ATLANTA'S URBAN ECOSYSTEM SERVICES

A NEIGHBORHOOD COMPARISON ANALYSIS

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May 2018

Atlanta's Urban Ecosystem Services: A Neighborhood Comparison Analysis

Calculating Storm Water Runoff and PM10 Filtration

At the Parcel Level in Northwest Atlanta

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An applied Research Paper to the Faculty of the School of City and Regional Planning

Georgia Institute of Technology

In Partial Fulfillment of the Requirements for the Degree

Masters of City and Regional Planning

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April 30th, 2018

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1. Introduction

The City of Atlanta is at the heart of one of the fastest growing metropolitan regions in the United States, with a projected population of 7.9 million residents by 2040 (ARC, 2015). This growth comes with many opportunities, as well as significant challenges. Studies have shown that the latest waves of development have been unprecedentedly rapid and came at the expense of critically important, natural resources. These features form the identity of the city itself and provide critical functions for city residents and require new protections from development pressures (Lo and Yang, 2002) (Hartshorn and Ihlanfeldt, 1993). As noted in the "State of Atlanta Greenspace" report, the city has implemented regulations to protect green spaces, flood plains, and urban tree canopy but environmental resources could benefit from improved stewardship as these assets have been increasingly damaged by development (Project Green Space, 2009). However, there has been recognition and coordination by city agencies to implement policies aimed at providing, protecting, or restoring these assets as evidenced by a review of the city's documents guiding development and resource management.

At the same time, the city has also become increasingly prescient of, and active against, the threat posed by climate change. It completed its climate action plan in 2015, is one of 211 cities to locally implement the Paris Accord, and clinched the last spot in the 100 Resilient Cities network culminating in a Resilience Plan released in 2017. Additionally, measures such as the recent TSPLOST ballet initiative focusing on encouraging multi-model transportation improvements, active transportation networks, and strengthening the link between development and existing transportation infrastructure shows the cities commitment to mitigating CO2 emissions and taking steps towards realistically considering the need for adaptation.

As promising as these achievements are, they fall short of explicitly reflecting the concepts and values essential to changing the relationship between nature and people in the urban context. Urban greenspace and green infrastructure is often understated, understudied, and therefore, undervalued in the services it provides to city residents in the form of ecosystem services. Studies of ecosystem services grew out of forestry science and ecology and has only recently been applied to nature in the context of cities but there have been promising findings regarding the ability of small natural areas in urban areas to provide multifaceted advantages to urbanites.

Increasingly, it has become understood that urban green spaces are not only beholden to bio-physical variables, they are also indelibly tied to the socio-economic landscapes they are embedded in and this factors into best practices for their management (Elmqvist et al. 2004). Atlanta's stated goals of effectively managing its natural resources, fostering greater coordination between city agencies, and increasing its resilient capacity represent an opportunity, as an urban ecosystem service framework could potentially satisfy these goals simultaneously while changing public attitudes towards environmental stewardship (Derkzen et al. 2017). Many studies have used different methods to quantify ecosystem services. The aim of this work is to perform a literature review exploring these methods and then apply a methodology to identify and map regulating ecosystem service provision in the City of Atlanta. Specifically, this will focus on services related to surface runoff mitigation and air purification. The main research question to be answered: Which neighborhoods in my study area are the most productive in terms of regulating ecosystem service provision? How can local decision frameworks regarding land use and development leverage these areas in coming decades?

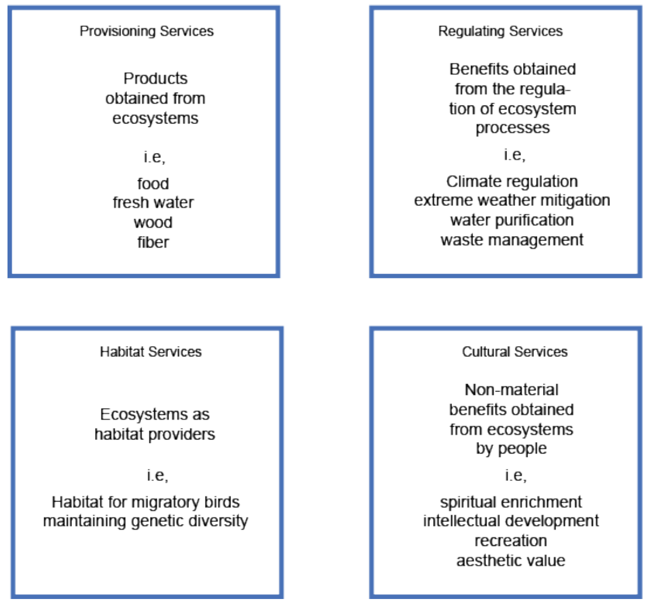
2. Literature Review

2.1 What are Urban Ecosystem services?

In their work, Pickett et al. 2001 defines urban ecosystems as "those in which people live at high densities, or where the built infrastructure covers a large proportion of the land surface" (Pickett et al. 2001). Furthermore, people are increasingly likely to live in these areas as the rate of urbanization increases across the globe, many developed nations already feature urbanized populations in upwards of 80 percent (Worldbank, 2017). Due to the dynamics of ecosystems generally, urban ecosystems often extend far beyond the legal boundaries of cities themselves. For example, urban ecosystems encompass the watersheds, air sheds, and far-flung food networks that sustain urban habitability. This has influenced their study as systematic and comprehensive understanding is essential to promote effective management from a decision-making perspective. Typically, ecosystems are conceptualized in planning through the normative design of environmental amenities for urban residents while ecologists focus more on accounting for specific geochemical budgets of urban metropolises (Sukopp, 1998). As interdisciplinary approaches are encouraged in the field of urban planning, quantitative ecological practices offer a means to bolster normative arguments about the role of ecology in the urban planning process (McIntyre, Knowles-Yanez, & Hope, 2000).

Just as ecosystem services narrowly interpret general ecological functions through their relevancy to human activities, urban ecosystem services filter this subset to those services that occur around, or directly benefit, those within our urban environments (Gómez-Baggethun, 2013). Generally, ecosystem services have been defined in three broad ways. According to Costanza et al. (1997), they are: "The benefits human populations derive, directly or indirectly from ecosystem functions." The Millennium Ecosystem Assessment (MA, 2005) describes them as: "The benefits people obtain from ecosystems" (MA, 2005). Daily (2007) describes them as: "The conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life." These definitions underpin a debate in the contested realm of ecosystem service study, with some arguing that they detrimentally frame the human-nature relationship as an exploitative endeavor while others hold that these conceptions reconnect urban society to nature as it is increasingly conceptualized (Schroter et al., 2014).

According to TEEB (2010), and seen in Figure 1, these Ecosystem services can be broken into 4 main divisions:



2.2 Focus of Study: Regulating Ecosystem Services

Regulating ecosystem services are primarily contributed by green infrastructure embedded within cities. A working definition of green infrastructure is supplied by Naumann et al. (2011) whose authors stated;

"Green infrastructure is the network of natural and semi-natural areas, features and green spaces in rural and urban, terrestrial, freshwater, coastal and marine areas, which together enhance ecosystem health and resilience, contribute to biodiversity conservation and benefit human populations through the maintenance and enhancement of ecosystem services…" (Naumann et al., 2011)

These include features (such as parks, public green space, allotments, green corridors, street trees, urban forests, roof/vertical gardens, and private gardens) that are not constrained to a specific land cover/type and therefore are heterogeneous in distribution, form, and size (Cameron et al., 2012).

Additionally, this characteristic means that the prevalence or dearth of equitable green infrastructure planning can reproduce disparities seen in other aspects of city management (Jennings and Gaither, 2015). Through effective spatial planning, multi-functional ecosystem services can be leveraged from green infrastructure to remedy these disparities (Meerow & Newell, 2017).

In the context of cities, regulating ecosystem service provision has been identified in the form of the benefits found in Table 1.

Regulating Service	Benefit	Indicators	Notable References
Water flow regulation and runoff mitigation	Percolation of water by soil and vegetation	Soil infiltration capacity[1]	(Booth & Jackson, 1998; J. B. Ellis & Marsalek, 1996; Villarreal & Bengtsson, 2005)[2]
Urban temperature regulation	Urban vegetation providing shade, blocking winds, and creating humidity	Leaf Area Index [1]	(Alexandri & Jones, 2008; Robitu, Musy, Inard, & Groleau, 2006)[2]
Noise reduction	Reduction of traffic noise through deflection/dispersion of sound waves	Leaf area (m^2) and distance to roads (m); noise reduction [dB(A)]/vegetation unit (m)[1]	(Aylor, 1972; Ishii, 1994; Kragh, 1981; Tyagi, Kumar, & Jain, 2006)[2]
Air purification	Filtering and fixation of gases	PM_{10} µm pollutant flux ($g/cm^2/s$) multiplied by tree cover (m^2)[1]	(Chaparro & Terrasdas, 2009; Escobedo, Kroeger, & Wagner, 2011; Escobedo & Nowak, 2009; C.Y. Jim & Chen, 2009)[2]
Moderation of extreme climate events	Physical barrio and absorption of kinetic energy	Cover density of vegetation barriers separating built areas from the sea[1]	(R. Costanza et al., n.d.; Danielsen et al., 2005)[2]
Wastewater treatment	Removal and breakdown of nutrients	P,K,Mg and Ca in mg/kg compared to given soil and water quality standards [1]	(Lee & Scholz, 2007; Vauramo & Setälä, 2010)[2]

Table edited based on Jong, 2015[1] and Elmqvist et al 2004[2]

2.2.1 Mechanism of Provision: Air Purification (PM_{10} Filtration)

There is a significant epidemiological connection between PM10 particulate pollution and negative cardiovascular and cardiopulmonary health outcomes, as demonstrated in Englert's review in 2004 (Englert, 2004). Generally, these relate to elevated mortality and hospital admission rates seen where concentrations are elevated in the urban environment. The dynamics that underpin the relationship are a matter of increased study and gaps exist around the specific mechanisms of PM10 impact. However, literature has grown around the role that socioeconomic factors can play in vulnerability of severe health impacts. With relevancy to city planning decision making, particularly these impacts have been identified as effecting the elderly, infants, and persons already suffering from chronic cardiopulmonary diseases, increasing the likelihood that they experience elevated rates of morbidity and mortality (Pope A.C 3rd, 2000).

Medina-Ramon created a 36 city study of which Atlanta was a participant (Medina-Ramon et al., 2006) Statistical data on air pollution (Ozone and PM10) and hospital admissions, revealed clear relationships in the cities participating in the analysis. In Atlanta, they found significant increased risks for chronic obstructive pulmonary disease (COPD) and pneumonia in connection with high ambient levels of these two pollutants. Additionally, they reveal the seasonal nature of these impacts which are most pronounced during the warmer months of summer, although the effect was generally seen across the whole year. Interestingly, the article makes the connection that this elevation may not be due to increased ambient concentrations, but rather, increased exposure as individuals spend more time outdoors.

