

Urban Green Space and Public Health in the U.S.: The role of green policy in improving health outcomes

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Abstract

This study examined the relationship between green space and public health outcomes across six cities in the United States as well as the role of green space policy in promoting health. Green space is suggested to improve health outcomes through various pathways such as facilitating mental rejuvenation, promoting physical activity, and encouraging social connection between community members. Using existing data, I analyzed the correlations between percentage of green space present in six U.S. cities and the prevalence of four different health metrics. I included an adjustment for social factors as confounding variables. I found a consistent negative relationship between the prevalence of poor mental health and percent green space. The results also provided some evidence of additional factors that may be influencing the use of green space and the prevalence of health outcomes within each city. The study as a whole is indicative of the complex dynamic between green policy, urban green spaces, and public health.

Preface

The basis for this research originally stemmed from my passion for nature and environmental conservation as well as my interest in healthcare. I have always loved being in nature and have experienced the immense benefits it provides. I think that as a human race we are losing touch with nature and taking for granted the natural places that allow us to exist. As the world becomes more urbanized and digitally oriented, there will be greater pressure on natural spaces and the respect that is placed on them. Likewise, it will become more challenging to experience nature in its purest form and reap the benefits that green spaces provide us. How will we combat these challenges? I want to determine the relationship between health and nature and develop ways to maintain this relationship through space and time.

I could not have achieved my current level of success without a strong support group: my committee members, each of whom has provided crucial and patient advice and guidance throughout my research process. Thank you all for your unconditional support.

Table of Contents

Introduction	1
Background	2
What is Urban Green Space?.....	3
History of Urban Greenery	4
Policy role in maintaining green space.....	6
Role of Public Green Space in Health Outcomes.....	7
<i>Mental health:</i>	8
<i>Cardiac Outcomes</i>	10
<i>Stroke:</i>	11
<i>Diabetes:</i>	12
Methods	13
Study Cities	13
Measures of Green Space	14
Measures of Public Health Outcomes	14
Measures of Socioeconomic Status	15
Data Manipulation.....	16
Statistical Analysis	16
Results	17
Discussion	24
Implications.....	33
Conclusion	36
Bibliography.....	37

Introduction

Green spaces in urban communities hold high levels of importance in maintaining the human-nature connection as well as in providing many services for urban populations. This is especially important as more people are moving to cities and the overall urban population of the United States is growing. The average annual growth rate in the United States is 0.62% per year, however, some states show growth rates closer to 1.5% per year (Frey, 2018). Many studies have looked at the value of green space in terms of social benefits as well as the ecosystem services provided by green space such as urban canopies and tree cover. However, the social benefits and more specifically the health benefits related to urban green space are less defined.

As urban populations continue to grow, the burden of disease has shifted from infectious diseases to non-communicable chronic diseases such as obesity, cancers and cardiac disease (Amano et al, 2018). Likewise, incidence rates of psychosis, depression and other mental illnesses have increased with growing urbanization (Amano et al, 2018). This suggests that there is a link between the presence of urban green space and the overall health of populations residing in urban centers. Whether through an indirect or direct relationship, the relationship between health and the environment is of increasing importance in maintaining the socioenvironmental quality of urban communities. This is especially true as the expected urban population of the globe is expected to increase by almost 60% by 2050 (Amano et al, 2018). In general, the amount of accessible and beneficial green areas in a city may relate to the sustainability policy implemented into the community. Sustainable cities may focus on energy efficiency, recycling, and other sustainable policies, however, it may be that sustainable cities are likely to promote public green spaces such as trails, parks, street trees, and open space into their policy measures.

Public health outcomes, however, are not always considered when implementing such environmental policies, when maybe they should be.

My thesis looks at the relationship between green space and public health outcomes across major urban centers in the U.S and assesses if these relationships are stronger in communities with more policies related to green space. My hypotheses are that higher levels of green space are correlated with better public health outcomes and that cities with more emphasis placed on green space will experience better health outcomes associated with green space. Overall, I hypothesize that there is a step ladder of outcomes where high quality environmental policy measures lead to improved access to public green space which in turn improves population health among the community.

This paper is an analysis of the relationship between health and green space as well as a general overview of policy measures that influence green space outcomes in urban centers. The specific aims and objectives of this paper include: first, a detailed review of the literature focusing on the health outcomes associated with urban green space and the general influencers of sustainability policy, and second, a data analysis of existing health outcomes and green space measures across six cities to understand the relationship between green space and health outcomes in various locations as well as the relationship between policy and urban green space.

Background

There are many studies on how accessibility to green space impacts health outcomes, mainly through indirect pathways such as increased physical activity and increased social connection, both of which can affect other health outcomes, such as obesity, cardiovascular disease, and depression. The pathways between green space and each health outcome it is associated with is unclear.

What is Urban Green Space?

With an ever increasing movement of people into urban areas, there have been extensive and permanent land use changes in the United States as well as globally (Skold et al, 2018). These land use changes alter the built environment; the collection of human modified places such as schools, homes, roads, workplaces, parks, and public green space (Srinivasan et al, 2003). Public green space refers to parks and reserves, riparian areas, greenways, trails, community gardens, and nature conservation areas (Wolch et al, 2014). The idea of a “livable city” is one that promotes walkability of streets, sociability of public spaces, access to recreation and nature, the journey to work, safety, and health (Southworth, 2016). On the other hand, the idea of a “sustainable city” is one that is planned and managed to promote sustainable living for both present and future generations (Park, 2017). Urban green spaces are a major component of most livable and sustainable cities and thus have great importance both on social factors and ecological factors (Amano et al, 2018). Economic, social, environmental, and ecological factors play into the making of sustainable cities with community wellbeing and urban green space falling under the ecological component of sustainability. Economic factors include utility services, green infrastructure, and local ownership. Environmental components take into account recycling services and water use while social factors include equity and community safety. Ecological factors on the other hand encompass the human nature interaction and urban habitats such as public green space (Park, 2017). Public green space and wildland areas tend to receive a lot of attention for economic and environmental purposes; however, urban green space is a huge component of the ecological scale within “sustainable cities”. Unfortunately, these factors are not always fully addressed in community planning and management (Park, 2017).

Public green space provides many benefits to urban communities both from an environmental and a social perspective. Open space and park environments provide an aesthetic place for social and recreational activities. This encourages physical activity, enhances social ties and promotes physical and mental recuperation (Nutsford et al, DATE). Overall, public green spaces offer s a place for people to enjoy the outdoors and socialize, reducing stress and benefiting urban dwellers (Stone, et al, 2015). Aside from protecting the health of the urban population, green areas support the ecological integrity of nature and provide ecosystem services to the community. These ecosystem services include but are not limited to, “improving air quality, reducing storm water runoff, mitigating the urban heat island effect, and providing habitat for wildlife” (Park et al, 2017). Measures of percent green space and percent tree cover can be used to indicate the amount of quality green space present in a community.

History of Urban Greenery

There is a deep-seeded love for nature across human history, from Native American religion, to current debates on preservation of public lands. Urban green spaces pull out our rooted relationship with nature and use it to improve mental and physical wellbeing.

Preservation of open space ranks among America’s most deeply rooted traditions. Civic green spaces were very important in the establishment of early cities (Griffith et al, 2011). Human settlements often lead to removal, replacement, and alteration of most natural vegetation. This leads to a sense of ownership by groups and individuals who place value of urban spatial patterns higher than the value of vegetative areas (Goldstein et al, 1983). Early planners related the island biogeography theory, which posits that to urban landscape architecture, which is still considered in modern planning. The main focus however, was to maximize wildlife and

vegetation biodiversity. Controversy revolved and still persists around the idea of one large green space in a subdivision or many small green areas. Most times, the earliest green spaces and open space existed as part of the natural environment (Goldstein et al, 1983). There was a lot of difficulty in conceptualizing green space as a necessary component of the built environment.

