy membership values derived from different attributes, and these values are calculated with their fuzzy logics: 1) When the greenness of spatial objects shows that they will play an important role in improving the quality of urban environment (Khan 2006; Tzoulas et al. 2007) , the higher potential to urban open space can be reached, and then their membership function can be defined as Figure 4-4 A; 2)When the imperviousness of spatial objects show that they will not contribute to enhancing urban environmental quality (Arnold and Gibbons 1996), the lower potential to urban open space can be reached, and their membership function can be defined as Figure 4-4 B; 3) When the attributes of spatial objects shows that they are open to the sky but have no influence on improving urban environmental quality (Pierzynski, Sims and Vance 2005), the higher possibility can be reached, but the limit of soil-covered lands should be considered (Figure 4-4 C). Formation of actual membership function is based on the actual conditions of spatial objects, and it will be better to define the membership functions according to the sample data of the study area, even though they might be different from place to place. The membership values of attributes can be based on the information of land use and land cover in spatial units (parcels, grids, or census tracts).

Remote sensing data and techniques often a good solution to extract data on greenness, imperviousness, and brownness. High-resolution images, such as Quickbird (2.4 m resolution) and IKONOS (4 m resolution), and object-oriented classification methods provide the best data and techniques to identify land use and land covers (Figure 4-5). However, it is possible to use medium-resolution images, such as Landsat (30m resolution), with per-pixel classification or subpixel analysis if we intend to produce open space mapping for larger spatial units, such as census tracts or the specific size of the grids.

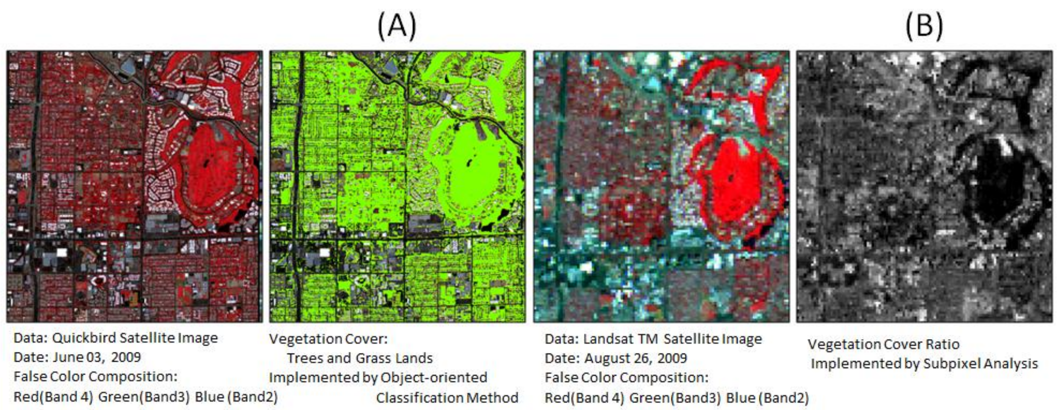


Figure 4-5. Extraction of greenness for parcels from a high-resolution image with object-oriented approach (A) and greenness for grids from a medium-resolution image with subpixel analysis

To show how to calculate and interpret fuzzy open space values, three examples with two different sizes are provided before advancing to case studies. In the case of an arid city, an urban park usually consists of large grasslands, trees, and public facilities; natural landscapes are covered by less-vegetation, and a residential property might have relatively more vegetation than natural lands (Figure 4-6). Based on this composition of land uses, we produce basic fuzzy open space value (BFV) and size-considered fuzzy open space value (SFV) (Table 4-2). In this case analysis, we extracted three variables of greenness, imperivousness, and brownness from Figure 4-6 first and then produced BFV and SFV based on three values. To identify the effect of size value, we made two attempts for two different sizes: 1) The case that all three samples have same size (100m²) and 2) The case that three examples have different sizes (A (Urban Park): 50,000m² / B (Natural Landscape): 50,000m² / C (Residential Property): 100m²). In the first attempt, Example A has higer BFV than others with higher greenness value, and Example C also has a significant value compared with Example A and B. Even though the natural landscape (Sample B) has higher openness (greenness + brownness), it is lower than the urban park (Example A). In the second case of different sizes, Sample B has a higher SFV with large area, but SFV of Example A is also relatively high. The SFV of the residential property (Example C) is much lower than other larger samples. The comparison for BFV and SFV will be discussed more in Case Study sections.

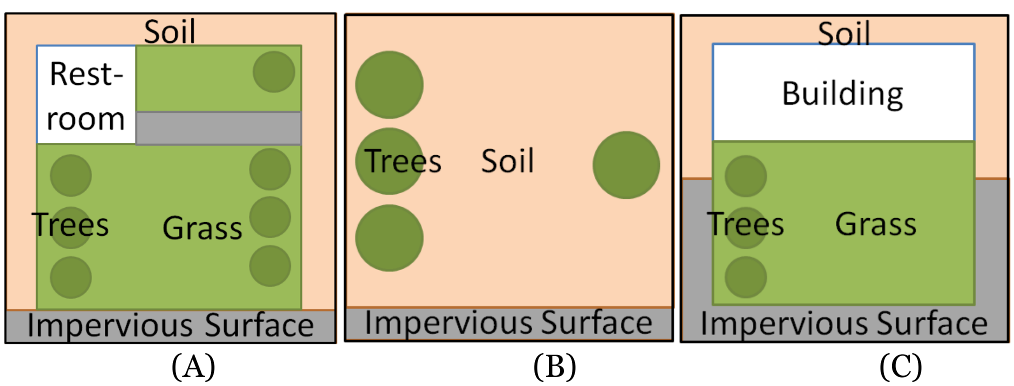


Figure 4-6. The examples of urban park (A), natural landscape (B), and residential property (C) in an arid city

Table 4-2. BFV and SFV values for the examples

Item	A (Urban Park)		B (Natural Landscape)		C (Residential Property)
	A1	A2	B1	B2	
Vegetation-covered Area (m^2)	60.00	30,000	12.56	6,500	40.00
Impervious Surface Area (m^2)	14.00	7,000	10.00	5,000	42.00
Soil-covered Area (m^2)	26.00	13,000	77.44	38,500	18.00
Greenness	0.60	0.60	0.13	0.13	0.40
Imperivousness	0.14	0.14	0.10	0.10	0.42
Brownness	0.26	0.26	0.77	0.77	0.18
Size (m^2)	100	50,000	100	50,000	100
BFV	0.967	0.967	0.946	0.946	0.602
SFV	0.971	3.152	0.950	3.075	0.604

4.5 Case Study 1: Phoenix, Arizona

As the representative area for desert cities, we investigated the City of Phoenix, which has a wide a range of greenness ranging from native desert with sparse vegetation to irrigated dense vegetation. The Phoenix metropolitan area is one of the fastest growing areas in the United States, and the population of Phoenix was 1,445,632 in 2010 (U. S. Census Bureau 2011b).

Urban open space has become an important component for urban environmental quality and sustainability with population increase and urbanization in Phoenix. As mentioned earlier, urban open spaces in Phoenix are expected to offer various roles, such as urban heat island mitigation, storm water management, and recreation opportunities. The variance of greenness in natural landscapes through urban parks makes a difference in the roles and influences of open spaces on the urban environment. The sample study area for fuzzy open space mapping is located in central part of the city of Phoenix and has an area of about 13.9 square kilometer (10.5 by 13.2 kilometer) (Figure 4-7).

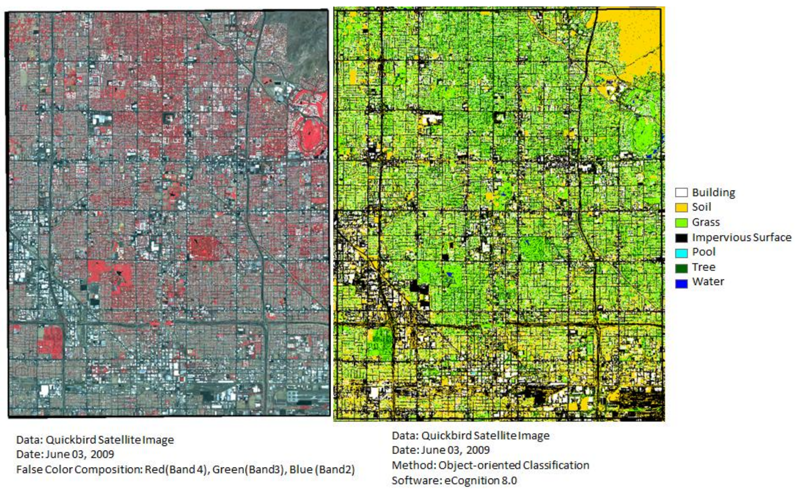
Figure 4-7. Phoenix sample study area

4.5.1 Data and Method

To identify land cover information for the sample area in Phoenix, we used Quickbird high-resolution satellite image, which was dated July 22, 2005. The satellite images were interpreted using an object-oriented classification method in eCognition 8.0 and Erdas Imagine 9.3 software. For a spatial object unit, we used parcel data, which were produced in 2008 for the city of Phoenix by Maricopa County Assessor's Office. From parcel data, we extracted information regarding ownership, land use, and area.

To produce fuzzy membership values of the sample area in Phoenix, we first conducted a classification of the Quickbird image (Figure 4-8).

Object-oriented classification was used to create seven classes: 1) trees and shrubs, 2) grass lands, 3) soil, 4) buildings, 5) impervious surface, 6) pool, and 7) water. From the classified image, we made maps for greenness, imperviousness, and brownness (Figure 4-9).



(A) (B)

Figure 4-8. Quickbird satellite image (A) and object-oriented classification output (B)

Figure 4-9. A satellite image, greenness, imperviousness, and brownness for Phoenix

4.5.2 Research Findings

To compare binary and fuzzy open space mapping methods, we produced binary and fuzzy open space maps and estimated the open space areas from both methods. Figure 9 shows binary open space mapping. Figure 4-10 A shows only public open space, and both public and private open spaces are mapped in Figure 4-10 B. Private open spaces include private residential community open spaces and undeveloped vacant lands that are privately owned. These open spaces can be categorized by types of urban open spaces, such as agriculture land, cemeteries, educational open spaces (schools and campuses), golf courses, natural landscapes, parks, residential open spaces, road buffers, sports and recreation centers, and vacant land (Figure 4-10 C).

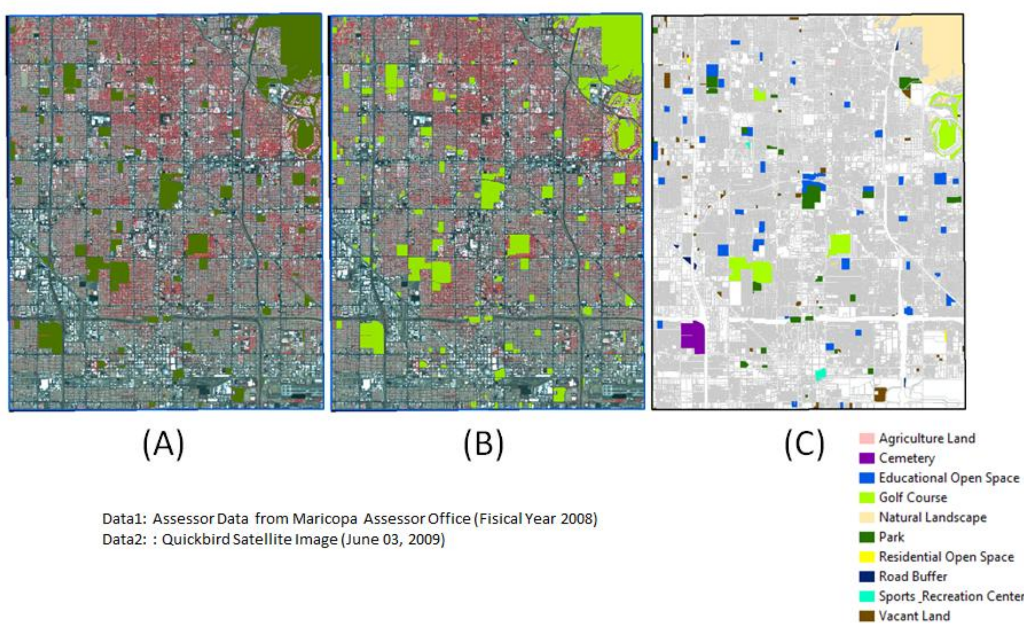
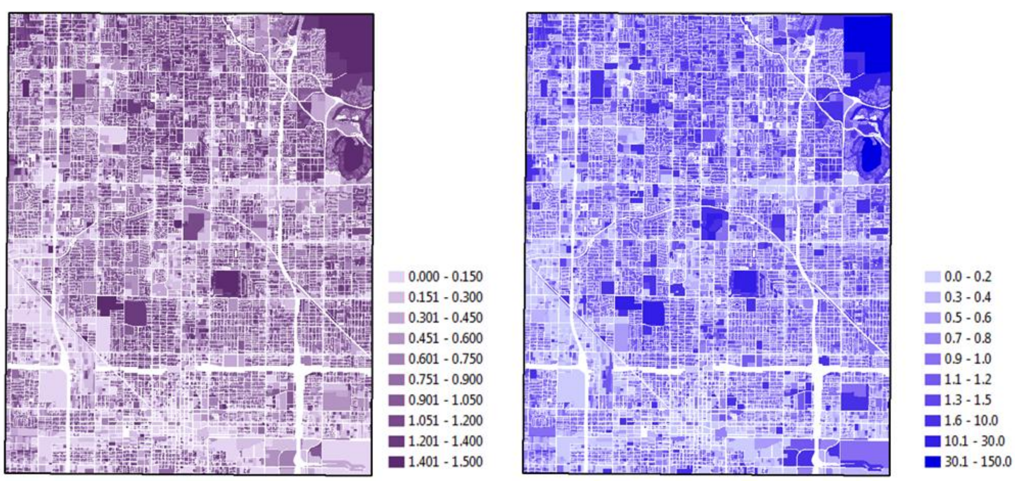


Figure 4-10. Binary open space mapping for public open space only (A) and both public and private open spaces (B), and open space category map (C)

Figure 4-11 shows fuzzy open space mapping generated by two basic fuzzy combinations (BFV and SFV). In this fuzzy open space mapping, we used 20,000 as area adjustment value, α, because park size in urban areas is typically less than 5 acres. Dark color patterns have higher membership values and those objects have a greater potential to serve as urban open space. As expected, large natural landscapes, parks, and golf courses have relatively higher values. It is important to recognize that BFV of residential properties, which have a large open area and plenty of vegetation, are similar or higher than that of small natural landscapes and neighborhood parks (Figure 4-12). In addition, educational open spaces in the arid city are one of the major open spaces covered by more greenness.



(A) (B)

Figure 4-11. BFV (A) and SFV (B) for the sample study area in Phoenix

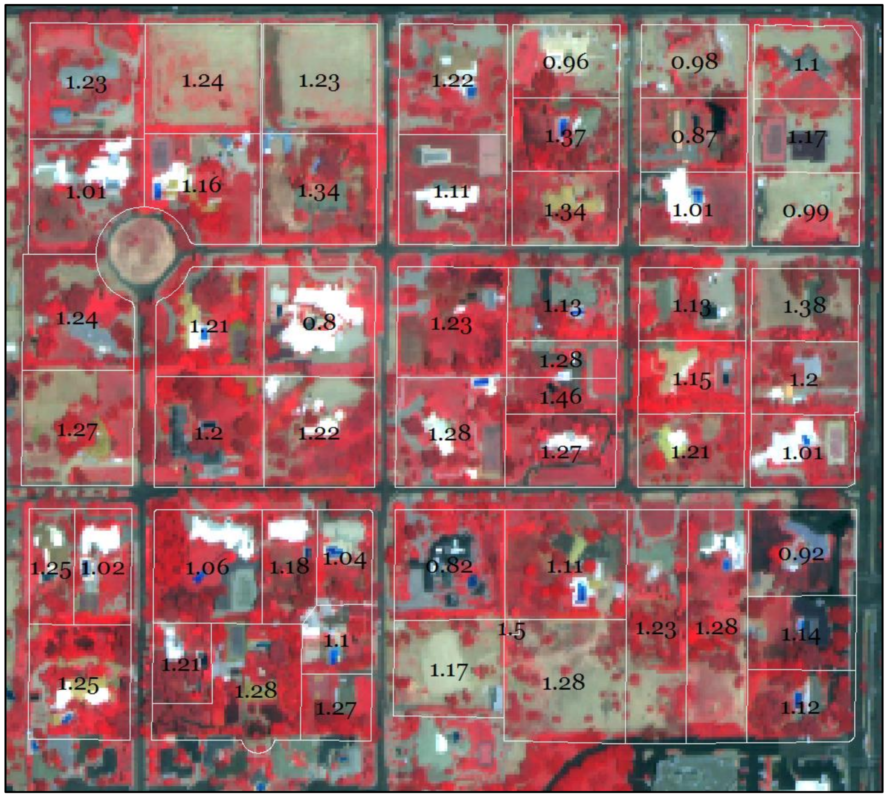


Figure 4-12. BFV of Large residential properties

Table 4-3. Area comparison for binary and fuzzy open space mapping

	Binary Open Space		Fuzzy Open Space (SFV)	
Area (km²)	Public Only	11.229	High (SFV > 3.0)	7.532
	Public and Private	11.827	Moderate (SFV > 2.0)	9.190
			Low (SFV > 1.0)	31.335
			No Fuzzy Open Space (SFV <= 1.0)	75.502
Total Area (km²)	106.837			

We compared two different types of open space mapping: the area from binary open space mapping is 11.827 km², and that from fuzzy open space mapping is 31.335 km², 11.07 percent and 29.33 percent of total area respectively (Table 4-3). Fuzzy open space mapping allows us 1) to measure the magnitude for the features of urban open space and 2) to identify other spatial objects in addition to open spaces, which are identified by land use information from parcel data.

4.6 Case Study 2: The Comparison between Arid and Humid Cities

Urban open spaces in arid and humid cities have different landscape characteristics. Urban open spaces in Phoenix are usually shrub-dominant areas with irrigation-required vegetation, and those in Tallahassee are fully covered by large and tall trees (Figure 4-13). Recognizing the differences of arid urban open spaces may lead the possibility that urban open spaces in arid cities may have some limitation for cities and people to provide their functions. For example, parks containing the majority of shrubs may have no effect of the mitigation of UHI and no aesthetic value, but people may use trails for hiking and horse riding. However people may prefer not to use urban parks and visit natural landscapes in hot summer because it is too hot to be there in arid cities. There may be a difference influence on environmental quality between grass-dominant and tree-dominant spaces. Therefore, environmental situations in arid cities require a different emphasis analytically than do situations in humid climate cities. Urban planners and designers must understand what constitutes the 'quality' of urban open space in desert cities and how it can be achieved. To better understand an urban open space in an arid city, it is necessary to identify the benefits of open spaces correctly and effectively. This comparison analysis helps to understand why it is necessary to investigate urban open spaces with the fuzzy concept.

Figure 4-13. Urban open spaces in Phoenix (A) and Tallahassee (B)

4.6.1 Study Area and Data

Tallahassee is the capital city of Florida, and it has a humid subtropical climate (Figure 4-14). The population of Tallahassee was 181,376 in 2010, and it has shown a 20.4 percent population increase since 2000. Both Phoenix and Tallahassee are extremely hot in the summer, but the climate of Tallahassee is different than that of Phoenix in terms of precipitation (Figure 4-15). The annual precipitation of Tallahassee is 1,605.5 mm, but that of Phoenix is 210.6mm. The urban landscape is the important difference between two cities. Phoenix has a desert landscape, whereas Tallahassee has a plentiful urban forest. To identify land cover information of the city of Tallahassee, we used an object-oriented classification method with GeoEye-1 high-resolution satellite image, which was dated January 23, 2011. We also used parcel data, which were produced in 2009, for a spatial object unit in Tallahassee. To produce fuzzy membership values of the sample area in Tallahassee, we conducted object-oriented classification with GeoEye-1 and produced maps for greenness, imperviousness, and brownness (Figure 4-16).