Numerous processes determine how urban air pollution is purified but studies have shown that green infrastructure, particularly urban tree canopies, contribute through dry deposition of gases and particulate matter onto surfaces as these materials are fixed to the plants surface from the air (Bolund &

Hunhammer, 1999). This dry deposition is facilitated by gravity sedimentation or impaction of pollutants onto leaf surfaces. Variables such as plant species, canopy area, pollutant type, and local meteorological conditions factor into the rate of this deposition and can change how effectively urban trees provide these services (Fowler, 2002). Additionally, these rates can vary based on tree type (coniferous or deciduous). Once particles are deposited they can sometimes be washed off by rainfall, thereby transferring to soils, or re-suspended back into the air. This re-suspension displays a large degree of variability based on meteorological conditions. Studies show this variation to be anywhere from 10-90% resuspension with common values of 50% (Jim & Chen, 2008).

2.2.2 Mechanism of Provision: Storm water Runoff Mitigation

The work of Rose and Peters (2001) compares streamflow characteristics for the urban catchments of Atlanta in comparison to rural catchments in the same watershed. In their work, they presented 5 primary mechanisms by which development and urbanization can impact catchment flow regimes, presenting as:

- More rain contributions to surface runoff
- Decreased lag time between precipitation events and runoff/more responsive catchment areas
- Larger peak flow magnitudes in urban catchments
- Low flows from reduced groundwater storage recharge

By comparing Atlanta's urban catchments with its rural counter parts over a significant historical period, they identified differences in their statistical analysis that show evidence of these previously noted effects. Takeaways from their analysis are in line with insights from general reviews of urban hydrology and the effects of urbanization on water sheds (Shuster et al., 2005). Specifically, they found that there is as much as a 30-100% increase in peak flows for Atlanta's urban catchments in comparison to its rural counterparts. In addition, base flows in Atlanta's urban water sheds are as much as 25-40% lower than in the less urbanized catchment areas.

According to literature, Runoff mitigation and storm water management ES is provided by 3 dominant processes. These are the urban tree canopies ability to intercept and reduce the amount of water reaching impervious or pervious surfaces, the ability of urban vegetation and green infrastructure to slow water across its surface facilitating the infiltration of water into soils, and evapotranspiration of diverted water from vegetation (Whitford et al., 2001; Cameron et al., 2012; Xiao & McPherson, 2002). As areas urbanize, the amount of soil becoming sealed by impervious surfaces increases. Whether it be buildings, roads, or other city infrastructure, this prevents water from infiltrating into soil which contributes to increased storm water during rain events (Prokop, 2011). Like other ecosystem services, provision differs based on what type of green infrastructure is providing the service. Large evergreen trees have been shown to contribute through interception while grasses contribute primarily by infiltration (Jong 2015). Studies have shown that these effects reduce and attenuate storm water runoff, lowering the risk of urban floods and improve the urban water balance among other advantages (Bengtsson et al., 2005; Mentens et al., 2006; VanWoert et al., 2005). However, soils integral role in ecosystem service provision is also reflected in the sharp reduction of numerous service provisions when it is sealed and mismanaged (Artmann, 2014).

2.3 How can ecosystem services contribute to urban adaptation and resilience planning?

Urban resilience has seen increasing attention in recent decades as climate change impacts have moved from the realm of projected future to everyday lived experience. Starting from the 1st Intergovernmental Panel on Climate Change (IPCC) report and culminating in the 5th edition, the evidence and certainty around anthropogenic climate change and global warming trends has moved from increased probability to high confidence and near certainty from a scientific standpoint (Bindoff et al., 2013).

As noted in the 4th National Climate Assessment:

"Stabilizing global mean temperatures below 3.6°F (2°C) or lower relative to preindustrial levels require significant reductions in net global CO_2 emissions relative to present-day values before 2040 and likely requires net emissions to become zero or possibly negative later in the century. Accounting for the temperature effects of non CO_2 species, cumulative CO_2 emissions are required to stay below about 800 GtC in order to provide a two-thirds likelihood of preventing 3.6°F (2°C) of warming, meaning approximately 230 GtC more could be emitted globally. Assuming global emissions follow the range between RCP8.5 and RCP4.5 scenarios, emissions could continue for approximately two decades before this cumulative carbon threshold is exceeded. (High Confidence)" (NCA4, 2017)

The NCA4 report provides context for how climate change is influencing changes in the southeast where Atlanta is located. Specifically, the report finds that while the annual mean precipitation for the southeast is projected to decrease, there will be an increase in the intensity of the precipitation events that do occur. It attributes this prediction on the well-established physical law known as the Clausius-Clapeyron relationship, which explains a 6-7% increase in precipitation intensity with every Celsius degree of surface temperature increase. However, there is still uncertainty as to the degree that this relationship translates to changes in precipitation at the global scale (KNMI, N.B.D). While study results across the country show a mix of increasing and decreasing 20-year return values for seasonal maximum 1 day precipitation totals over the 1948-2015 period, the southeast has displayed a marked increase (Easterling et al., 2017). These effects do not stop at precipitation, there is also evidence that climate change will influence detrimental changes to air quality. IPCC reports suggest that regional air quality will respond to global climate change and that the two systems are coupled (IPCC, 2001). Some have put forward that in 30 years, the number of red alert days (days in which it is too unhealthy to stay outside for prolonged periods), could double in Atlanta due to increases in smog-producing precursor pollutants (Curry, 2008).

2.3.1 Working Definition of Resilience

Much like ecosystem services, urban resilience is a contested topic of study. As it has grown in popularity, numerous permutations of form and focus have displayed in its application. In literature, its origins have been credited with the seminal work of ecologist C.S Holling. As an ecologist, he used the concept to evolve our understanding of ecological systems from the antiquated notion that they were ecosystems were static systems, to the more informed conception that they are continually dynamic, fluidly moving from one stable state to another through the interactions of matter and energy in their closed systems. He conceptualized resilience primarily as the ability of systems to integrate a disturbance without meaningfully upsetting its qualitative existence or structure (Holling, 1973).

In its resilience strategy released in 2017, the City of Atlanta defines resilience as “The capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and thrive no matter what kinds of chronic stresses and acute shocks they experience” (100 Resilient Cities, 2017). In comparison, a bibliographic review by Meerow et al. (2015) offers the following definition for use in policy and urban research, as it captures the underlying tensions embodied in debates around resilience, and this is the lens through which we will look at regulating ecosystem services:

“Urban resilience refers to the ability of an urban system-and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales-to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity” (Meerow et al. 2015).

Resilience planning requires increasing the flexibility of practitioner mindset, institutional structure, and public perception of what nature means in relation to urban areas. Grimm et al. 2000, in establishing the “ecology of cities” framework, holds that cities must be looked at as the sum of their heterogeneous parts, that the way matter and energy are generated inside or outside the city but consumed within has to be accounted for in line with many ecological approaches of study and explicitly communicated. With relevance to this study, these methods include detailing the ecological effects of land-use change and the spatial distribution of resources and populations using the modeling of land-use through remote sensing and GIS (Grimm et al. 2000).

Integrating ecosystem services into the urban planning process shows potential to contribute to sustainable development goals and create better outcomes in conservation of ecosystem services during the development process, although there is still little formal guidance on best practices for integrating ecosystem service frameworks into this process (Woodruff and Bendor, 2016). There have been some strides recently at developing these frameworks. Multi Decision Criteria Assessments have been identified as an effective means to influence and change development patterns to consider ecosystem services (Gret-Regamey et al. 2017). Looking to Stockholm Sweden, you can even find an example of a city whose primary resilience strategy is embodied in fostering and leveraging the effective management of ecosystem services through a variety of schemes (Kaczorowski 2014). When taken together, this displays the growing consensus regarding the value of ecosystem services in resilient capacity building.

2.3.2 Air purification

Baro et al. (2014) looks at the ability for urban forests regulating ecosystem services in Barcelona, Spain to contribute to specific environmental policy targets (air quality and climate change mitigation). They note the techno-centric framing focus of policy-making, as it overly relies on technical measure, neglecting the potential of urban green spaces to contribute to these goals (Baro et al.2014). Using the ITree Eco model, they found that 305.6 tons of pollutants were removed by Barcelona's urban green spaces, with an economic value of $2.38 million dollars with PM10 being the most effectively removed pollutant at 166 tons per year. In the United States, a study of urban trees across the nation found that they remove as much as 711,000 metric tons of pollutants and are an effective means of improving air quality to reach clean air standards (Nowak et al. 2006).

2.3.3 Runoff Mitigation

As more intense precipitation events are predicted for the southeast, Atlanta is growing as fast as it ever has. It is important that we consciously leverage the ability of GI to mitigate impacts from the inevitable increases in severe runoff events. As noted by Ferguson (2012):

"There is now growing international acceptance that strategic planning of urban systems needs to increase the resilience of infrastructure, ecosystems, community and the economy by adopting an adaptive paradigm that embraces uncertainty and complexity and provides adaptive capacity through flexibility, diversity and redundancy in its solutions"-(Ferguson, 2012).

Ideally, an effectively implemented, explicit ecosystem service framework for urban resilience could contribute in transitioning to these new kinds of systems. A related study on the concept of a water sensitive city, noted that this kind of city would recognize that our traditional values of open space and landscape features don't demonstrate understanding of the ecological functioning of these spaces including the way that sustainable water management can consciously harness regulating ecosystem service provision (Wong & Brown, 2009). A study analyzing the effectiveness of bio swales using trees and engineered soils, found that GI features can reduce runoff and pollutant loads by as much as 88.8% and 95.4% respectively in comparison with compacted urban soil that was used in the control site. Only 3% of the rainfall that fell on the treatment site contributed to water running off the site (Xiao & McPherson, 2011). In addition, there are increasingly resources providing guidance for the creation of this kind of infrastructure (Day & Dickenson, 2008).

2.4 What methods for analysis currently exist to measure urban regulating ecosystem services?

A quantitative review of studies that model and map ecosystem services found that they are typically studied in Europe, North America, and China while focusing heavily on regulating ecosystem services.

Within this subset, the degree to which these studies consider multiple services varies considerably (Hass et al., 2014). There is, however, increasing demand for research and mapping efforts around ecosystem services generally and urban ecosystem services in particular (Larondelle & Haase, 2012; Carpenter et al., 2009). An impediment to this process has been the disparate processes of ecosystem quantification and non-monetary accounting including the lack of standardized methodology or universal indicators used in studies thus far (Burkhard et al., 2012).

As mapping of ecosystem services has become more commonplace, and the pressing need to operationalize results increases, researchers are moving to fill in this gap. A blueprint for mapping and modelling ecosystem services has been developed which provides a two-part documenting scheme which captures the broader context that studies will be taking place in as well as the attributes that will be mapped and modelled. In addition, the literature review provides information about the most common methodologies and indicators used in ecosystem service mapping projects (Crossman et al., 2013). The following table synthesizes this into the indicators that will be used in the analysis of this report.