The environmental movement of the 1970's brought renewed attention to the importance of green space and shifted focus from economic conditions and job creation to environmental issues and health. This included recognition of green space as a necessary part of city infrastructure in order to support livelihoods in urban environments, similar to roads and sewer systems (Griffith et al, 2011). Following the environmental movement, the Greenway Movement emphasized the importance of deliberately planned spaces and encouraged purchase of land for parks and recreational space. This movement was fueled by concerns for both mental and physical health, both of which are supported by urban green space (Griffith et al, 2011).

In recent response to urban sprawl, the Smart Growth Movement has been emphasized by many policy makers and communities. This movement calls for more compact development and more protection of land from development (O' Connell, 2008). This involves new patterns of development and restoration of city centers through walkable neighborhoods, mixed land use and preservation of green space (Griffith et al, 2011). This is in conjunction with the New Urbanism Architectural Movement which seeks to manage growth in a way that will enhance the quality of life for community residents; through the incorporation of green space (Griffith et al, 2011). Through time, community residents and policy makers have realized the importance of green space and more emphasis has been placed on its role in human wellbeing as well as city sustainability.

Policy role in maintaining green space

Cities are very complex entities that have many characteristics that result in their success or failure. The state of the local economy, social involvement, infrastructure and public health often determine the success of a city. However, a city leadership's level of involvement also plays a big role in shaping outcomes (Galenieks, 2017). This is especially true when looking at the relationship between municipal policies and the built environment of a city center (Galenieks, 2017).

Policy plays a very large role in the composition of urban landscapes including urban green space. Local governments in the United States are able to protect or restrict lands from development. This is usually through regulatory land use controls and infrastructure decisions (Schmidt et al, 2009). These actions are often not permanent and are subject to future change. Therefore, local governments have transitioned to more permanent development protections such as conservation easements (Schmidt et al, 2009). Conservation easements have seen a large amount of growth and success in recent decades with \$44 billion of approved funding nationally from 1998-2006 (Schmidt et al, 2009). In 2006, all New Jersey counties approved taxes to fund land acquisition programs. This is an example of how there is increasing demand to use financial mechanisms as a substitute or complement to zoning and other land regulations (Schmidt et al, 2009). Financial policy decisions regarding green space may eventually lead to improved urban green space within city centers. Similarly, landscape structure and vegetation levels are often determined by urban development policies and zoning codes (Kim et al, 2012). There is a strong relationship between regulations and vegetation patterns in urban areas, as land development codes are associated with protection of urban forests in residential areas (Kim et al, 2012). Large lot zoning policies often lead to greater sprawl and forest cover while small lot sizes and large

building footprints often lead to reduced vegetation cover and green space (Kim et al, 2012). In general, land use ordinances as well as the idea of ecologically planned neighborhoods play a big role in land parcel layout as well as urban green space patterns (Kim et al, 2012). However, the resultant trade-off between benefits of urban green space and city management obstacles may constrain the structure of public green areas (Kim et al, 2012).

Policy regarding urban street trees is also of importance when thinking about the relationship between policy measures and urban green space. Street trees are a form of public green space and provide many benefits to city residents. However, the national trend for urban tree cover has shown a decline of approximately 0.27% of city land per year or a loss of about 4 million trees per year in U.S. urban centers. (Galenieks, 2017). Trees are being removed due to budgetary constraints, new street construction, or diseases, resulting in a decline of public green space. Cities have an opportunity to improve their urban tree coverage and percentage of urban green space by implementing more focused and strategic planning and policy measures (Galenieks, 2017). Proactive policy approaches prove to be the most successful in maintaining urban green space. This is primarily reliant on policies, guidelines, dedicated committees, master plans, and more strategic land use patterns (Galenieks, 2017). With these measures in place, a city can be sure to preserve urban green areas as well as urban street trees.

Role of Public Green Space in Health Outcomes

The field of environmental health, or the effect of the physical and social environment on public health, has a great importance when looking at the built environment and its role in public health (Srinivasan, 2003). Public green space has many roles in influencing health outcomes both directly and indirectly. City environments are home to 80% of Americans, with 90% of their

time being spent indoors (Sugiyama et al, 2018). Due to the fact that “health behaviors” are habitual and are stimulated by the environment one lives in, urban environments are a huge determinant of what health behaviors people engage in (Sugiyama et al, 2018). Thus, daily behaviors in urban areas are in response to health outcomes and vices versa (Takemi et al, 2018). Green spaces in urban environments can take on many forms from parks to community gardens and tree lined streets to open space. These spaces can be tailored to fit the urban environments in which they reside. Due to this fact, urban green space may hold substantial ability to enhance population health (Takemi et al, 2018).

In the United States, the leading causes of death are heart disease, respiratory disease, and mental illness, which are all chronic diseases (Sugiyama et al, 2018). Urbanization is linked with a shift in the burden of disease from acute infections to these chronic diseases (Amano et al, 2018). Public green space is part of the urban environment and the linkage between health and the built environment has potential widespread effects on health outcomes such as mental health, cardiac diseases, stroke, and diabetes (Amano et al, 2018).

Mental health: Green spaces in urban environments are correlated to mental health outcomes through many factors. The idea of “biophilia” is the leading concept driving this connection. Biophilia refers to the fact that humans cannot be separated from nature and that contact with nature is the essence for psychological well-being (Zhou, 2010).

There are two pathways that are most influential on the relationship between green space and mental wellbeing. The first pathway deals with the role of nature in relaxation and recuperation, which ultimately lowers stress levels (Nutsford et al, 2013). Higher levels of green space are associated with lower levels of perceived stress (Roe et al, 2013). In a study done by Roe et al, there was a steeper decline in cortisol (a stress hormone) secretions in people exposed

to high levels of stress followed by extended periods of time spent in green areas. Urban green space was determined as an independent predictor of the circadian cortisol cycle, suggesting that natural areas present in urban city centers have the potential to lower cortisol levels and in turn perceived stress of community members. This idea is supported by Ulrich's psycho-evolutionary model where stress reduction occurs from immediate response to visual stimuli provided by natural settings (Roe et al, 2013). Similarly, Kaplan's Restoration Theory states that natural settings are inherently rich in stimuli which invokes involuntary attention, which can lead to restoration from mental fatigue when one is viewing nature (Roe et al, 2013). Things such as natural sounds, lack of urban sounds, and smells influence mood improvement and shape our daily actions and relationship with stress (Irvine et al, 2009). Physical contact with nature may also lead to more pleasure and gratification among users (Zhou, 2010). In general, urban green space promotes mental recuperation through visual and auditory stimuli, physical interactions with the natural world, and through our inherent connection with nature.

The second pathway is through planned and coincidental social interaction that takes place in green space which can improve community ties and community well-being (Nutsford et al, 2013). Urban green space is a place for people to play and socialize, which can benefit urban dwellers (Stone et al, 2015). These spaces facilitate social connection, similar to the way that high rise buildings and crowding lead to disconnection.

Social connection ultimately enhances social ties (Zhou, 2010). In more sustainable cities, with more green space, there are greater levels of social capital. Both bridging and bonding social ties are generated through unplanned and planned social interaction. Places such as community trails, parks, and tree covered areas provide places for these interactions to occur, thus favoring the building of social ties (Cabrera et al, 2015). Aspects of the built environment

have been shown to improve social capital (Cabrera et al, 2015) A study done by Coley et al (1997) found a positive relation between the presence of green public facilities and social ties. A study done by Ewert and Heywood (1991) found that taking part in activities in natural environments had a stimulation effect on social contacts and social cohesion (Maas et al, 2018). Similarly, a study done by Maas et al (2018) found that people living in areas with more green space feel less lonely. In a study done by Zhou et al (2010), it was found that more community engagement and bonding between community members reduced social gaps and improved mental well being leading to a decline in mental illnesses such as depression. In general, there is wide range of evidence suggesting links between green space and social capital, green space and health, and social capital and health.

Cardiac Outcomes: Cardiovascular disease (CVD) is one of the leading causes of morbidity and mortality in U.S. populations (Tomosiunas et al, 2014). Risk factors for CVD include physical inactivity, unhealthy diet, smoking, hypertension, diabetes, and high cholesterol (Kim et al, 2106). Reducing CVD based on these risk factors revolves around controlling high blood pressure and high cholesterol as well as improving physical activity and making lifestyle changes, such as reducing stress (Tomosiunas et al, 2014).