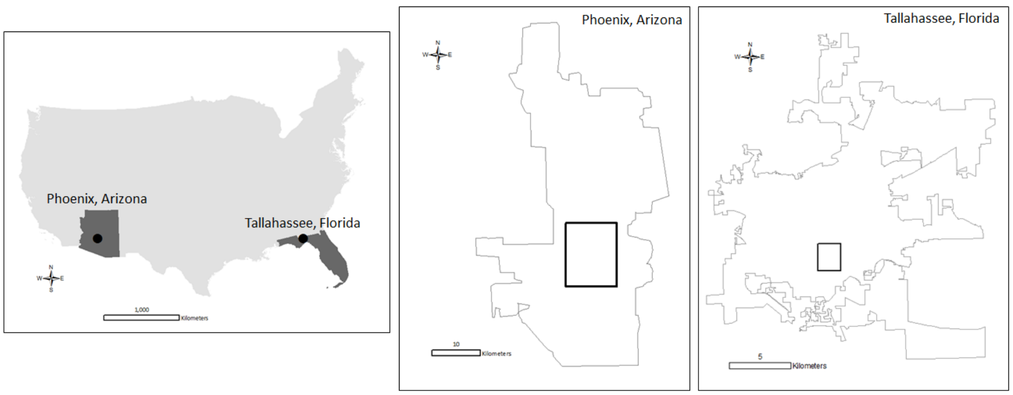


Figure 4-14. Sample study areas, Phoenix in Arizona and Tallahassee in Florida

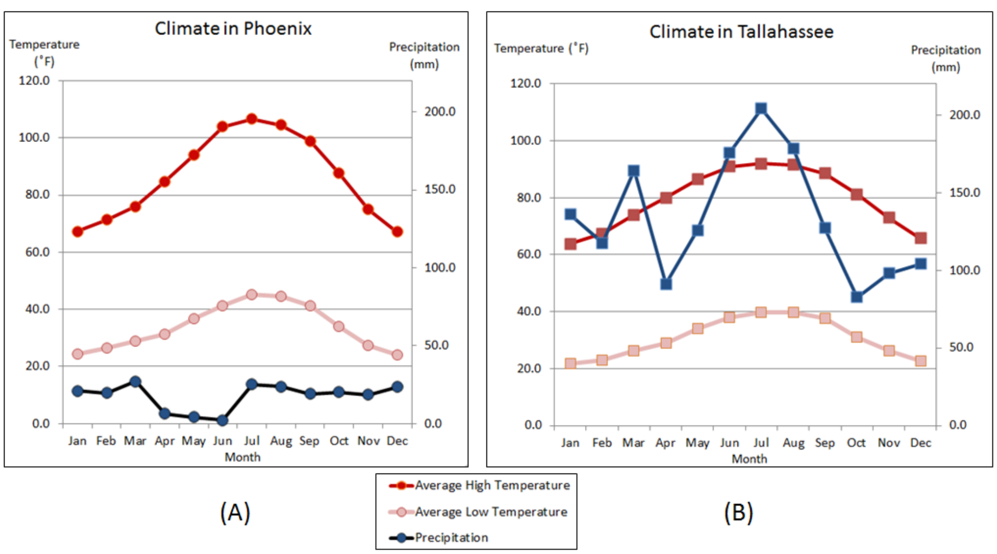


Figure 4-15. The Climate of Phoenix (A) and Tallahassee (B)
Source: http://www.weather.com

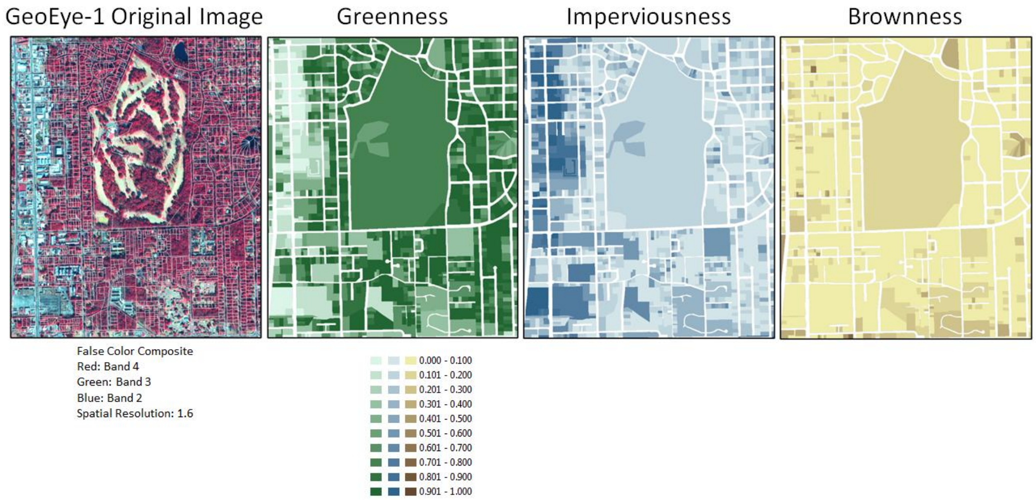


Figure 4-16. Greenness, imperviousness, and brownness for Tallahassee sample area

4.6.2 Research Findings

Based on estimated urban open space attribute maps (Figure 4-16), we produced BFV and SFV for the sample area in Tallahassee (Figure 4-17). In the BFV map, residential areas, which are on the right side of the map, have higher fuzzy open space values than a golf course, which is located in the central part of the map. However, the golf course has the highest SFV, and natural landscapes have much higher SFV than BFV. Comparing Phoenix and Tallahassee, golf courses and natural landscapes have relatively high fuzzy open space value in both cities, as expected. The variance of FOV for natural landscapes in Phoenix is larger than those in Tallahassee. In addition, residential properties in Tallahassee have relatively higher BFV and SFV than commercial areas, but only large residential properties have high values in Phoenix (Figure 4-18).

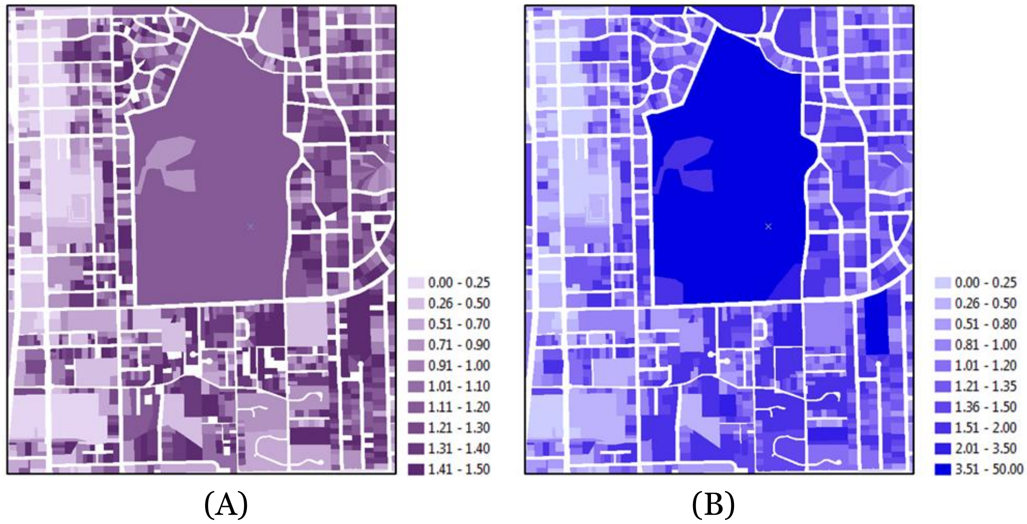


Figure 4-17. BFV (A) and SFV (B) for the sample area in Tallahassee

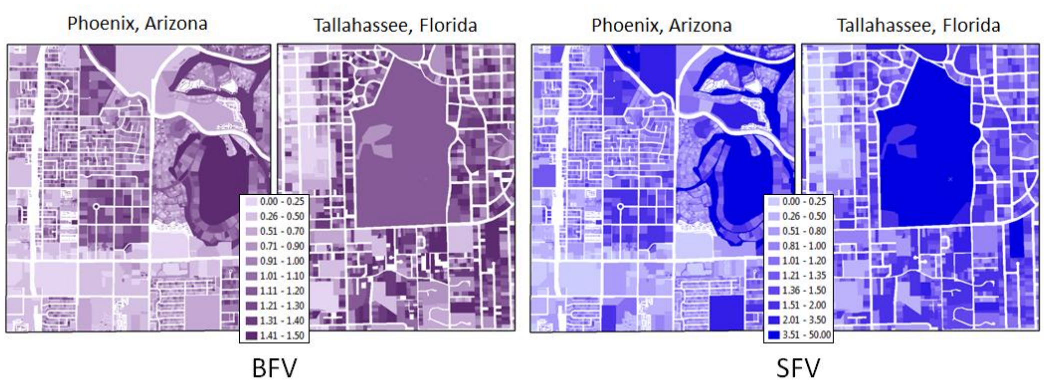


Figure 4-18. Comparison of BFV and SFV in Phoenix and Tallahassee

To identify the FOV of residential properties and compare it between the two cities, the age of the properties was examined with the FOV. Older properties tend to have higher FOV in the properties of both cities, but the properties of Phoenix show more positive relationship with FOV than those of Tallahassee (Table 4-4).

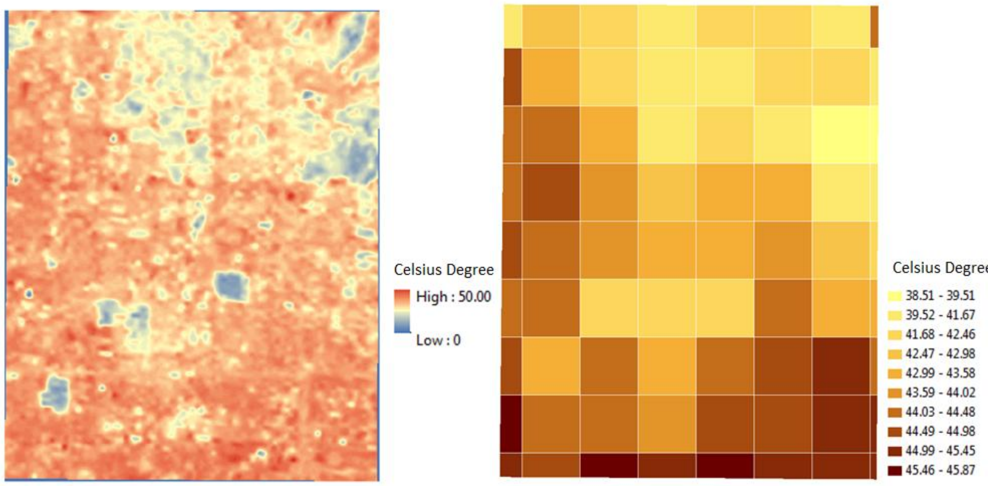
Table 4-4. Correlation coefficient between age and FOV of residential properties in Phoenix and Tallahassee

Region	Variables	Correlation Coefficient
Phoenix	BFV	0.435**
	SFV	0.436**
Tallahassee	BFV	0.226**
	SFV	0.066*

** Correlation coefficient is statistically significant at 0.01.
* Correlation coefficient is statistically significant at 0.05.

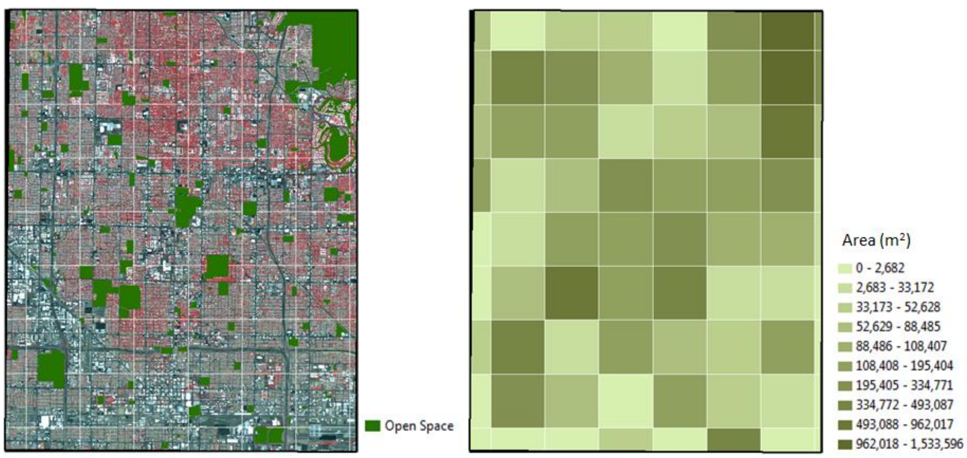
4.7 Case Study 3: Examination on the Environmental Benefits

Fuzzy open space mapping was applied to examine the urban environment. Greenness and imperviousness are key factors in determining urban surface temperature, and we applied the fuzzy open space mapping to examine the urban heat island mitigation effect of urban open spaces. We also compared binary and fuzzy open space values in determining the impact of open spaces on the mitigation of urban surface temperature. In this analysis, the spatial object unit for fuzzy open space values is a 1 mile by 1 mile grid. Landsat Thematic Mapper (TM) used in this analysis was taken on 26 August 2009 (row 37, path 37). Thermal band data was used to produce surface temperature (Figure 4-19 A), and then the average value was produced for each 1-mile grid (Figure 4-19 B). From binary open space mapping, the area of open spaces was also estimated for each grid (Figure 4-20). Two basic and size-considered fuzzy open space values were calculated based on compositional land cover data for 1 mile by 1 mile grids (Figure 4-21).



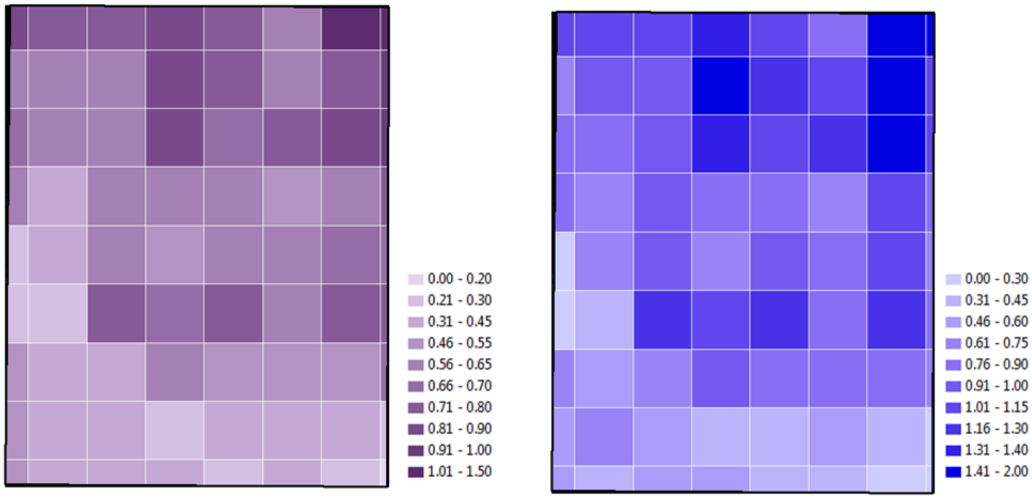
(A) (B)

Figure 4-19. Surface temperature in the sample study area in Phoenix



(A) Open Spaces (Public and Private) (B) Open Space Area in Grids

Figure 4-20. Binary open space mapping (A) and open space area in 1 mile grids (B)



(A) (B)

Figure 4-21. BFV (A) and SFV (B) of 1 mile girds for Phoenix sample area

To verify the validity of fuzzy open space values, we conducted correlation analyses. The dependent variable is the average surface temperature, and explanatory variables include binary open space area, open area (total area – impervious surface area), BFV and SFV. According to the correlation analysis output, SFV is highly negatively correlated with surface temperature (Table 4-5), but binary open space has the lowest correlation coefficient (-0.362). This result also indicates that SFV is relatively more effective to examine the influence of open spaces on urban environment.

Table 4-5. Correlation between surface temperature and open space variables

Variables	Correlation Coefficient
Binary Open Space Area	-0.362**
Open Area (Total Area – Impervious Surface Area)	-0.425**
BFV	-0.690**
SFV	-0.748**

** Correlation coefficient is statistically significant at 0.01.

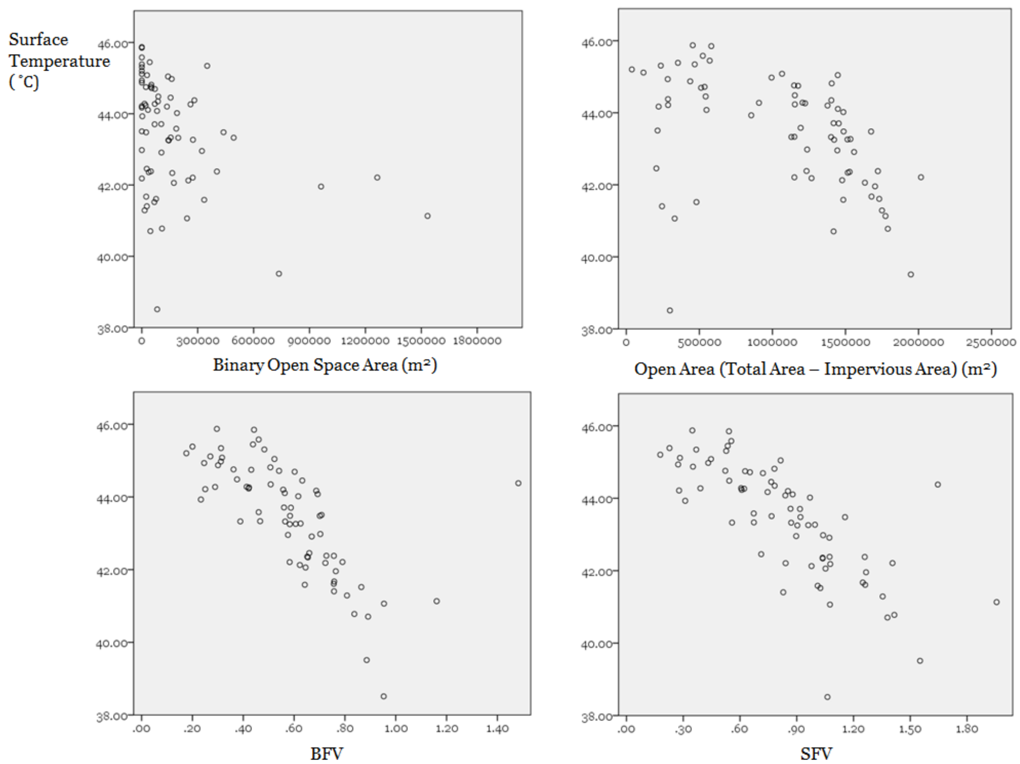


Figure 4-22. Scatter plots for the relationships between surface temperature and open space variables

4.8 Implication of the Case Studies on Fuzzy Open Space Mapping

This study applies fuzzy set theory to define urban open space in the context of spatial decision-making using geographic information systems and remote sensing. With urban expansion and rapid population growth, the importance and demand of urban open spaces continues to increase with the interest in sustainability in urban areas. The growing demand for a high quality of life has coincided with a deep concern for the availability and quality of urban open space in spite of ambiguous delineation. Various factors, such as size, shape, diversity, greenness, and facilities, as well as the distribution, development, and management of urban open spaces, play a decisive role in defining urban open spaces to satisfy the demand for a better understanding of urban open spaces with different characteristics.

In this research, fuzzy set theory represents an alternative approach to classic set theory for the solution of subjectivity, vagueness, or ambiguity in defining and characterizing urban open spaces. Fuzzy characterization offers a better representation in the nature of urban land use. The hierarchical structure in the characteristics of urban open spaces can be explored, such as more-vegetated or less-vegetated and large or small open areas. Thus, the level or degree of attributes can be defined as membership functions for urban open space mapping and delineation.

A more objective and comprehensive delineation scheme is required to establish a better understanding of the urban environment. Urban open space improves urban environmental quality and allows us to advance sustainable living in cities. Accordingly, the understanding of the characteristics of different types of open spaces in an urban matrix may guide local authorities in the long-term planning process. Standards and criteria for the residential development are required to ensure a high-quality landscape in residential areas. The quality and sustainability of urban environment is dependent on many factors: climate constraints, vegetation status, human behavior and management, and economic availability. These factors are interdependent and varied with spatial objects in urban areas. Fuzzy open space mapping can be a solution to evaluate the condition of residential areas and surrounding areas. Thus, less-vegetated residential areas are required to propose new green parks or supporting existing ones. The decision-making process for urban open space planning and management needs more comprehensive information about urban environment.

Some possible extensions can be made to improve the utility of the fuzzy open space approach. First, this fuzzy open space delineation and mapping applies to parcel units in urban areas. It is possible to apply the fuzzy approach to different spatial objects and scale for urban open spaces, such as grids and city level. Another potential extension of fuzzy open space delineation and mapping is to consider two different focuses on environmental and social aspects. Different fuzzy logic rules can be used with environmental and social focuses in combining fuzzy membership values of urban open space attributes. Greenness has more weight values than other factors for the application of environmental focus, while imperviousness has more of a positive impact to increase the usability of recreational purposes for urban open spaces for the application of social focus. For example, parking lots and facilities are required for people to use open spaces with social purposes. Therefore, we might use imperviousness reversely when it applies to environmental and social focuses. Imperviousness can also be applied to two different fuzzy rules for public spaces, and residential and commercial land uses. Finally, ownership does not apply to produce fuzzy open space values. However, it might be used to apply different rules of the other four factors for public and private spaces. It also can be interpreted with an accessibility level. For example, public spaces, such as parks and public golf courses, have easier accessibility than private spaces, such as private gardens in gated communities. The accessibility of spatial objects can be ranked in accordance with their types.

The limitations of this research involved: 1) The difficulty of data collection and construction, 2) The possibility of being subjective in assigning and combining fuzzy membership values, and 3) The need to validate this approach for more cities. For the case studies of this research, we used parcel data and high-resolution satellite images. It might have limited accessibility to use parcel data, and it should be expensive costs to get high-resolution satellite images.