Ecosystem service	Process	Example	Indicators/Proxy	Notable References
Runoff mitigation	Percolation and Regulation of Runoff	Soil and vegetation percolate water during heavy or prolonged precipitation events	Soil Infiltration Capacity: % sealed relative to permeable surfaces	Villarreal and Bengtsson (2005)
Air Purification	Filtering and fixation of gases and particulate matter	Removal and fixation of pollutants by vegetation barriers, especially thick vegetation	O3, SO2, NO2, CO, and PM10 µm removal (tons yr−1) multiplied by tree cover (m2)	Chaparro and Terradas (2009)
Urban Temperature Regulation	Photosynthesis, shading, and evapotranspiration	Trees and other urban vegetation	Leaf Area Index; Temperature decrease	Bolund and Hunhammar (1999)

		provide shade, create humidity and block wind	by tree cover×m2 of plot trees cover (°C)	

2.5 Notable Mapping Studies

Connecting the mapping of supply with social demand is one way that ecosystem service assessment results can be more effectively integrated into decision making processes (Baro et al., 2016). The work of McPhearson et al. (2013) performs this kind of analysis using an assessment integrating a social-ecological methodology. Their study models and maps a bundle of ecosystem services from vacant lands while simultaneously integrating the social conditions of the neighborhoods in their case study city (New York, USA). Then, by creating a statistical matrix, they identify which areas have overlapping low ecological value and high social need. In this way, GI interventions can be better targeted to these areas (McPhearson et al., 2013). Another notable methodology is seen in the work of Derkzen et al. (2015), this study uses high resolution data to map regulating ecosystem services in Rotterdam, Netherlands. Focusing on urban green space, the study determines the supply based on the districts of the city and makes connections between the composition and configuration of different bundles of urban ecosystem service provision (Derkzen et al. 2015).

2.6 Literature Review Conclusion

In conclusion, there is a strong background in literature undergirding the practice of mapping ecosystem services. These studies are situational and rely on a range of different methods and indicator values. In addition, the body of literature supports the argument that implementing measures enhancing and preserving ecosystem services can contribute to climate adaptation planning efforts as well. While there have been recent studies quantifying and visualizing the urban tree canopy of Atlanta, to my knowledge, there hasn't been a study in the last decade as to the state of ecosystem services in this municipal area that capitalizes on recent advancements in high resolution satellite imagery. This is important as the city embarks on a conscious move to explicitly prioritize conservation and enhancement of urban ecosystems and the methodology laid out in the proceeding study can assist with this task.

3.0 Methodology

The aim of this work is to apply a methodology to map regulating ecosystem service provision for a defined study area in the City of Atlanta. Specifically, surface runoff and air purification will be the main focus of the analysis. The results of this analysis will identify study area neighborhoods that are increasingly offering these services through the use of a hotspot analysis tool. Finally, the analysis section will conclude with a look at how frameworks for land use and development might change to better leverage these areas in coming decades.

As seen in Figure 1, the study area for this analysis is the Northside region of Atlanta located in the northwest portion of the city. This area was chosen because of its land cover mix which includes a well-established forested tree canopy with commercial development, medium density residential housing, single-family residential housing, and relatively large fields. The cluster of commercial development found in the study area is also associated with a major highway. 1-75 runs from southwest to northeast through the study area and gives a contrast to more winding suburban road networks found in the study area. Additionally, this area is known for its affluence and there are empirically supported connections between affluence and greenspace provision, which likely contributes to the relatively intact nature of the study area tree canopy.

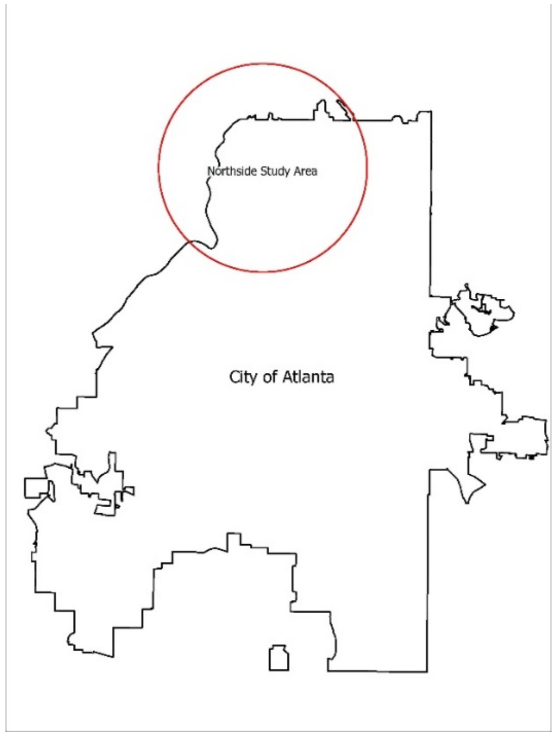


Figure 1. Study Area in Atlanta Context

3.1 Image Classification

The methodology for classification of study imagery followed the process used in the 2014 Atlanta urban tree canopy study (Giarrusso and Smith, 2014). The data set consists of Digital Globe WorldView 2 satellite imagery. The spatial resolution of the dataset is 2-square meters and captures 11-bits per pixel. The imagery is multispectral with 8-bands of information. Figure 2 displays these bands as well as the areas they occupy on the electromagnetic spectrum.

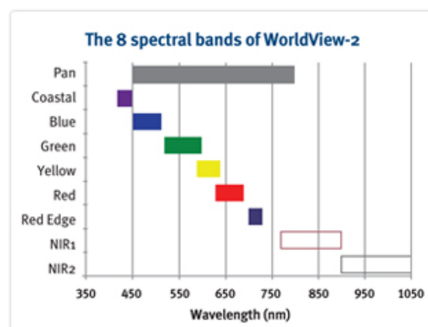


Figure 2. Obtained from LandInfo (2018)

The single imagery tile used for the classification was taken on October 6th 2014 and can be seen in Figure 3.

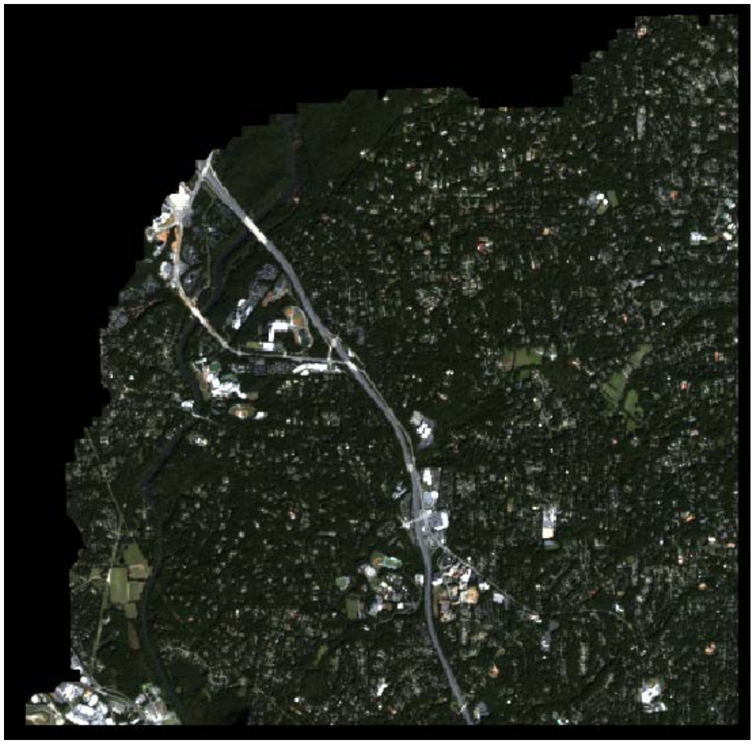


Figure 3. Quickbird Imagery from Northside Study Area

The primary classification categories for the imagery can be seen in Figure 4:

Land Cover	Color
Trees	Dark Green
Non-Tree Vegetation	Light Green
Impervious Surfaces	Gold
Water and shadow	Black
Soils	Brown

Figure 4. Reclassification Legend

This study uses the Iterative Self-Organizing Analysis (ISODATA) clustering method for image classification. This method relies on the statistical grouping of pixel values using their radiometric similarity and has a robust historical use in image classification of natural and urban environments.

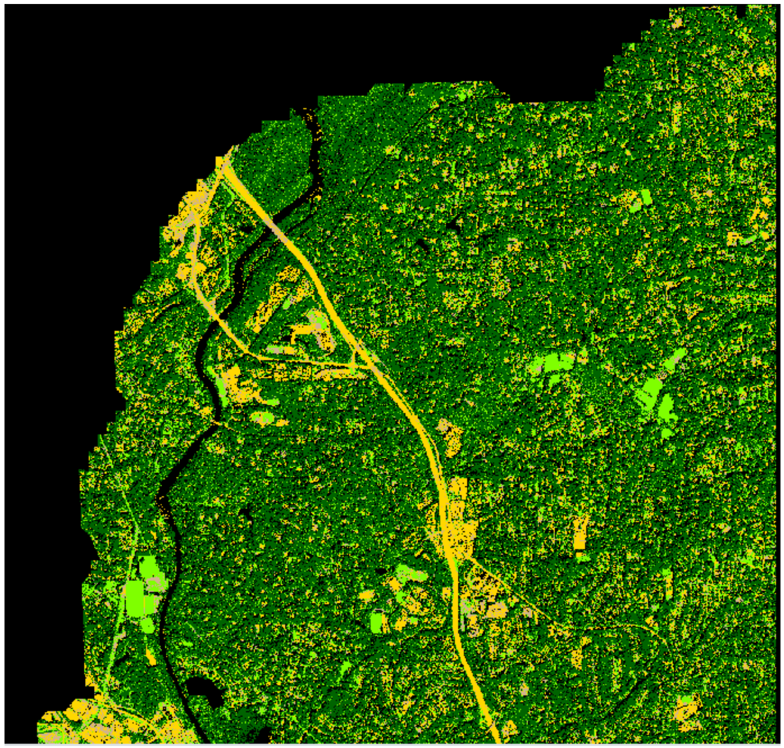


Figure 5. Reclassified image tile

Once this classification is performed, as seen in Figure 5, the image can be brought into ArcGIS for the analysis process using model builder and other spatial tools.

3.2 Calculation of runoff

The runoff mitigation is calculated as the amount of rain runoff mitigated by parcels during a 24 hour, 100-year design storm event with normal antecedent soil moisture conditions and communicated as a total runoff amount. A typical rainfall event for the City of Atlanta is a 7.50 inch precipitation event (NOAA, 2018). Runoff is determined through the application of the USDA Soil Conservations Services curve number methodology, a practice widely accepted by state and federal agencies (USDA, 1986). A limitation to this approach is that it assumes a level surface rather than considering topography. However, by combining considerations of hydrologic soil group and the amount of land cover on each parcel, the amount of runoff from each parcel can be reliably predicted. Using a technique adapted from

Whitford et al. (2001), Weng (2001), improved by Pandit and Gopalakrishan (1996), and elucidated in Tratalos et al. (2007), the following equation describes surface runoff:

$$P_e = \frac{(P - 0.2S)^2}{(P - 0.8S)}$$

Where: P_e denotes total surface runoff

P denotes the precipitation amount

S is the maximum potential runoff retention

S is calculated as 2540/CN – 25.4

Due to the poor nature of mapping and surveying of urban soils, a blanket hydrologic soil group designation (sandy loam) will be applied for every parcel in a similar manner as the Tratalos et al. (2007) study and additionally, the default curve numbers will be adopted from their study as well. These define curve number as follows based on Landcover: sealed surfaces, 98; trees, 55; grass and non-tree vegetation, 58. Additionally, water and shadows as a designation was given the same curve number as non-tree vegetation due to the strong prevalence of these pixels in areas of vegetation. As a rough estimate, we believe that this is an acceptable assumption and that it will not significantly influence the results of the analysis.

