Local Environment
The International Journal of Justice and Sustainability

ISSN: 1354-9839 (Print) 1469-6711 (Online) Journal homepage: https://www.tandfonline.com/loi/cloe20

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LOCAL ENVIRONMENT, 2017
VOL. 22, NO. 11, 1338–1357
https://doi.org/10.1080/13549839.2017.1345878

Equitable distribution of green stormwater infrastructure: a capacity-based framework for implementation in disadvantaged communities

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ABSTRACT
This study seeks to understand the factors that influence the variability in distribution of public and private sector investments in green stormwater infrastructure (GSI) projects across the diversity of neighbourhoods in the City of Philadelphia, PA, U.S.A. using indicators of community context and capacity. For this study, context is defined as characteristics of disadvantaged communities and capacity as factors that facilitate individual and collective action. Community context and capacity are deemed integral to the success of the Philadelphia GSI programme as the Philadelphia Water Department is relying upon collaborative approaches to facilitate public investments in neighbourhoods and voluntary implementation of GSI practices on publically and privately owned lands. Private sector investments in GSI mandated by stormwater regulations for new construction and major rehabilitation also are assessed in relation to these two sets of indicators. The geographic information systems and statistical analyses reveal an inequitable distribution of GSI projects, which largely is driven by market forces. The paper concludes with a community capacity-based framework to prioritise public sector investment in disadvantaged communities to achieve more equitable distribution of GSI projects and associated benefits.

ARTICLE HISTORY
Received 27 May 2016
Accepted 24 May 2017

KEYWORDS
Community capacity; equitable development; environmental justice; green stormwater infrastructure; GIS analysis

Introduction

Green infrastructure is a popular approach to stormwater management because it has the potential to provide greater triple bottom line benefits – environmental, social, and economic – than traditional grey infrastructure (U.S. Environmental Protection Agency 2014b). For this reason, the U.S. Environmental Protection Agency (EPA) has encouraged the more than 700 municipalities with combined sewer systems to implement green stormwater programmes to comply with regulatory goals (U.S. Environmental Protection Agency 2014a). With the recent expansion of the environmental justice framework to address the equitable distribution of environmental goods in addition to environmental risks (Agyeman 2005, Walker 2012) comes a call for research to understand how such environmental amenities are being distributed (Dunn 2010, Jennings *et al*. 2012). Emerging research on the equitable distribution of green amenities amongst urban socioeconomic groups (Heynen *et al*. 2006, Wendel *et al*. 2011, Davis *et al*. 2012, Harlan *et al*. 2013) indicates that there is reason to be concerned

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that limitations such as historic inequitable development patterns and the privatisation of green amenities may influence the distribution of green stormwater infrastructure (GSI).

GSI programmes implemented to comply with EPA regulations are designed to reduce and manage stormwater flows to prevent flooding and improve water quality as well as to achieve broader environmental and public benefits than traditional piped solutions. Individual projects include natural elements (i.e. rain gardens, street trees, and wetlands) as well as engineered techniques including, for example, bio-infiltration trenches, green roofs, and porous pavement, which are designed to mimic the hydrology of natural landscapes. Scholars and practitioners alike have lauded the range of ecological benefits such as improvements in water quality with vegetated projects also contributing to improvements in air quality, creation of wildlife habitat, energy conservation, and climate change mitigation (Yang *et al*. 2008, Flynn and Traver 2013, Wang *et al*. 2015). Social benefits include reductions in heat-related deaths and stress, promotion of physical activity, and improved safety (Dunn 2010, Wolf 2014, Kondo *et al*. 2015). With respect to economic outcomes, studies (Philadelphia Water Department 2009c, Dunn 2010) also have documented increases in job creation and residential property values as well as reductions in infrastructure construction costs.

There are a range of local policy approaches to implement GSI programmes including direct public investment, regulatory mandates embedded in building permits, and incentives to spur voluntary implementation (Dunn 2010). Each comes with its own challenges. Public investment in infrastructure is the traditional approach to implementation. However, GSI requires land-based improvements at the source of stormwater run-off instead of the typical end-of-pipe infrastructure improvements. To this end, public investments seek to enhance the hydrologic performance of publically owned land including streets, rights of ways, schools, parks, and the like; yet, public lands owned by the water authority, the typical implementing agency, may make up a marginal share of the targeted implementation area. For example, the Philadelphia Water Department (PWD) owns less than 1% of the impervious surfaces in its combined sewer overflow (CSO) areas (Philadelphia Water Department 2009b). Thus, implementing GSI on public lands requires a policy approach that facilitates collaborations between the water authority, municipal departments, impacted communities, and other stakeholders (Wendel *et al*. 2011, Travaline *et al*. 2015). While collaborative approaches to environmental programme implementation have resulted in successful implementation of voluntary and mandatory policies (Potapchuk and Crocker 1999, Mandarano 2008, Mandarano *et al*. 2008), implementation may be hampered by the variability in capacity of urban neighbourhoods to serve as effective partners. Poor and minority communities often are overburdened by adverse environmental impacts or are underserved by environmental benefits such as green spaces because they lack the capacity to engage in local decision-making processes (Chaskin 2001, Emery and Flora 2006).