4.9 Chapter Conclusions

In this study, we have developed a new methodology based on fuzzy set theory to delineate urban open spaces. Traditional delineations of urban open spaces have the drawbacks of having no standard and being static. Thus, the traditional delineation of urban open spaces has formed by ‘crisp’ typology. Therefore, typology has a fixed value and there is no associated variability for the characteristics of spatial objects in urban areas. The reason we need a new approach to define urban open spaces is that it might be a problem in arid cities to consider both open space and green space as the same properties because the impacts of urban open space might be different between arid and non-arid environments.

An urban open space is usually classified mainly according to its multifunctional features. This classification was applied to urban open spaces with a binary typology. A new approach to delineate urban open spaces was tested to validate fuzzy open space mapping with sample areas from Phoenix, Arizona and Tallahassee, Florida. The domain of attributes for urban open space should be firstly examined to make use of fuzzy sets. Therefore, the fuzzy membership function can be defined based on a number of compulsory attributes in spatial objects in urban areas.

The results of the case studies provide that several benefits can result from new approach of urban open space delineation. The application to Phoenix sample area showed the variability in green vegetated park and natural landscapes as well as residential properties with different size and landscapes. BFV and SFV were also effective to identify the different physical characteristics of land-cover between Phoenix and Tallahassee sample areas. The surface temperature was also closely related with BFV and SFV, which were representative values for a space potentially characterized by open space land-cover. Since all urban spaces are recognized as objects that determine the quality of the urban environment, it is possible to have comprehensive and interrelated understanding of the urban environment.

The comprehensive delineation of urban open spaces is also a useful framework to compare the difference of the urban environment between arid and humid cities. Furthermore, the recognition of potential impacts of various land use and land cover has important implications in understanding environmental, social and economic roles of urban open spaces.

CHAPTER 5

URBAN OPEN SPACES FOR URBAN ENVIRONMENT AND RESIDENTS: COMPREHENSIVE APPROACH

5.1 Introduction

Urban open spaces contribute to improve the quality of urban environment and life (McPherson 1992; Giles-Corti et al. 2005; Jiao and Liu 2010). Environmentally, urban open spaces mitigate urban heat island (Shin and Lee 2005; Chang, Li, and Chang 2007), control storm water (Sanders 1986), enhance biodiversity, and reduce air and water pollution (Kuttler and Strassburger 1999; Yin et al. 2011). In addition, they provide recreational opportunities as well as psychological and physical relaxation to residents (De Vries et al. 2003; Schipperijn et al. 2010). These environmental and social roles have also influenced housing prices and characteristics of residential properties in surrounding areas (Cho, Poudyal, and Roberts 2008). Urban open space is considered an essential component for a more comfortable urban environment. The problem involved in examining the influences of open spaces on urban environment is that limited number of research has an effort to synthesize open spaces' benefits even though there have been some discussions for the integration of research topics on urban open spaces.

5.2 Background

The greenness and structure of urban open spaces is a key factor to determine their quality and roles on urban environment. There is evidence that urban open spaces have an important role in reducing urban environmental problems. However, different vegetation of urban open spaces has different influences on their roles in urban environments. Vegetation richness and diversity in urban open spaces influence on environmental quality and biodiversity (Sandström et al. 2006; Fuller et al. 2007) and are usually formed in accordance with types of open spaces (Kong and Nakagoshi 2006), such as parks, mountains, and golf courses. Greenness is also perceived as an important factor for human health (Tzoulas et al. 2007; Leslie et al. 2010). Additionally, natural green landscapes have a positive influence on the restoration of stress and fatigue (Groenewegen et al. 2006). Poudyal et al. (2009a) considered their spatial pattern and structural diversity in examining the values of urban open spaces and found that people preferred less large open spaces, square-shaped and straight-edged open spaces to small pieces and irregular ones. Chang, Li and Chang (2007) also examined the cooling effect of different sized urban parks. They found that the larger parks have stronger cooling effect than smaller ones.

The usage of urban parks varies in regions due to climate conditions, unequal distribution, and socioeconomic variations (Van Herzele and T. Wiedemann 2003; Giles-Corti et al. 2005; Comber et al. 2008).

Comfortable environment of urban open space has been focused recently to maximize the effectiveness of people's usage (Lwin and Murayama 2011). Distance from residential properties to urban parks seems to influence representatively on the frequent of usage (Dubin and Sung 1987; Giles-Corti et al. 2005).

Economic research on the benefits of urban open spaces has focused on the amenity value of open spaces. Many existing studies show that housing prices increase with the proximity to urban open spaces (Geoghegan et al. 2003, Song and Knaap 2004). Positive benefits of open spaces, proximity to public parks, golf courses, and natural landscapes, raise housing values considerably (Correll, Lillydahl and Singell 1978; Frech and Lafferty 1984; Do and Grudnitski 1995; Bolitzer and Netusil 2000). Furthermore, Tyrväinen (1997) found that an increasing portion of total forested area in the housing district had a positive influence on apartment price, but the effect of small parks was not clear. In contrast, Anderson and West (2006) did not show that the size of urban parks or green areas had a significant amenity effect. There also have been studies that estimate the willingness to pay for open space using the contingent valuation method (Breffle, Morey, and Lodder 1998). They found that protection and restoration of forest ecosystems is an economic good that people are willing to support. The higher price paid by customers for houses that have urban open spaces compared with those without open spaces directly reflects the market value of the open spaces (Altunkasa and Uslu 2004).

Furthermore, recent research has considered the different types and quality of urban open spaces in examining their influences on urban environment (Cho et al. 2008). The difference between arid and non-arid cities, especially different climate and vegetation condition, was not explored to identify environmental, social and economic characteristics of urban open spaces. In addition, there have been suggestions that the roles of urban open spaces are interconnected and need to be moving toward a comprehensive understanding, generally distinguished from existing research which examined the single factor of urban open spaces. Also, recent studies have tried to combine fragmented topics for urban open spaces (De Ridder et al. 2004, James et al. 2009). De Ridder et al. (2004) suggested the methodology to evaluate the impact of open space on urban environmental quality and well-being. James et al. (2009) also described the research priorities for urban open spaces and suggested the comprehensive approach to examine the impact of open space on urban environment.

Moreover, this study was designed to address the demand of comprehensive understanding the roles of urban open spaces by examining their environmental, social and economic impacts and exploring the consequences of how these influences are interconnected. Theoretical framework of fuzzy open space and newly designed measurement of W-green index were used in identifying a comprehensive picture of urban open spaces in an arid city. Different types of open spaces and different conditions of surrounding areas can be identified with W-Green index and fuzzy open space values (FOV). W-Green index is a measurement to quantify vegetation status in urban open spaces with density and height information of vegetation, including tree, shrub and grass. FOV applies to identify physical characteristics and quantifies greenness, imperviousness, and brownness. The ultimate goals of this research are 1) to categorize urban open spaces using W-Green index and fuzzy open space values, 2) to identify the effects of the greenness in urban parks and surrounding areas on thermal environment, 3) to describe the physical activities of people in urban open spaces, and 4) to examine the spatial patterns and characteristics of residential properties considering the location and quality of urban open spaces.

5.3 Research Questions

1) How can urban parks be categorized by W-green index and fuzzy open space values (FOV)?
2) How do different types of urban parks and surrounding areas based on W-green index (grass-dominant, shrub-dominant, and mixed-vegetation parks) and FOV in an arid city influence on the mitigation of urban surface temperature?

3) What is the influence on park use and people's activities of different types of urban parks based on W-green index and FOV?
4) What is the relationship between housing prices considering the proximity to open spaces and different types of urban open spaces based on W-green index and FOV?

5.4 Methods

This paper describes three different types of analyses undertaken in twelve urban parks in Phoenix metropolitan area. Each one of environmental, social and economic issues of urban open spaces was examined to have comprehensive understanding of their influences on urban environment. First, this study identifies the difference of vegetation status between urban open spaces within cities based on W-Green index and FOV. Categorized urban open spaces were examined to compare and confirm different qualities of open spaces to different influences on urban environment in environmental, social and economic aspects: 1) Surface Temperature and Urban Parks, 2) Observation of Physical Activities in Urban Parks, and 3) Housing Prices and Urban Parks.

5.4.1 Study Area

The parks selected for my study area are situated in the Phoenix metropolitan area. The Phoenix metropolitan area is largely characterized by desert landscape created by arid and hot climate conditions. The population of Phoenix metropolitan area was 2,972,357 in 2010 (U. S. Census Bureau 2011b), and it is one of the fastest growing urban areas in United States according to the U.S. Census. With the rapid urban growth, the demand of urban open spaces has been increased to improve the quality of life in urban area. This research examined twelve urban parks considering size, vegetation cover and location. Ten parks are located in Tempe, and the other two parks of Buffalo Ridge and Sun Ray parks, were selected from Phoenix because they have more specific shrub-dominant and grass-dominant landscapes, respectively. Moeur Park is also shrub-dominant open space, but Buffalo Ridge Park is located in the residential area. Sun Ray Park is green-vegetated open space with various facilities for group activities, but it is surrounded by shrub-dominant natural landscapes, such as South Mountain. In addition, Tempe is relatively small and largely occupied with residential areas for Phoenix metropolitan area, so there might be less variance of land-cover than Phoenix. Twelve urban parks were investigated to find environmental, social and economic characteristics of urban open spaces in an arid city (Table 5-1 and Figure 5-1).

Table 5-1. The location and description of twelve urban parks

Urban Parks	Location	Facility and Equipment	Other Main Landscape
① Clark	Central Tempe Residential Area	Softball field, Two Ramada, Two Beach Volleyball Courts, Basketball Court, Swimming Pool, Playground	Arizona State University
② Daley	Central Tempe Residential Area	Two Softball Fields, Two Ramada, Basketball Court, and Restroom	Arizona State University
③ Corbell	Southeast Tempe Residential Area	Two Soccer Fields and Basketball Court, Ramada, and Playground	Kyrene De Los Ninos Elementary School
④ Indian Bend	North Tempe Residential Area	Basketball Court, Two Tennis Courts, and Playground	Rio Salado Golf Club
⑤Hudson	Central Tempe Residential Area	Two Ramada, Basketball and Volleyball Courts, Playground, Skateboard ground, and Restroom	Arizona State University
⑥ Scudder	Southeast Tempe Residential Area	Playground	Rover Elementary School Fees College Preparatory Middle School
⑦ Stroud	Southeast Tempe Residential Area	Soccer Field, Basketball Court, Playground	-
⑧ Redden	Southeast Tempe Residential Area	Two Basketball Fields and Playground	Kyrene Del Norte Elementary School
⑨ Celaya	South Tempe Residential Area	Soccer and Basketball Fields, Playground	Kiwanis Park Benedict Sports Complex
⑩ Sun Ray	South Phoenix Residential Area	Two Softball Fields, Two Tennis Courts, Basketball Field, Soccer Field, Trail, Playground, and Restroom	South Mountain
⑪ Buffalo Ridge	North Phoenix Residential Area	Two Softball Fields, Two Basketball Fields, Restroom, Playground	North Canyon High School
⑫ Moeur	North Tempe	Seven Ramada	Papago Park Rolling Hills Golf Club, Tempe Town Lake

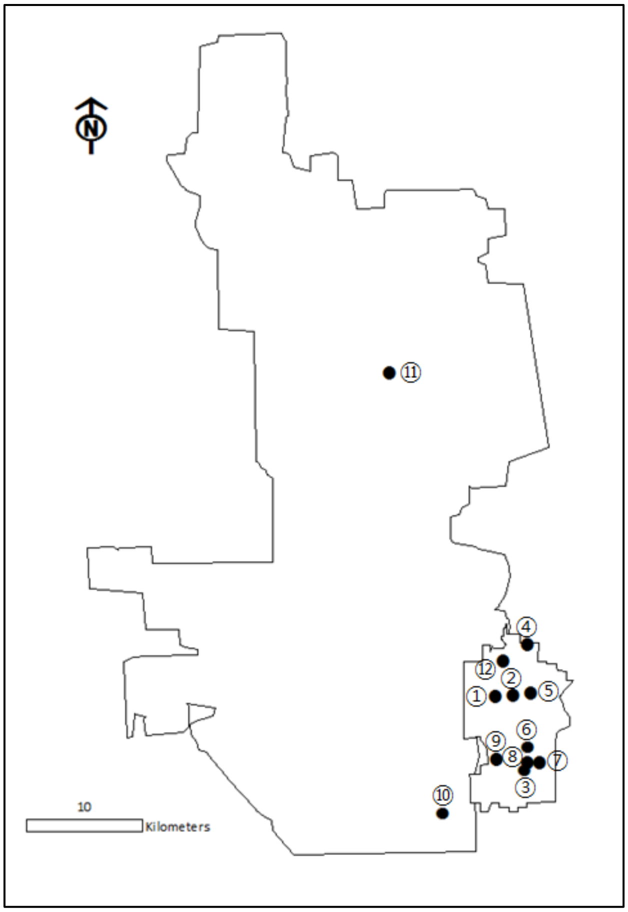


Figure 5-1. The location of twelve urban parks in Phoenix and Tempe

5.4.2 Data Collecting and Processing

The data for this research were remotely sensed satellite images, field survey data, and geographic information system (GIS) data. Quickbird satellite images taken on June 03, 2009 were used to identify land use and land cover in urban areas and to extract vegetation cover information for urban open spaces using object-oriented classification method, and Landsat Thematic Mapper (TM) satellite image taken on August 13, 2010 (5:54 pm) was used to derive surface radiance temperature. To note, the climatological data on August were examined

(National Climatic Data Center 2010) to validate the date of Landsat TM. The average temperature on August 13 was 98 degrees Fahrenheit with no cloud, and the temperature difference between maximum and minimum on August was less than 10 degrees.

The spectral resolutions of Quickbird and Landsat TM images are 2.4m and 30m, respectively. First, Landsat TM image was calibrated by atmospheric correction and then used to derive surface temperature (Markham and Barker 1986). To calculate the spectral radiance value from the digital number (DN) of band 6, the following equation (Equation 5-1) was used:

$$L_\lambda = \frac{(LMAX_\lambda - LMIN_\lambda)}{QCALMAX} QCAL + LMIN_\lambda \qquad (5\text{-}1)$$

where, *QCAL*=Calibrated scaled radiance in units of DN
$LMIN_\lambda$=Spectral radiance at *QCAL*=0
$LMAX_\lambda$=Spectral radiance at *QCAL*=*QCALMAX*
QCALMAX=Range of rescaled radiance in DN

The spectral radiance value (L_λ) was then converted to absolute temperature in degrees, Kelvin using Equation 5-2.

$$T = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda}+1\right)} \qquad (5\text{-}2)$$

where, *T*=Effective at-satellite temperature in Kelvin
L_λ=Spectral radiance in W / ($m^2 \cdot sr \cdot \mu m$)
K_2=Calibration constant 2 in Kelvin
K_1=Calibration constant 1 in W/($m^2 \cdot sr \cdot \mu m$)

Field data were also collected to examine the physical activities in urban open spaces. Various factors influence on people's use of urban open space (Schipperijn et al. 2010) including the distance to open space (Boyle 1983; Just 1989; Giles-Corti et al. 2005; McCormack et al. 2006), facilities, gender (Richardson and Mitchell 2010), race (Dai 2011) and age (Mäkinen and Tyrväinen 2008). To find the pattern of open spaces' visitors, the survey was constructed based on SOPARC (System for Observing Play and Recreation in Communities) developed by McKenzie et al. (2006). Data for physical activities in twelve urban open spaces were collected with following from the Physical Activity Coding Rules (see Table 5-2). Data collection for each park was implemented in August 2010 and 2011 (two week days and two weekend days in each year). Furthermore, to examine the effect of the hot environment, the month of August (average temperature: 94 °F) was chosen as a time when outdoor activity might be limited with severely hot weather in Arizona. There were three time periods for observation: 7 am – 9 am; 12 noon – 2 pm; and 5 pm – 7 pm.

Table 5-2. Physical Activity Coding Rules

Activity Category	Description
Personal Information	Sex, Age Level, and Race
Time Periods	Morning (07:00 – 9:00) / Noon (12:00 – 14:00) / Evening (17:00 – 19:00)
Group	Activity with more than 10 people
Individual	Less than 10 people
Facility-focused	Use of facilities in parks (e.g. Soccer or Softball Fields)
Vegetation-required	Activity performed on or under vegetation (Tree or Grass)
Infrequent usage	Performed infrequently (e.g., Picnic)
Regular Activity	Usually performed regularly (e.g., Sports and walking)

Parcel assessor data from the Maricopa County Assessor Office, which were produced in 2009, were also used to investigate single family residential properties. Census tracts and block groups were applied to identify physical and socioeconomic characteristics for surrounding areas of urban open spaces. As a result, in this research, single family residential properties sold in 2005 and 2006 were extracted to avoid problems caused by time variations.

5.4.3 Analysis

Each environmental, social, and economic research was implemented to examine the comprehensive benefits of urban open spaces and to compare the effects of different types of open spaces. Before conducting three application analyses, hierarchical cluster analysis was conducted to find groups of similar open spaces with W-Green index and FOV and to categorize the open spaces based on the output of cluster analysis. Based on the categorization, each one of environmental, social and economic topics was investigated to understand the roles and benefits of urban open spaces in an arid city (Figure 5-2).

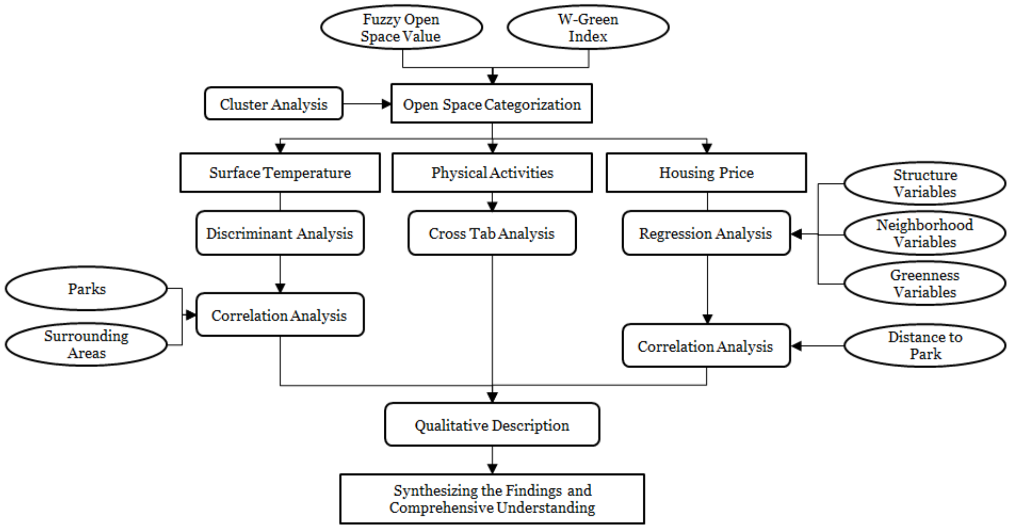


Figure 5-2. Research flow for three analyses on comprehensive examination of open space benefits

First, the purpose of environmental research is to find the relationship between surface temperature and green-vegetated parks. Average surface temperature data, which were calculated from Landsat TM, were assigned to 100m by 100m grids. Correlation analyses were conducted to find both the relationship between W-green index and surface temperature within the parks and the relationship between land cover /FOV and surface temperature in surrounding areas. Discriminant analysis was also conducted to investigate differences between categories on the basis of surface temperature, distance to park, FOV, and land cover areas.

Second, social research was conducted to examine the physical activities in urban parks. Physical activities are classified in the following categories: group and individual, facility-focused and vegetation-required, and daily pattern. The patterns of these activities were identified using a cross tab analysis.

For economic research, hedonic pricing approach was applied to examine the amenity value of urban open spaces on housing prices. It is a method to estimate the price for a good with its characteristics and assesses the implicit prices for a variety of features associated with the property including structural components, surrounding situation, and environmental factors. Structural and neighbourhood related values of houses included to control the price effects of houses and surrounding areas (Poudyal et al. 2009b). The explanatory variables used to explain the housing price included variables representing structure, greenness, and neighborhood of residential properties (see Table 5-3). Further, structural variables include floor space, number of rooms, number of floors, pool, size, and the period the house was built. Neighborhood-related variables are distance to major school and roads. Greenness-related variables are vegetation ratio, the distance to nearest urban open space, and fuzzy open space values.

These variables were used to produce adjusted housing prices. To control other variables except urban open space related variables, I produced adjusted prices based on the best-fit pricing models. With the adjusted prices, I was able to find the relationship between housing prices and the distance to nearest urban open space. The linear regression analysis was implemented to find the relationship between the adjusted price and the distance to urban parks considering W-Green index level.

