

**Complicated Simplicity:
A Case Study on Urban Open Spaces in Phoenix Metropolitan Area**

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Abstract

Urban open space provides environmental, social, and economic benefits to cities and their dwellers. Nevertheless, most of urban open space studies are based in humid cities where open spaces are green with dense vegetation. Arid city open spaces are different from humid city spaces, and the primary difference is that arid city open spaces have a wide range of “greenness” ranging from native desert with sparse vegetation or irrigated with dense vegetation. This research proposes to investigate the quality of open spaces in arid cities with GIS and remote sensing. This research therefore aims to develop a new designed measurement, a “Green Index” for greenness of urban open spaces and explore the characteristics of open spaces in arid cities using the green index. We apply the green index to quantify and qualify the scope of greenness in these spaces. The green index is calculated with three density values of tree, shrub, and grass. Based on the produced green index, I categorize and delineate arid open spaces. The green index is useful to understand the functionality and quality of open spaces with fuzzy set theory. This research will provide better insight into how to describe, plan, and prioritize the functions and types of open spaces for sustainable living.

This paper intends to build a comprehensive framework for analyzing urban open spaces in an arid city. Urban open space is vital to the function, livability, and aesthetic character of the urban environment. Water and air quality, storm-water management, wildlife habitat, recreational opportunities, and human comfort are all depend 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. 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.

Geographic Information Science and Technologies allow us to control for the heterogeneity of urban open spaces, and this paper is particularly relevant in a desert city where vegetation is scarce and limited. In addition, if we make a plan to develop and design a new urban park, an important issue is how we maximize its effects on urban environment environmentally and socially and minimize the cost to develop and maintain. Therefore, multiple geographic information analysis techniques should be applied and combined to understand complicated geographic phenomena and develop a law or theory. The urban open space research should be implemented with the cooperative works, and this helps to establish future collaboration-research environment.

Keywords: Green Index, Open Space, Arid City, Remote Sensing, GIS, Green Index

1. Introduction

1.1 GIScience and Urban Environment

A combination of geographic information system (GIS), remote sensing technology, and ground survey of urban land use and surface characteristics can be an ideal strategy for collecting data and investigating the characteristics of urban environment. GIS has been recognized a useful tool to solve geographic problems (Longely et al. 2005) and represent geographic information, and remote sensing data and techniques have been identified as an important tool to monitor urban land use and extract urban features. In addition, research procedures and analyses for urban environment have multiple components and become complicated, and it is necessary to maximize resources from various research methodologies and academic fields. This paper highlights a significance of GIScience in examining and understanding the characteristics and quality of urban open spaces in arid cities. We investigate the characteristics of urban open space as a key component of urban environment in arid cities through remote sensing techniques and GIS and suggest the application of combined methods to identify and rectify multiple functions of open spaces in arid cities.

1.2 Open Spaces in Cities

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. Urban open space provides these benefits to cities and their residents to advance to sustainability and improve the quality of life.

Urban open space is a key component to sustainable living in cities because they provide both environmental and social, and economic benefits. Urban open space provides a range of tangible environmental benefits, such as mitigating urban heat island (UHI) as well as air and water pollution (Yu and Hien 2006, Cavanagh et al. 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). Understanding the key functions of urban open spaces is an important part to help improve their effectiveness, both for better management of existing open spaces as well as better design of new ones.

1.3 Urban Environment in Arid Cities

Desert cities, such as Phoenix and Las Vegas, have showed the fastest urban growth in the United States. Urban environment research in arid cities is essential because the population growth in desert cities continues to explode. Urban planners and government officers need to

consider how to manage urban environment in desert cities to advance sustainable cities and improve the quality of life for cities' residents.

Extensive research on urban open spaces shows that there are environmental, social, and economic benefits (Tyrväinen 1997, Groenewegen et al. 2006, James et al. 2009). Nevertheless, most of these studies are based in humid cities where open spaces are also “green” spaces with dense vegetation. This paper proposes to explore the characteristics of urban open spaces in arid cities. Arid city open spaces are different from humid city spaces. The primary difference is arid city open spaces have a wide range of “greenness” ranging from native desert with sparse vegetation or irrigated 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. Most natural open spaces are composed of shrubs with small number of trees and little or no turf. The sources of greenness in other open spaces are irrigated vegetation cover of turf grass and more shrubs, and larger trees. This means that all arid urban open spaces do not have 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. To better understand urban open space in an arid city, it is necessary to identify the benefits of open spaces correctly and effectively. The following facts should be considered carefully:

- Environmental: Open space with less green may not help to improve air quality and to mitigate urban heat island.
- Social: People may have different use and satisfaction with different quality of greenness in urban open spaces.
- Economic: The impact of open spaces on housing prices may vary with their greenness. Furthermore, maintenance cost to city will be different with the different types of open spaces and vegetation covers.