Green space can play a role in mitigating the behavioral and environmental risks of CVD by potentially increasing physical activity, alleviating psychosocial stressors, increasing social interaction, and reducing exposure to air pollution and noise (Kim et al, 2016). In a study done by Kim et al, people residing in greener environments showed a reduced risk for health outcomes such as diabetes and high blood pressure, which eventually reduces the prevalence of cardiac diseases (2016). On a similar note, hyperlipidemia may also be negatively associated with green space. Hyperlipidemia or high blood pressure is a critical risk factor for developing CVD (Kim et

al, 2016). Green spaces may have a role in positively modifying lipid profiles, through physical activities and stress reduction. A similar study done by Kim et al showed that prevalence of high blood pressure decreased as access to parks and green space increased. Similarly, access to green space was associated with the likelihood of an individual to take part in physical activity, which is suggested to be a pathway to cardiac outcomes (Kim et al, 2016).

Stroke: Stroke is one of the leading causes of serious long term disability across the U.S. Over 6.8 million Americans age 20 and above have had at least one stroke in their lifetime (Wilker et al, 2014). This is a big percentage of the population and thus mitigation of risk factors is critical in preventing mortality and morbidity from stroke. Neighborhood-level characteristics have been reported to predict stroke prognosis and mortality. These risk factors are also extremely important post-stroke as recovery from stroke is often challenging. In a study done by Wilker et al (2014), living in an area with more green space was found to be associated with a lower mortality following stroke, even after adjustment for demographic and clinical factors. Similarly, proximity to green space was also found to lower mortality post ischemic stroke (Wilker et al, 2014). In fact, among the cohort used in this study, the lowest quartile of green space showed the highest mortality from stroke. Therefore, green space may exposure may be an independent predictor of survival following stroke.

There are a few mechanisms that can help explain this association. Lower levels of stress, lower levels of urban noises, and lower levels of pollutants are factors that improve prevention of stroke as well as prognosis following stroke (Wilker et al, 2014). Social isolation and depression also are indicator of poor prognosis post stroke. Urban green spaces can provide nature sounds which replaces urban noise, and the trees and plants present within these spaces can improve air quality. Both of these provisions may combat stroke risk factors, by improving mental health and

reducing stress. Public green spaces may also promote social contact which may directly benefit stroke patients by reducing social isolation and depression (Wilker et al, 2014). In general, there are many intermediate mechanisms by which public green space provides which lowers outcomes and mortality of stroke. However, greater research on the relationship between green space and stroke outcomes needs to be studied.

Diabetes: Green space has also been shown to influence the prevalence of diabetes in a community. In a study done by Muller et al (2017), community members in an urban city center in Germany, showed a negative correlation between prevalence of diabetes and distance to green areas. There were lower odds of type II diabetes in greener areas. Distance also played a factor, as people living closer to greener areas showed lower levels of diabetes. Similarly, a lack of green space doubled the odds of type II diabetes in certain neighborhoods within the city, which showed that lower proportions of green space were correlated with higher odds of having diabetes (Muller et al, 2017).

The relationship between diabetes and green space is influenced by two potential pathways. One being that stress is related to type II diabetes. Since green space has been shown to reduce stress levels and increase well-being, there is an indirect pathway to reducing diabetes levels through the presence of urban green space. Physical activity and recreation are a second pathway that potentially may lead to lower levels of diabetes among urban populations. Green spaces such as parks and trails provide a means for physical activity and recreation which in turn improves health and lowers chances of developing type II diabetes (Muller et al, 2017).

Methods

Research was conducted primarily through scholarly literature review related to green space and health as well as statistical analysis of data sets relevant to the project. Census tract data was used to investigate the relationship between presence of urban green space and health outcomes across urban city centers in the United States. The methods involved using two models relating green space and public health outcomes. The first model took into account solely green space and health while the second model took into account the socioeconomic factors that also play a role in health. This was done separately for each of the six cities in this study.

Study Cities

I chose six major cities across the United States, three of which can be labeled as conventional, or lacking advanced sustainability measures, and three of which can be labeled as leading sustainability cities across the nation. I chose these six cities based on sustainability plans already implemented within the city center, as well as a national ranking score indicating the most sustainable cities in the U.S. The sustainable cities of this study include New York, NY, Minneapolis, MN, and Austin, TX. These three cities are above the “average” level of sustainability using the national sustainability rankings and have extensive sustainability plans being carried out based on my analysis of those plans. The conventional cities included in this study are Phoenix, AZ, Tampa, FL, and Pittsburgh, PA. These three cities are below the “average” level of sustainability using the national sustainability rankings.

There are big differences between cities that will be accounted for when analyzing the data. Factors such as socioeconomic status, demography, and education level all vary between the chosen cities of study and were adjusted for in the regression models of the statistical

analysis. One limitation of the methods behind choosing city centers was data availability and the ability to match cities included in the EPA EnviroAtlas, a database encompassing data sets regarding green space and ecosystem services, with cities included in the CDC 500 Cities Project, a database encompassing health data for 500 cities across the United States.

Measures of Green Space

To understand the amount and access to green space in the chosen cities, I employed one measure of green space taken from the EPA EnviroAtlas. The EPA EnviroAtlas organizes environmental data with 1-meter coverage at the census block group level. The greenspace metric I used was percent green space. This particular green space measure relates to land cover characteristics present within each selected city. The land cover measure classifies every 1 km of land within a city into the following categories: trees, forest, grass and herbaceous areas, agriculture, and wetlands. Then to get percent of green space at the census block group, researchers at the EPA utilized one-meter aerial photography through remote sensing to create the land cover data. The block group data had to then be converted to the census tract level to match the format of the corresponding health data. I carried this out by averaging the % green space for all block groups within a census tract separately for all six cities.

Measures of Public Health Outcomes

I selected four health outcomes that have been shown in previous work to be related to green space exposure from the 500 Cities Project, developed by the CDC. The metrics I decided on are prevalence of mental health, diabetes, stroke, and high cholesterol by census tracts of each of my six cities. The mental health variable was characterized as the percentage of people who reported being mentally unwell for 14+ days. Stroke, diabetes, and high blood pressure were

measured as a percentage of adults 18 years and older who had been diagnosed with the condition.

Measures of Socioeconomic Status

Health is a complicated topic as many factors influence community health, especially in urban environments. Therefore, other factors that influence health must be considered when looking at the relationship between green space and health. The socioeconomic factors that I adjusted for in each regression model were percent unemployment, median income, education level measured as the percentage of population with a bachelor's degree, percentage of the population below the poverty line, and the percentage of the population with access to health insurance (Table 1). I pulled these variables from Social Explorer, a database which stores social data at the census tract level. In order to determine the % of the population with a bachelor's degree, I added up the individuals with a bachelor's degree or higher educational attainment, and found a percentage based on the entire population. The same method was used to determine the percent of the population below the poverty line. I used the amount of people under a baseline poverty level divided by the census tract population to get a percentage of people below the poverty line.

Table 1: Socioeconomic Factors present in six city centers across the U.S.

City	Austin, TX	Minneapolis, MN	New York, NY	Tampa, FL	Phoenix, AZ	Pittsburgh, PA
Population	950,715	422,331	8,623,000	385, 430	1,626,000	302,407
Unemployment (%)	8.029	7.55	10.56	10.79	9.32	8.925
Median Income (\$)	54,960.63	67,673.7	56,275.86	52,876.50	58,574.22	52,321.53
Education Level (% w/ Bachelors Degree)	51.41	63.47	85.35	58.95	56.74	65.63
% Below Poverty Line	19.27	14.23	21.85	18.53	18.11	15.46
% w/ access to health insurance	77.31	90.72	84.76	81.97	83.18	91.61

Data for all social indicators was taken at the census tract level from an existing database:

Social Explorer

Data Manipulation

I converted green space data from block group to census tract by converting the code for each block group to census tract. This was done by removing the 12th digit in the FIPS code for block group to give the 11-digit FIPS code for census tract. I then aggregated the green space percentages within each census tract to get the average percent of green space for each census tract across all block groups within each city. I merged the converted green space data with the existing health data as well as the social data by census tract to give a complete data set to be used in the analysis.