Table 5-3. Explanatory Variables

Group	Variable
Structure-related Group	- Number of Rooms and floors - Age - Living Square Footage - Pool Existence
Greenness-related Group	- Vegetation Ratio - Distance to Urban Parks - Fuzzy Open Space Value for Surrounding Areas
Neighbourhood-related Group	- Distance to Major Roads - Distance to Schools

5.5 Research Findings

5.5.1 Urban Parks and Surrounding Areas

Twelve parks were categorized based on their W-Green index and surroundings' fuzzy open space values (Figure 5-3 and Table 5-4 and 5-5). Sun Ray Park has the highest W-Green index, and Buffalo Ridge and Moeur parks have relatively low values. Grass-dominant parks have slightly higher values than other parks with mixed vegetation and shrub-dominant lands. In examining the physical condition for surroundings of urban parks, Sun Ray, Buffalo Ridge, and Moeur parks have relatively higher fuzzy open space values with large shrub-dominant natural landscapes in surrounding areas. Other parks have similar values with range from 0.440 to 0.581 (except Hudson). Sun Ray Park has the highest W-Green index for itself, but does not have relatively higher FOV for surrounding areas because the surrounding area of the park is shrub-dominant area even though the park is fully covered by green-vegetation (Figure 5-4). On the contrast, Buffalo Ridge Park also has similar FOV with Sun Ray Park but much lower W-Green index. Clark Park has relatively low FOV because of commercial area in its surrounding area. Based on the result of cluster analysis with W-Green index and FOV (Figure 5-5), open spaces were divided into the following three groups: 1) only green vegetated park in residential area 2) green-vegetated park with shrub-dominant natural landscapes, and 3) shrub-dominant natural landscape and parks. The first group was then divided into large community park and small neighborhood park, so four categories were formed (Table 5-6).

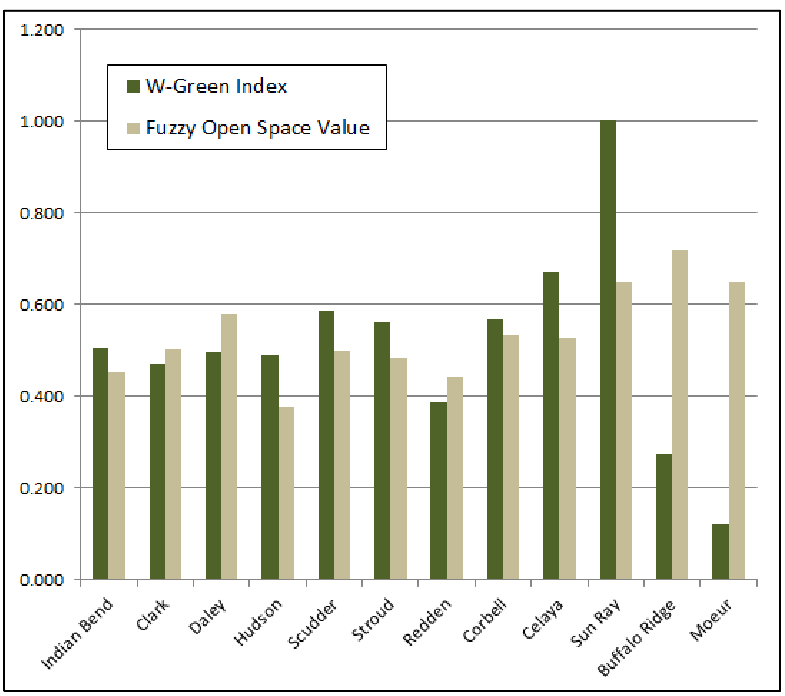


Figure 5-3. W-Green index and FOV of twelve urban parks

Table 5-4. Main green landscape and W-Green index of twelve urban parks

Urban Parks	Green Landscape	Size (m^2)	W-Green Index
Clark	Mixed-vegetation	40,379	0.471
Daley	Mixed-vegetation / More and Higher Trees	54,444	0.496
Corbell	Grass-dominant	56,943	0.568
Indian Bend	Mixed-vegetation	30,274	0.505
Hudson	Mixed-vegetation	17,643	0.490
Scudder	Grass-dominant	17,550	0.586
Stroud	Grass-dominant	23,001	0.563
Redden	Mixed-vegetation	18,708	0.386
Celaya	Grass-dominant	25,223	0.671
Sun Ray	Grass-dominant / Mixed-vegetation / More and Higher Trees	71,749	1.002
Buffalo Ridge	Shrub-occupant	127,491	0.273
Moeur	Shrub-occupant	32,066	0.120

Table 5-5. Physical characteristics of surrounding census tracts (block groups) of twelve urban parks

Urban Park	Total Area (km^2)	Vegetation Area (km^2)	Impervious Surface Area (km^2)	Exposed Soil Area (km^2)	FOV
Clark	2.720	0.720	1.138	0.842	0.503
Daley	5.610	1.568	1.269	1.243	0.581
Corbell	1.317	0.273	0.479	0.544	0.533
Indian Bend	1.280	0.235	0.594	0.444	0.451
Hudson	0.670	0.181	0.402	0.084	0.376
Scudder	1.331	0.291	0.589	0.433	0.500
Stroud	1.227	0.135	0.498	0.569	0.484
Redden	1.236	0.243	0.592	0.387	0.442
Celaya	1.000	0.232	0.418	0.344	0.528
Sun Ray	1.761	0.315	0.589	0.851	0.649
Buffalo Ridge	3.354	0.688	1.013	1.634	0.719
Moeur	4.303	0.724	1.383	2.177	0.648

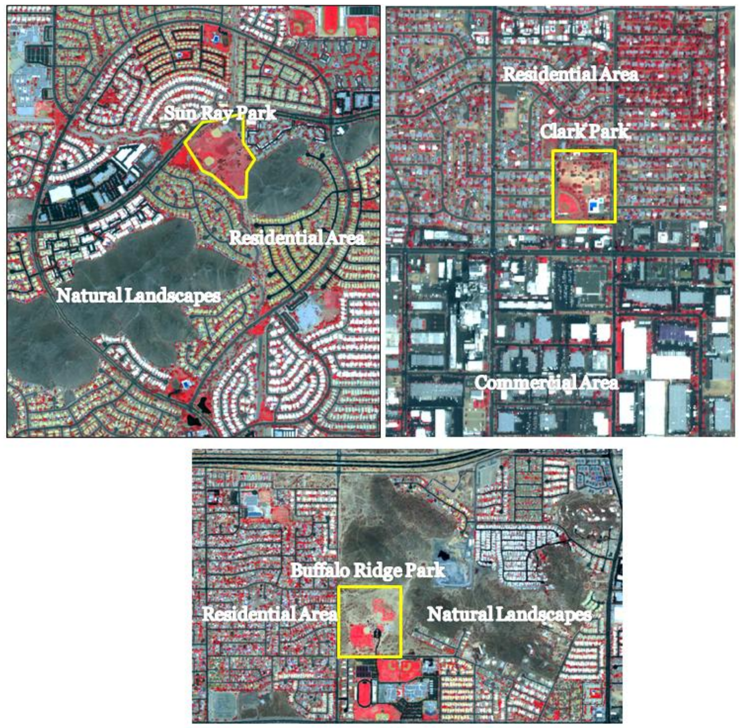


Figure 5-4. Satellite images for Sun Ray, Clark, and Buffalo Ridge parks
Source: Quickbird satellite image, false color composition (Band 4: Red, Band 3: Green, and Band 2: Blue)

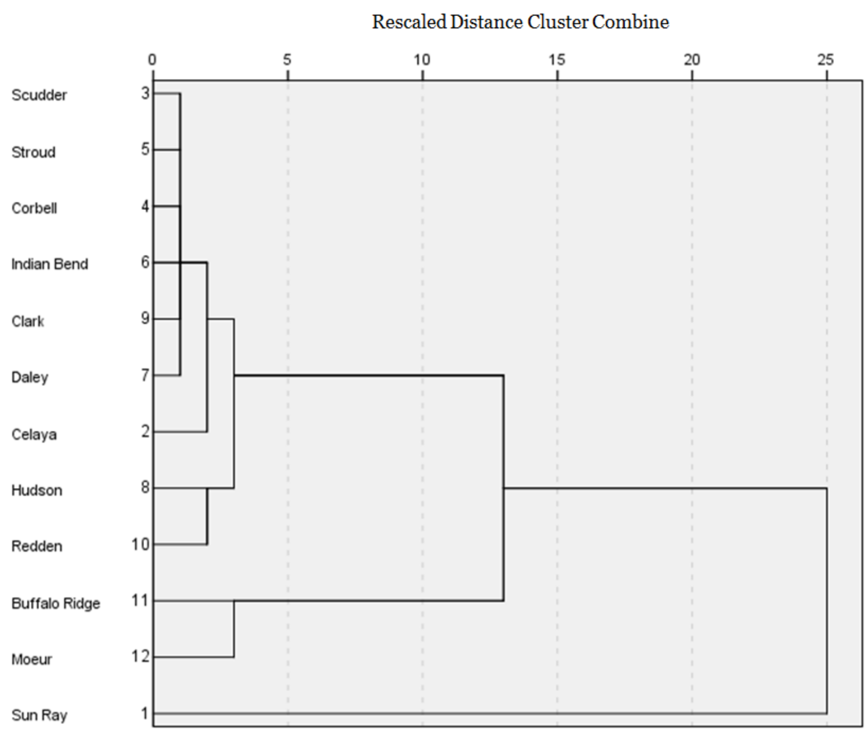


Figure 5-5. Dendrogram using complete linkage from cluster analysis

Table 5-6. Urban parks categorization

Category	Urban Open Spaces
1) Only Large green vegetated park	Clark, Daley, Corbell
2) Only Small green vegetated park	Indian Bend, Hudson, Scudder, Stroud, Redden, Celaya
3) Green-vegetated park with shrub-dominant natural landscapes	Sun Ray
4) Shrub-dominant natural landscape and parks	Buffalo Ridge and Moeur

5.5.2 Surface Temperature and Urban Parks

Urban parks with green vegetation were clearly cooler than their surroundings. However, the cooling effects of urban parks were different based on their vegetation types, size, and surrounding area. Figure 5-6 shows surface radiant temperature in August 13, 2010. First, we investigated the relationship between parks' surface temperature and W-green index. Based on the output of correlation analysis, W-green index has a clear negative relationship with surface temperature within the parks (correlation coefficient value = -0.690). In addition, surface temperature data in 100m × 100m grids were compared with physical characteristics of open spaces' surrounding areas. Examined temperature and land-cover values, FOV and vegetation cover area shows generally negative relationship with the interpolated surface temperature (Table 5-7 and Figure 5-7). However, Category 3 and 4, including Sun Ray, Buffalo Ridge, and Moeur, shows negative with vegetation area and positive with exposed soil area.

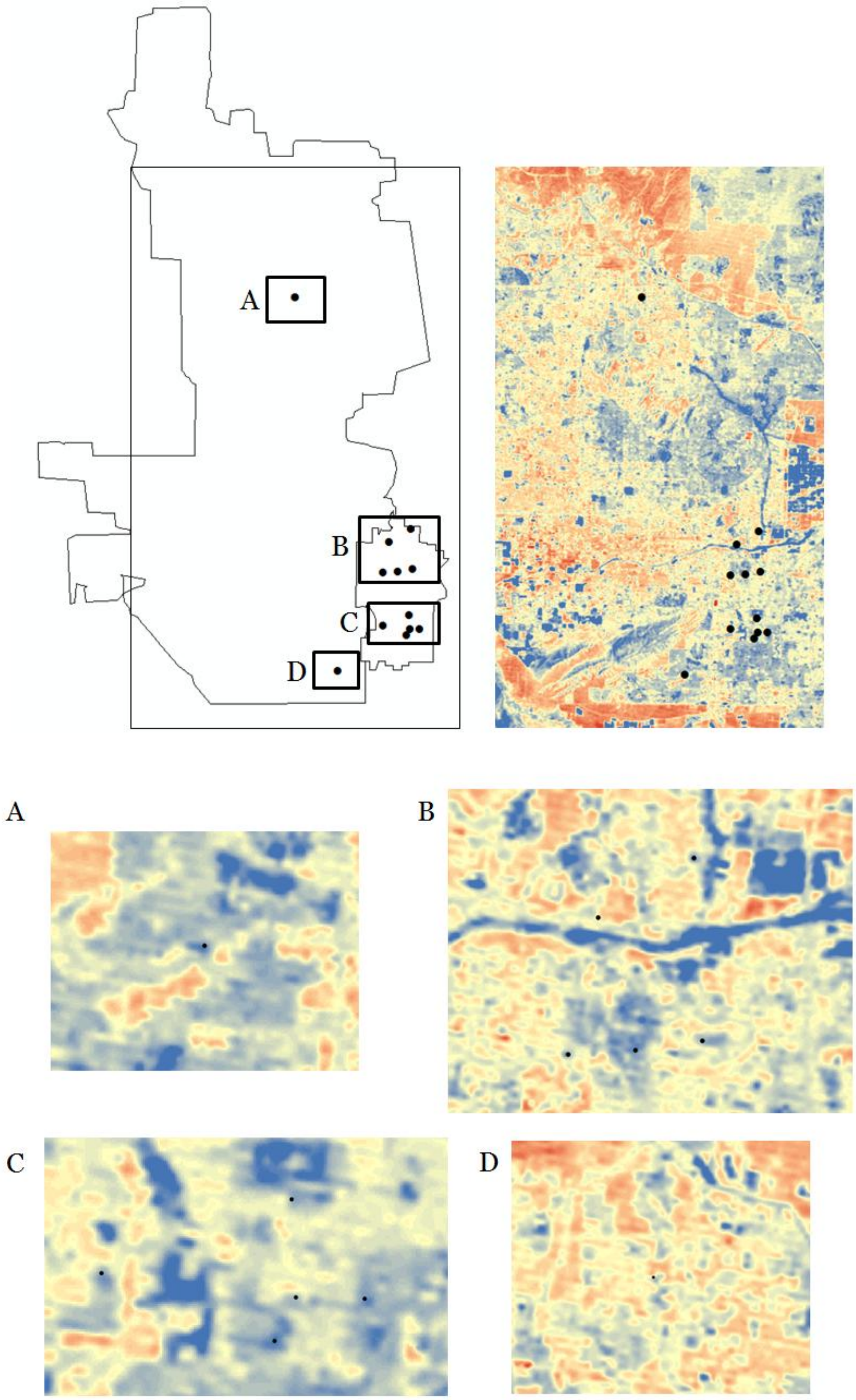


Figure 5-6. Surface temperature in Phoenix metropolitan area

Table 5- 7. Correlation between surface temperature and the area of land cover/ FOV of surrounding census tracts (block groups) of urban parks

Urban Park	FOV	Vegetation	Impervious Surface	Exposed Soil
Clark	-0.592**	-0.664**	0.469**	0.226**
Daley	-0.566**	-0.552**	0.360**	-0.131**
Corbell	-0.670**	-0.706**	0.393**	(0.094)
Indian Bend	-0.536**	-0.509**	0.437**	-0.037**
Hudson	-0.600**	-0.646**	(-0.111)	(0.104)
Scudder	-0.571**	-0.254**	0.587**	(0.090)
Stroud	-0.211*	-0.346**	(0.090)	-0.241**
Redden	-0.347**	-0.211*	0.397**	(0.040)
Celaya	-0.303**	-0.607**	(0.190)	0.360**
Sun Ray	(0.352)	-0.683**	-0.231**	0.678**
Buffalo Ridge	(0.073)	-0.437**	-0.114*	0.290**
Moeur	(-0.028)	-0.611**	0.100*	0.363**

** Correlation efficient values are statistically significant at 0.01.
* Correlation efficient values are statistically significant at 0.05.
Values in parenthesis are not statistically significant.

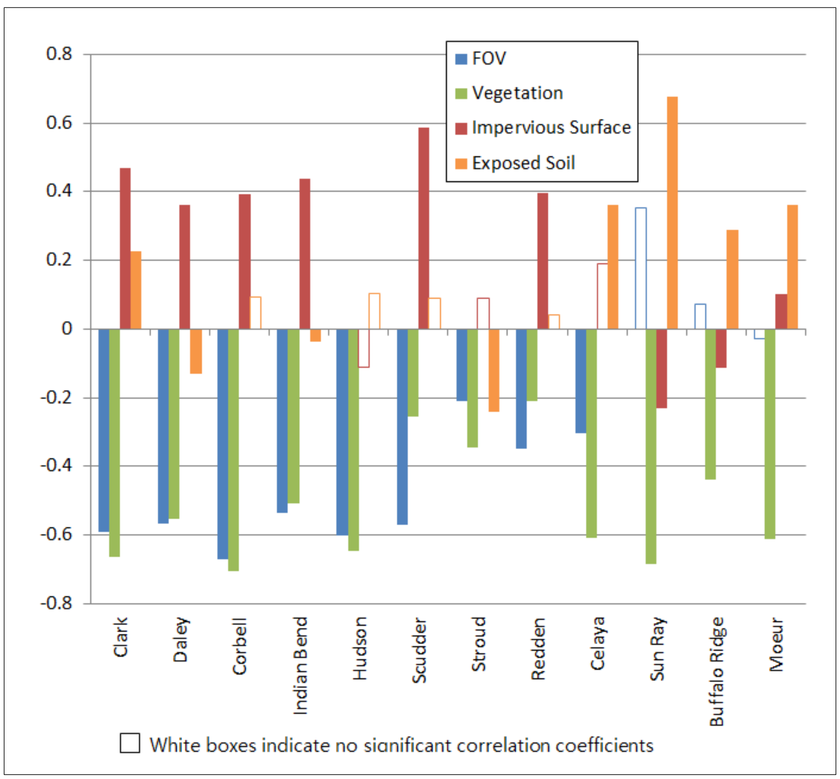


Figure 5- 7. Correlation between surface temperature and the area of land cover/ FOV of surrounding census tracts of urban parks

Figure 5-8 shows that the relationship between surface temperature and physical characteristics for all 100m grids in twelve parks' surrounding areas. As the results for individual parks' surrounding areas, vegetation is highly negatively correlated with surface temperature (Figure 5-8 and Table 5-8). Soil-covered area influences to increase surface temperature. Even though the area of exposed soil tends to increase the fuzzy open space value, it has positive influence to increase surface temperature. After eliminating the grids, whose soil areas are larger than 4,200 m^2 (one standard deviation above the mean value), the correlation coefficient value of FOV is higher than those of other variables (Figure 5-9 and Table 5-8). Therefore, fuzzy open space values should be carefully applied with the consideration of regional characteristics.

Table 5- 8. Correlation between surface temperature and the area of land cover/ FOV of surrounding census tracts (block groups) of urban parks

Urban Park	Vegetation	Impervious Surface	Soil	FOV
All Grids	-0.624**	0.220**	0.350**	-0.145**
Grids excluding Soil Dominant Area	-0.655**	0.598**	0.052**	-0.679**

** Correlation efficient values are statistically significant at 0.01.

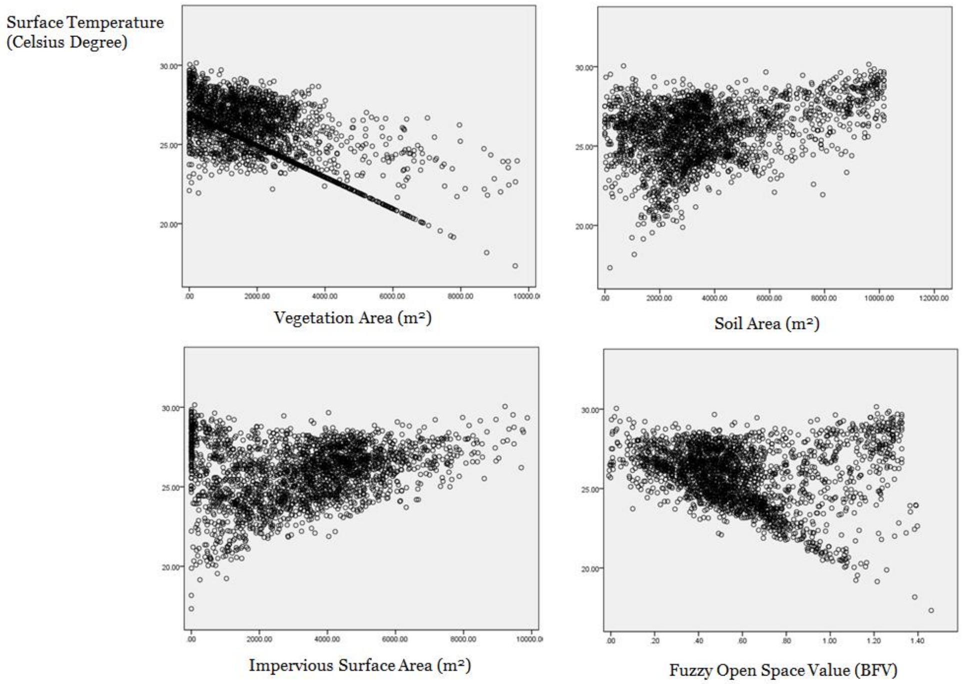


Figure 5- 8. Scatter plots for the relationship of surface temperature with land cover/ FOV for surrounding areas of urban parks

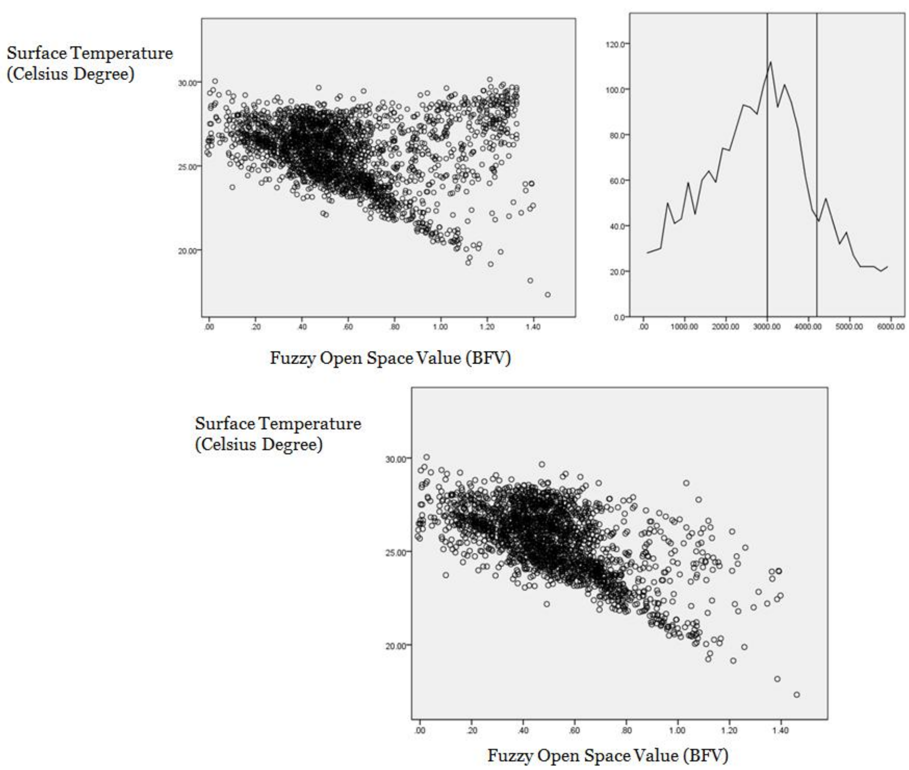


Figure 5- 9. Scatter plots for the relationship between surface temperature and FOV after excluding soil-dominant grids

Based on the output of discriminant analysis, there are mean differences between surface temperature, FOV, and vegetation area depicted in Table 5-9 and Table 5-10 provides strong statistical evidence of significant differences between means of four categories of open spaces with high value F's. Figure 5-10 shows that the grids in category 1 have clear negative relationship between surface temperature and FOV. The grids in category 2 also have slightly negative relationship between them, but those in category 3 and 4 have no or even positive relationship (Table 5-11).