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 hot summer because it is too hot to be there in arid cities. 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.

1.4 Research Purposes

The broad objective of this paper is to show the application of multiple methods and the needs of interdisciplinary research with the roles of GIScience. The paper therefore aims 1) to develop a new measurement of greenness and to represent effectively the characteristics for

urban open spaces in arid cities using GIS and remote sensing techniques and 2) to discuss and suggest the extent and connection of environmental, social and economic impacts of open spaces on desert cities and the people living there.

2. Study Area and Data

2.1 Study Area

The study areas for this research are the metropolitan area of Phoenix, Arizona (Figure 1). This area has hot desert climate (Bwh) with extremely hot summers and temperate winters. Phoenix is one of the fastest growing cities in the USA. Urbanization has a negative impact on open spaces within cities (Kong and Nakagoshi 2006), and the demand for open spaces may also increase with population increase. In Phoenix and Tempe, there are two kinds of open spaces: public and private open spaces. Urban open spaces in Tempe include civic, open space, recreational/cultural and vacant lands, which are 17.4% of total lands (Table 1). This research focuses on urban public open spaces because private open space as private property may not be designated as open space for the purpose of public planning.

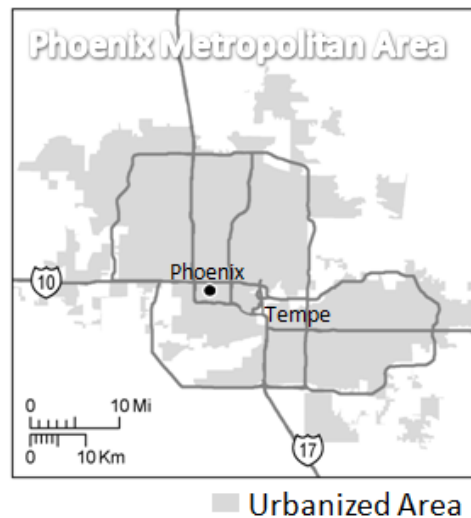


Figure 1. The Location of Phoenix metropolitan area, Arizona

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). Tempe plans to have at least 15.38 acres of open space per 1,000 residents in 2030 (City of Tempe 2003). This result mentions that it is important to understand the status of existing open spaces and the impact of new open space's development in Tempe.

Table 1. Tempe Existing Land Use Categories

Land Use	Acres	Percent of Total Existing Land Use
Residential	9076.014	44.8%
Commercial	2827.69	14.0%
Mixed Use	11.32	0.06%
Industrial	3236.21	16.0%
Civic	296.59	1.5%
Educational	713.09	3.5%
Open Space	1467.12	7.2%
Water	432.52	2.1%
Private Open Space	412.77	2.0%
Recreational/Cultural	185.29	0.9%
Vacant	1581.21	7.8%
City Total	20240	

[Source] City of Tempe. 2003. Tempe General Plan 2030

2.2 Data

Primary data sources used in this research include: (1) Landsat Thematic Mapper images and Quickbird images taken in May 2005; (2) Parcels data from Maricopa Association of Governments; (3) 150m Grid Cells; (4) Google Earth; and (5) Field Survey inventories. For the main data collection, Quickbird high-resolution and Landsat TM images are classified into soil, vegetation and impervious surface, and ground truth inventories are conducted for the confirmation of data and more detail information. The field works were performed on May 2008 and May 2009 for the city of Tempe. During the field works, the primary data are collected by investigating green elements in urban open spaces and by comparing prior-constructed information from remotely sensed data.

3. Methods

This paper examines open spaces in an arid city with extended view and discusses what issues can or should be considered in implementing research. First, we describe a green index, which is designed to evaluate the quality of urban open spaces and then suggest a comprehensive framework to understand open spaces in arid cities. Finally, we discuss research considerations for urban open space in Phoenix metropolitan area.