As mentioned previously, this runoff mitigation method relies on the hydrologic soil group (which we have already designated as sandy loam), the SCS curve numbers (adopted from Tratalos study), and the predominant land cover on each parcel to then apply the runoff equation for each pixel in the reclassified image within the parcel boundaries. Therefore, the first step is to determine a predominant land cover designation for each parcel. Using the reclassified raster layer and the zonal statistics tool, a majority land cover is determined for each parcel which will be used to designate the predominant land cover in the curve number equation. Next, the “Feature to Point” tool was used to convert the centroid of each parcel into a point feature. While this introduces some error into the analysis, as some parcels are irregular in shape and returned null values, this step was essential to provide an input for the “Extract Values to Points” tool used in the next step of the analysis. After the extraction process, the point layer was spatially joined back to the original parcel file and the attribute table was cleaned. This left a new field containing the majority land cover for each parcel for use in the next step.

The second step is to use this newly created land cover field to populate a record for each parcel with the appropriate curve number. This was accomplished using the field calculator tool and a python code block. This short block of code returns the appropriate curve number designation by looking at the raster value from the majority land cover field. Following this, the final records of runoff per square meter and the total runoff per parcel are created and populated by the following equation, where CN represents curve number:

$$7.5 - \ .2\ (\frac{2540}{CN} - 25.4)\text{\textasciicircum}2)/7.5 - .8(\frac{2540}{CN} - 25.4)$$

This total runoff amount is in cubic inches, which can be converted to cubic meters and then normalized by size of each parcel for mapping. Figure 6 displays retention in inches per square meter for each land cover type and Figure 7 displays the total runoff in cubic meters.

Land Cover Type	Retention per square meter
Trees	4.15 inches
Non-tree veg	3.67 inches
Impervious	.10 inches
Shadow and water	3.67 inches

Soil	3.24 inches

Figure 6. Retention per Square Meter

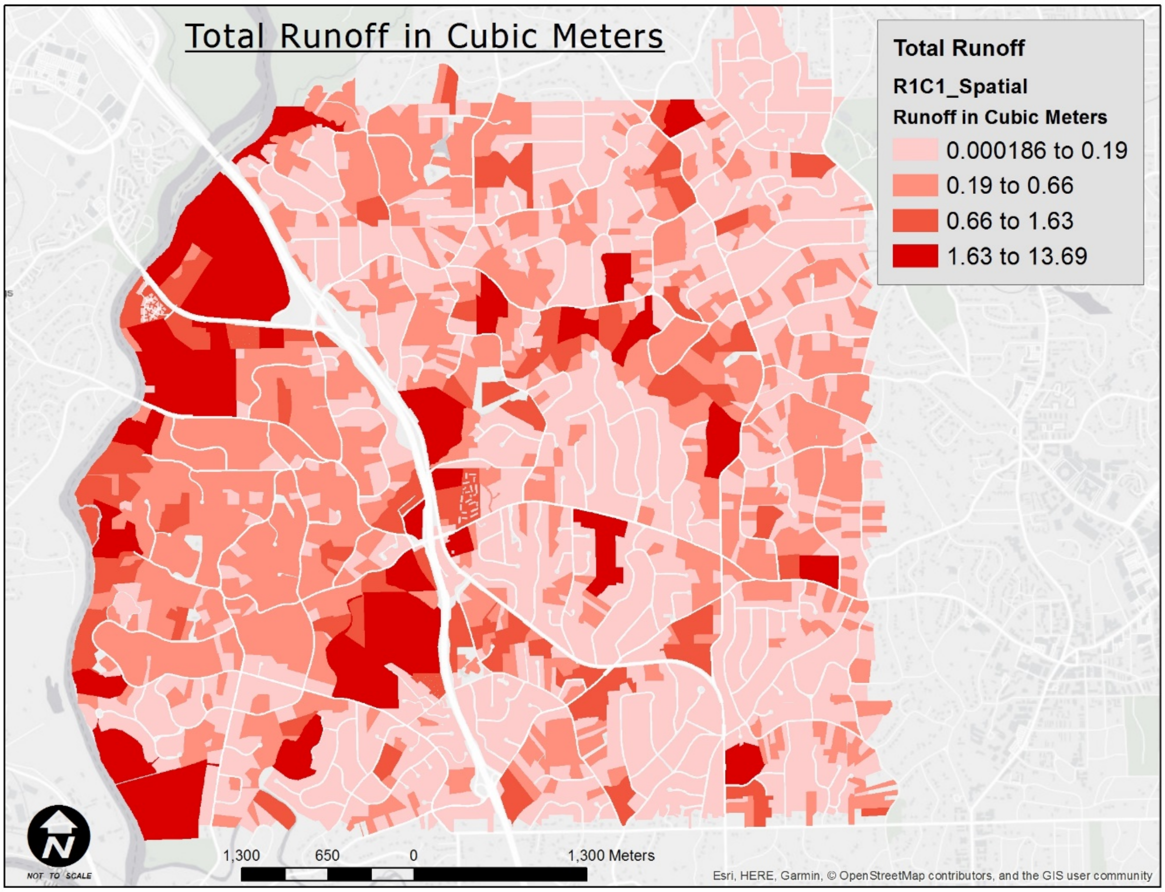


Figure 7. Results of Total Runoff Calculation

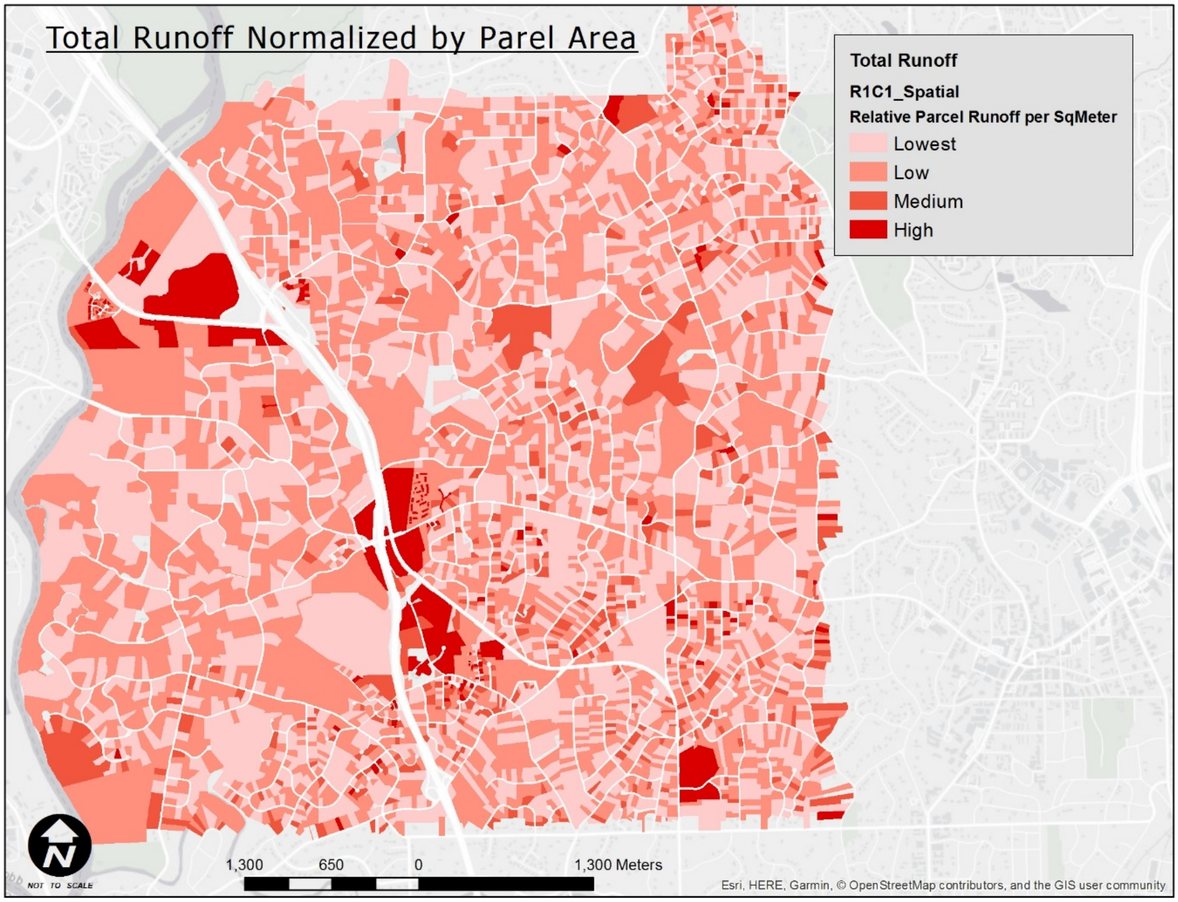


Figure 8. Total Runoff Normalized by Parcel Area

Figure 8 displays the total runoff normalized by the parcel area. The purpose of this normalization is to standardize the runoff total against the total area in square meters. Due to the nature of the equation, the larger the parcel size the more likely it is that the total runoff will be high. While it is useful to know the total volume of runoff from parcels, normalizing by the parcel area allows you to put more weight on the parcels land cover characteristics and suppresses the influence of parcels that are just comparatively large in area. In this way, you can identify key smaller parcels that display unusually high runoff values most likely due to the extent of impervious surfaces within their boundaries making it easier to identify where targeted interventions might be necessary.

3.3 Air Purification

Air purification rates in this study are provided by literature (McPhearson et al, 2013) and based on the studies of Nowak et al. 2002, Yang et al .2008, and Escobedo et al. 2009. These studies provide measures of PM10 filtration by trees and fine vegetation. There is a significant difference between the PM10 filtration rates detailed in these studies for trees, but this study will use the measure from the Escobedo et al. 2009 study because the climactic context is more similar to the study area. This rate was determined to be 12.5 g/m^{2}yr (Escobedo et al, 2009). The PM10 filtration rate of fine vegetation is provided as 1.12 g/m^{2}yr (Yang et al, 2008). In order perform to the analysis, the area of coarse and fine vegetation per parcel is obtained using the “Tabulate Area” tool as detailed earlier in the study. Figure 9 displays the total provision of air filtration. This is then normalized by size of each parcel in square meters and displayed in figure 10.