Table 5-9. Group statistics table

Category		Mean	Standard Deviation
1	Vegetation Area	2730.244	1744.004
	Soil Area	2652.410	1286.902
	Impervious Area	2584.054	1483.367
	FOV	.598	.228
	Surface Temperature	24.231	1.700
2	Vegetation Area	1837.923	1243.399
	Soil Area	3158.732	1598.778
	Impervious Area	4321.054	1395.572
	FOV	.467	.170
	Surface Temperature	26.044	1.398
3	Vegetation Area	1575.130	1594.793
	Soil Area	4257.130	2957.584
	Impervious Area	2944.166	2215.633
	FOV	.649	.344
	Surface Temperature	25.860	1.619
4	Vegetation Area	1727.407	1660.736
	Soil Area	4670.344	2885.805
	Impervious Area	2933.456	2395.931
	FOV	.680	.368

Table 5-10. Tests of equality of group means table

Variable	Wilks' Lambda	F	df1	df2	df3	sig.
Surface Temperature	.640	450.65	1	3	2400	.000
FOV	.559	270.34	2	3	2400	.000
Impervious Area	.504	210.96	3	3	2400	.000
Vegetation Area	.490	163.629	4	3	2400	.000
Soil Area	.486	131.876	5	3	2400	.000

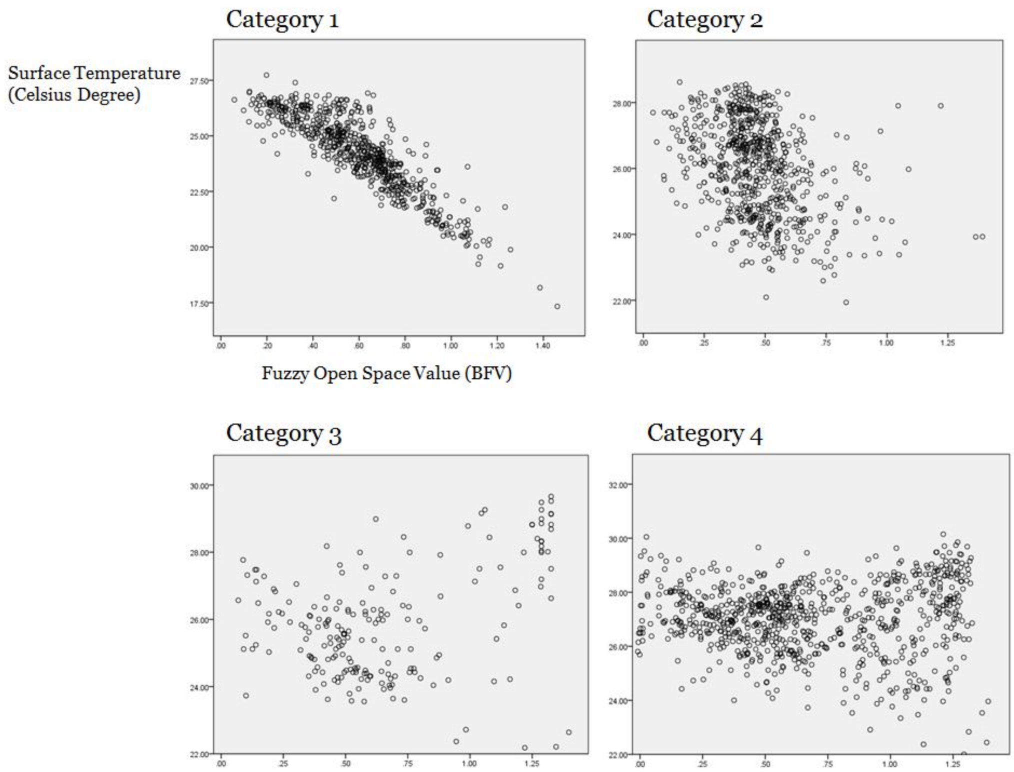


Figure 5- 10. Scatter Plots for the relationship surface temperature with land cover/ FOV for surrounding areas of urban parks

Table 5- 11. Correlation between surface temperature and FOV in parks' surrounding areas based on the categories of urban parks

Urban Park	Category 1	Category 2	Category 3	Category 4
Correlation Coefficient	-0.883**	-0.376**	0.352**	(0.112)

** Correlation efficient values are statistically significant at 0.01.
Values in parenthesis are not statistically significant.

5.5.3 Investigating the Physical Activities in Parks

The main patterns of physical activities in urban parks can be divided into group and individual participants, most of whom are white (62.36 percent) and male (76.42 percent) (Table 5-12). Generally, group activities were explored in the evening and individual participants were found both at morning and evening. From noon to 2pm, few activities were found in urban parks with severe hot weather (Table 5-13). Individual activities were usually explored in the morning, and group activities were performed in the afternoon, especially after 5pm. Most physical activities are facility-focused with Ramada, table, softball and soccer fields, and playground, but group sports activities, such as softball and soccer, are required lawn area (Table 5-14 and 5-16).

As evidence, Table 5-14 shows that 57.60% of people fulfilled group activities, such as large family group party or sports, and 42.40% of people fulfilled individual activities, such as walking, jogging, and playing at the playground (Figure 5-11 and 5-13). 51.50% of events are facility-related activities, such as playing basketball and soccer, playing in at the playground, or Part at Ramada table (Figure 5-12 and 5-13). However, only 32.00% of activities are vegetation required events, such as playing in lawn area or resting under trees. All group activities are facility-focused, and 85.04% of them are vegetation-required. These facts indicate that both regular (walking or sports) and infrequent (picnic) activities are not related with greenness of urban parks. However, group activities are almost required greenness in the parks. Specifically, people sitting on the grass were not found in all twelve parks. Most people used a Ramada, which was covered by canopy because they needed to escape from hot and sunny condition. Shade areas from trees were also one of main places for people to sit and rest, but people did not have any priority the shade areas from trees. In addition, people who came for group activity drive, rather than walk to the park.

Table 5-12. Number of people involved in activities in twelve parks

Total	Race				Sex		Age			
Number of People	White	Black	Hispanic	Other	Male	Female	Child	Teen	Adult	Senior
882	550	38	124	170	674	208	106	254	516	6

Table 5-13. Daily and weekly patterns of activities in twelve parks

Total (Number of People)	Morning (7:00-9:00)	Noon (12:00-14:00)	Afternoon (17:00-19:00)	Week	Weekend
882	233	22	627	583	299

Table 5-14. Categorizing physical activities in twelve parks

Category	Number of People	Ratio (of Total Number of People)	Number of Events	Ratio (of Total Number of Events)
Group	508	57.60%	22	11.00%
Individual	374	42.40%	178	89.00%
Facility-focused	760	86.17%	103	51.50%
Vegetation-required	502	56.92%	64	32.00%
Total Activity	882	100.00%	200	100.00%

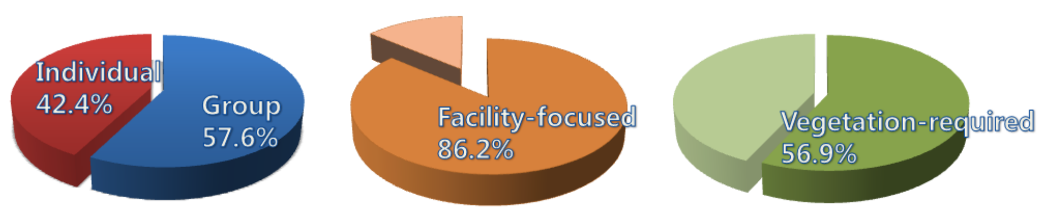


Figure 5-11. Ratio of number of people for physical activities

Figure 5-12. Ratio of number of events for physical activities

Table 5-15. Number of people and events in parks with types of physical activities

Urban Park	Total		Group		Individual		Facility-focused		Vegetation-required	
	People	Event	People	Event	People	Event	People	Event	People	Event
Clark	82	6	60	2	22	4	80	5	62	4
Daley	74	26	0	0	74	26	50	12	20	10
Corbell	56	36	0	0	56	36	28	10	16	14
Indian Bend	16	8	0	0	16	8	10	4	12	6
Hudson	112	26	56	2	56	24	102	16	4	4
Scudder	0	0	0	0	0	0	0	0	0	0
Stroud	134	12	122	2	12	10	126	4	126	6
Redden	30	8	0	0	30	8	30	8	0	0
Celaya	36	2	36	2	0	0	36	2	36	2
Sun Ray	296	54	214	10	82	44	264	28	226	18
Buffalo Ridge	2	2	0	0	2	2	0	0	0	0
Moeur	44	20	20	4	24	16	34	14	0	0
Total	882	200	508	22	374	178	760	103	502	64

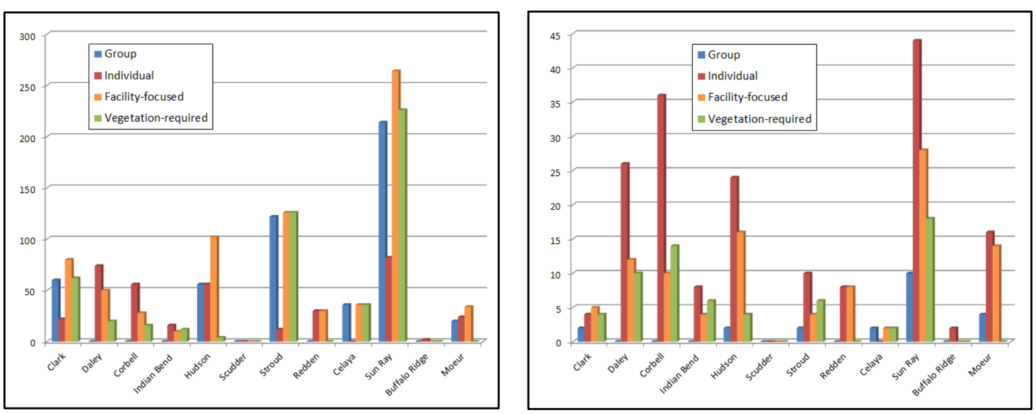


Figure 5-13. Ratio of number of people (Left) and events (Right) for physical activities in individual twelve urban parks

Sun Ray Park has the most activities in both group and individual, and Scudder and Buffalo Ridge parks have small number of people who use parks (Table 5-15 and 5-16). The parks that have group sports facilities have more physical activities than those without sports facilities. There is large variance between neighbourhood parks, Hudson and Stroud have relatively more physical activities with facility-focused, but Hudson has low number of people and events of vegetation-required activities. Hudson Park has various facilities, such as a playground, Ramada, basketball field, and skateboard ground even though it is small size of urban park. In addition, many group and individual activities were found at Hudson and Stroud parks, which have relatively low FOV. Buffalo Ridge and Moeur parks, which have the lowest W-green index, have also low physical activities. In the case of group activity, most people used their car to visit the parks, so FOV of surrounding areas has little relationship with number of group activities. Another point is that the parks near downtown, which are Daley and Clark, showed negative usage, such as the occupation of homeless people because of easy accessibility and many facilities.

Table 5-16. Main physical activities in twelve urban parks

Urban Parks	Main Physical Activities
Clark Park	- Resting in the Ramada - Playing Softball - Walking
Daley Park	- Resting in the Ramada and under trees - Riding a Bicycle - Walking - Playing Basketball
Corbell Park	- Walking (with dogs) / Running - Playing on the Playground - Dinner Party at the Table
Indian Bend Park	- Walking - Resting in the Table - Playing Tennis
Hudson Park	- Walking (with dogs) - Riding a Bicycle and Skateboard - Dinner Party at the Table and Ramada - Playing on the Playground
Scudder Park	- No Activity Observed
Stroud Park	- Walking (with dogs) - Playing Soccer - Playing on the Playground
Redden Park	- Playing on the Playground - Playing Basketball
Celaya Park	- Playing Soccer
Sun Ray Park	- Playing on the Playground - Running / Walking (with dogs) - Playing Softball / Soccer / Cricket / Football - Riding a Bicycle - Picnic
Buffalo Ridge Park	- Running
Moeur Park	- Dinner Party in the Ramada - Walking - Riding a Bicycle and Resting

5.5.4 Housing Price and Urban Parks

The surrounding areas of twelve parks do not have any significant difference in mean housing price, and fuzzy open space values also do not have any significant relationship with mean housing price and household income (Table 5-17). Moeur Park was eliminated from the analysis because there are no single family residential houses in the surrounding area. Residential properties sold in 2005 and 2006 were used to predict regression models. Different variables were used, but livable area and vegetation area are two main factors to explain the variance of housing prices in surrounding area of urban parks (Table 5-18).

Based on predicted models, adjusted sale prices that control other factors were produced to examine the relationship between sale price and distance to park. Correlation analysis was implemented between two variables, only two parks, Daley and Corbell, show the distance decay effect of green open space (Figure 5-14). These two parks are relatively larger than others (Table 5-19). Sun Ray and Buffalo Ridge parks are also large, but they have high FOV with large natural landscapes in surrounding areas. Other parks have positive or no relationships between sale price and distance to parks. The Distance decay effect of green open space was expected in higher W-green index open spaces, but the parks should be enough to be large and have little influences from other landscapes in surrounding areas. Small neighborhood parks were little influenced to the variance of housing price in surrounding residential properties.

Table 5-17. The socio-economic description for surrounding census tracts (block groups) of twelve parks

Urban Park	Population	Mean Housing Price ($) (Since 2000)	Mean Household Income ($)	FOV
Clark	6,254	194,740	38,735	0.503
Daley	9,107	269,775	38,750	0.581
Corbell	2,105	219,526	72,176	0.533
Indian Bend	3,224	189,823	42,213	0.451
Hudson	2,144	174,228	-	0.376
Scudder	1,860	238,561	67,301	0.500
Stroud	2,071	320,076	70,550	0.484
Redden	2,685	213,206	63,612	0.442
Celaya	3,182	208,513	48,024	0.528
Sun Ray	3,774	233,935	66,406	0.649
Buffalo Ridge	4,288	210,453	-	0.719
Moeur	-	-	-	0.648

Table 5-18. Predicted models for single family residential properties

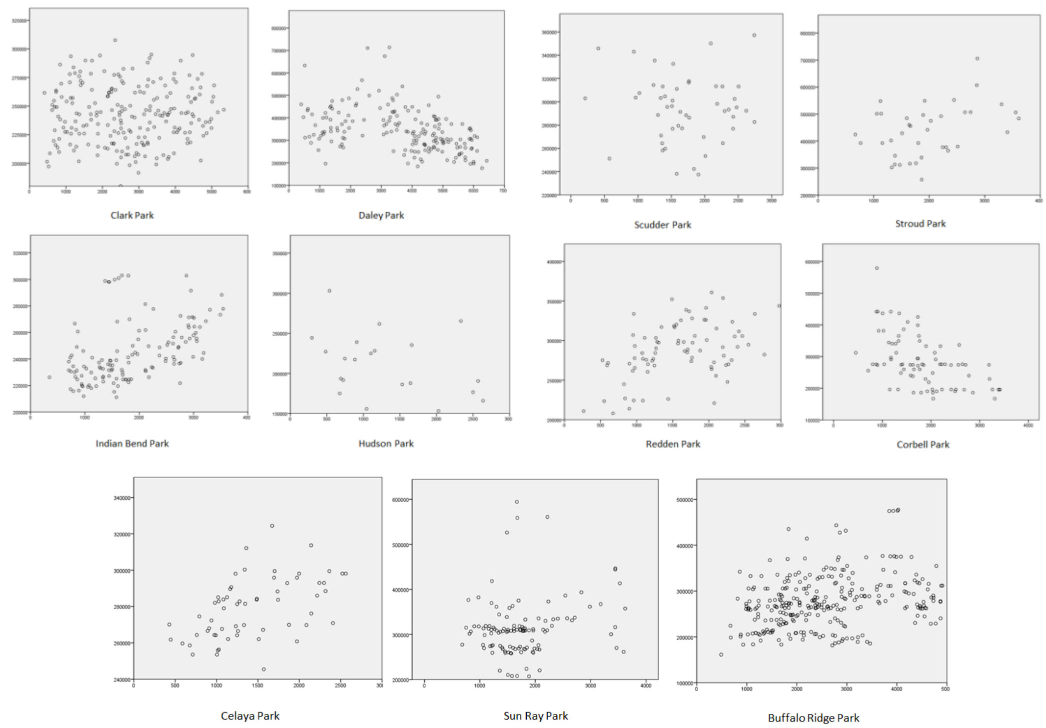
Urban Park	Predicted Model	R^2
Clark	SP = 130335.330 + 163.659×VA + 56.467×S	0.204
Daley	SP = 31010.290 + 187.432×VA + 139.296×S	0.611
Corbell	SP = 27550.935 + 157.829×S	0.768
Indian Bend	SP = 210901.405 + 55.205×S + (-1757.879)×S + 12.924×DS	0.203
Hudson	SP = 133919.909 + 19.213×VA	0.249
Scudder	SP = 60016.787 + 97.463×VA + 113.195×S	0.629
Stroud	SP = -90825.346 + 171.070×S + 4721.402×A	0.686
Redden	SP = 146184.999 + 89.750×S + (-30.520)×DR + 68.808×VA	0.451
Celaya	SP = 230916.449 + 52.060×S + (-2241.651)×A	0.283
Sun Ray	SP = 25024.365 + 24.335×VA + 169.082×S	0.696
Buffalo Ridge	SP = 63881.634 + 132.096×S + (-1534.011)×A + 5.050×DS + 15.958×DR	0.651
Moeur	-	-

SP: Sale Price ($) / VA: Vegetation Area (square feet)/ S: Size of Livable Area (square feet) / A: Age (year) / DR: Distance to Road (meter) / DS: Distance to School

Table 5-19. Correlation between adjusted price and distance to park

Urban Park	Correlation Efficient	W-Green Index	FOV	Size (m^2)
Clark	(0.013)	0.471	0.503	40,379
Daley	-0.408**	0.496	0.581	54,444
Corbell	-0.535**	0.568	0.533	56,943
Indian Bend	0.468**	0.505	0.451	30,274
Hudson	(-0.335)	0.490	0.376	17,643
Scudder	(-0.046)	0.586	0.500	17,550
Stroud	0.390*	0.563	0.484	23,001
Redden	0.448**	0.386	0.442	18,708
Celaya	0.507**	0.671	0.528	25,223
Sun Ray	0.198*	1.002	0.649	71,749
Buffalo Ridge	0.305**	0.273	0.719	127,491
Moeur	-	0.120	0.648	32,066

** Correlation efficient values are statistically significant at 0.01.
* Correlation efficient values are statistically significant at 0.05.
Values in parenthesis are not statistically significant.



Y: Adjusted Sale Price ($) / X: Distance to Park (meter)
Figure 5-14. Scatter plots for the relationship between distance to park and adjusted housing sale price

Daley and Corbell parks, which have significantly negative relationships, were also examined to find the impact of properties' vegetation-covered ratio on housing price and park (Table 5-20). This output shows that the influence of the distance to the parks is bigger in the properties whose vegetation cover ratio is less than 30 percents.