3.1 Developing a Green Index

The research challenge is concerned with urban remote sensing to examine the greenness of urban open spaces in an arid city. As a newly designed measurement for urban open spaces, a green index may be a useful tool to quantify the greenness and openness of urban open spaces in an arid city and to understand the functionality and quality of urban open spaces. Quantification of open space patterns is a prerequisite for monitoring and assessing open spaces in urban area (Kong and Nakagoshi 2006). Using QuickBird images, base classification maps are created to get the information of vegetation cover. This research designs a new conceptual framework of “Green Index” and uses a mixed methodology to investigate urban open spaces in an arid

environment. In order to measure the greenness of urban open spaces, we develop a “Green Index” and to empirically test it in Tempe, Arizona. A “Green Index” can, therefore, assist to understand the greenness of urban open spaces with the information of density and height for urban vegetation and forests through the analysis of high-resolution image and ground survey (Figure 2).

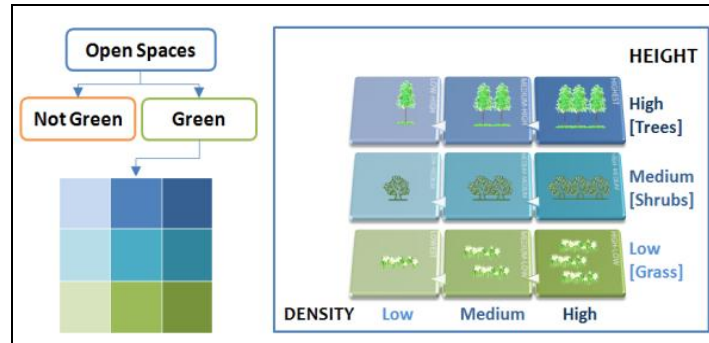
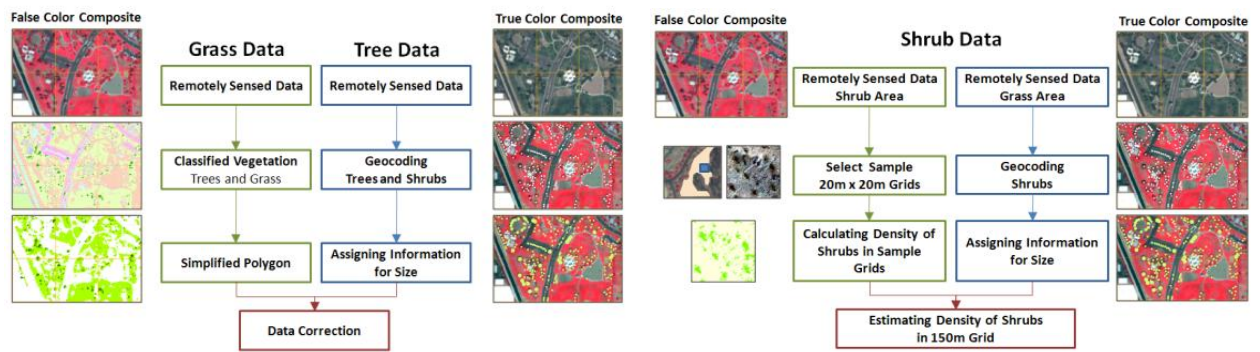


Figure 2. The Basic Conceptual Framework for a Green Index

The first step is the construction of data set for green index (Figure 3). Using object-oriented and per-pixel (maximum likelihood) classification methods, the Quickbird images of Phoenix and Las Vegas is classified into vegetation, soil, and impervious. Raster data classification maps are converted to polygon feature data with a simplified outline function, and the area of grass land is extracted from converted vector data set. Trees and shrubs are geocoded and estimated the areas with a Quickbird images and Google Earth. Based on this geocoded map, field works are implemented to confirm the number of trees and shrubs in open spaces to assign size, height and type of trees.

Final output is a “Green Index” calculated with three density values of grass, shrub, and tree (Figure 4). In pilot study, I produce one simple green index and three weighted green index (Figure 5), and I will try to find more appropriate weighted index with various considerations. First, simple green index (SGI) is calculated from sum of the areas of three trees, shrubs and grass divided by open space area. Simple green index 1.0 means that whole area is covered by green. It can have more than 1 and means that three elements are overlaid on the ground with all covered by green. Three kinds of weighted green index are calculated with NDVI and Tree weight. For first weighted green index (WGI 1), the area of trees is increased by 50% of existing value to give the weight to trees. I assume that a tree provide us green landscape as well as shaded area, and it is more helpful to reduce urban heat island effect. Second weighted green index (WGI 2) is SGI multiplied by mean NDVI, and third weighted green index (WGI3) is calculated after standardizing of NDVI. This may make the green index have more difference between vegetated and non vegetated area.