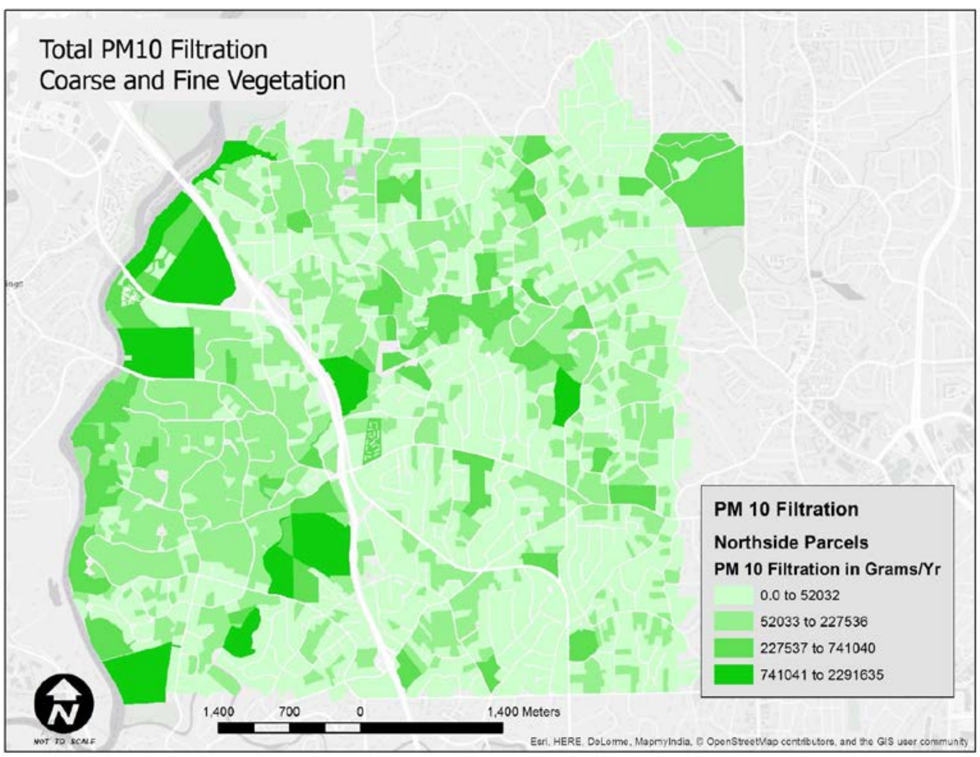


Figure 9. Total Annual PM10 Filtration by Coarse and Fine Vegetation

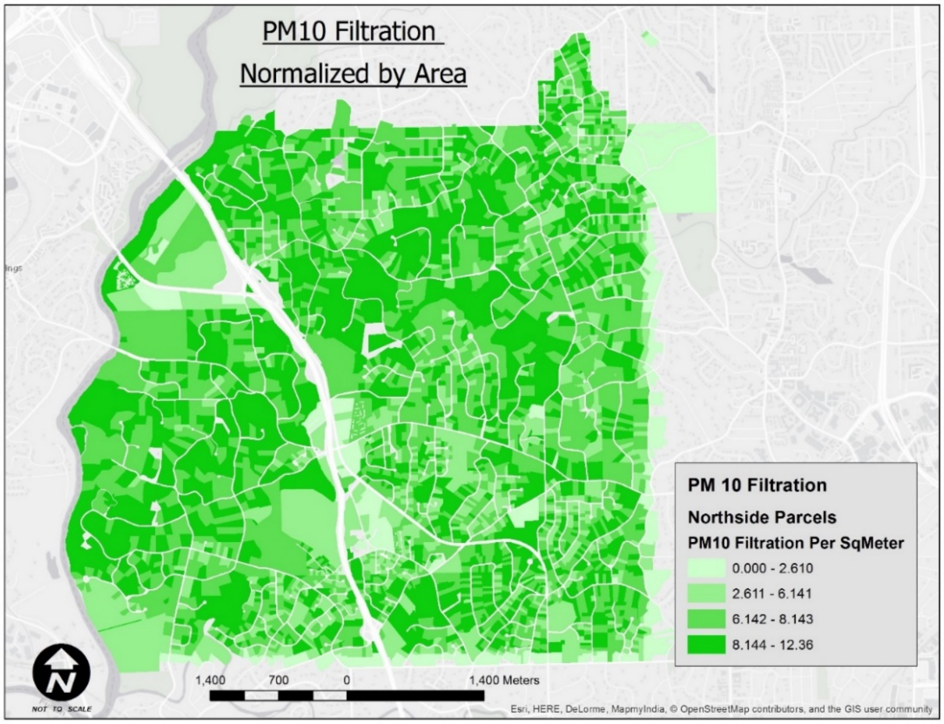


Figure 10. Annual PM10 Filtration Normalized by Area

3.4 Hotspot Analysis

Although the main aim is to quantify the provision of ecosystem services from each individual parcel, it is also useful to determine where these services cluster within the neighborhoods of the study area in order to inform how spatially explicit development policy changes can be targeted in the future. In order to perform this step, the ArcMap hotpot analysis (Getis-Ord GI*) tool is applied. This tool identifies statistically significant hot spots and coldspots using Getis-Ord Gi* statistics. This calculates statistics for each feature in the dataset and uses the resulting p-values and z-scores to display high or low value clusters in a new feature layer. Each features Gi* statistic returns a z-score. Statistically significant, positive z-scores represent a hotspot (shown in red) where larger positive values reflect a more intense clustering of high values. This concept applies for statistically significant cool spots as well but in the opposite direction. Statistically significant, smaller negative z-scores (shown in blue) represent a more intense clustering of low values (ESRI, 2018).

3.4.1 Hotspot Analysis of Runoff

Following the calculation of the total runoff amount, a hotspot analysis was performed in order to determine which neighborhoods displayed high or low clustering of runoff. Figure 11 details the results of this analysis. From this, it can be seen that high runoff areas appear to cluster near the commercial corridor at the meeting point of the Randall Mill, Pleasant Hill, and Margaret Mitchell neighborhoods. Additionally, the White Water Creek and the southern tip of the Paces Neighborhood also feature hotspots due to the large parcels in this area that have a high proportion of impervious surfaces and soils.

Significant cold spots are concentrated to the northwest and southwest of the area as well as to the south west. This might be due to the high number of contiguous small single family parcels that are heavily forested.

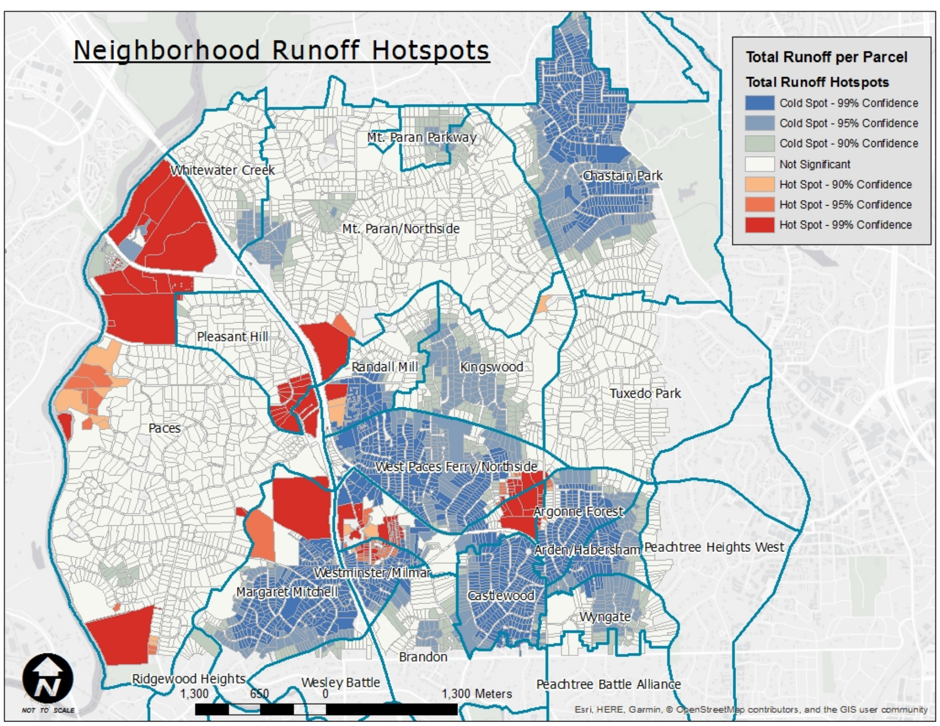


Figure 11. Runoff Hotspots with Neighborhood Boundaries

3.5 Hotspot Analysis of Air Purification

Figure 12 displays PM10 filtration hotspots around the study area based on the total amount of filtration per parcel. Intense hotspots appeared to cluster in areas that had a more mixed palette of coarse and fine vegetation. Particularly, this can be seen in the south portion of the Mt. Paran/Northside, Paces, and Pleasant Hill neighborhoods. Cold spots stretch along the commercial corridor spanning from the south Randall Mill area down to the Westminste/Milmar neighborhoods. This information would be useful when determining the siting of different land uses in the area, by being able to identify locations where vegetation may be overtaxed in providing purification services.

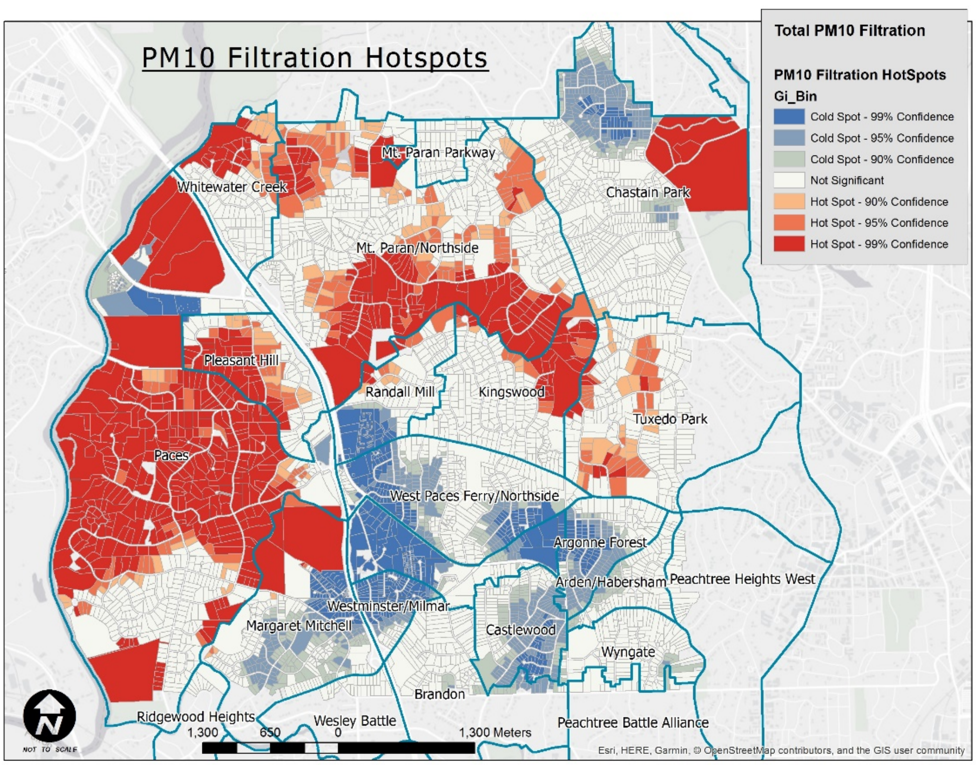


Figure 12. PM10 Filtration Hotspots with Neighborhood Boundaries

3.6 Limitations to study

A limitation to the analysis comes from the classification errors introduced during the classification process. Specifically, these included instances of trees being mistaken for non-tree vegetation, the inability to discriminate between water and shadow, and tendency of soil and impervious areas to be miss categorized. This was due to the spectral similarities between these pixels and the clustering methods performed by the ISODATA analysis method. Measures can be introduced to clean the data further, such as the application of kernel smoothing techniques that use the neighborhood of each pixel to refine the categorization. However, time restraints for the analysis precluded the use of these methods. Additionally, some parcels over the course of the model analysis were given null designations because of mismatches between their shapes and the tools applied in the analysis method as well as those parcels that are along the edges of the study imagery and whose centroids technically fall in adjacent imagery tiles.