Statistical Analysis

To estimate the association between green space and the selected outcomes, I ran linear models for each health outcome for each city in R version 3.3.2 (RStudio, 2015). In the first round of models, the outcomes variables were prevalence of mental health, high cholesterol,

diabetes, and stroke, and the predictor variable was the percentage of green space in each city of study. The unit of analysis for each city's regressions was the census tract. These models showed the unadjusted association between green space and each health outcome. I then did a second model for each city that included socioeconomic status variables (Table 1) as additional predictor variables in each model. Based on variable inflation, the percentage of people under the poverty line in each city was not included in the second model of analysis because it was highly collinear with the other variables. I then compared the associations between green space and each health outcome across the cities, focusing on whether the relationship between green space and public health outcomes were different for the two types of cities in regards to sustainability measures.

Results

The six cities used in this study include Austin, TX., Minneapolis, MN., New York, NY., Tampa, FL., Phoenix, AZ., and Pittsburgh, PA. Out of the six cities, three cities were found to be “sustainable” and three were found to be “conventional”. Austin, Minneapolis, and New York were found to be more sustainable than the remaining three cities, and thus were labeled as sustainable. Tampa, Phoenix, and Pittsburgh were found to be far less sustainable, and thus were labeled as conventional cities.

Across all six cities, average percent green space varied widely. Phoenix, AZ showed the lowest percentage of green space while Austin, TX showed the highest percentage of green space (Table 2). Both Phoenix, AZ and New York, NY had wide ranges of percent green space ranging from 3.3% to 65% in Phoenix and 0.38% to 90% in New York (Table 2) This suggests great variability in the city spatial patterning of green areas. Similarly, average percent green space varied widely across cities. Phoenix showed 17.835% while Tampa showed 59.48% (Table 2).

The level of sustainability of the city was not associated with the percentage of green space present, as both Tampa, FL and Pittsburgh, PA had higher average levels of green space when compared to New York, NY and Minneapolis, MN, both of which are more sustainable cities (Table 2). However, more sustainable cities had better average health outcomes in each individual city. All three sustainable cities showed lower average prevalence for all four health outcomes than the conventional cities of study (Table 2).

Table 2: Characteristics of Green Space and Health across six urban cities in the U.S.

City	Minimum Green Space (%)	Maximum Green Space (%)	Average Green Space (%)	Average Prevalence of Mental Health (%)	Average Prevalence of High Cholesterol (%)	Average Prevalence of Diabetes (%)	Average Prevalence of Stroke (%)
Austin	30.04	88.52	63.65	11.17	30.65	8.26	2.10
New York	0.38	90.0	24.92	12.39	34.35	11.49	3.12
Minneapolis	5.81	70.52	46.50	10.99	29.10	7.15	2.52
Tampa	15.48	82.742	59.48	14.19	34.37	12.78	3.82
Pittsburgh	9.10	85.79	52.09	13.69	35.76	11.03	3.78
Phoenix	3.38	65.09	17.835	14.05	35.456	9.88	2.92

Analysis was done at the census tract level for both percent green space and average % prevalence of each health outcome

The first model of statistical analysis comparing solely percent green space and crude prevalence of health outcomes (unadjusted for socio-economic status), showed no clear pattern between green space and specific health outcomes, however some significant relationships were found. Significant relationships between green space and health outcomes were found in all six cities of study, yet not all four health outcomes were significant in all four cities. For example, in Tampa, FL,- I found mental health, diabetes, and stroke to be negatively associated with percent green space (effect estimates for the association between a one unit increase in % green space is

associated with this much change in prevalence of mental health: -0.062, 95% CI = (-0.115, -0.008)) (diabetes: -0.090, 95% CI = (-0.179, -0.002)) (stroke: -0.04, 95% CI = (-0.075, -0.004)) (Table 3). However, high cholesterol did not show a significant association with percent green space in Tampa (-0.013, 95% CI = (-0.098, 0.072)).

In Austin, TX, a sustainable city of study, mental health was negatively correlated with green space (-0.093, 95% CI = (-0.122, -0.064)) (Table 3) and high cholesterol was positively correlated with green space (0.079, 95% CI = (0.029, 0.131)) (Table 3) in the unadjusted model. When socioeconomic factors were introduced in Model 2, these relationships changed. Mental health was no longer significantly related to green space and the relationship became positive (0.012, 95% CI = (-0.006, 0.031)) (Table 4). High cholesterol remained positively correlated with average % green space (0.089, 95% CI = (0.035, 0.143)) (Table 4). Diabetes became positively correlated with green space in Model 2 (0.56, 95% CI = (0.027, 0.086)) (Table 4). Stroke remained insignificant from Model 1 to Model 2.

In New York, NY, all four health outcomes were significantly associated with green space in Model 1. Mental health was the only health outcome that showed a negative correlation to green space. In Model 2, the results remained consistent with Model 1. All four health metrics remained significantly associated with green space. Mental health was the only negative correlation (-0.03, 95% CI = (-0.037, -0.027)) (Table 4). High cholesterol, diabetes, and stroke were all positively associated with green space (0.067, 95% CI = (0.054, 0.079)) (0.045, 95% CI = (0.037, 0.053)) (0.015, 95% CI = 0.011, 0.017)) (Table 4). The strength of each association declined when transitioning from Model 1 to Model 2.

In Minneapolis, MN, mental health, high cholesterol, and diabetes were significantly associated with green space (Table 3), however, when social variables were accounted for, only

one relationship remained significant. In Model 2, diabetes was positively associated with green space (0.038, 95% CI = (0.005, 0.069)) (Table 4). The direction of this relationship changed from Model 1 to Model 2 in which diabetes was negatively correlated in Model 1. The relationships between the remaining three health metrics, mental health, high cholesterol, and stroke and percent green space were insignificant (Table 4).

In Tampa, FL, a “conventional city” all four health metrics showed a negative relationship with green space in Model 1 (Table 3). Mental health, diabetes, and stroke were significant (Table 3). In Model 2, only mental health remained significantly associated with percent green space, showing a negative relationship (-0.03, 95% CI = (-0.054, -0.009)) (Table 4). The remaining health metrics showed an insignificant relationship with green space in Model 2 (Table 4).

In Pittsburgh, PA, high cholesterol, diabetes, and stroke showed a positive correlation with green space (Table 3). Mental health showed no relationship. When social variables were introduced, these patterns remained, however, the strength of the relationships decreased. In Model 2, all four health metrics, mental health, high cholesterol, diabetes, and stroke, respectively, were significantly positively associated with percent green space (0.018, 95% CI = (0.004, 0.033)) (0.129, 95% CI = (0.093, 0.166)) (0.052, 95% CI = (0.020, 0.085)) (0.019, 95% CI = (0.006, 0.031)) (Table 4).

In Phoenix, AZ, all four health metrics showed negative associations in Model 1. These relationships remained consistent in Model 2, even when social variables were accounted for. The strength of each relationship declined from Model 1 to Model 2. Mental health was negatively associated with green space (-0.03, 95% CI = -0.047, -0.199)) (Table 4). High cholesterol was negatively associated with green space (-0.09, 95% CI = (-0.133, -0.047)) (Table

4). Diabetes and stroke were also negatively related with percent green space (-0.04, 95% CI = (-0.064, -0.018)) (-0.02, 95% CI = (-0.025, -0.010)) (Table 4).

In terms of sustainable vs. conventional cities, there was no clear distinction between relationships found in either type of city or between the two types of cities within Model 2. In the sustainable cities of study, diabetes showed a consistent positive relationship with green space in Austin, New York, and Minneapolis, respectively (0.56, 95% CI = (0.027, 0.086)) (0.045, 95% CI = (0.037, 0.053)) (0.038, 95% CI = 0.005, 0.069)) (Table 4), which is not what I had hypothesized. Mental health showed significant relationships in four out of the six cities, however, the relationship direction and city characterization (sustainable versus not sustainable) did not show a clear pattern. High cholesterol also showed no clear distinction between sustainable and conventional cities and the relationship between green space and high cholesterol within them (Table 3). There is also no clear pattern when looking at the relationship between stroke and green space across the sustainable cities of study versus the conventional cities of study (Table 4).