Table 5-20. Correlation between sale price and distance to park considering properties' vegetation cover in Daley and Corbell

Urban Park	Properties with more than 30% vegetation covered area	Properties with less than 30% vegetation covered area	W-Green Index
Daley	-0.279**	-0.285**	0.496
Corbell	(-0.313)	-0.568**	0.568

** Correlation efficient values are statistically significant at 0.01.
Values in parenthesis are not statistically significant.

5.5.5 Comprehensive Understanding of Urban Open Spaces

The findings reveal the clear variance between urban open spaces in an arid city with regard to the influences on urban environment. Even though the main purposes of urban open spaces are to provide recreational, relaxation opportunity and to control storm-water, they have a wide range of roles in various aspects of urban environment. I found a statistically significant interaction between the greenness of urban open spaces with surface thermal environment, but not with economic attributes of urban areas. Socially, the output of the observation of physical activities in the parks indicates that the effect of facilities is stronger for types and frequency of activities and visits whereas greenness is little important for physical activities in urban open spaces. Attributes of urban parks clearly provide cues about how it is to be used, but temporal characteristics of park use are not exactly explained by them but by climate condition.

As shown in Table 5-21, Clark and Corbell showed positive influences to reduce surface temperature and to decrease housing price. However, Clark and Daley showed different patterns of temperature mitigation impacts even though they have similar W-green index and FOV. The numbers of activities in Category 2 open spaces are varied in each park, but main physical activities are similar (except Hudson Park). Sun Ray, Category 3, and Buffalo Ridge / Moeur, Category 4, had the opposite influences on environmental and social aspects. They have similar FOV but there is a large difference in their W-green index values. Generally, parks with lower FOV and higher W-Green index have more negative relationship between distance to park and surface temperature, such as Corbell and Hudson parks, and have more positive relationship between number of people's activities, such as Hudson and Sun Ray parks.

Table 5-21. Comprehensive description of twelve urban parks' impacts

Urban Parks	Environmental	Social	Economic
Category 1 - Clark - Daley - Corbell	- Clark: No Influence - Daley and Corbell: Positive to reduce temperature	- Clark and Daley: Located in near Tempe Downtown and Homeless Occupation - Daley and Clark: One of the places that have more individual activities	- Daley and Corbell: Negative between distance to park and adjusted sale price - Clark: No Impact
Category 2 - Indian Bend - Hudson - Scudder - Stroud - Redden - Celaya	- Scudder, Stroud, Redden: No Influence - Indian Bend, Hudson, Celaya: Positive to reduce temperature	- The number of activities are varied in each park - Main Physical Activities: Walking and Jogging / Playing Soccer and Basketball / Playing on the Playground	- No or positive relationship
Category 3 - Sun Ray	- Positive to reduce temperature	- Most active park use	
Category 4 - Buffalo Ridge - Moeur	- Buffalo: Little Influence - Moeur: No Influence	- A small number of activities observed	

5.6 Discussion

This research shows that urban open spaces have two different benefits for urban environment, which are environmental and social values. Both are difficult to estimate numeric values, but the roles of urban open spaces have clear environmental and social purposes and influences on urban environment and residents. These roles of urban open spaces include 1) environmentally urban heat island mitigation, biodiversity, storm-water management, and air purification, and 2) socially recreation, relaxation, and meeting. These values also are also closely associated with economic issues in cities.

A possible limitation of this research could be to examine each one of three environmental, social and economic aspects. Storm-water management and biodiversity are also important roles of urban open spaces. Negative use of urban parks should be socially considered to maximize the opportunity of recreation and relaxation. In addition, the cost to manage urban open spaces should be considered to maintain urban sustainability and to maximize the effect of urban open spaces.

5.7 Chapter Conclusions

This research focused on green-vegetated and locational factors of urban open space in examining its impacts on urban environment. The quality and physical characteristics of urban open spaces influence on how people use and why they visit open spaces (Kaczynski et al. 2009), and it also determines the impacts of open spaces on urban environment. Urban open spaces play a key role to reduce surface temperature and act as cool islands. However, non-green open spaces with less vegetation have no or less impact to influence to change the climate of their surrounding area. However, greenness is not the major determinant of park use in the arid city. Due to hot and dry climate conditions, there were the physical activities after sunset. Many previous studies showed that land use and landscape quality of the surroundings of urban open spaces are key factors to determine their amenity value (Smith, Poulos, and Kim 2002; De Ridder et al. 2004), but this study do not confirm the influences of housing price from urban parks.

All in all, encouraging xeric landscaping for residential properties, the city should provide greener environment for people to have more fresh and comfortable living environment by installing “green” open space. Thermal comfort from the shade by trees and canopy is the key issue for people in using urban parks, but there is no priority of the shade from trees. However, the potential suggestion can be trails covered by trees, so people can walk around the park under tree shade. People for individual activities are accessed by foot, and people who came for group activities used their cars to visit urban parks. For example, baseball and softball, as well as soccer fields are not for the residents who live around them, however most of the people came by car. The parks that have group sports facilities, including Ramada should have enough parking spaces for people to use.

CHAPTER 6

CONCLUSION

This dissertation aimed to understand open spaces in an arid city. To achieve this ultimate goal, I implemented theoretical, methodological, and application research. The first component of this dissertation is to develop a "W-Green Index" to quantify vegetation density and height in urban open spaces and to apply open spaces in Tempe, Arizona. The second effort to identify "urban open space" in an arid city is through the introduction of a new theoretical idea of fuzzy open space. The third research is a comprehensive approach to investigate the impacts of urban open spaces, environmentally, socially, and economically. The following section discusses the major findings of the dissertation and describes the broader context of scientific research. The rest of the chapter suggests an overview of directions for future research.

6.1 Overview of the Three Studies in Dissertation

The first part of this dissertation described the newly designed measurement of vegetation information in urban parks and open spaces. This section provided the conceptual framework to quantify the height and density of vegetation in open spaces. This paper applied and tested the "W-Green index" to various types of open spaces in Tempe. Most parks in Tempe were grass-dominant with higher W-Green index, while natural landscapes were shrub-dominant with lower W-Green index. Even though the argument for the validation of W-Green index has a difficulty from the comparison with NDVI in this sample case study, W-Green index has the advantage to explain vegetation composition and structural characteristics in open spaces. The limitation of this research is that high resolution satellite images and field surveys are required for data collection.

The second research of this dissertation suggested a new theoretical framework for defining and delineating urban open spaces. Fuzzy open space delineation and mapping help to identify the landscape characteristics and potential influences of urban open spaces. Research findings indicated that two fuzzy open space values, BFV and SFV, are effective to the variability in different land-use types and between arid and humid cities. The produced fuzzy open space mapping by BFV and SFV was successfully applied to examine the relationship with surface temperature.

The third effort of this dissertation examined the environmental, social and economic impacts of urban open spaces considering previously developed "W-Green index" and "fuzzy open space values." The outputs of three analyses showed that the different qualities and types of open spaces, including size, greenness, equipment (facility), and surrounding areas, have different patterns in the reduction of surface temperature and the number of physical activities. The variance in housing prices through the distance to park was, however, not clear in this research. Nevertheless, the application of FOV and W-Green index was helpful to interpret the research on environmental, social and economic factors of urban open spaces.

6.2 Discussion on a Synthetic Framework for Urban Open Space

In this dissertation, W-green index was applied to binary open space delineation, and fuzzy open space mapping was suggested and designed for a theoretical framework to investigate the physical and social characteristics of urban environment in terms of urban open spaces. W-green index is a methodological tool to quantify the greenness of urban open spaces, and fuzzy open space mapping is a theoretical picture to see how urban environment is. The W- green index can be applied to residential and commercial areas and all other spatial objects in urban environment, and it can make possible W-green index to be used as a tool to measure the fuzzy values for the greenness of urban environment, which I used just vegetation cover ratio in this dissertation.

W-green index is a tool to quantify greenness, so it is useful to the influence of vegetation type and quality on urban environment. Even though W-green index identifies the physical characteristics of urban environment, it can apply to environmental as well as social and economic research topics. Different vegetation types and qualities on urban open spaces have different impacts on environmental quality (Chen and Wong 2006; Yin et al. 2007), social behaviour (Goličnik and Ward Thompson 2010), and economic amenity value (Cho, Poudyal, and Roberts 2008).W-green index can be used as a tool to to identify the different characteristics of vegetation types for environmental, social, and economic research on urban open space.

Fuzzy open space delineation and mapping can be helpful to identify the demand of urban open spaces and to clarify their purposes. The physical and social characteristics of urban environment should be considered to plan and design urban open spaces. Various purposes of urban open spaces, such as recreation opportunity, stormwater mangement, green landscaping, biodiversity, and thermal comfort, should be suitable to regional, climatic, and socioeconomic characteristics. In addition, brownness of urban open space should be a key issue for sustainable environment and needs to be considered both for conservation and development even though brownness do not have no or negative influence to improve environmental quality and to provide recreational opportunity.

Furthermore, the application of W-green index to fuzzy open space mapping helps to identify the relationship between benefits of open spaces and types of vegetation. For ecological and recreational efforts, a green connection or network is the essential paradigm to make a connection of green landscapes within cities. Fuzzy open space mapping and W-Green index can be applied to identify spatial configuration of urban environment and manage connected green and open landscapes.

6.3 Broader Implications of the Dissertation

This dissertation contributes to better understand open spaces in an arid city and builds a synthetic framework for analyzing arid city open spaces. Urban open space is vital to the function, livability, and aesthetic character of the urban environment. The growing demand for a high quality of life has coincided with a deep concern for the availability and quality of urban open spaces. Although the backgrounds for development and management of urban open space are different depending on cities and countries, it is widely accepted that urban open spaces impart a range of benefits to urban dwellers including recreational opportunities, improved air quality, better public health, among other. Water and air quality, storm-water management, wildlife habitat, recreational opportunities, and human comfort are all dependent on services provided by urban open spaces. It is important to establish the specific requirements and objectives for urban open spaces and to recognize the difference of arid and non-arid open spaces. This is the way to avoid the misunderstanding that results from trying to create and manage urban open spaces with neither priorities nor consideration of climatic conditions.

This dissertation is worthwhile to control for the heterogeneity of urban open spaces, and it is particularly relevant in a desert city where vegetation is scarce and limited. In addition, if it is necessary to make a plan to develop and design a new urban park, an important issue is how to maximize its effects on urban environment environmentally and socially and to minimize the cost to develop and maintain. This dissertation helps expand the view for arid urban environment and play a key role in establishing a strategy and finding decision-makings.

The increase of human needs and complexity of geographic phenomena cause complicated simplicity in implementing research analyses and achieving research goals. Most phenomena can be understood with systematic and comprehensive view. Urban climatologists, planners, engineers, architects, geographers, urban foresters and others should have cooperation to conduct urban open space research. Urban open spaces should be implemented with the cooperative works with other colleagues, and this helps to establish future collaboration-research environment. Multiple geographic information analysis techniques should be applied and combined to understand geographic phenomena. GIScience can play a key role to combine the works from various academic fields and have reliable data and analyses.

6.4 Future Research

Urban environments in arid and humid cities have different physical and social characteristics. Recognizing potential benefits and limitations from arid urban open spaces will be required to develop and maintain them in desert cities, which have shown fast urban growth and increasing population. All three previously-described studies have potential research topics to extend the applicability of theoretical and methodological frameworks provided in this dissertation.

First, fuzzy open space mapping can be applied in different scales of parcel, census tracts, and cities. By approaching the difference between cities in this way, this dissertation and potential research can lead to better understanding of the roles of open space and the sustainability in urban environment within cities as well as between cities. Second, W-Green index, which was applied to existing open spaces in this dissertation, can be also applied to residential properties to characterize their landscape patterns. The variance of vegetation in residential properties as well as open spaces is also an important factor to understand urban environment. Finally, the research on the impacts of open spaces on urban environment has many research topics and the possibility of a connection between the topics (Figure 6-1). Environmentally, the quality of storm-water is related with land-cover and land-use, and fuzzy open space mapping can make a contribution to identify the connection of storm-water and land-cover in urban areas. As an effort to combine environmental and social issues of open spaces, the spatial patterns of physical activities within parks can be examined and connected with thermal comfort. In addition, spatial diversity and heterogeneity should be considered in examining the relationship between housing price and open spaces. Spatial hedonic models can be applied to identify this relationship with the consideration of fuzzy open space mapping and W-Green index.

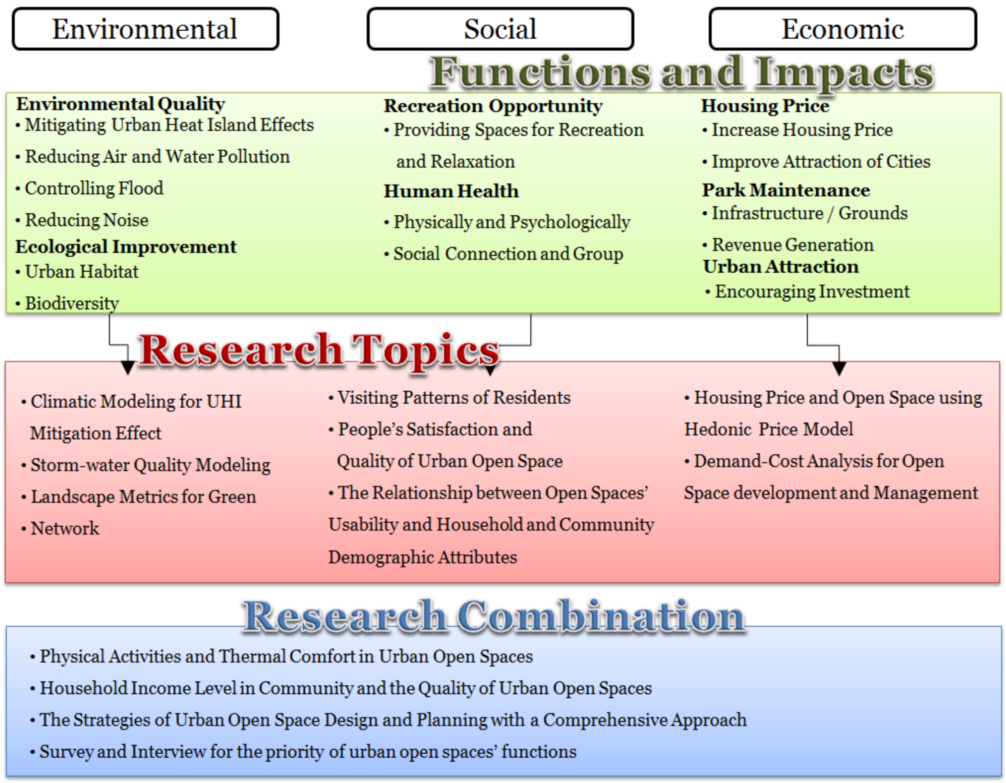


Figure 6-1. Urban open space functions and potential research topics

The final component of research potential is to compare and synthesize the outputs from the dissertation with the viewpoints of planners and professionals on urban environment. Surveys and interviews of academic professionals and governmental officers are required to understand how the functions of urban open spaces are prioritized and how they aim to serve cities and the residents. The functions that determine the influences of urban open spaces can be categorized as the following: Environmental functions (controlling flood/ mitigating urban heat islands/ improving ecological biodiversity), Social functions (providing recreation opportunity/ providing relaxation spaces/

improving social connection), and Costs (labor to manage urban open spaces/ water consumption to maintain vegetation in urban open spaces). In addition, these potential studies will help with planning the strategic allocation of urban open spaces. For example, high quality of open spaces can be supported to low-income population and communities if it is assumed that higher income level households and communities have better private gardens and open spaces. It will be helpful in improving the development and management of open spaces with better understanding of their influences on urban environment.

REFERENCES

Acharya, G., and L. L. Bennett. 2001. Valuing open space and land use patterns in urban watersheds. *Journal of Real Estate Finance and Economics* 22: 221-237.

Adams, W. M. 2006. The future of sustainability: Re-thinking environment and development in the twenty-first century. Report of the IUCN Renowned Thinkers Meeting, 29-31 January 2005. http://cmsdata.iucn.org/downloads/iucn future of sustainability.pdf (last accessed 01 March 2010).

Altunkasa, M. F., and C. Uslu. 2004. The effects of urban green spaces on house price in the upper northwest urban development area of Adana (Turkey). *Turkish Journal of Agriculture and Forestry* 28: 203-209.

Anderson, L. M., and H. K. Cordell. 1988. Influence of trees on residential property values in Athens, Georgia (U.S.A.): A survey based on actual sales prices. *Landscape and Urban Planning* 15: 153-164.

Anderson, S., and S. West. 2006. Open space, residential property values and spatial context. *Regional Science and Urban Economics* 36: 773-789.

Arnold, C. L., and C. J. Gibbons. 1996. Impervious surface coverage: The emergence of a key environmental indicator. *Journal of the American Planning Association* 62(2): 243-258.

Austin, M. E. 2004. Resident perspectives of the open space conservation subdivision in Hamburg Township, Michigan. *Landscape and Urban Planning* 69: 245-253.

Barbosa, O. J. A. Tratalos, P. R. Armsworth, R. G. Davies, R. A. Fuller, P. Johnson, and K. J. Gaston. 2007. Who benefits from access to green space? A case study from Sheffield, UK. *Landscape and Urban Planning* 83: 187-195.

Bell, S., A. Montarzino, and P. Travlou. 2007. Mapping research priorities for green and public urban space in the UK. *Urban Forestry and Urban Greening* 6(2): 103-115.

Benz, U. C., P. Hofmann, G. Willhauck, I. Lingenfelder, and M. Heynen. 2004. Multi-resolution, object-oriented fuzzy analysis of remote sensing data for GIS-ready information. *ISPRS Journal of Photogrammetry and Remote Sensing* 58: 239-258.

Binaghi, E., P. Madella, M. G. Montesano, and A. Rampini. 1997. Fuzzy contextual classification of multisource remote sensing images. *IEEE Transactions on Geoscience and Remote Sensing* 35(2): 326-340.

Bolitzer, B., and N. R. Netusil. 2000. The impact of open spaces on property values improved by landscaping with trees. *Southern Journal of Applied Forestry* 9: 162-166.

Boyle, R. Survey of the use of small parks. *Australian Parks and Recreation*: 41-43.

Breffle, W. S., E. R. Morey, and T. S. Lodder. 1998. Using contingent valuation to estimate a neighborhood's willingness to pay to preserve undeveloped land. *Urban Studies* 35: 715-728.

Bruse, M. 2007. Simulating human thermal comfort and resulting usage patterns of urban open spaces with a Multi-Agent System, in Wittkopf, St. and Tan, B. K. eds., *Proceedings of the 24th International Conference on Passive and Low Energy Architecture PLEA*: 699-706.

Burgess, J., C. M Harrison, and M. Limb. 1988. People, parks and the urban green: a study of popular meanings and values for open spaces in the city. *Urban Studies* 25: 455-473.

Ca, V. T., T. Asaeda, and E. M. Abu. 1998. Reduction in air conditioning energy caused by a nearby park. *Energy and Buildings* 29: 83-92.

Carr, S., M. Francis, L. Rivlin, and A. Stone.1992. *Public Space*. New York: Cambridge University Press.

Cavanagh, J. E., P. Zawar-Reza, and J. G. Wilson. 2009. Spatial attenuation of ambient particulate matter air pollution within an urbanized native forest patch. *Urban Forestry and Urban Greening* 8: 21-30.

Chang, C., M. Li, and S. Chang. 2007. A preliminary study on the local cool-island intensity of Taipei city parks. *Landscape and Urban Planning* 80: 386-395.

Chen, B., O. Adimo, and Z. Bao. 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: 76-82.

Chen, Y., and N. H. Wong. 2006. Thermal benefits of city parks. *Energy and Buildings* 38: 105-120.

Chiesura, A. 2004. The role of urban parks for the sustainable city. *Landscape and Urban Planning* 68: 129-138.

Cho, S., N. C. Poudyal, and R. K. Roberts. 2008. Spatial analysis of the amenity value of green open space. *Ecological Economics* 66: 403-416.

Chudnovsky, A., E. Ben-Dor, and H. Saaroni. 2004. Diurnal thermal behavior of selected urban objects using remote sensing measurements. *Energy and Buildings* 36: 1063-1074.

City of Tempe. 2003. General Plan 2030. Tempe, Arizona.

__________. 2008. City of Tempe 2007 Community Attitude Survey. Tempe, Arizona.

Comber, A., C. Brunsdon, and E. Green. 2008. Using a GIS-based network analysis to determine urban greenspace accessibility for different ethnic and religious groups. *Landscape and Urban Planning* 86: 103-114.

Correll, M. R., J. H. Lillydahl, and L. D. Singell. 1978. The effects of greenbelts on residential property values: Some findings on the political economy of open space. *Land Economics* 54: 207-217.

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton, and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. *Nature* 387: 253-260.

Cross, Valerie, and Aykut Firat. 2000. Fuzzy objects for geographical information systems. *Fuzzy Sets and Systems* 19-36.