Another limitation of the study comes from the use of majority parcel designations for the calculation of parcel runoff. The analysis was at a relatively fine scale in that it looked at the parcel level, but by relying on majority landcover designations based on overall parcel it will tend to over or under estimate the total service provision of each parcel. Ideally, runoff would be calculated on a pixel by pixel bases and then added together for each parcel. Additionally, the methodology applied to calculate surface runoff assumes a level surface, even though other methods emphasize the role topography plays in determining the amount of runoff from rain events. Air purification for each parcel could further be refined by considering the various deposition rates for different kinds of trees that may make up a stand rather than relying on the application of standard, generalized values.

Another limitation is seen in the hotspot analysis. There is a discordance between parcel and neighborhood boundaries, where some neighborhoods only feature a portion of their parcels for the analysis due to the other parcels being in another image tile from the original dataset. This tends to undercount the provision of services in the neighborhoods at the edge of the image tile

3.7 Discussion and Future Work

In performing this analysis, this study aims to combine methodologies measuring ecosystem services at the parcel/neighborhood level in Atlanta in order to act as a proximate indicator of potential climate resilience services contributed by urban green spaces in the city. That being said, resiliency is a multi-faceted concept that encompasses exposure, vulnerability, as well as adaptive capacity. By measuring ecosystem services based climate resilience purely through environmental provision of services, the socioeconomic aspects of resiliency are not explicitly captured. In future work these should be measured and integrated into the analysis to better represent areas in need of intervention. In the future this study could also be expanded to include a larger number of ecosystem services and a larger extent of analysis (i.e. covering the whole city).

Using the model developed in this study, ecosystem service provision across numerous city neighborhoods can be quantified and meaningfully compared after classification of imagery for the larger study area. In the future, the results of a model such as this could be could be integrated into more accurate impact fees on development in order to capture the externalities of these undervalued services. There a numerous ways to carry out this task but one method could be the integration of a monetization module for the ecosystem service model, quantifying the dollar value of provided ecosystem services (Primmer and Furman, 2012). However, this method is slightly controversial as some have validly argued that this method may not adequately capture the externalized value of nature to undergird every human process as well as the framing of nature as only valuable in relation to human activities.

Future work expanding the model could include more ecosystem services and stack their provision along with the previously mentioned socioeconomic measures to give a better picture of the tradeoffs between services in their provision. In addition, these considerations could be more formally stated in future plans managing urban ecosystems including but not limited to the future urban ecological framework plan being developed by the city. While it is unfeasible to attempt to map every ecosystem services provided by urban ecosystems, including indicators related to overall ecosystem health (such as biodiversity measures, or measures of greenspace connectivity) would be a useful addition. This is mainly due to the fact that there is empirical evidence that biodiversity degradation has been tied to reduction of ecological resilience and longer recovery times in response to a disturbance, both factors with implication in the age of climate change (Bernhardt-Römermann et al, 2011)(Elmqvist et al, 2003).

3.8 Challenges Facing the Integrating Ecosystem Services into Atlanta Governance and Policy structures

Ecosystem governance in Atlanta is complicated by a variety of factors. Particularly, the number of discrete geographic units with administrative land-use responsibilities leads to difficulties in effective ecosystem management (Cash et al, 2006). Governments generally, including the City of Atlanta, operate in a development context that is increasingly divorced from direct state action, influenced by a variety of competing agendas at numerous scales facilitated across the private, public, and nonprofit sectors (Wilkinson et al, 2013).

Addressing the role that land-use planning and management decisions have in destroying currently undervalued or largely unrealized services requires a concerted effort explaining what the concept is, how it’s benefits are distributed, and where they are provided in a context relative to Atlanta’s policy stakeholders and individual residents. While limited in scope, the results of this study and the mapping process generally offers a viable means of representing ecosystem services in the Atlanta context, at a scale relevant to numerous stakeholders.

However, as empirically noted, many land use practitioners don't necessarily understand the concept of ecosystem services to begin with (Nielelä et al, 2010). Generally, land use planning using the ecosystem service framework can be most closely captured by current practices regarding "Sustainable Development". The municipal ordinance for Atlanta guiding its sustainable development design standards makes no mention of ecosystem services in the decision making process and, furthermore, mainly consists of building scale considerations guided by the LEED rating system (City of Atlanta, 2003). A lack of base level knowledge of ecosystem services in the urban context hampers their integration into decisions making frameworks that could be adopted by the city in order to mitigate the impacts of climate change.

Notable in this discussion is the fact that knowledge alone is not enough to encourage action related to effective ecosystem service management. As expressed by Wilkinson et al,

"It is clear then that advancing the urban biodiversity and ecosystem services agenda is only in part a question of proving the biological science; a dominant challenge seems to lie in the institutional capacity to govern biodiversity and ecosystem services as well as in shifting the way science is viewed and used in an urban setting characterized by conflicting views and interests among stakeholders."- Wilkinson et al, 2013

Many of the challenges for ecosystem service management in the urban context stem from this dynamic. Due to the inherently political nature of the process, institutional gaps arise where responsible parties are either unable to marshal the level of information required for effective management or they lack the support of formal structures to guide conscious planning for ecosystem services.

3.8.1 Policy Recommendations

As I have demonstrated in this study, it is possible to quantify and map urban ecosystem services at a scale relevant to individual neighborhood and land use policy decision making. This study's method can be used as a foundation and improved on through integration of suggestions in the future work section in order to carry out a city wide, ecosystem service mapping project. This can be used as a benchmark to track the impacts of development in the future, as well as a communication tool to relevant stakeholders including the general public. Through the inclusion of these measures, the city would be able to track the effects of climate change as well as the effectiveness of its proposed greenspace, resilience, and park space plans in a way that is not only relevant to people but to the larger ecosystem that the city, and humanity, is embedded in.

The documents guiding development in Atlanta, while stating a focus on increasing the targeted introduction of green infrastructure and the encouragement of park space, do not feature discussions of ecosystem management at a scale relevant to increasing biodiversity and general ecosystem performance. This kind of framework would ideally be composed of a conscious strategy of greenspace acquisition and rehabilitation on the part of the city that seeks to increase the connectivity and species richness of green spaces across the city with smaller scale supporting interventions carried out by civil service organizations in partnership with community members. To achieve these goals, I recommend the city adopt three predominant strategies: (1) Augmenting urban design strategies to integrate a reconciliation ecology framework, (2) adopting an ecological land-use complementation framework for future land-use decision making, and (3) identifying midscale ecosystem service managing organizations throughout the city and providing them structural support with an emphasis on participatory ecological governance from the community.

Reconciliation ecology is based on the understanding that cities are a unique ecosystem, one so disturbed by human intervention that ecological restoration necessitates whole sale reinvention. Ideally, this intervention carries principles that integrate the use of native/non-native species, feature community scale horticulture, and modify urban habitats to more closely mimic ecological contexts, offering beneficial value to species other than humans (Seabrook et al, 2011)(Lundholm & Richardson, 2010). Examples of this include understanding the way that urban infrastructure and greenspace can act as an analogue for species habitats and designing buildings, utility poles, street installations and green spaces to encourage their use by other species. Examples of this can be augmenting development codes to promote green walls of varying composition and constituent media or creating tree planting standards that thoughtfully encourage different ecosystem compositions across Atlanta.

Ecological land use complementation uses ecological insights to propose methods of clustering heterogeneous ecosystem types within an urban setting, enhancing the provision of ecosystem services (Colding, 2007). Patch ecosystems already characterize urban landscapes, with species supporting ecosystem provision often needing multiple goods to thrive in a given season. By encouraging the consolidation of these ecosystem patches, functional ecological units can be formed. In order to encourage these kinds of juxtapositions, the Atlanta could identify ecosystems for consolidation and utilize zoning overlays or variances and work with organizations to acquire the land for consolidation into clustered ecosystem areas. Through the application of the ecosystem service mapping tool, Atlanta could also identify complementary ecosystems around the city and set conservation targets that impose more stringent protections on them reflecting their unique advantages.

The final suggestion, to identify external midscale ecosystem management organizations and structurally support them, is suggested in order to introduce the amount of flexibility necessary for effective urban ecosystem governance. A prime example of an Atlanta organization that facilitates a midscale managing role is Trees Atlanta. This organization not only promotes collective action in the form of tree planting and upkeep using volunteers, it also promotes decentralized social learning about the role of trees and why they are vital to successful cities. This increases the environmental literacy of the city and cultivates a viable political group to mobilize on issues related to the protection of greenspace and ecosystem services. As previously mentioned, urban ecosystems are characterized by a variety of scales and through responsibly encouraging organizations the city can cultivate a resource better able to assess the health of lower scale ecosystem components (Ernstson et al, 2010).

In order for the city to encourage the viability of these organizations, the city should focus on creating the social networks that these organizations need to trade information and lower the social cost of transactions. This could be done through an establishment of a consolidated research/information hub where ecological organizations can upload their research in order to provide information to similar groups operating in the same sphere (same scale intervention). Additionally, the city could create a task force for ecosystem service protection to act as a midscale broker between likeminded organizations (cross scale intervention). This task force would meet regularly and create the bonding and bridging social ties that are important to maintaining the viability of these organizations. By focusing on collaborative partnership with ecosystem service middle managing organizations, partnerships emphasizing legitimate dialogue and negotiation, Atlanta can increase the effectiveness of its ecological governance structure.

4.0 Conclusion

The primary goal of this study was to compile a literature backing the argument for ecosystem services as a climate adaptation and resilience planning strategy and then create a model able to map ecosystem services in the City of Atlanta. Specifically, this study uses remote sensing and GIS methods to quantify ecosystem service provision of study area neighborhoods in Northwest Atlanta. Although a significant number of ecosystem services are provided in the urban context, this study focuses on air purification and runoff mitigation services because these are the predominant services provided by green infrastructure.