With respect to GSI investment on private property, a two-pronged approach includes regulatory mandates and voluntary implementation. A notable drawback associated with reliance on regulations mandating the implementation of GSI in new development and major redevelopment projects is the potential to have a limited impact especially in largely built out urban communities. For example, in Philadelphia where GSI is mandated in new development and redevelopment, it is estimated to impact only 1% of the impervious cover per year although 55% of the impervious area is privately owned (Philadelphia Water Department 2009b). Such mandates also privatise investment in GSI and embed it in the local real estate market, which are likely to result in urban poor and minorities being underserved (Heynen *et al*. 2006). Lastly, voluntary private investment in GSI relies on motivating property owners through carrot and stick approaches including educational programmes and financial incentives. This approach also could result in unequal distribution of GSI as poor residents and underserved neighbourhoods may not have the capacity to implement or maintain GSI and thus may rely on public investment to produce localised triple bottom line benefits (Heynen *et al*. 2006).

This paper focuses on developing a better understanding of the community-based factors that influence the variability in the distribution of public and private investments in GSI in the City of Philadelphia through an assessment of projects implemented between 2011 and 2015 in response to the

EPA's acceptance of the City's CSO Long-Term Control Plan Update (Philadelphia Water Department 2009a). Because this study employs a social-spatial analysis, the term community refers to community of place within Gordon Walker's typology of communities (Walker 2011). The researchers explore equitable distribution of GSI projects through the lens of community context and capacity. Community context includes the set of socioeconomic characteristics typically used to define and assess disadvantaged communities in the environmental justice literature. Community capacity is assessed through a set of variables used to measure community capitals, which are relevant measures of a community's capacity to engage in collective action (Emery and Flora 2006). This analysis reveals that there is an inequitable distribution of GSI within Philadelphia associated with private investment and to a lesser extent public investment. A positive correlation between community capacity and implementation also is observed. These results are used to develop a much-needed strategy to target disadvantaged communities for green infrastructure investment, with level of capacity as a key factor, to achieve more equitable distribution patterns within Philadelphia. The authors conclude with policy recommendations to promote a just distribution of GSI projects and associated benefits that are transferrable to other cities employing GSI programmes to meet the goals of CSO regulations as well as cities implementing other environmental programmes.

Philadelphia's Green City Clean Waters programme

Philadelphia has received national acclaim for its commitment to implementing a green stormwater management approach in its Combined Sewer Overflow Long-Term Control Plan Updated (Philadelphia Water Department 2009a), also known as Green City Clean Waters. Over the 20-year programme timeline, the PWD will invest approximately $2 billion to green more than 4000 acres of impervious surface. Policy approaches employed by the PWD include stormwater regulations mandating GSI in new development and major retrofit projects. In 2009, PWD also phased-in stormwater parcel-based billing, which charges a monthly stormwater fee based on each parcel's amount of impervious surface. This utility fee is meant to act as a financial incentive to motivate property owners to undertake voluntary GSI retrofits. The carrot counterpart to parcel-based billing is the stormwater management incentive programme grant, which provides up to $100,000 per impervious acre for eligible projects on non-residential properties (Philadelphia Water Department, nd). In addition, the PWD identified eight collaborative approaches (i.e. Green Streets, Green Schools, Green Public Facilities, Green Public Open Spaces, Green Industry, Institutions, Commerce and Business; Green Driveways; Alleys and Green Parking, and Green Homes) to implement GSI on publically and privately owned lands. To date, the PWD has initiated several programmes including for example modifications to the zoning code to include green parking standards, development of a Green Streets Design Manual, campus design guidelines, and identification of stormwater management enhancement districts targeting multi-property areas such as universities and business parks. To help identify potential community partners, the PWD created the Community Input website allowing stakeholders and community-based organisations to identify schools, recreation centres, parks, public spaces, and parking lots where they would like to see green stormwater projects implemented.