Model 1

Table 3: Unadjusted model of health outcomes in relation to % green space in six U.S. cities

	Health Outcome							
	Average Prevalence of Poor Mental Health		Average Prevalence of High Cholesterol		Average Prevalence of Diabetes		Average Prevalence of Stroke	
City	Slope	95% CI	Slope	95% CI	Slope	95% CI	Slope	95% CI
Austin, TX	-0.093*	-0.122, -0.064	0.079*	0.029, 0.131	-0.010	-0.044, 0.023	-0.005	-0.015, 0.006
New York, NY	-0.51*	-0.69, -0.33	0.073*	0.059, 0.087	0.052*	0.039, 0.065	0.020*	0.016, 0.025
Minneapolis, MN	-0.079*	-0.121, -0.38	0.094*	0.037, 0.15	-0.003*	-0.044, -0.038	-0.006	-0.023, 0.009
Tampa, FL	-0.062*	-0.115, -0.008	-0.013	-0.098, 0.072	-0.090*	-0.179, -0.002	-0.04*	-0.075, -0.004
Pittsburgh, PA	0.029	-0.001, 0.06	0.168*	0.119, 0.217	0.103*	0.054, 0.152	0.04*	0.0213, 0.06
Phoenix, AZ	-0.16*	-0.197, -0.125	-0.13*	-0.165, -0.085	-0.13*	-0.157, -0.096	-0.043*	-0.053, -0.033

Slope represents the linear association between % green space and % prevalence of each health outcome. Analysis was done at the census tract scale.

* means statistically significant at the $p < 0.05$ level

Model 2

Table 4: Adjusted model of health outcomes in relation to % green space in six U.S. cities

	Health Outcome							
	Average Prevalence of Poor Mental Health		Average Prevalence of High Cholesterol		Average Prevalence of Diabetes		Average Prevalence of Stroke	
City	Slope	95% CI	Slope	95% CI	Slope	95% CI	Slope	95% CI
Austin, TX	0.012	-0.006, 0.031	0.089*	0.035, 0.143	0.56*	0.027, 0.086	0.014	-0.005, 0.024
New York, NY	-0.03*	-0.037, -0.027	0.067*	0.054, 0.079	0.045*	0.037, 0.053	0.015*	0.011, 0.017
Minneapolis, MN	-0.008	-0.030, 0.015	-0.11	0.045, 0.165	0.038*	0.005, 0.069	0.011	-0.002, 0.024
Tampa, FL	-0.03*	-0.054, -0.009	0.033	-0.039, 0.104	-0.035	-0.097, 0.027	-0.017	-0.044, 0.010
Pittsburgh, PA	0.018*	0.004, 0.033	0.129*	0.093, 0.166	0.052*	0.02, 0.085	0.019*	0.006, 0.031
Phoenix, AZ	-0.03*	-0.047, -0.199	-0.09*	-0.133, -0.047	-0.04*	-0.064, -0.018	-0.02*	-0.025, -0.010

Slope represents the linear association between % green space and % prevalence of each health outcome. Analysis was done at the census tract scale.

* means statistically significant at the $p < 0.05$ level

Discussion

Health is a very complicated topic drawing from many disciplines and social factors. When combined with environmental issues and the idea of urban green space, health becomes even more difficult to describe. This study looked at the relationship between green space and health. Although some significant relationships were found, many of the results were inconclusive. My main hypothesis was that an increase in green space would lead to a benefits in health outcomes such as decreased mental health, high cholesterol, stroke, and diabetes. The findings of this study show the complex nature of health as well as the complex relationship between green space and health in urban centers. Some health metrics showed a negative relationship with percent green space, which is consistent with my hypothesis. However, some relationships proved to show a positive correlation between health and green space which is not consistent with my expectations. My hypothesis that increasing green space will lead to improved public health was primarily supported by the results found in Model 1, where no social variables were accounted for. However, there are many studies that show links between health outcomes and socioeconomic status.

The socio-ecological framework recognizes that social determinants and both the physical and natural environment interact, influence behavior and health (McMorris et al, 2014). Health disparities among populations are due to not only environmental conditions, but also the quality of social and physical living conditions. These factors include conditions such as quality of local schools, pollution, poverty, crime levels, and quality of food (Braverman et al, 2011). Access to green space is being increasingly recognized as an environmental justice issue as green space and health disparities are engrained in larger contexts of ethics and human rights, both currently and in the past (Wolch et al, 2014). Distribution of green space disproportionately

benefits predominately white and more affluent communities (Wolch et al, 2014). Differentially distributed green space is primarily due to philosophies of park design, history of land development, and histories of class and ethno-racial inequality as well as state oppression (Wolch et al, 2014). These ideas then accumulate, creating inequalities due to income, ethno-racial characteristics, age, and gender, which also play a large role in the unequal distribution of green space. In a study done by Casey et al (2011), 1528 cities across the United States showed residents of color and lower income living in neighborhoods had less vegetation in their neighborhoods than their wealthier white counterparts. It is clear that socioeconomic variables have influence on green space and the social distribution of environmental goods and resources, such as parks or green neighborhood areas. Likewise, in a study done by Pearce et al (2011), health outcomes were found to vary substantially across neighborhoods. Sociologically disadvantaged places tended to have significantly poorer health (Pearce et al, 2011). There is a connection between both health and socioeconomic variables as well as urban green space and socioeconomic variables. The second set of linear models drew upon this relationship between socioeconomic factors, health and green space.

The goal of Model 2 was to determine if the inclusion of socioeconomic variables such as income, education, poverty, etc. had any impact on the relationship between green space and health across the six cities studied in Model 1. The inclusion of socioeconomic variables did influence the data found in Model 1. Many of the significant relationships found in Model 1 were no longer present in Model 2, or the direction of the relationship shifted from negative to positive, showing that increasing green space leads to increased prevalence of the measured health outcomes. This finding is indicative of the complex nature of health and the relationship health has with natural places.

In terms of specific health outcomes, mental health remained negatively related with green space from Model 1 to Model 2. This relationship held across all cities except for Austin, where the relationship was insignificant, and in Pittsburgh, where the relationship became positive. As green space increased across cities, the prevalence of mental health declined. This relationship held true even when social factors were adjusted for, showing a striking relationship between green space and mental health across urban city centers.

High cholesterol and diabetes were the most common health outcomes, behind prevalence of poor mental health, to show significant relationships with green space in all six cities. This relationship was usually positive, however. Both Minneapolis and Phoenix showed negative correlations between prevalence of diabetes and percent green space as well as prevalence of high cholesterol and green space. Stroke was the least common health outcome to be significantly correlated with green space, present only in New York, Pittsburgh, and Phoenix. The direction of this relationship was not consistent across cities as both positive and negative correlations were present. In general, my hypothesis that more green space in a city leads to improved health outcomes was supported when social variables were not considered. When socioeconomic variables were included, the data as a whole showed no concrete pattern between green space and health outcomes, aside from prevalence of poor mental health.

Both green space and health outcomes are influenced by a wide range of factors including socioeconomic factors, and this study was simply too constrained to include all of the determinants of health and the socioeconomic factors that play a role in public health outcomes. Within the statistical analysis, I did not measure enough socioeconomic variables to draw some conclusions from my data. There are many other determinants of health such as diet, gender, age, engagement with the community and so on. The American Journal of Public Health lists the most

important influencers of health and health outcomes as “quality of experiences in the early years, education and building personal and community resilience, good quality employment and working conditions, having sufficient income to lead a healthy life, healthy environments, and priority public health conditions” (Authors, 2014). This study drew upon a few of these influencers, yet not all of them were considered.