Following the application of these methods, a hotspot analysis tool was used in order to statistically determine where these services concentrate in the given study area. The results of which can be used in order to target changes to development regulations in order to conserve or enhance the features in this geography that are offering the most benefit. A subsequent policy discussion details some challenges to integrating effective ecosystem governance structures in Atlanta but resolves by suggesting three frameworks that can be applied by the city in order to increase its efficacy.

Generally it is quite clear that there are advantages from ecosystem services that align with the stated goals of the City of Atlanta. Additionally, while there are notable challenges, it is clear that the methods and frameworks to capitalize on these services are currently backed by empirical findings and available for integration into the city's existing policy/environmental governance frameworks. It is my hope that the city will pivot towards these frameworks in the near future as Atlanta carves a new path forward in its highly urbanizing future.

Bibliography

100 Resilient Cities (2017). “Resilient Atlanta: Actions to Build an Equitable Future”.

Alexandri E., Jones P., (2008). “Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates” *Building and Environment*, *43*(4), 480–493. doi:10.1016/j.buildenv.2006.10.055

Artmann M. (2014). “Assessment of Soil Sealing Management Responses, Strategies, and Targets toward Ecologically Sustainable Urban Land Use”. AMBIO. Pg. 530-541

Aylor, D. (1972) “Noise Reduction by Vegetation and Ground” *The Journal of the Acoustical Society of America*, *51*(1B), 197. doi:http://dx.doi.org/10.1121/1.1912830

Baro F, Palomo I, Zulian G, Vizcaino P, Haase D. (2016) “Mapping ecosystem service capacity, flow , and demand for landscape and urban planning: A case study in the Barcelona metropolitan region” *Land Use Policy* Pg. 405-417

Bernhardt-Römermann M, Gray A, Vanbergen J.A, Bergès L, Bohner A, Brooker W.R, Bruyn D.L, Cinti D.B, Dirnböck T, Grandin U, Hester J.A, Kanka R, Klotz S, Loucougaray G, Lundin L, Matteucci G, Mészáros I, Oláh V, Preda E, Prévosto B, Pykälä J, Schmidt W, Michele E.T, Vadineanu A, Walkdmann T, Stadler J. (2011). “Functional traits and local environment predict vegetation responses to disturbance: a pan-European multi-site experiment” *Journal of Ecology. Vol. 99, Issue 3*

Bindoff, N. L., P. A. Stott, K. M. AchutaRao, M. R. Allen, N. Gillett, D. Gutzler, K. Hansingo, G. Hegerl, Y. Hu, S. Jain, I. I. Mokhov, J. Overland, J. Perlwitz, R. Sebbari, and X. Zhang (2013) “Detection and attribution of climate change: From global to regional” T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J.

Bolund P., Hunhammar S. (1999) “Ecosystem services in urban areas” *Ecological Economics 29, 293–301.*

Booth, D. B., & Jackson, C. R. (1998). “Urbanization of Aquatic Systems: Degradation Thresholds, Stormwater Detection, and the Limits of Mitigation”. *Journal of the American Water Resources Association*, *33*(5).

Brasseur G., Roeckner E. (2005) “Impact Of Improved Air Quality On The Future Evolution Of Climate” *Geophysical Research Letters,* Vol. 32, L23704, doi: 1029/2005GL023902

Burkhard B., Petrosillo I., Constanza R. (2010) “Ecosystem services – bridging ecology, economy and social sciences” *Ecological Complexity*. 7, 257–259.

Cameron, R. W. F., Blanuša, T., Taylor, J. E., Salisbury, A., Halstead, A. J., Henricot, B., & Thompson, K. (2012). “The domestic garden - Its contribution to urban green infrastructure” *Urban Forestry and Urban Greening*, *11*, 129–137.doi:10.1016/j.ufug.2012.01.002

Carpenter, S.R., Mooney, H.A., Agard, J., Capistrano, D, Defries, R.S. Díaz S., Dietz,T., Duraiappah A.K., Oteng-Yeboah A., Pereira H.M., Perrings C., Reid, W.V.,Sarukhan, J., Scholes, R.J., Whyte, A., (2009). “Science for managing ecosystem services: beyond the millennium ecosystem assessment”*Proc. Natl. Acad. Sci.* U.S.A. 106 (5), 1305–1312,.

Cash, D. W., W. Adger, F. Berkes, P. Garden, L. Lebel, P. Olsson, L. Pritchard, and O. Young. 2006. Scale and cross-scale dynamics: governance and information in a multilevel world. Ecology and Society 11(2): 8. Retrieved from: http://www.ecologyandsociety.org/vol11/iss2/art8/

Chaparro, L., Terradas, J. (2009) “Ecological services of urban forest in Barcelona” *Institut Municipal de Parcs i Jardins Ajuntament de Barcelona, Àrea de Medi Ambient.*

Colding J. (2007) “’Ecological Land-use complementation’ for building resilience in urban ecosystems” *Landscape and Urban Planning. Vol 81, Issue 1-2: Pg. 46-55*

Costanza, R., Wilson, A., Troy., A., Voinov, A., Liu, S., & D'Agostino, J. (n.d.). "The Value of New Jersey ' s Ecosystem Services and Natural Capital". *Institute for Sustainable Solutions*, New Jersey.

Crossman D.N, Burkhard B, Nedkov S, Willemen L, Petz K, Palomo I, Drakou G.E, Martin-Lopez B, McPhearson T, Boyanova K, Alkemade R, Egoh B, Dunbar B.B, Mas J. (2013) "A blueprint for mapping and modelling ecosystem services" *Ecosystem services*. pg. 4-14

City of Atlanta. (2003) "Chapter 75-Sustainable Development Design Standards" *Municipal Ordinance: Ord. No. 2003-108, § 2(Exh. A), 12-9-03*. Retrieved from: https://library.municode.com/ga/atlanta/codes/code_of_ordinances?nodeId=PTIICOORENOR_CH75SUDEDEST_S75-1PO

Curry A. (2008) Local Warming: Consequences of Climate Change for Atlanta. Retrieved from: http://curry.eas.gatech.edu/climate/pdf/atlanta_rev.pdf

Daily G.C, (Ed.). (1997). "Nature's Services" *Island Press*, Washington, D.C

Danielsen, F., Sørensen, M. K., Olwig, M. F., Selvam, V., Parish, F., Burgess, N. D.,Suryadiputra, N. (2005). "The Asian tsunami: a protective role for coastal vegetation" *Science (New York, N.Y.)*, *310*(October), 643. doi:10.1126/science.1118387

Day, S.D. and S.B. Dickinson (eds.) (2008) "Managing Stormwater for Urban Sustainability Using Trees and Structural Soils". Virginia Polytechnic Institute and State University, Blacksburg, VA.

Derkzen L.M, Teeffelen VA.J, Verburg H.P. (2017) "Green infrastructure for urban climate adaptation: how do residents' views on climate impacts and green infrastructure shape adaptation preferences?" *Landscape and urban planning* Vol. 157, pg. 106-130

Easterling, D.R., K.E. Kunkel, J.R. Arnold, T. Knutson, A.N. LeGrande, L.R. Leung, R.S. Vose, D.E. Waliser, and M.F. Wehner (2017) "Precipitation change in the United States" In: *Climate Science Special Report*: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 207-230, doi: 10.7930/J0H993CC.

Ellis, J. B., & Marsalek, J. (1996). "Overview of urban drainage: environmental impacts and concerns, means of mitigation and implementation policies" *Journal of Hydraulic Research*, *34*(6), 723–732. doi:10.1080/00221689609498446

Escobedo, F. J., & Nowak, D. J. (2009). "Spatial heterogeneity and air pollution removal by an urban forest" *Landscape and Urban Planning*, Vol. *90*, pg. 102–110. doi:10.1016/j.landurbplan.2008.10.021

Englert, N. (2004). "Fine particles and human health- a review of epidemiological studies" *Toxocology Letters* Vol. 149, issues 1-3, pg. 235-242

Escobedo, F. J., & Nowak, D. J. (2009). Spatial heterogeneity and air pollution removal by an urban forest. *Landscape and Urban Planning*, *90*(3-4), 102-110. doi:10.1016/j.landurbplan.2008.10.021

Escobedo, F. J., Kroeger, T., & Wagner, J. E. (2011). "Urban forests and pollution mitigation: Analyzing ecosystem services and disservices" *Environmental Pollution*, *159*(8-9), 2078–2087. doi:10.1016/j.envpol.2011.01.010

ESRI. (2018). "How Hot Spot Analysis (Getris-Ord Gi*) Works". *ArcGIS for Desktop. Retrieved from: http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-statistics-toolbox/h-how-hot-spot-analysis-getis-ord-gi-spatial-stati.htm*

Elmqvist T, Folke C, Nyström M, Peterson G, Bengtsson J, Walker B, & Norberg J. (2003). "Response Diversity, Ecosystem change, and Resilience" *Frontiers in Ecology and the Environment. Vol 1, Issue 9: Pg 488-494*

Ernstson, H., S. Barthel, E. Andersson, and S. T. Borgström. 2010. Scale-crossing brokers and network governance of urban ecosystem services: the case of Stockholm. *Ecology and Society* **15**(4): 28. Retrieved from: http://www.ecologyandsociety.org/vol15/iss4/art28/

Ferguson C.B, Frantzeskaki N, Brown R.R (2013) “A strategic program for transitioning to a water sensitive city” *Landscape and Urban Planning*. Vol: 117, Pg. 32-45

Folland, C.K., T.R. Karl, J.R. Christy, R.A. Clarke, G.V. Gruza, J. Jouzel, M.E. Mann, J. Oerlemans, M.J. Salinger and S.-W. Wang, 2001: Observed Climate Variability and Change. In: Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881pp.Ishii, M. (1994). Measurement of road traffic noise reduced by the employment of low physical barriers and potted vegetation. *Inter-Noise*, *29*(31), 595–597.

Fowler D, (2002) “Pollutant deposition and uptake by vegetation” J.N.B. Bell, M. Treshow (Eds.), *Air Pollution and Plant Life (secoed ed)*, Wiley, Chichester pp. 43-67

Giarrusso, T and Smith, S. (Spring 2014). “Assessing Urban Tree Canopy in the city of Atlanta; a Baseline Canopy Study” *The City of Atlanta, Arborist Division.*

Grêt-Regameya A., Altwegg J., Siréna E.A, Striena M.J., Weibela B. (2017) “Integrating ecosystem services into spatial planning—A spatial decision support tool” Vol. 165. Pg. 206-219

Grimm B.N, Grove G.J, Pickett A.T.S, Redman L.C. (2000) “Integrated Approaches to Long-Term Studies of Urban Ecological Systems: Urban ecological systems present multiple challenges to ecologists—pervasive human impact and extreme heterogeneity of cities, and the need to integrate social and ecological approaches, concepts, and theory”. *Bioscience. Vol. 50., Issue 7. Pg. 571-584*

Hartshorn, T. and K. R. Ihlanfeldt. 1993. The dynamics of change in Atlanta: An analysis of change over the past two decades. Research Atlanta, Inc., 82 pp.