Grass Info



Trees and Shrubs Info

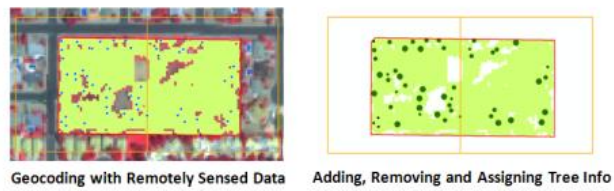


Figure 3. Data Construction and Correction

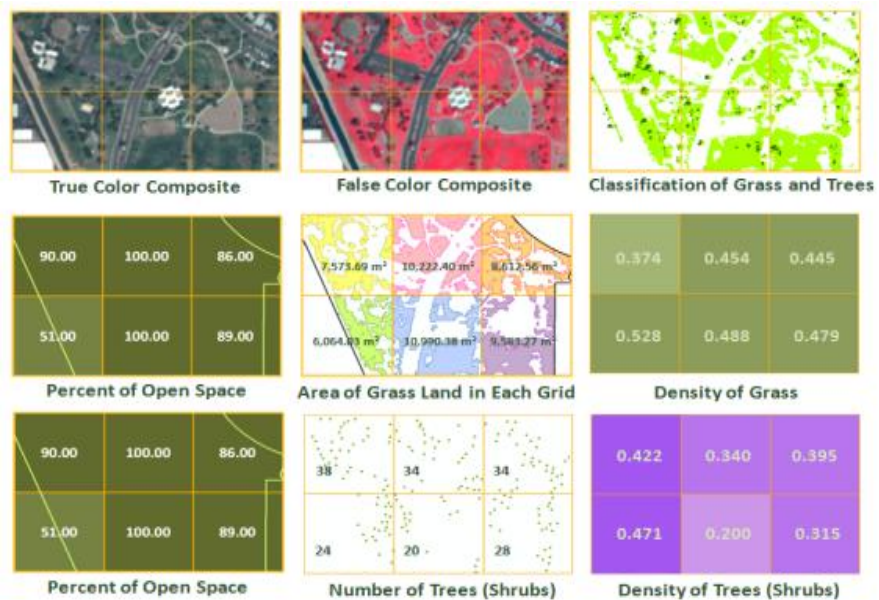


Figure 4. Calculating Density of Each Element

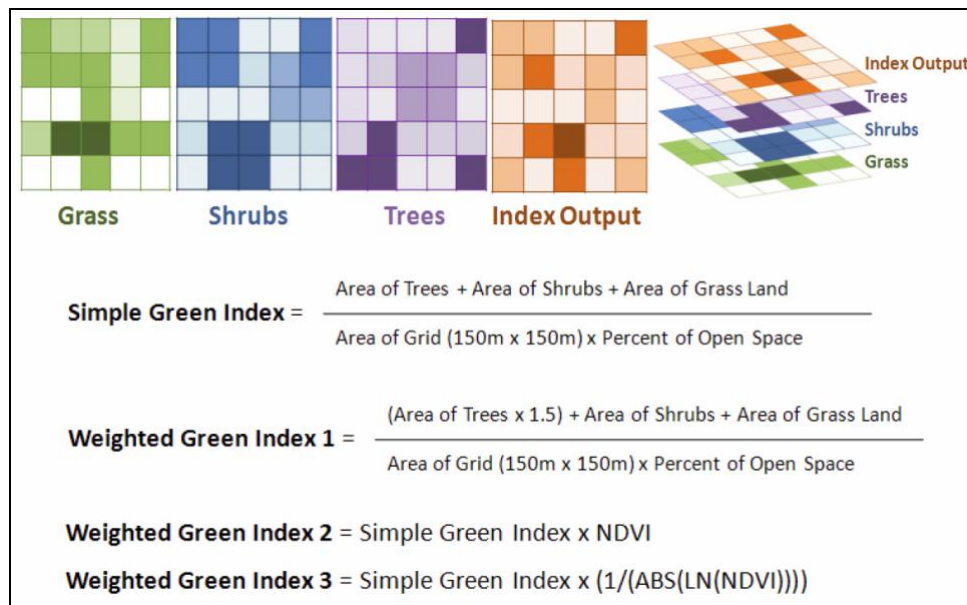


Figure 5. Calculating the Green Index

3.2 Testing a Green Index for Urban Open Spaces in Tempe

A green index can be applied to urban open spaces in an arid environment. Previously defined urban open spaces in Tempe are used to test a green index. The greenness of urban open spaces in Tempe is evaluated and mapped using previously designed a green index. In this research, 20 sample sites are selected under the consideration of locations (Zip Code) and types of urban open spaces. Following table is general characteristics of 20 sample sites for a green index research in Tempe.

Cole and Scudder parks have higher tree density values, and Tempe Diablo Stadium and Twin Butte Preserve have lower density values for trees (Table 4). Twin Butte Preserve as a natural resource has the highest density of shrubs and the lowest density of grass land. Moeur Park has relatively low density of grass because it has two sides of grass and shrub areas.

According to the result of green index of urban open space in Tempe, Celaya, Scudder, Waggoner and Goodwin parks have higher simple green index values than other parks (Table 5). Neighborhood Park is higher than Ballfield complex, natural resource and other urban open space. Moeur Park, Twin Butte Preserve, and Double Butte Cemetery show low values for all four indices. Goodwin Neighborhood Park has the highest green index in 20 sample sites. As shown Figure 14, Goodwin Park has good quality of grass and many large trees throughout the park. Generally, Regional Open Space and Community Park may include park area as well as recreation center and parking lot, but Neighborhood Park is almost composed with only green vegetation and forest. This is the main reason of higher green index in Neighborhood Park than others. Large number of shrubs occupy most area of natural landscapes like Twin Butte Preserve with an arid environment. Twin Butte Preserve's green index is 0.108, the lowest of sample sites.