Since the inception of the programme in 2009 through May 2015, 370 GSI projects have been implemented. In order to understand the spatial distribution, the authors obtained geographic information systems (GIS) data from the PWD and then analysed the data using ArcGIS desktop software. The analysis was done for residential census tracts[1] that fall within Philadelphia's CSO areas. Three separate analyses were run: public GSI implementation, regulatory-driven private GSI implementation, and voluntary private. Each analysis was run to determine the count of GSI projects per census tract. The GSI project data were available both as points and polygons.[2] After allocating the PWD's data to census tracts, the tracts were classified into five classes (1–5; lowest to highest) using the natural breaks methodology in ArcGIS. Figure 1 presents the spatial distribution and ranks of census tracts (1–5) of GSI projects in Philadelphia's CSO area. From left to right, the maps show all GSI projects, public GSI projects, and private GSI projects.

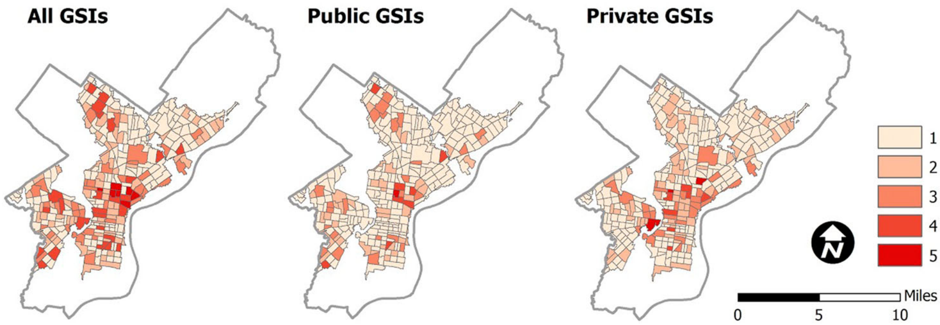

Figure 1. All, public, and private GSI projects.

Neighbourhood dynamics and urban environmental management

This study seeks to understand how neighbourhood characteristics may influence the implementation of urban environmental management programmes. In doing so, it draws from the literature on environmental justice, environmental planning/sustainability, and community development to ground the selection of variables. Historically, environmental justice has been associated with overburdening poor and minority populations with environmental toxins related to locally unwanted land uses, with income and race being the key characteristics to define disadvantaged communities (Cutter 1995, Bullard and Johnson 2000, Bowen 2002). However, more recent scholarship (Agyeman 2005, Heynen *et al*. 2006, Wendel *et al*. 2011, Davis *et al*. 2012, Jennings *et al*. 2012, Walker 2012) claims unequal access to the environmental goods, for example, green spaces and their quality of life benefits, is an environmental justice concern too. This emerging body of research also tends to focus on assessing two aspects of the neighbourhood context: minority composition and poverty. While these core community characteristics have been used consistently over time and align with how the EPA characterises environmental justice populations (U. S. Environmental Protection Agency 2015), more recent studies include additional variables to understand factors that may influence variation in the distribution of environmental goods as well as impacts on other types of disadvantaged populations. For example, elderly, youth, and single parents were additional indicators of disadvantaged populations used to assess populations with marginal access to traditional green spaces in East Tampa, Florida (Wendel *et al*. 2011). A recent study spanning the fields of public health and urban environmental management showed strong relationships with documented heat-related deaths and neighbourhood effects, which were measured as concentrations of populations of minorities, poverty, low education attainment, elderly, and elderly and living alone. In addition, the authors uncovered correlations between high concentrations of minority and poverty populations with unvegetated areas suggesting that these populations were more vulnerable because their neighbourhoods lacked the outdoor cooling effects, an environmental benefit of vegetation (Harlan *et al*. 2013).

Heynen *et al.* (2006) also assessed correlations with rentership and vacancy, based on the argument that low-income neighbourhoods are impacted by the process of disinvestment, and showed that residential disinvestment has a negative effect on the distribution of urban trees in Milwaukee. Other indicators of long-term disinvestment are high levels of neighbourhood problems and social disorder such as vacant land/buildings, crime, prostitution, and substance abuse (Foster-Fishman *et al*. 2007). Lack of economic mobility for lower-income children, which perpetuates disadvantage in communities, has recently been shown to be strongly correlated with communities with higher percentages of single-parent households, racial and economic segregation, and income inequality (Chetty *et al*. 2014). Finally, Robert Sampson's (Sampson *et al*. 2002, Sampson 2008) ongoing research related to problem behaviours and health-related outcomes suggests that there are geographic "hot spots" characterised by concentrations of multiple forms of disadvantage (i.e. poverty, race, single-parent households) (Sampson *et al*. 2002). Although the majority of studies view these community characteristics as constraints, it is important to note a handful of studies have revealed that neighbourhood problems, high levels of social disorder, and crises can precipitate individual and collective activism (Goodman *et al*. 1998, Foster-Fishman *et al*. 2007).