Dai, D. 2011. Racial/ethnic and socioeconomic disparities in urban green space accessibility: Where to intervene? *Landscape and Urban Planning* 102: 234-244.

De Ridder, K., V. Adame, A. Banuelos, M. Bruse, M. Burger, O. Damsgaard, J. Dufek, J. Hirsch, F. Lefegre, J. M. Perez-Lacorzana, A. Thierry, C. Weber. 2004. An integrated methodology to assess the benefits of urban green space. *Science of the Total Environment* 334-335: 489-497.

De Vries, S., R. A. Verheu, P. P. Groenewegen, and P. Spreeuwenberg. 2003. Natural environemtns – healthy environemtns? An exploratory analysis of the relationship between greenspace and health. *Environment and Planning A* 35: 1717-1731.

Do, A. Q., and G. Grudnitski. 1995. Golf courses and residential house prices: An empirical examination. *Journal of Real Estate Finance and Economics* 10: 261-270.

Dubin, R. A., and C-H. Sung. 1987. Spatial variation in the price of housing: Rent gradients in non-monocentric cities. *Urban Studies* 24: 193-204.

Dwyer, J. F., E. G. McPherson, H. W. Schroeder, and R. A. Rowntree. 1992. Assessing the benefits and costs of the urban forest. *Journal of Arboriculture* 18(5): 227-234.

Faryadi, S., and S. Taheri. 2006. Interconnections of urban green spaces and environmental quality of Tehran. *International Journal of Environmental Research* 3: 199-208.

Frech, H. E., and R. N. Lafferty. 1984. The effect of the California Coastal Commission on housing prices. *Journal of Urban Economics* 6: 105-123.

Fridgen, J. J., N. R. Kitchen, K. A. Sudduth, S. T. Drummond, W. J. Wiebold, and C. W. Fraisse. 2004. Management zone analyst (MZA): software for subfield management zone delineation. *Agron. Journal* 96: 100-108.

Fuller, R. A., K. N. Irvine, P. Devine-Wright, P. H. Warren, and K. J. Gaston. 2007. Psychological benefits of greenspace increase with biodiversity. *Biology Letters* 3: 390-394.

Fung, T., and W. L. Siu. 2001. A study of green space and its changes in Hong Kong using NDVI. *Geographical and Environmental Systems* 5: 111-122.

Geerken, R., and M. Ilaiwi. 2004. Assessment of rangeland degradation and development of a strategy for rehabilitation. *Remote Sensing of Environment* 90: 490-504.

Geoghegan, J. 2002. The value of open spaces in residential land use. *Land Use Policy* 19: 91-98.

Geoghegan, J., L. A. Wainger, and N. E. Bockstael. 1997. Spatial landscape indcies in a hedonic framework: an ecological economics analysis using GIS. *Ecological Economics* 23(3): 251-264.

Geoghegan, J., L. Lynch, S. Bucholtz. 2003. Capitalization of open spaces into housing values and the residential property tax revenue impact of agricultural easement programs. *Agricultural and Resource Economics Review* 32: 33-45.

Germann-Chiari, C., and K. Seeland. 2004. Are urban green spaces optimally distributed to act as places for social integration? Results of a geographical information system (GIS) approach for urban forestry research. *Forest Policy and Economics* 6: 3-13.

Giles-Corti, B., H. Broomhall, M. Knuiman, C. Collins, K. Douglas, K. Ng, A. Lange, and R. J. Donovan. 2005. Increasing walking: How important is distance to, attractiveness, and size of public open space? *American Journal of Preventive Medicine* 28: 169-176.

Gill, S. E., J. F. Handley, A. R. Ennos, and S. Pauleit. 2007. Adapting cities for climate change: the role of the green infrastrucutre. *Built Environment* 33: 115-133.

Gobster, P. H. 1998. Urban parks as green walls or green magnets? Interracial relations in neighborhood boundary parks. *Landscape and Urban Planning* 41: 43-55.

Goličnik, B., and C. Ward Thompson. 2010. Emerging relationships between design and use of urban park spaces. *Landscape and Urban Planning* 94: 38-53.

Gómez, F., L. Gil, and J. Jabaloyes. 2004. Experimental investigation on the thermal comfort in the city: relationship with the green areas, interaction with the urban microclimate. *Building and Environment* 39: 1077-1086.

Graetz, R. D. 1987. Satellite remote sensing of Australian rangelands. *Remote Sensing of Environment* 23: 313-331.

Groenewegen, P. P., A. E. van den Berg, S. de Vries, and R. A. Verheij.2006. Vitamin G: effects of green space on health, well-being, and social safety. *BMC Public Health* 6: 149.

Guhathakurta, S., and P. Gober. 2007. The impact of the Phoenix urban heat island on residential water use. *Journal of the American Planning Association* 73(3): 317-329.

Hagen, A. 2003. Fuzzy set approach to assessing similarity of categorical maps. *International Journal of Geographical Information Science* 17(3): 235-249.

Hartig, T., G. W. Evans, L. J. Jamner, D. S. Davis, and T. Gärling. 2003. Tracking restoration in natural and urban field settings. *Journal of Environmental Psychology* 23: 109-123.

Hofmann, P. 2001. Detecting urban features from IKONOS data using an object-oriented approach. *The Remote Sensing and Photogrammetry Society Proceedings*.

Huete, A. R. 1988. A soil-adjusted vegetation index (SAVI). *Remote Sensing of Environment* 25: 295-309.

Hume, C., J. Salmon, and K. Ball. 2005. Children's perceptions of their home and neighborhood environments, and their association with objectively measured physical activity: a qualitative and quantitative study. *Health Education Research* 20: 1-213.

James, P., K. Tzoulas, M. D. Adams, A. Barber, J. Box, J. Breuste, T. Elmqvist, M. Frith, C. Gordon, K. L. Greening, J. Handley, S. Haworth, A. E. Kazmierczak, M. Johnson, K. Korpela, M. Moretti, J. Niemelä, S. Pauleit, M. H. Roe, J. P. Sadler, and C. Ward Thomson. 2009. *Urban Forestry and Urban Greening* 8: 65-75.

Jiao, L., and Y. Liu. 2010. Geographic field model based hedonic valuation of urban open spaces in Wuhan, China. *Landscape and Urban Planning* 98: 47-55.

Jordan, C. F. 1969. Derivation of leaf-area index from quality of light on the forest floor, *Ecology* 50: 663-666.

Kaczynski, A., L. Potwarka, B. Smale, and M. Havitz. 2009. Association of parkland proximity with neighborhood and park-based physical activity: Variations by gender and age. *Leisure Science* 31(2): 174-191.

Kaplan, R., and S. Kaplan. 1989. *The experience of natural: a psychological perspective*. New York: Cambridge University Press.

Kestens, Y., M. Theriault, and F. D. Rosiers. 2004. The impact of surrounding land use and vegetation on single-family house prices. *Environment and Planning B, Planning and Design* 31: 539-567.

Khan, M. E. 2006. *Green Cities*. Washington: Brookings Institution Press.

Kong, F., and N. Nakagoshi. 2006. Spatial-temporal gradient analysis of urban green spaces in Jinan, China. *Landscape and Urban Planning* 78: 147-164.
Kong, F., H. Yin, and N. Nakagoshi. 2007. Using GIS and landscape metrics in the hedonic price modeling of the amenity value of urban green space: A case study in Jinan City, China. *Landscape and Urban Planning* 79: 240-252.

Kuttler, W., and A. Strassburger. 1999. Air quality measurements in urban green areas – a case study. *Atmospheric Environment* 33: 4101-4108.

Kweon, B., W. C. Sullivan, and A. R. Wiley. 1998. Green common spaces and the social integration of inner city older adults. *Environment and Behavior* 30: 832-858.

Laliberte, A. S., E. L. Fredrickson, and A. Rango. 2007. Combining decision trees with hierarchical object-oriented image analysis for mapping arid rangelands. *Photogrammetric Engineering and Remote Sensing* 73: 197-207.

LaPaix, R., and B. Freedman. 2010. Vegetation structure and composition within urban parks of Halifax Regional Municipality, Nova Scotia, Canada. *Landscape and Urban Planning* 98: 124-135.

Leslie, E., T. Sugiyama, D. Ierodiaconou, and P. Kremer. 2010. Perceived and objectively measured greenness of neighbourhoods: Are they measuring the same thing? *Landscape and Urban Planning* 95: 28-33.

Li, H. X., and V. C. Yen. 1995. *Fuzzy Sets and Fuzzy Decision Making*. Boca Raton: CRC Press.

Lwin, K. K., and Y. Murayama. 2011. Modelling of urban green space walkability: Eco-friendly walk score calculator. *Computers, Environment and Urban Systems* 35: 408-420.

Lynch, K. 1972. The openness of open space. In *Arts of the Environment*, ed. G. Kepeds. New York: George Braziller.

Madanipour, A. 1996. Design of Urban Space: An inquiry into a Socio-Spatial Process. London: Wigley.

Mäkinen, K., and L. Tyrväinen. 2008. Teenage experiences of public green spaces in suburban Helsinki. *Urban Forestry and Urban Greening* 7: 277-289.

Markham, B. L., and J. L. Barker. 1986. Landsat MSS and TM post-calibration dynamic ranges, exoatmospheric reflectances and at-satellite temperatures. *EOSAT Landsat Technical Notes* 1: 3-8.

Maruani, T., and I. Amit-Cohen. 2007. Open space planning models: a review of approaches and methods. *Landscape and Urban Planning* 81: 1-13.

Mathieu, R., C. Freeman, and J. Aryal. 2007. Mapping private gardens in urban areas using object-oriented techniques and very high-resolution satellite imagery. *Landscape and Urban Planning* 81: 179-192.

McCormack, G. R., B. Giles-Corti, M. Bulsara, and T. J. Pikora. 2006. Correlates of distances traveled to use recreational facilities for physical activity behaviors. International Journal of Behavioral Nutrition and Physical Activity 3: 18 doi: 10.1186/1475868-3-18

McKenzie, T. L., D. A. Cohen, A. Sehgal, S .Williamson, and D. Golinelli. 2006. System for observing play and recreation in communities (SOPARC): Reliability and feasibility measures. Journal of Physical Activity and Health: S208-222.

McPherson, E. G. 1992. Accounting for benefits and costs of urban greenspace. *Landscape and Urban Planning* 22: 41-51.

Montandon, L. M., and E. E. Small. 2008. The impact of soil reflectance on the quantification of the green vegetation fraction from NDVI. *Remote Sensing of Environment* 112: 1835-1845.

Myint, S. W., and G. S. Okin. 2009. Modelling land-cover types using multiple endmember spectral mixture analysis in a desert city. *International Journal of Remote Sensing* 30: 2237-2257.

Myint, S. W., C. P. Giri, L. Wang, Z. Zhu, and S. Gillette. 2008. Identifying mangrove species and their surrounding land use and land cover classes using an object oriented approach with a lacunarity spatial measure. *GIScience and Remote Sensing* 45(2): 188-208.

National Climate Data Center. 2010. Local climatological Data, August 2010 for Phoenix, Arizona.

The Weather Channel. Monthly average temperature and precipitation for Phoenix, Arizona and Tallahassee, Florida. http://www.weather.com (last accessed 10 August 2011).

Oh, K. S., and J. J. Hong. 2005. The relationship between urban spatial elements and the urban heat island effect. *Journal of Urban Design Institute of Korea* 6: 47-63.

Ostir, K., T. Veljannovski, T. Podobnikar, and Z. Stancic. 2003. Application of satellite remote sensing in natural hazard management: the Mount Mangart Landside case study. *International Journal of Remote Sensing* 24: 3983-4002.

Pauleit, S. 2003. Perspectives on urban green spaces in European cities. *Built Environment* 29: 89-93.

Pickup, G. 1989. New land degradation survey techniques for arid Australia: problems and prospects. *Australian Rangeland Journal* 11: 74-82.

Pierzynski, G. M., J. T. Sims, and G. F. Vance. 2005. *Soils and Environmental Quality*. Boca Raton: CRC Press.

Poudyal, N. C.; D. G. Hodges; B. E. Tonn, and S. Cho. 2009a. Valuing the Diversity, Spatial Pattern and Configuration of Open Space Plots in Urban Neighborhood. *Forest Policy and Economics* 11: 194-201.

Poudyal, N. C.; D. G. Hodges; J. M. Bowker; and H. K. Cordell. 2009b. Evaluating natural resource and outdoor recreation amenities in human life expectancy production function. *Forest Policy and Economics* 11: 253-259.

Richardson, E. A., and, R. Mitchell. 2010. Gender differences in relationships between urban green space and health in the United Kingdom. *Social Science and Medicine* 71: 568-575.

Saito, I., O. Ishihara, and T. Katayama. 1990/1991. *Energy and Buildings* 15: 493-498.

Sander, H., and S. Polasky. 2009. The value of views and open space: estimates from a hedonic pricing model for Ramsey County, Minnesota, USA. *Land Use Policy* 26: 837-845.

Sanders, R. A. 1986. Urban vegetation impacts on the hydrology of Dayton, Ohio. Urban Ecology 9: 361-376.

Sandström, U. G., P. Angelstam, and G. Mikusiński. 2006. Ecological diversity of birds in relation to the structure of urban green space. *Landscape and Urban Planning* 77: 39-53.

Sanesi, G., and F. Chiarello. 2006. Residents and urban green spaces: the case of Bari. *Urban Forestry and Urban Greening* 4: 124-134.

Schipperijn, J., O. Ekholm, U. K. stigsdotter, M. Toftager, P. Bentsen, F. Kamper-Jørgensen, and T. B. Randrup. 2010. Factors influencing the use of green space: Results from a Danish national representative survey. *Landscape and Urban Planning* 95: 130-137.

Schaffer, R., and N. Smith. 1986. The gentrification of Harlem?. *Annals of the Association of American Geographers* 76: 347-365.

Schuyler, D. 1986. The New Urban Landscape: the Redefinition of City Form in 19th Century America. Baltimore: John Hopkins University Press.

Seeland, K., S. Dübendorfer, and R. Hansmann. 2009. Making friends in Zurich's urban forests and parks: The role of public green space for social inclusion of youths from different cultures. *Forest Policy Economics* 11: 10-17.

Shin, D., K. Lee. 2005. Use of remote sensing and geographical information systems to estimate green space surface-temperature change as a result of urban expansion. *Landscape and Ecological Engineering* 1(2): 169-176.

Shutes, R. B. E., D. M. Revitt, A. S. Mungur, L. N. L. Scholes. 1997. The design of wetland systems for the treatment of urban run off. *Water Science and Technology* 25: 19-25.

Solecki, W. D., and J. M. Welch. Urban parks: green spaces or green walls? *Landscape and Urban Planning* 32: 93-106.

Song, Y. B. 2005. Influence of new town development on the urban heat island: the case of the Bundang area. *Journal of Environmental Sciences* 17: 641-645.

Song, Y., and G. Knaap. 2004. Internally connected, no commercial, with a touch of open space: The neighborhoods of new homes in the Portland metropolitan area. *National Center for Smart Growth Research & Education*. http://www.smartgrowth.umd.edu/research/pdf/SongKnaap_NewPortlandNeighborhoods_DateNA.pdf (last accessed 6 February 2010).

Smith, V. K., C. Poulos, and H. Kim. 2002. Treating open space as an urban amenity. *Resource and Energy Economics* 24: 107-129.

Sugiyama, T., and C. Ward Thompson. 2008. Associations between characteristics of neighbourhood open space and older people's walking. *Urban Forestry and Urban Greening* 7: 41-51.

Symeonakis, E., and N. Drake. 2004. Monitoring desertification and land degradation over sub-Saharan Africa. *International Journal of Remote Sensing* 25: 573-592.

Tansey, K., I. Chambers, A. Anstee, An Denniss, and A. Lamb. 2009. Object-oriented classification of very high resolution airborne imagery for the extraction of hedgerows and field margin cover in agricultural areas. *Applied Geography* 29: 145-157.

The Weather Channel. Monthly average temperature and precipitation for Phoenix, Arizona and Tallahassee, Florida. http://www.weather.com (last accessed 10 August 2011).

Troy, A., and J. M. Grove. 2008. Property values, parks, and crime: A hedonic analysis in Baltimore, MD. *Landscape and Urban Planning* 87: 233-245.

Tueller, P. T. 1989. Remote sensing technology for rangeland management applications. *Journal of Range Management* 42: 442-453.

Tyrväinen, L. 1997. The amenity value of the urban forest: an application of the hedonic pricing method. *Landscape and Urban Planning* 37: 211-222.

Tyrväinen, L., K. Mäklnen, and J. Schipperijn. 2007. Tools for mapping social values of urban woodlands and other green areas. *Landscape and Urban Planning* 79: 5-19.

Tyrväinen, L., and A. Miettinen. 2000. Property prices and urban forest amenities. *Journal of Environmental Economics and Management* 39: 205-223.

Tzoulas, K., and P. James. 2004. Finding links between urban biodiversity and human health and well-being. Paper presented at 4th International Postgraduate Research Conference on the Built and Human Environment, Salford, 29th March – 2nd April 2004. http://www.els.salford.ac.uk/ urbannature/ interactive/Downloads /Kosta%20IPRC.doc (last accessed 6 February 2010).

Tzoulas, K., K. Korpela, S. Venn, V. Yli-Pelkonen, A. Kazmierczak, J. Niemela, and P. James. 2007. Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review. *Landscape and Urban Planning* 81: 167-178.

United Nations. 1987. Report of the World Commission on Environment and Development. General Assembly Resolution 42/187. http://www.un.org/documents /ga/res/42/ares42-187.htm (last accessed 6 February 2010).

U.S. Census Bureau. 2011a. Federal Register. Available at: http://www.census.gov/geo/www/ua/fedregv76n164.pdf (last accessed 10 Aug 2011).

______________. 2011b. Census 2010 Summary File 1. Available at: http://www2.census.gov/census_2010/04-Summary_File_1. (last accessed 10 Aug 2011).

Van Herzele, A., and T. Wiedemann. 2003. A monitoring tool for the provision of accessible and attractive urban green spaces. *Landscape and Urban Planning* 63: 109-126.

Wang, F. 1990 Fuzzy supervised classification of remote sensing images. *IEEE Transactions on Geoscience and Remote* Sensing 28(2): 194-201.

Weicher, J., and R. Zerbst. 1973. The externalities of neighborhood parks: An empirical investigation. *Land Economics* 49: 99-105.

Wentz, E. A., W. L. Stefanov, C. Gries, and D. Hope. 2006. Land use and land cover mapping from diverse data sources for an arid urban environments. *Computers, Environment and Urban Systems* 30: 320-46.

Wu, J. J., and A. J. Planiga. 2003. The influence of public open space on urban spatial structure, *Journal of Environmental Economics and Management* 46(2): 288-309.

Yin, S., C. Jingping, C. Liping, S. Zhemin, Z. Xiaodong, W. Dan, and W. Wenhua. 2007. Effects of vegetation status in urban green spaces on particle removal in a street canyon atmosphere. *Acta Ecolgocia Sinica* 27: 4590-4595.

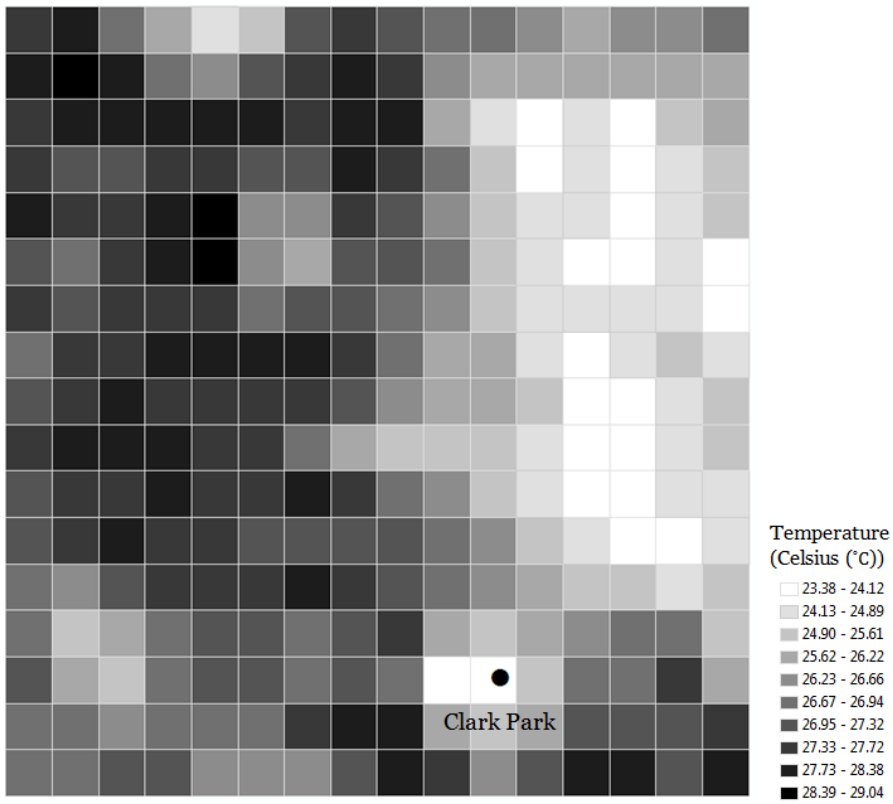
Yin. S. Z. Shen, P. Zhou, X. Zou, S. Che, and W. Wang 2011. Quantifying air pollution attenuation within urban parks: an experimental approach Shanghai, China. *Environmental Pollution* 159: 2155-2163.