Table 4. The Result of Green Index of Urban Open Space in Tempe

Open Spaces	Density of Trees	Density of Shrubs	Density of Grass
Celaya Park	0.237	0.000	0.871
Indian Bend Park	0.207	0.002	0.402
Arredondo Park	0.189	0.000	0.508
Scudder Park	0.331	0.000	0.769
Wagoner Park	0.169	0.000	0.945
Moeur Park	0.036	0.017	0.131
Benedict Park	0.040	0.002	0.550
Daley Park	0.193	0.004	0.526
Tempe Beach Park	0.041	0.001	0.476
Redden Park	0.160	0.005	0.525
Hudson Park	0.285	0.003	0.551
Goodwin Park	0.251	0.000	0.979
Tempe Diablo	0.015	0.001	0.547
Twin Butte	0.016	0.105	0.091
Double Butte Cemetery	0.213	0.001	0.289
Stroud Park	0.096	0.000	0.834
Corbell Park	0.123	0.000	0.819
Cole Park	0.354	0.000	0.582
Clark Park	0.087	0.000	0.643

Table 5. The Result of Green Index of Urban Open Space in Tempe

ID	Name	SGI	WGI1	WGI2	WGI3
1	Daley Park	0.7223	0.9853	0.3709	1.0836
2	Tempe Beach Park	0.5182	0.7562	0.1504	0.4188
3	Clark Park	0.7304	1.0518	0.2944	0.8039
4	Arredondo Park	0.6961	0.9499	0.3625	1.0668
5	Scudder Park	1.1004	1.4850	0.6108	1.8694
6	Redden Park	0.6899	0.9524	0.2530	0.6877
7	Cole Park	0.9362	1.2274	0.2541	0.7179
8	Wagoner Park	1.1135	1.5858	0.4953	1.3745
9	Indian Bend Park	1.1311	1.5718	0.6556	2.0739
10	Celaya Park	1.1077	1.5432	0.5206	1.4671
11	Stroud Park	0.9301	1.3470	0.3488	0.9482
12	Corbell Park	0.9424	1.3521	0.4675	1.3445
13	Moeur Park	0.1831	0.2484	0.0467	0.1341
14	Alegre Park	0.7241	1.0448	0.2151	0.5965
15	Goodwin Park	1.2302	1.7198	0.6576	1.9644
16	Hudson Park	0.8390	1.1145	0.3902	1.0960
17	Tempe Diablo Stadium	0.5626	0.8359	0.2544	0.7088
18	Benedict Sport Complex	0.5915	0.8665	0.1696	0.4736
19	Twin Butte Preserve	0.1081	0.1537	0.0474	0.1310
20	Double Butte Cemetery	0.5026	0.6471	0.1657	0.4529

3.3 Mapping the Green Index

The outputs of the green index are mapped in grid levels and open space units to validate the green index and find the way to represent it effectively. Figure 6 and 7 are to compare the outputs of SGI and WGI3 with open space units and 150m grids. We also draw a map for four green index values with a bar graph (Figure 8).