Table 1 highlights the socioeconomic variables that were deemed most relevant to characterising disadvantaged neighbourhoods in this study.

A community's capacity to participate and act as an effective partner in collaborative approaches to community change also is relevant to understanding the success of urban environmental management programmes. Sustainable development and environmental justice advocates agree that community participation in environmental programmes such as green spaces planning better integrates social and environmental quality outcomes (Beatley and Manning 1997, Agyeman 2005, Wheeler 2013). However, a city's commitment to civic environmentalism does not ensure that all populations can participate equally, largely because disadvantaged populations have diminished capabilities to participate or preferences for alternative modes of participation. An assessment of coalition building and the formation of collaborative structures in eight communities participating in a healthy community initiative found that demographic and economic characteristics influenced who participated in a coalition, who was hired, and how coalitions functioned (Kegler *et al*. 2010). A follow-up study (Kegler *et al*. 2011) confirmed that economic issues, socioeconomic differences, language barriers, and immigrant status inhibited participation in coalitions.

Assessments of community development, community leadership, and capacity building programmes (Emery and Flora 2006, Apaliyah *et al*. 2012, Mountjoy *et al*. 2014, Mandarano 2015, Meenar 2015, Monroe *et al*. 2016) demonstrate the utility of using community capitals, an asset-based model, to define and develop measures of community capacity. Assessments using community capitals stem from Ferguson and Dickens' definition of community development as a process that " … produces assets that improve the quality of life for neighbourhood", in which the assets are physical, intellectual and human, social, financial and political capitals (1999). The community capitals framework (CCF), established by the National Rural Funders Collaborative, builds on this conception of community development and provides a system to measure increases in " … seven different components of community capital: natural, cultural, human, social, political, financial and built capitals" (Emery and Flora 2006). The CCF serves as a sound foundation to build a rubric for assessing the characteristics of communities that can attract investment in the form of green infrastructure.

Table 2 presents the seven capitals that comprise the CCF, definitions drawn from the literature, the variable used in this study to measure each capital, and the corresponding data source. Due to the EPA grant limitations on human subject research, data for the variables are limited to secondary sources. Thus, the authors were unable to measure social capital because this would have entailed

Table 1. Community context variables.

Variables	Data	Data source
Minority	Per cent minority population	American Community Survey (ACS), 2012
Black	Per cent Black/African-American alone	
Hispanic	Per cent Hispanic alone	
Asian	Per cent Asian alone	
Poverty	Per cent of individuals below poverty in last 12 months	
Single parent	Per cent of single-parent households	
Violent crime	Density of violent crime incidents	Philadelphia Police Department, Stage 1 Crimes, 2013
Vacant	Per cent of total acres per census tract that are vacant	PWD Parcels Data, 2014
Single parent	Per cent of single-parent households	American Community Survey (ACS), 2012
Income inequality	Income inequality	

Table 2. Capacity definitions, variables, and data.

Capital	Definitions	Variables	Data	Data source
Human	Individual's knowledge, leadership skills, education, attitudes, and other characteristics (Chaskin 2001, Scheffert 2007, Apaliyah *et al*. 2012, Apaliyah and Martin 2013) that enhance productivity (Putnam 2000) and when created enable individuals to act in new ways (Coleman 1988).	Bachelor degree+	Per cent of population over 25 with bachelor degree or higher	American Community Survey, 2012
Social	Networks of relationships that enable individuals and communities to build other capitals and to advance their interests by accessing resources (Coleman 1988, Emery and Flora 2006, Green and Haines 2012)	Not Measured		
Cultural	Norms: sense of community or duty, commitment or responsibility to serve and improve the community (Chaskin 2001, Briggs 2004, Lelieveldt 2004, Apaliyah and Martin 2013, Mountjoy *et al*. 2014).	CPI Graduates	Number of CPI graduates in a neighbourhood	Philadelphia City Planning Commission, CPI
Political	Ability to access power brokers and resources (Emery and Flora 2006) or capacity to access or to influence decision-making affecting quality of life (Green and Haines 2012).	Community Organisations	Count of community organisations	Philadelphia City Planning Commission, Philadelphia Association of Community Development Corporations, Philadelphia Federal Reserve
Financial	Monetary resources available to invest in the community (Ferguson and Dickens 1999, Emery and Flora 2006).	Median Income	Median household income ($)	American Community Survey, 2012
Built	The physical assets, infrastructure, real estate and equipment that support a community (Ferguson and Dickens 1999, Emery and Flora 2006).	Public Property	% of Total Area Per Census Tract that is Publicly Owned	Philadelphia City Planning Commission, PWD
Natural	The natural resources and amenities (Emery and Flora 2006) such as water resources (Etuk *et al*. 2013) and green space (Emery and Flora 2006).	Green Space	% of Total Area Per Census Tract that is Natural Green Space	Philadelphia Parks and Recreation

conducting surveys or interviews to determine networks of relationships between individuals or organisations that are relevant to implementing GSI.