Zhu, G., and D. G. Blumberg 2004. 2004. An urban open space extraction method: Combining spectral and geometric characteristics. *Geo-spatial Information Science* 7: 249-254.

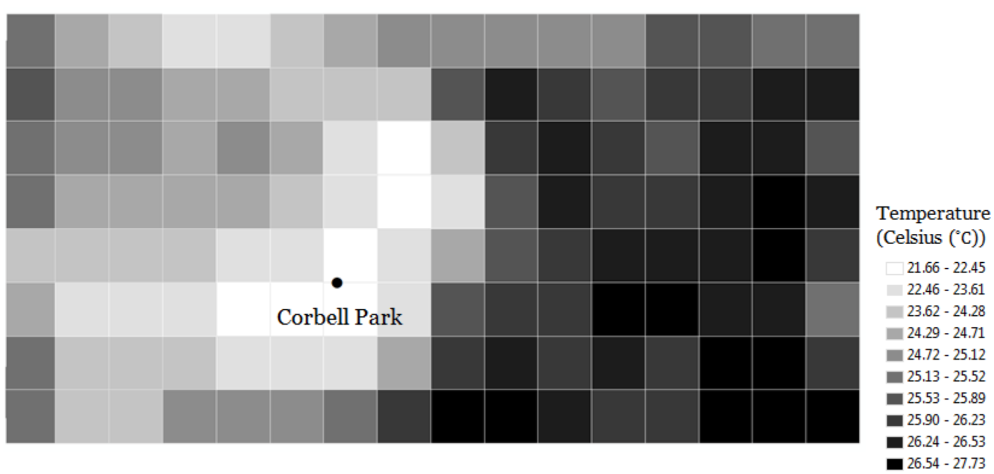
APPENDIX A

SURFACE TEMPERATURE MAPS FOR SURROUNDING AREAS OF TWELVE PARKS

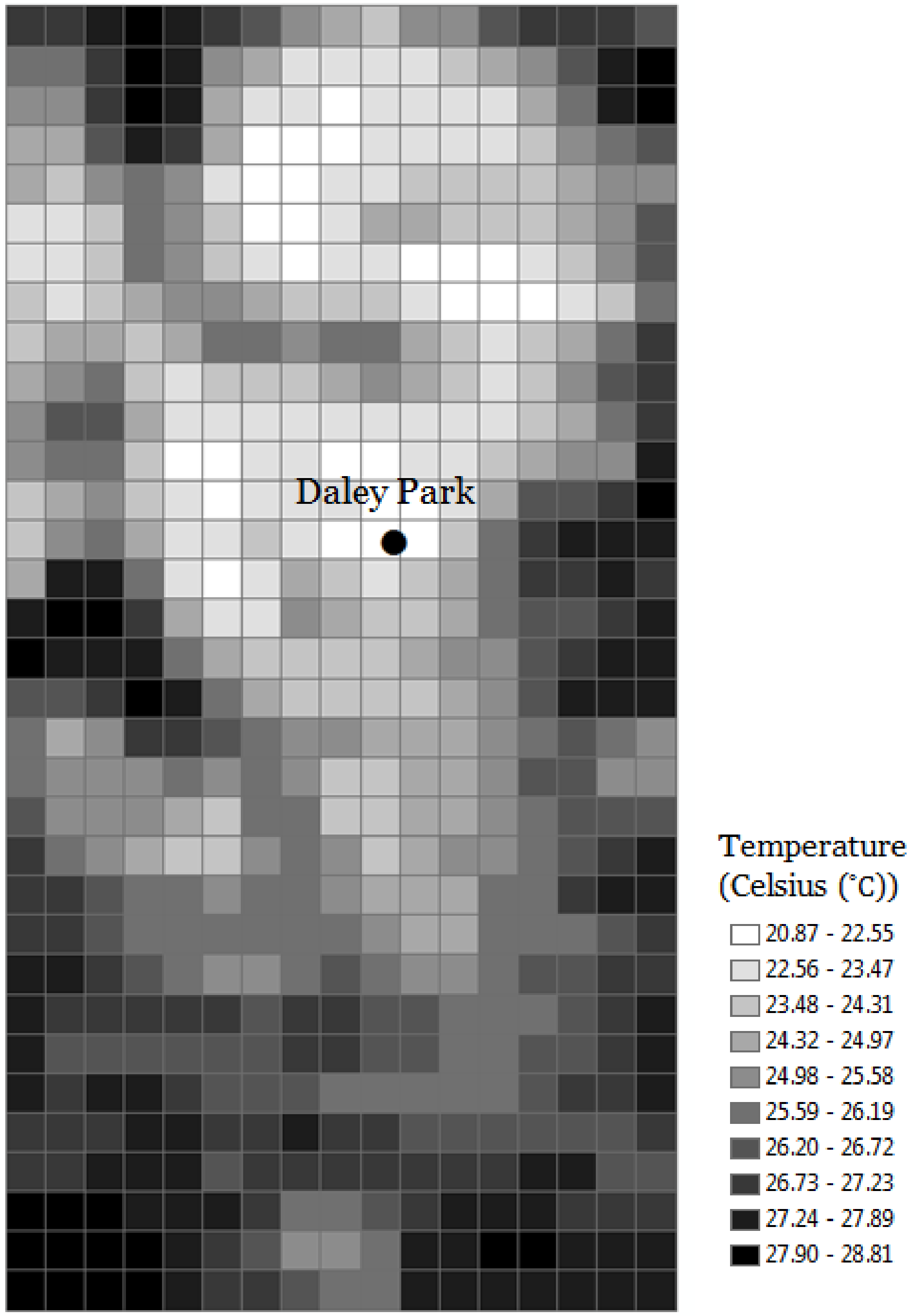
(A) Clark Park



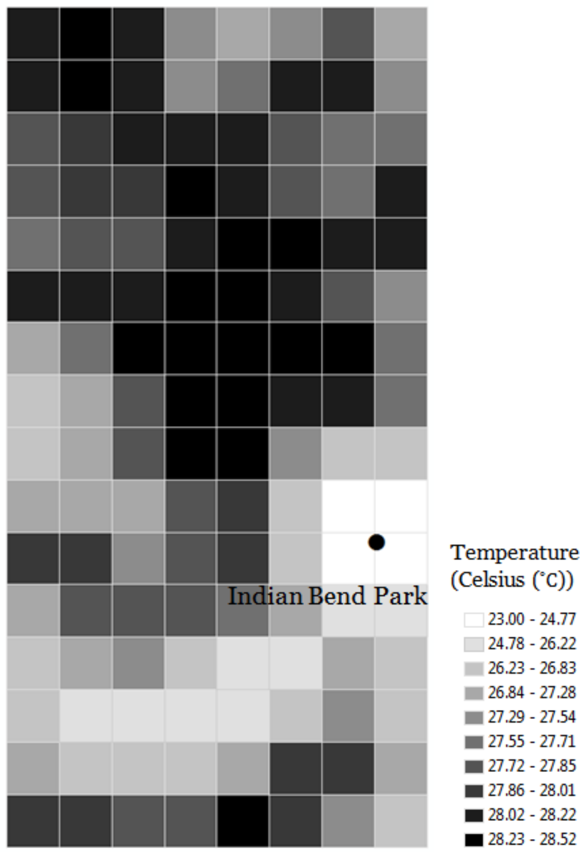
(B) Corbell Park



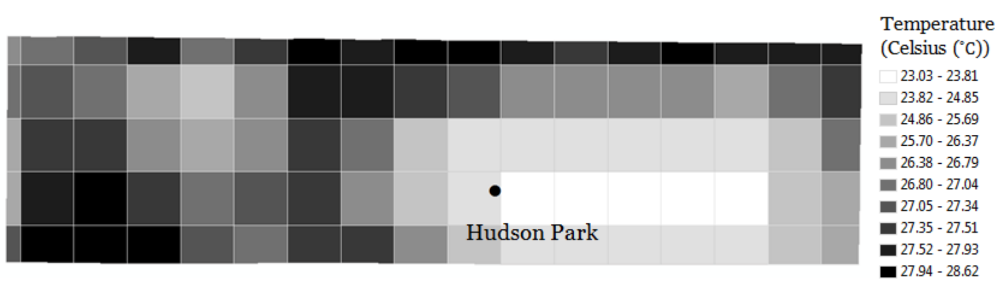
(C) Daley Park


Daley Park
Temperature (Celsius (˚C))
20.87 - 22.55
22.56 - 23.47
23.48 - 24.31
24.32 - 24.97
24.98 - 25.58
25.59 - 26.19
26.20 - 26.72
26.73 - 27.23
27.24 - 27.89
27.90 - 28.81

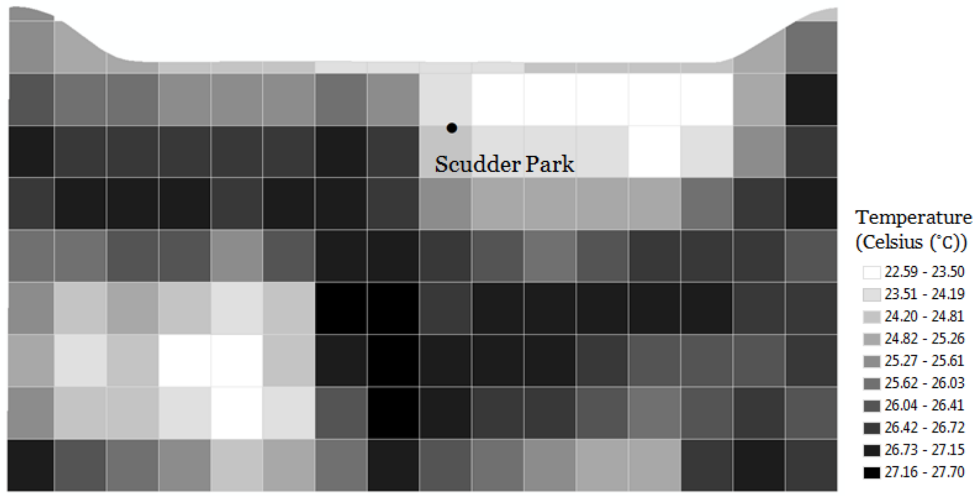
(D) Indian Bend Park



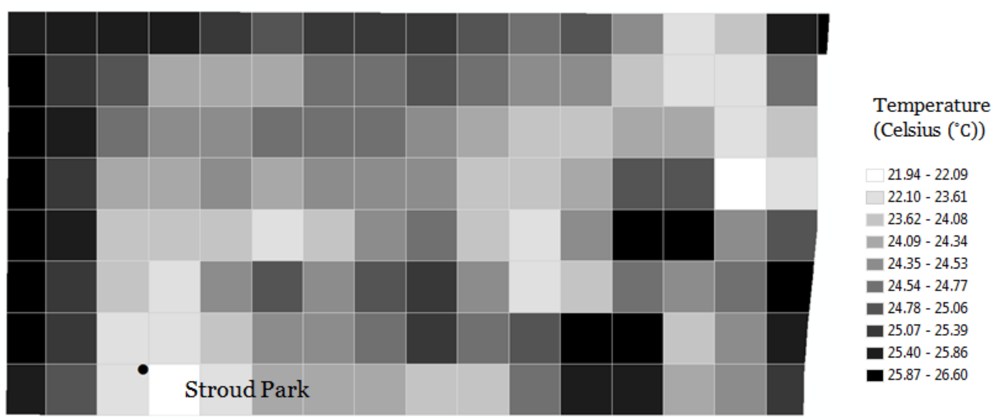
(E) Hudson Park



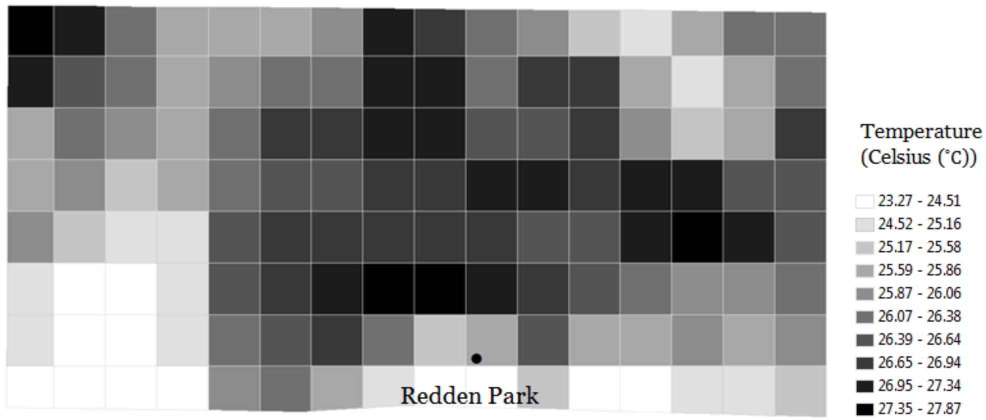
(F) Scudder Park



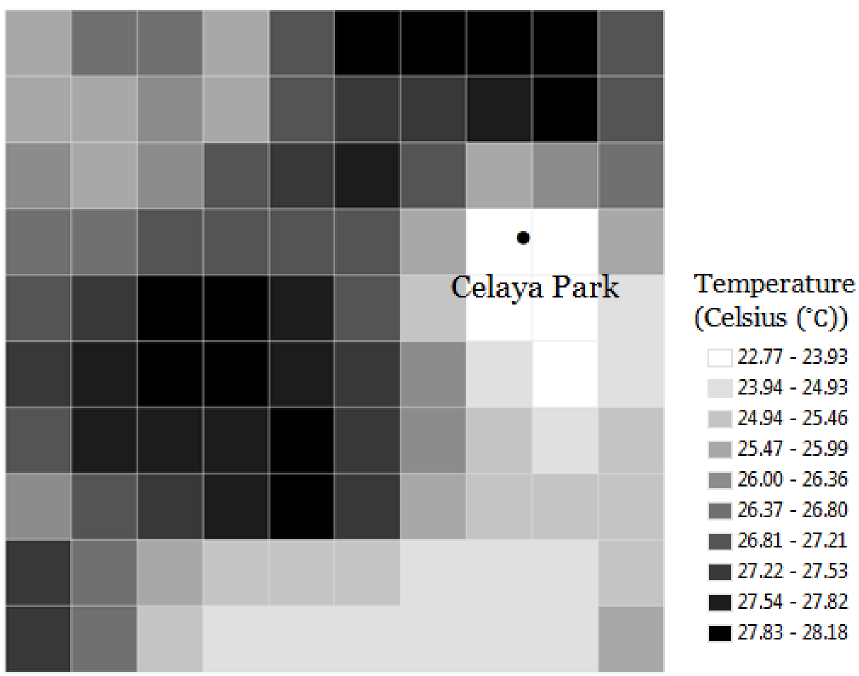
(G) Stroud Park



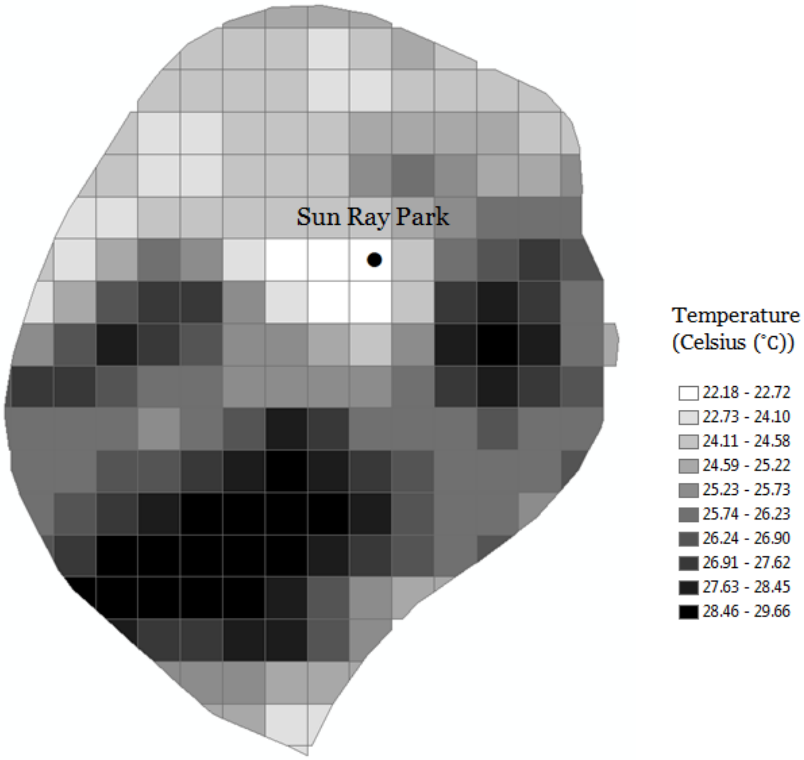
(H) Redden Park



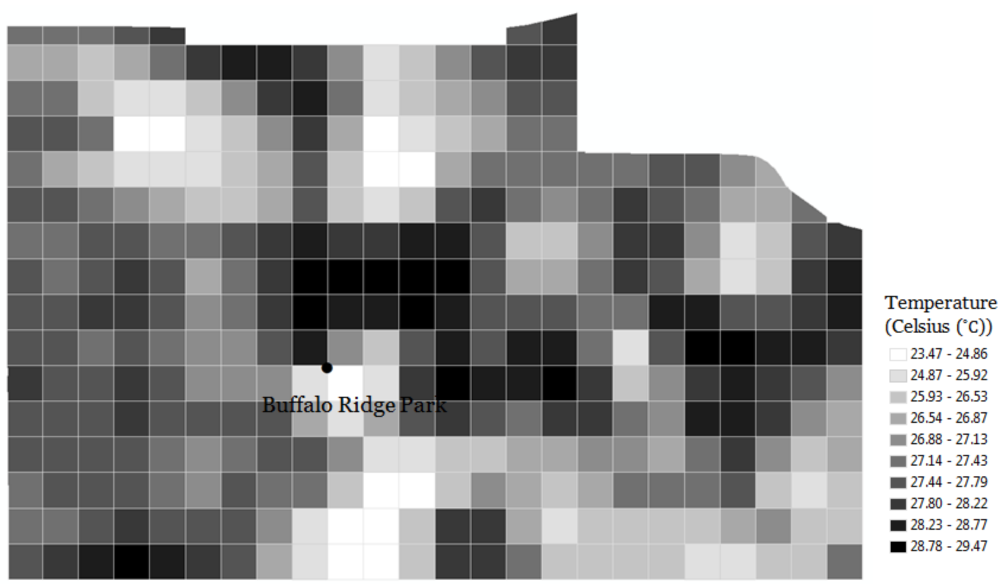
(I) Celaya Park



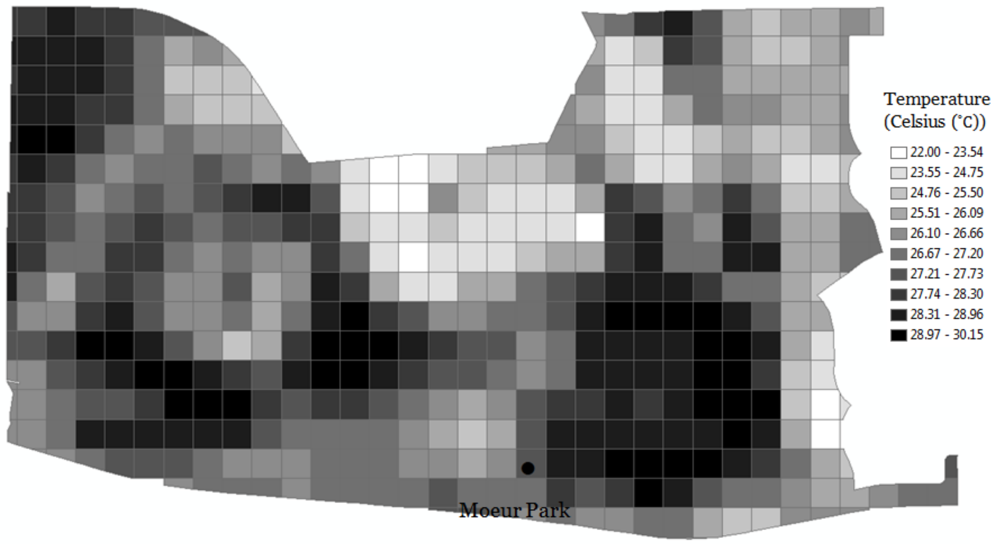
(J) Sun Ray Park



(K) Buffalo Ridge Park



(L) Moeur Park



Temperature
(Celsius (°C))
22.00 - 23.54
23.55 - 24.75
24.76 - 25.50
25.51 - 26.09
26.10 - 26.66
26.67 - 27.20
27.21 - 27.73
27.74 - 28.30
28.31 - 28.96
28.97 - 30.15
Moeur Park