Compared output maps with open space units, the green index maps with 150m grids are more interpretable for each open space, and the maps of open spaces units might cause misinterpretation. For example, Twin Butte Cemetery has relatively low green index for both simple and weighted values based on the results with open space units, but some grids in the cemetery have high green index values (Figure 9). Additionally, WGI 3 makes more distinguishable maps than other indices.

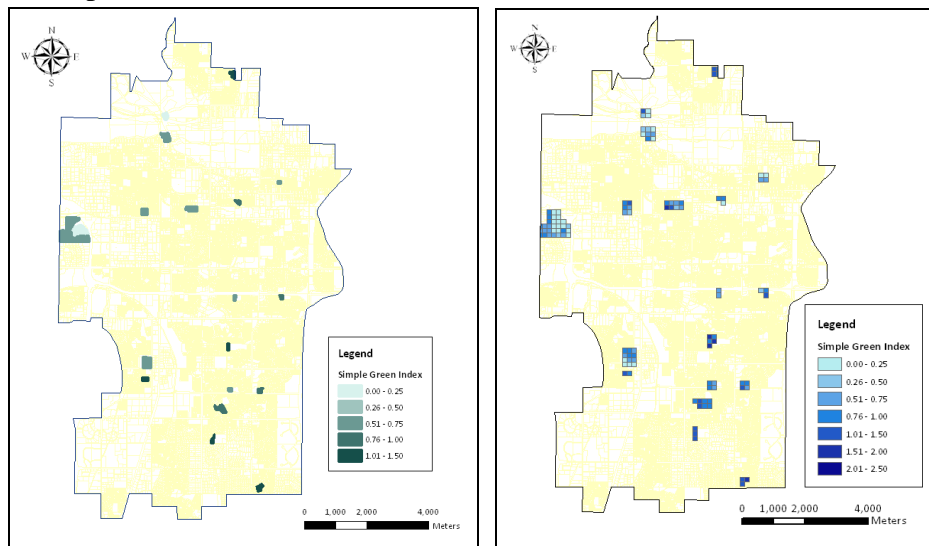


Figure 6. Simple Green Index with Open Space Units (Left) and Grids (Right) for Selected Open Spaces

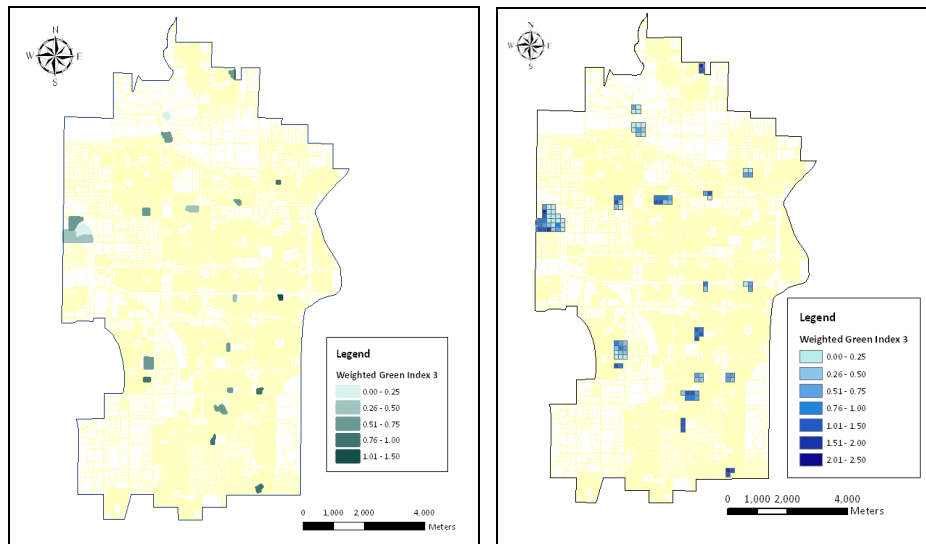


Figure 7. Weighted Green Index 3 with Open Space Units (Left) and Grids (Right) for Selected Open Spaces