On a similar note, the data sets used were measured at the census tract level and I found few significant relationships at this level of measurement. This forces the consideration of the ecological fallacy as well as the Modifiable Areal Unit Problem. The Modifiable Areal Unit Problem exists when spatial patterns are artificially generated and data that occurs in unique individuals or unique locations is grouped together to create a broader data pool (Ervin, 2018). The aggregate unit of the census tract draws upon group data rather than individual level data. Other than mental health, the relationships between green space and the remaining three measured health metrics at the census tract level did not support my hypothesis and were largely insignificant. These relationships may have been significant if a different aerial unit was used or if the analysis had been done with data on individuals rather than composite measures at the census tract level. The ecological fallacy occurs when a statistic or value found for a group is applied to the one individual of that group (Ervin, 2018). Conclusions made at the census tract level can not be assumed to stand at the individual level. There may be, in fact, a significant relationship between green space and the four health metrics of this study when measured at the individual level rather than at the census tract level, however they cannot be assumed based on the results in this study. This is especially true in regards to health outcomes that rely on mental health pathways and physical activity pathways, as both of these pathways rely on individual behavior choices as.

There are many pathways that have been suggested in regards to health and green space, many of which were explored in this study. Mental health proved to be the only consistent relationship with green space that supported my main hypothesis. With an increase in green space, the average prevalence of mental health declined in four out of the six studied cities. This supports the ideas found in previous studies. Green space may reduce the prevalence of poor mental health through recuperation and relaxation (Nutsford et al, 2013). Nature provides both visual and auditory stimuli which may aid in reduction from mental fatigue among individuals immersed in it (Roe et al, 2013). Similarly, green space in the studied cities may increase social interaction. Urban green spaces facilitate social connection and the building of social ties (Cabrera et al, 2015). In a study done by Zhou et al (2010), more social connection and bonding between community members was associated with a decline in the prevalence of mental illnesses such as depression. My results show a decline in the prevalence of poor mental health with increasing green space in four of the six studied cities which may very easily be due to the suggested pathways in which nature influences mental wellbeing: recuperation and relaxation and facilitation of community engagement.

In regards to the other two cities, Pittsburgh and Austin, the relationship was positive. Nature may not necessarily decrease stress in all groups of individuals. Green space and areas of nature may provide more stress for people rather than reducing it, which may be why this result was opposite of my hypothesis. This could largely be due to the way people perceive the green areas within their community. In general, people harbor complex perceptions of urban green space. On one side, people aspire for the benefits green space provides and appreciate nature (Jim et al, 2012). On the other side, some studies have shown that people associate urban green space with insecurity and crime (Jim et al, 2012). People who find urban green space attractive,

beneficial, and safe tend to use it more and reap the mental health benefits, while people who find urban green space unsafe or unattractive will use it less or accumulate higher stress levels while using it (Jim et al, 2012). This may lead to the inverse relationship between mental health and green space found in Austin and Pittsburgh or it could be due to other reasons. People may also not be using green space to its fullest potential and therefore they may not be reaping the health benefits that green space provides, especially through the pathways associated with mental wellbeing.

Similarly, different metrics of green space may matter more for mental health than what was analyzed in the green space metric used in this data analysis. What people view from their home, office, etc., may have more of an impact on their mental well being than being physically immersed in nature. Visible landscape is believed to affect human beings in many ways, especially in regards to mental health (Velarde et al, 2007). Environmental perception is primarily multi-sensory, and although it is not restricted to vision, vision is the most important sense in terms of yielding information about outdoor environments (Velarde et al, 2007). A significant part of the satisfaction and psychological benefits derived from nature does not require being in it but rather having a view of it (Kaplan, 1992). Nature scenes have been associated with improved well being, reduced anxiety, restorative effects, and reduced stress. There may be more health benefits from noticing and observing nature rather than performing activities in it, in reference to mental health outcomes. (Velarde et al, 2007). My results did not take into account the way in which people were engaging with the green spaces being measured. This may be an important factor in the development of mental health outcomes over time and a main reason why my findings did not show negative relationships between mental health and green space across all six cities.

In terms of high cholesterol and diabetes, many studies have suggested that the physical activity pathway is the main form in which green space impacts these health outcomes. Areas with more green space may facilitate more physical activity by community members, in turn reducing prevalence of high cholesterol and diabetes (Kim et al, 2016) My results do not show a consistent negative relationship between either high cholesterol and green space, or diabetes and stroke. In fact, many of the relationships between these two health outcomes and green space were positive, showing an increase in prevalence as the amount of green space increases. In a study done by Ord et al., the amount of green space tended not to be related with the physical activity levels of urban residents (Ord et al., 2013). This challenges the idea that green space acts as a venue to engage in physical activity and may explain the results found in Model 2. On the same note, aesthetics and accessibility of green space may be playing a role in the way people are using green space in the studied cities, yet it was not measured in this study.

Urban green space is a valuable resource for individual wellbeing as well as community well being, however, there is a critical importance of aesthetics and accessibility of green space in regards to physical activity (Jim et al, 2012). The sole presence of a park or green area may not fully capture the impacts of green space on physical activity or obesity, which influence both high cholesterol and diabetes. Park characteristics or the possible congestion of urban green spaces may play a role in people not wanting to engage in physical activity within green areas (Wolch et al, 2014). In addition, the characteristics of urban green spaces play a large role in the ability of people to use it in ways that promote physical activity. The use of green space is not only determined by it's location in a neighborhood, but also by the presence of bike paths, sidewalks, views, or other factors that promote use and physical activity (Casey et al, 2017). The green space metric used in this study did not look at the specific characteristics and amenities of

each green area, which may be why many of the results showed a positive relationship between green space and high cholesterol as well as green space and diabetes. It may be that the percent green space metric did not look at green spaces that promote physical activity or provide resources for people to engage in activity, which is why my data did not support the physical activity pathway suggested in many studies.

Similar to high cholesterol and diabetes, stroke is a complicated health outcome and its relationship to green space is still unclear. A study done by Orioli et al (2019) showed a possible inverse relationship between green space and stroke. My study found a similar inverse relationship in two out of the six cities I studied, however the remaining results were largely insignificant. There are many other important factors related to stroke risk, other than the surrounding natural environment, such as low socioeconomic status, high levels of noise, and high levels of air pollution (Orioli et al, 2019). My study did not look at the levels of air pollution or noise present in green areas, which may matter more than the physical presence of parks, trees, and greenness. Similarly, many studies find a benefit of green space for patients recovering from stroke, through the three pathways of mental recuperation, social interaction, and physical activity (Wilker et al, 2014). My study looked at prevalence of stroke rather than stroke recovery. It may be that green space is more important for post-stroke recovery and may not be associated with reducing the risk of stroke in individuals residing in urban city centers. With the data I used, I was not able to assess the relationship between stroke recovery and green space, however, it may be that the same pathways between green space and health suggested for mental health and cardiac health hold for stroke recovery. The census data I used in this study also did not provide information on relevant risk factors such as smoking habits, body mass index, diet, alcohol intake, or social engagement behaviors, all of which are important to take

into consideration when looking at stroke risk (Wilker et al, 2014).

My study also looked at the potential differences between sustainable and conventional cities. This relates to my second hypothesis that more sustainable cities will have higher levels of green space and therefore better health outcomes. My results showed no clear pattern of health outcomes within individual cities and no clear pattern of health outcomes between sustainable and conventional cities. The data was overall not consistent with my hypothesis. In Phoenix for example, all four health metrics showed a negative relationship with percent green space. Phoenix was not characterized as a sustainable city. It may be that the relationship between green space and health does not rely on sustainability. Instead, there may be a threshold in which communities experience benefits from green areas. In Phoenix, the range of % green space is large. It may be that some areas within the city have only 3.0% green space. A slight increase in the percentage of green space, above a certain threshold, may cause significant health benefits for individuals. However, New York, a sustainable city, has a larger range for percent green space than Phoenix and the data did not show a similar pattern.