Hass D, Larondelle N, Andersson E, Artmann M, Borgstrom S, Breuste J, Gomez-Baggethun E, Gren A, Hamstead Z, Hansen R, Kabisch N, Kremer P, Langemeyer J, Rall L.E, McPhearson, T, Pauleit S, Qureshi S, Schwarz N, Voigt A, Wurster D, Elmqvist T. (2014) “A Quantitative Review of Urban Ecosystem Services Assessments: Concepts , Models, and Implementation” AMBIO Volume 43, Pg. 413-433

Holling C.S, (1973) “Resilience and Stability of Ecological Systems”. *Annual Review of Ecology and Systematics*. Vol. 4. pp. 1-23.

IPCC (2013) “Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change” [Stocker, T.F., D. Qin, G.-K.

J. Mentens, D. Raes, M. Hermy. (2006). “Roofs as a tool for solving the rainwater runoff problem in the urbanised 21st century” *Landscape and Urban Planning*. Vol. 77, pp. 217-226

Jennings V., Gaither C. (2015) “Approaching Environmental Health Disparities and Green Spaces: An Ecosystem Services Perspective” *Environmental Research and Public Health.*

Jim, C. Y., & Chen, W. Y. (2009). “Ecosystem services and valuation of urban forests in China” *Cities*, *26*(4), 187–194. doi:10.1016/j.cities.2009.03.003

KACZOROWSKA, Anna. “Ecosystem services and Urban Resilience” 50th ISOCARP Congress 2014

Kragh, J. (1981). “Road traffic noise attenuation by belts of trees” *Journal of Sound and Vibration*, *74*, 235–241. Retrieved from http://discovery.ucl.ac.uk/28439/

L. Bengtsson, L. Grahn, J. Olsson (2005) “Hydrological function of a thin extensive green roof in southern Sweden” *Nordic Hydrology* Vol. 36, Issue 3, pp. 259-268

Landinfo Worldwide Mapping LLC. (2018) “WorldView-2 50cm Global High-Resolution satellite Imagery”. Retrieved from: http://www.landinfo.com/WorldView2.htm

Larondelle N, Haase D (2012) “Urban ecosystem services assessment along a rural-urban gradient: A cross-analysis of European cities” *Ecological Indicators* Vol. 29, pg. 179-190

Lee, B. H., & Scholz, M. (2007) “What is the role of Phragmites australis in experimental constructed wetland filters treating urban runoff?” *Ecological Engineering*, Vol. *29*, Issue 1, pg. 87–95. doi:10.1016/j.ecoleng.2006.08.001

Lo, C.P., & Yang, X. (2002) “Drivers of land-use/Landcover changes and dynamic modeling for the atlanta, Georgia Metropolitan Area” *Photogrammetric Engineering & Remote Sensing*

McPherson G.E, Simpson R.J. (1999). “Carbon dioxide reduction through urban forestry: guidelines for professional and volunteer tree planters”

Lundholm T.J & Richardson, P. (2010) “Habitat analogues for reconciliation ecology in urban and industrial environments” *Journal of Applied Ecology. Vol 47, Issue 5. https://doi.org/10.1111/j.1365-2664.2010.01857.x*

McPhearson T, Kremer P, Hamsteat A.Z. (2013) “Mapping ecosystem services in New York City: Applying a social-ecological approach in urban vacant land” *Ecosystem Services* Vol. 5, pg. 11-26

Medina-Ramon M., Zanobetti A., Schwartz J. (2006) “ The Effect of Ozone and PM10 on Hospital Admissions for Pneumonia and Chronic Obstructive Pulmonary Disease: A National Multicity Study” *American Journal of Epidemiology*. Vol. 163, Issue no. 6, pg. 579-588

Meerow S, Newell J. (2017). “Spatial planning for multifunctional green infrastructure: Growing resilience in Detroit”. *Landscape and Urban Planning*. Vol. 159, pg. 62-75

Meerow S, Newell J.P, Stults M. (2016) “Defining Urban Resilience: A Review”. *Landscape and Urban Planning*. Vol. 147, pg. 38-39

Merjin de Jong (2015) “Ecosystem services delivery by urban green infrastructure in Utrecht, Netherlands: The role of domestic gardens and public green infrastructure in the delivery of three regulatory services” *Utrect University.* Retrieved from: http://www.adaptivecircularcities.com/wp content/uploads/2016/03/Ecosystem-services-delivery-by-urban-green-infrastructure-in-Utrecht.pdf

VanWoert N.D, Rowe D.B, Andresen J.A, Rugh C.L, Fernandez R.T, Xiao L. (2005) “Green roofs stormwater retention: effects of roof surface, slope, and media depth” *Journal of Environmental Quality* Vol. 34, pp. 1036-1044

Naumann S, Davis M, Kaphengst T, Pieterse M, Rayment M.(2011) “Design, implementation and cost elements of Green Infrastructure projects” *Final report to the European Commission, DG Environment, Contract no. 070307/2010/577182/ETU/F.1, Ecologic institute and GHK Consulting.*

Niemelä, J., Saarela, SR., Söderman, T. et al. Biodivers Conserv (2010) 19: 3225. https://doi.org/10.1007/s10531-010-9888-8

NOAA (2018). “NOAA ATLAS 14 POINT PRECIPITATION FREQUENCY ESTIMATES: GA”. *Hydrometeorological Design Studies Center: Precipitation Frequency Data Server.*

Nowak, D. J., Crane, D. E., Stevens, J. C., & Ibarra, M. (2002). *Brooklyn’s urban forest*.

Nowak D, Crane E.D, Stevens C.J. (2006) “Air pollution removal by urban trees and shrubs in the United States” *Urban forestry and urban greening.* Vol. 4, pg. 115-123

Pandit A, Gopalakrisnan G. (1996). “Estimation of Annual Runoff Coefficients by Continuous Simulation” *Journal of Irrigation and Drainage Engineering. Vol.122, Issue 4: Pg. 211-220*

Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp, doi:10.1017/CBO9781107415324.

Pope A.C. (2000) “Epidemiology of fine particulate air pollution and human health: biologic mechanisms and who’s at risk?” *Environmental Health Perspectives, Vol. 108, Supplement 4, pg. 713-723*

Primmer E, Furman E. (2012). “Operationalising ecosystem service approaches for governance: Do measuring, mapping, and valuing itegrate sector-specific knowledge systems?” *Ecosystem Services. Vol. 1, Issue 1: pg. 85-92*

Prokop, G., H. Jobstmann, and A. Scho¨nbauer (2011)“Report on best practices for limiting soil sealing and mitigating its effects”. *the European Commission, DG Environment, Technical Report-2011-50*, Brussels, Belgium, 231 pp.

Robitu, M., Musy, M., Inard, C., & Groleau, D. (2006). “Modeling the influence of vegetation and water pond on urban microclimate” *Solar Energy*, Vol. *80*, Issue. 4, pg. 435–447 doi:10.1016/j.solener.2005.06.015

Rose S, Peters E.N. (2001) “Effects of urbanization on streamflow in the Atlanta area (Georgia, USA): a comparative hydrological approach” *Hydrological Processes* Vol. 15, issue 8, pg. 1441-1457

Royal Netherlands Meteorological Institute (KNMI) (N.B.D). “Linking changes in hourly precipitation extremes to the clausius-Clapeyron relation”. Retrieved from: https://www.knmi.nl/kennis-en datacentrum/achtergrond/linking-changes-in-hourly-precipitation-extremes-to-the-clausius-clapeyron relation

Schröter M, van der Zanden E.H, van Oudenhoven A.P.E, Remme, R.P, Serna-Chavez H.M, de Groot R.S, Opdam P.(2014). “Ecosystem Services as a Contested Concept: a Synthesis of Critique and Counter-Arguments” *Conservation Letters*. Issue 7, pg. 514-523 doi:10.1111/conl.12091

Seabrook L, Mcalpine A.C, Bowen E.M. (2011) “Restore, repair, or reinvent: Options for sustainable landscape in a changing climate” *Landscape and Urban Planning. Vol 100, Issue 4: Pg. 407-410*

Shuster W.D, Thurston H.B, Warnemuende E., & Smith R.D. (2005) “Impacts of impervious surface on watershed hydrology: A review” *Urban Water Journal.* Vol. 2, pg. 263-275

Sukopp H. (1998) “Urban Ecology — Scientific and Practical Aspects” In: Breuste J., Feldmann H., Uhlmann O. (eds) Urban Ecology. Springer, Berlin, Heidelberg

Teeb (2010) “The economics of ecosystems and biodiversity” *Ecological and economic foundation* London: Earthscan; 2010.

Tratalos J, Fuller A.R, Warren H.P, Davies G.R, Gaston J.K. (2007). “Urban Form, biodiversity potential, and ecosystem services” *Landscape and Urban Planning Vol. 83, Pg. 308-317* doi:10.1016/j.landurbplan.2007.05.003

Tyagi V, Kumar K, Jain V.K.(2006). “A study of the spectral characteristics of traffic noise attenuation by vegetation belts in Delhi” *Applied Acoustics*, Vol. *67*, pg. 926–935. doi:10.1016/j.apacoust.2005.09.002

USDA Soil Conservation Service. (1986) “Urban Hydrology for Small Watersheds: TR-55”

Vauramo, S., & Setälä, H. (2010). “Urban belowground food-web responses to plant community manipulation - Impacts on nutrient dynamics” *Landscape and Urban Planning*. doi:10.1016/j.landurbplan.2010.04.004

Villarreal, E. L., & Bengtsson, L. (2005) “Response of a Sedum green-roof to individual rain events” *Ecological Engineering*. Vol. *25*, Issue 1–7doi:10.1016/j.ecoleng.2004.11.008

Weng, Q., 2001. Modelling urban growth effects on surface run-off with the Integration of Remote Sensing and GIS. Environ. Manage. 28, 737–748.

Whitford V, Ennos A.R., Handley J.F. (2001) “City form and natural process-Indicators for the ecological performance of urban areas and their application to Merseyside, UK”. *Landscape and Urban Planning*. Pg. 91-103

Wilkinson C., Sendstad M., Parnell S., Schewenius M. (2013) Urban Governance of Biodiversity and Ecosystem Services. In: Elmqvist T. et al. (eds) Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities. Springer, Dordrecht

Wong T.H, Brown R.R (2009) “The water sensitive city: principles for practice” *Water Science and Technology* Vol. 60, issue , pg. 673-682. doi: 10.2166/wst.2009.436.

Woodruff C.S, BenDor K.T. (2016) “Ecosystem services in urban planning: Comparative paradigms and guidelines for high quality plans” *Landscape and Urban Planning* Vol.152, Pg. 90-100

Worldbank (2017) Retrieved from: https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS

Xiao Q, McPherson G.E. (2011) “Performance of engineered soil and trees in a parking lot bioswale” Urban Water Journal Volume 8, issue 4

Xiao, Q. & McPherson, E.G (Urban Ecosystems (2002) 6: 291. https://doi.org/10.1023/B:UECO.0000004828.05143.67

Yang, J., Yu, Q., & Gong, P. (2008). Quantifying air pollution removal by green roofs in Chicago. *Atmospheric Environment*, *42*(31), 7266-7273. doi:10.1016/j.atmosenv.2008.07.003