Figure 8. The Green Index Outputs of Selected Urban Open Spaces in Tempe

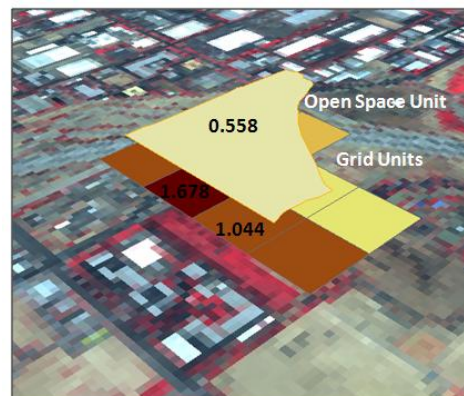


Figure 9. The Comparison of the Results from Two Different Analysis Unit

4. Suggesting a Comprehensive Framework for Urban Open Space Research

There are much interest in both the quality and the quantity of open space in urban areas (Swanwick 2003). In future research, I will design a prototype decision support system for the development and management of urban open spaces. The prototype can be applied to strategies for the creation of new urban open spaces as well as for the management of existing ones in supporting both the quality of life and sustainability. To achieve this ultimate purpose, this research develops the green index, and it will be used to categorize and characteristics of urban open spaces. Finally we will evaluate main three environmental, social and economic functions of arid urban open spaces with the green index

The significance of urban open spaces has been increased on the urban planning and research agenda with many existing studies focusing on the analysis of the environmental, social and economic benefits of urban open spaces. Each benefit of urban open spaces shows a contribution to urban environment, and it is sure to understand each of them (Figure 10). There is, however, little focus on the links between these benefits. To better understand urban open spaces, it is necessary for further research to be undertaken in a synthesized context. This research topic 3 will be composed of four sections, which are the analyses on 1) environmental, 2) social and 3) economic benefits of urban open space and 4) comprehensive understanding of urban open space functions. The main research question of this topic can therefore be “How effective are arid urban open spaces, and how well do they meet the needs of open spaces?” My hypothesis is that it depends on “types” and “quality” of open spaces, which are defined and measured in previous research topics. The green index will be used to delineate types and quality of open spaces.

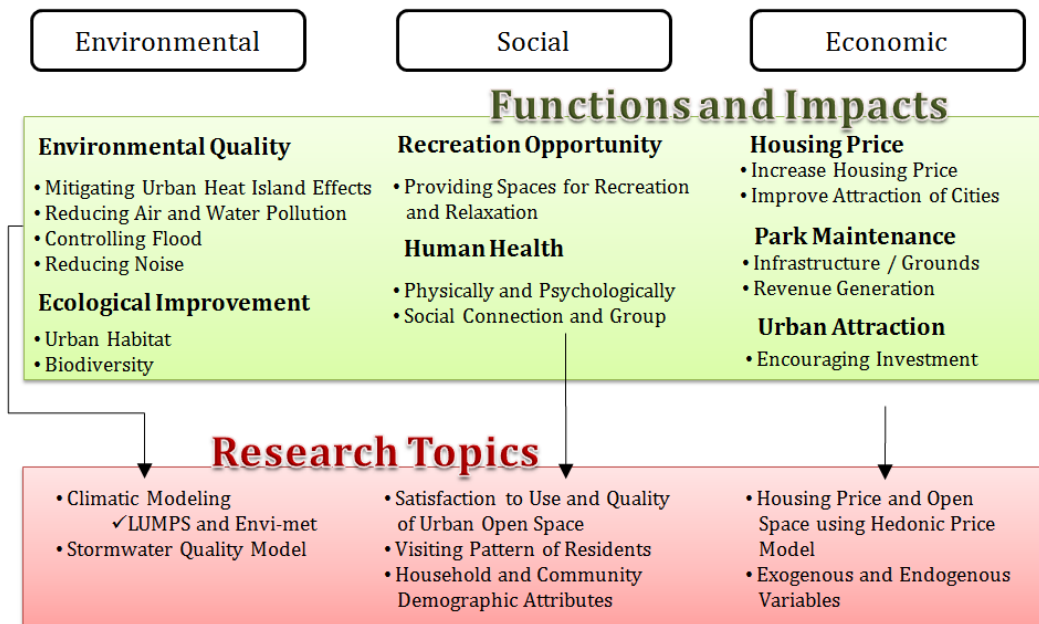


Figure 10. Urban Open Space Functions and Research Diagram

5. Summary and Discussion

5.1 Research Considerations for Urban Open Spaces in Arid Cities

Urban open space is a key element for sustainable city. 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 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. 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 others. The comprehensive roles of urban open