The spatial patterning of a city may also explain the inconsistency of results within the studied sustainable cities as well as between the studied conventional cities. Urban sprawl, or the complex pattern of land use, transportation, and social and economic development, may influence the accessibility and use of green spaces in cities (Frumken, 2002). The extension of cities into rural areas creates a “leapfrog” low-density pattern. This causes places such as parks or other urban green areas to be separated from each other. Separation of amenities introduces a greater need for cars by urban dwelling residents (Frumken, 2002). Studies show that low-density patterns are associated with less walking and other forms of physical activity which threatens health (Frumken, 2002). Cities, sustainable or conventional, that showed positive

relationships between health and green space, may be experiencing increased negative health outcomes due to increased urban sprawl. This may be overpowering the effects created by urban green areas. Similarly, sustainability measures prioritized in each city may not be related to urban sprawl or even green space. Therefore, the sustainability level of each city may not relate to the amount of green space, thus I did not see any clear patterns across cities or within city type.

Implications

As discussed above, further research is needed to clarify the complicated associations between green space, public health, and social influences. What methods relating to city planning and environmental policy best encourage physical activity, promote mental well-being, strengthen community ties, and decrease the influence of socioeconomic factors on health? Although this study focused solely on percent green space and four specific health metrics, it may be likely that other measures of green space have more advantageous impacts on health outcomes. It also is likely that there are many more significant outside factors that play a role in the use and benefits of urban green space.

In terms of future interventions, questions regarding policy, city design, neighborhood segregation, spatial patterning, food accessibility, and green space qualities need to be answered. In terms of city design, it may be that street network density, connectivity, and configuration impact rates of obesity, diabetes, high blood pressure, heart disease, and asthma (NewsRx, 2014). A study done by CU Denver (2014) found that increased intersection density was linked to reductions in obesity and diabetes rates. Similarly, the study found that there may be a correlation between wider streets and increased obesity and diabetes rates. Wider streets may be indicative of an inferior pedestrian environment (NewsRX, 2014). Walkable cities, or cities that

contain neighborhoods with shorter, more connected streets and with greater access to a variety of shops and amenities, may positively influence health outcomes (Maria et al, 2016). More walkable cities may lend themselves to increased walking, which increases the physical activity of community members, which is a suggested pathway to health (Maria et al, 2016). Studies have found that moving to an area with higher walkability is associated with a lower risk of hypertension. A study of adults in Australia found that neighborhood walkability, access to public transit stops, and having a variety of local destinations were predictors of whether participants walked for transportation (Knuiman et al, 2014). Things such as neighborhood amenities, street connectivity, and population density are important determinants of physical activity (Maria et al, 2016). The role of city design on health should be considered when planning cities and creating environmental design plans, especially through land use planning and zoning instruments.

The food environment of cities may also be associated with health outcomes present within communities. Cities with more fast food restaurants may have higher diabetes rates (NewsRX, 2014). Similarly, a high density of convenience stores across a city may be correlated with higher rates of obesity, as well as diabetes (NewsRX, 2014). Food retail in general is a major aspect of the built environment that has been under examined (Mah et al, 2016). Policies related to food environment could address things such as geographic access to food, consumer nutrition environments, and food and consumer information (Mah et al, 2016). Both public health officials and policymakers should play an important role in making the linkages between health and other policy goals explicit.

In general, longitudinal studies are needed to understand the effects of policy implementation in general and as related to green space, as well as the movement and migration

of people within a community. It may be that healthier people move into greener neighborhoods and that green space actually has a minimal impact on health. Similarly, it may be that people in cities do not use the green space that is provided and are not exposed to it in their home environment. Instead, they might be traveling to mountain ranges, ski areas, and other natural areas that are outside the city to recreate. More studies are needed to clarify how and where people use green space so that it can be implemented in ways that maximize its use by community members. More studies are also needed to determine which aspects of green space influence health the most. Studies show links between green space and reduced asthma due to the ability of trees to remove air pollutants (Horwitz et al, 2011), however, some studies also show increased asthma due to pollen. Studies also show that the ecological character and condition of wetlands is linked to health (Horwitz et al, 2011). Ecosystem services provided by green spaces may have more of an impact on health than the physical construction of urban green spaces but need to be understood more in depth.

More research paired with use of smaller spatial scale data and long-term data could lead to a better understanding of the relationship between green space and health and the impact it has on individuals. Smaller scale data allows for analysis at the individual or neighborhood level which may show more significant associations between green space and health outcomes among individuals in close proximity to parks, open space, etc. On the same note, cities should collect baseline data as well as data after implementation of green space policy measures in order to evaluate successes. This will provide a better picture of how and why people use and benefit from green space.

Conclusion

The association between urban green space and public health is a very complex relationship. From the beginning of human time, we have maintained a complex and dynamic relationship with the natural world. This idea is becoming especially important as urban populations across the globe are growing and natural places are being replaced with housing, highways, and social infrastructure. The impacts of creating useable and successful green areas in cities has the potential to influence health immensely. More research is needed to determine the roles of many outside factors that influence health and are related to the spatial patterning of green space exposure such as urban sprawl, food swamps, and city design. However, there are many studies suggesting that there are pathways between green space and health that ultimately reduce the prevalence of certain health outcomes.

This study has discussed the relationship between average percent green space and four different health outcomes: mental health, high cholesterol, diabetes, and stroke. The results show a significant negative relationship between mental health and green space, which deserves more in depth research and discussion. The data also shows that there are many outside factors which impact both health and the quality of urban green spaces. As is true for most public health outcomes, the impacts of green space and city design do not fall equally across the population, with socially disadvantaged groups being segregated or provided with lower quality areas. This aspect of green space and urban design should be taken into special consideration.

As we address public health concerns, further studies on the relationship between green space and health are needed. These studies may inform policymakers so that they can make policy recommendations that maintain the integrity of urban green space and community health outcomes for all populations and across future generations.

Bibliography

- Amano, T., Butt, I., & Peh, K. (2018). The importance of green spaces to public health: a multi-continental analysis. *Ecological Applications*, 28. 1472-1480. Retrieved from <https://esajournals-onlinelibrary-wiley-com.colorado.idm.oclc.org/doi/abs/10.1002/eap.1748>
- Anderson-Skold, Y., Klingberg, J., Gunnarsson, B., et al. (2018). A framework for assessing urban greenery effects and valuing its ecosystem services. *Journal of Environmental Management*, 205. 274-285. <https://doi.org/10.1016/j.jenvman.2017.09.071>
- Annerstedt van der Bosch, M., Mudu, P., & Uscila, V. (2015). Development of an urban green space indicator and the public health rationale. *Scandinavian Journal of Public Health*, 44, 159-167. <https://doi-org.colorado.idm.oclc.org/10.1177/1403494815615444>
- Boulder Parks and Recreation. (2014). *Boulder Parks and Recreation Department Master Plan*. Retrieved from https://www-static.bouldercolorado.gov/docs/MP_Layout_V7.8_Final_sm-1-201404020833.pdf?_ga=2.242747778.1848445389.1538061763-2130131083.1451575413
- Braverman, P., Kumanyika, S., Fielding, J., LaVeist, T., Borrell, L., Mandersheid, R. & Troutman, A. (2011). Health Disparities and Health Equity: The Issue Is Justice. *American Journal of Public Health*, 101, 149-155. doi:10.2105/AJPH.2010.300062
- Cabrera, J. & Najarian, J. (2015). How the Built Environment Shapes Spatial Bridging Ties and Social Capital. *Environment and Behavior*, 47(3), 239-267. DOI: 10.1177/0013916513500275
- Cairns, M., Cox, C., Zambrana, J., et al. (2017). Building multi country collaboration on watershed management: lessons on linking environment and public health from the Western Balkans. *Rev Environ Health*, 32, 15-22. Retrieved from...
- Casey, J., James, P., Cushing, L., Jesdale, B. & Morello-Frosch, R. (2017). Race, Ethnicity, Income Concentration and 10-Year Change in Urban Greenness in the United States. *Environmental Research and Public Health*, 14, 1-15. doi:10.3390/ijerph14121546
- Centers for Disease Control and Prevention (2014). *500 Cities Project: Local data for better health* [Data File]. Retrieved from <https://www.cdc.gov/500cities/>
- Chiu, M., Rezai, M., Maclagan, L., Austin, P., & Shah, B. (2016). Moving to a Highly Walkable Neighborhood and Incidence of Hypertension: A Propensity-Score Matched Cohort Study. *Environmental Health*

Perspectives, 124, 754.

- Ciciea, C. & Pirlogea, C. (2011). Green Spaces and Public Health in Urban Areas. *Theoretical and Empirical Researches in Urban Management*, 6, 83-92. Retrieved from https://www.jstor.org/stable/24873277?seq=1#metadata_info_tab_contents
- Cobbinah, P. & Darkwah, R. (2016). African Urbanism: the geography of Urban Greenery. *Urban Forum*, 27, 149-165. DOI 10.1007/s12132-016-9274-z
- Frunkin, H. (2002). Urban Sprawl and Public Health. *Public Health Reports*, 117.
- Galenieks, A. (2017). Importance of urban street tree policies: A Comparison of neighbouring Southern California cities. *Urban Forestry & Urban Greening*, 22, 105-110. <https://doi.org/10.1016/j.ufug.2017.02.004>
- Goldstein, E. L., Gross, M., & Degraaf, R. M. (1982/1983). Wildlife and greenspace planning in medium-scale residential developments. *Urban Ecology*, 7, 201–214.
- Horwitz, P. & Finlayson, M. (2011). Wetlands as Settings for Human Health: Incorporation Ecosystem Services and Health Impact Assessment into Water Resource Management. *Bioscience*, 61, 678-688. Retrieved from www.biosciencemag.org
- Irvine, K., Devine-Wright, P., Payne, S., Fuller, R., Painter, B., & Gaston., K.(2009) Green space, soundscape and urban sustainability: an interdisciplinary, empirical study. *Local Environment*, 14:2, 155-172, DOI: 10.1080/13549830802522061
- Jim, C.Y. & Shan, X. (2013). Socioeconomic effect on perception of urban green spaces in Guangzhou, China. *Cities*, 31, 123-131. <http://dx.doi.org/10.1016/j.cities.2012.06.017>
- Keeley, M. (2011) The Green Area Ratio: an urban site sustainability metric. *Journal of Environmental Planning and Management*, 54:7, 937-958, DOI: 10.1080/09640568.2010.547681
- Kim, H., Min, J., Kim, H, & Min, K. (2016). Parks and Green Areas are Associated with Decreased Risk for Hyperlipidemia. *International Journal of Environmental Research and Public Health*, 13, 1-11. doi:10.3390/ijerph13121205
- Kim, J. & Zhou, X. (2012). Landscape structure, zoning ordinance, and topography in hillside residential neighborhoods: A case study of Morgantown, WV. *Landscape and Urban Planning*, 108, 28-38. <http://dx.doi.org/10.1016/j.landurbplan.2012.07.011>

- Maas, J., M.E. Van Dillen, S., Vergeij, R. & Groenewegen, P. (2009). Social contacts as possible mechanism behind the relation between green space and health. *Health and Place*, 15, 586-595. doi:10.1016/j.healthplace.2008.09.006
- Maas, J., Verheij, R., Groenewegen, P., Vries, S. & Spreeuwenberg, P. (2016). Green space, urbanity, and health: how strong is the relation. *Epidemiol Community Health*, 2006, 587-592. doi: 10.1136/jech.2005.043125
- McMorris, O., Villeneuve, P., Su, J. & Jerrett, M. (2014). Urban greenness and physical activity in a national survey of Canadians. *Environmental Research*, 137, 94-100. <http://dx.doi.org/10.1016/j.envres.2014.11.010>
- Mincey, S., Schmitt-Harsh, M., & Thureau, R. (2013). Zoning, land use, and urban tree canopy cover: The importance of scale. *Urban Forestry and Urban Greening*, 12, 191-199. <http://dx.doi.org/10.1016/j.ufug.2012.12.005>
- Muller, G., Harhoff, R., Rahe, C. & Berger, K. (2017). Inner city green space and its association with body mass index and prevalent type 2 diabetes: a cross sectional study in an urban German city. *BMJ Open*, 8, 1-8, doi:10.1136/bmjopen-2017-019062
- NewsRx Health (2014). CU Denver study shows links between city and design and health (2014). NewsRx Health, 19
- Nutsford, D., Pearson, A.L. & Kingham, S. (2013). An ecological study investigating the association between access to urban green space and mental health. *Public Health*, 127, 1005-1011. <http://dx.doi.org/10.1016/j.puhe.2013.08.016>
- O'Connell, L. (2008). Exploring the social roots of smart growth policy adoption by cities. *Social Science Quarterly*, 89, 1356-1372. <https://doi-org.colorado.idm.oclc.org/10.1111/j.1540-6237.2008.00581.x>
- Ord, K., Mitchell, R., Pearce, J. (2013). Is level of neighbourhood green soace associated with physical activity in green space? *International Journal of Behavioral Nutrition and Physical Activity*, 10, 127. Retrieved from <http://www.ijbnpa.org/content/10/1/127>
- Park, S. (2017). A Preliminary Study on Connectivity and Perceived Values of Community Green Spaces. *Sustainability*, 9, 692. doi:10.3390/su9050692
- Pearce, J., Richardson, E., Mitchell, R. & Shortt, N. (2011). Environmental justice and health: A study of multiple environmental deprivation and geographical inequalities in health in New Zealand. *Social Science and Medicine*, 73, 410-420. doi:10.1016/j.socscimed.2011.05.039

- Roe, J., Thompson, C., Aspinall, P., Brewer, M., Duff, E., Miller, D., Mitchell, R. & Clow, A. Green Space and Stress: Evidence from Cortisol Measures in Deprived Urban Communities. *Environmental Research and Public Health*, 10, 4087-4103. Retrieved from www.mdpi.com/journal/ijerph ‘
- RStudio Team (2015). RStudio: Integrated Development for R. RStudio, Inc., Boston, MA
URL <http://www.rstudio.com/>
- Schmidt, S & Paulsen, K. (2009). Is Open-Space Preservation a Form of Exclusionary Zoning? The Evolution of Municipal Open-Space Policies in New Jersey. *Urban Affairs Review*, 45, 92-118.
10.1177/1078087408331122
- Social Explorer (2013-2018). [Data File] Retrieved from <https://www.socialexplorer.com>
- Southworth, M. (2016). Learning to make liveable cities. *Journal of Urban Design*, 21:5, 570-573.
<https://doi.org/10.1080/13574809.2016.1220152>
- Srinivasan, S., O’Fallon, L., & Dearry, A. (2003). Creating Health Communities, Healthy Homes, Healthy People: Initiating a Research Agenda on the Build Environment and Public Health. *American Journal of Public Health*, 93, 1446-1450. Retrieved from....
- Stone, A. E., Wu, J., & Alig, R. (2015). Urban Green Space and Vibrant Communities: Exploring the linkage in the Portland-Vancouver Area. *United States Department of Agriculture*.
- Sugiyama, T., Carvera, A., Koohsarib, J., & Veitchd, J. (2018). Advantages of public green spaces in enhancing population health. *Landscape and Urban Planning*, 178, 12-17.
<https://doi.org/10.1016/j.landurbplan.2018.05.019>
- Velarde, M.D., Fry, G. & Tveit, M. (2007). Health effects of viewing landscapes – Landscape types in environmental psychology. *Urban Forestry & Urban Greening*, 6, 199-212.
doi:10.1016/j.ufug.2007.07.001
- Wilker, E., Wu, C., McNeely, E., Mostofsky, E., Spengler, J., Wellenius, G. & Mittleman, M. (2014). Green space and mortality following ischemic stroke. *Environmental Research*, 133, 42-48.
<http://dx.doi.org/10.1016/j.envres.2014.05.005>
- Wolch, J., Byrne, J., & Newell, J. (2014). Urban green space, public health, and environmental justice: The challenge of making cities ‘just green enough’. *Landscape and Urban Planning*, 125, 234-244.
<http://dx.doi.org/10.1016/j.landurbplan.2014.01.017>

United States Environmental Protection Agency. (2018). *EnviroAtlas*. [Data File] Retrieved from <https://www.epa.gov/enviroatlas>

Zhou, X. (2010). Social benefits of urban green space: A conceptual framework of valuation and accessibility measurements. *Management of Environmental Quality: An International Journal*, 23(2), 173-189. DOI 10.1108/14777831211204921