spaces need to be understood in a synthetic context. The functions provided by various types of urban open spaces, such as urban parks, natural landscape, playgrounds, and road buffers, should be understood with their different characteristics of greenness and services. Phoenix metropolitan area has relatively low natural green vegetation with a hot and dry climatic characteristic. Urban open spaces with low vegetation cover should be understood with a different approach to previous concepts and methods. To solve this problem, a green index was designed and applied to urban open spaces in Tempe. Urban open space can be delineated in physical and functional views, and currently most regions have classified with its function. Most of all, understanding the characteristics and types of urban open space is requisite to develop appropriate a green index in an arid environment.

Therefore, urban climatologists, planners, engineers, architects, geographers, urban foresters and others should have cooperation to correctly and effectively conduct urban open space research. Urban open space research should be implemented with the cooperative works with other colleagues, and this helps to establish future collaboration-research environment. Geographic Information Science and Technologies allow us to control for the heterogeneity of urban open spaces, and this paper is particularly relevant in a desert city where vegetation is scarce and limited. In addition, if we make a plan to develop and design a new urban park, an important issue is how we maximize its effects on urban environment environmentally and socially and minimize the cost to develop and maintain. Therefore, multiple geographic information analysis techniques should be applied and combined to understand complicated geographic phenomena and develop a law or theory.

5.2 Complicated Simplicity in Urban Open Space Research

The variation of these benefits with the type of urban open spaces and their configuration is however less well known. It is necessary to evaluate and characterize urban open spaces in arid cities because arid open spaces have a large variation in greenness and amenity values. For example, correct understanding for the relationship between urban open space and environmental quality should be accompanied with better examining the greenness of urban open spaces. In addition, outdoor activities and relaxation in urban parks might be limited in severely hot season, and this means that social functions of open spaces cannot be achieved appropriately. This challenge is to assess the validity and effectiveness of a new method in examining the environmental and social effects of arid urban open spaces. Presumably, more and larger parks as well as more vegetation may increase management costs, especially water resources in desert cities. A green index also can be extended to consider water usage (Figure 11). Research unit with different scale also influences on research data and methods, which we can use in urban open space research. Research unit should be selected with the consideration of research purposes.

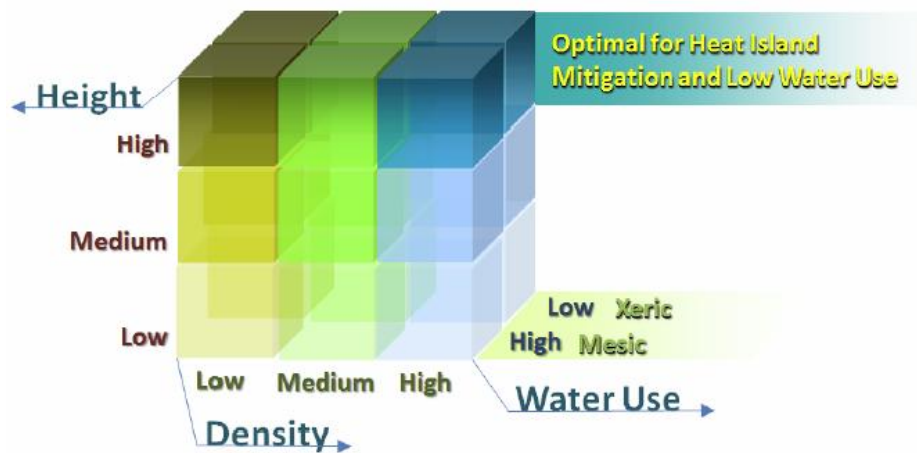


Figure 11. Extended Concept of Green Index

In summary, 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. GIScience can play a key role to combine the works from various academic fields and have reliable data and analyses.

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