For both context and capacity variables, the raw data were processed using ArcGIS to allocate values to census tracts within the CSO watershed. Then the tracts were classified into five classes (1–5; lowest to highest). Figures 2 and 3 present the spatial distribution of census tracts and indicate an inequitable spatial distribution of community context and capacity, respectively. The following section presents a statistical analysis to highlight the relationships between each of the context and capacity variables and projects implemented under Philadelphia's green infrastructure approach to stormwater management.

Philadelphia's community characteristics and GSI implementation

The primary aim of this statistical analysis is to contribute to our understanding of when a community's characteristics may negatively or positively influence implementation of GSI programmes. This

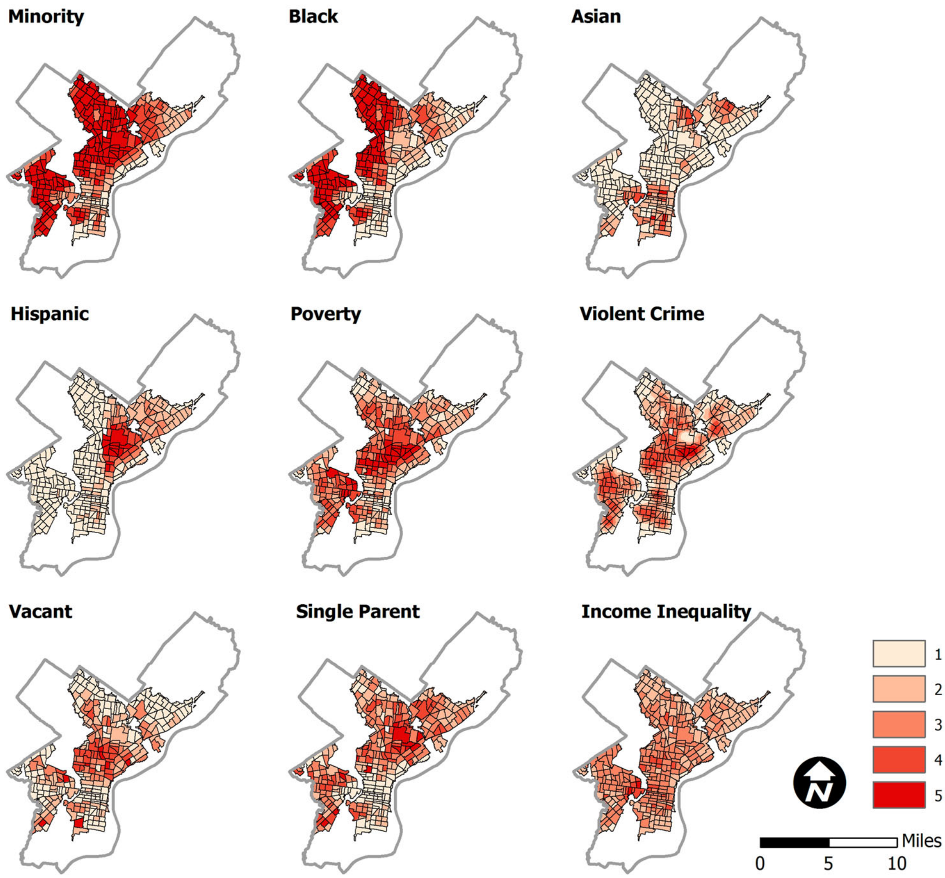

Figure 2. Context variables – Ordinal Ranks of Census tracts.

entailed identifying the associations between the sets of community context and capacity variables with data on GSI implementation at the census tract level. Before presenting these results, it is important to note the limitations of this approach. The context, capacity, and GSI implementation data all were classified (1–5; lowest to highest) for each census tract with Philadelphia's CSO areas as noted earlier. This data processing results in ordinal data (1–5; lowest to highest), for which the best quantitative assessment that could be done is a bivariate correlation using Spearman rank-order correlations. Correlations in the following tables marked ** are significant at the .01 level and * are significant at the .05 level.

Community context and implementation

Herein we consider community context as a basis for explaining the distribution pattern of GSI projects in Philadelphia. This analysis aids in understanding the relationships between the PWD's three policy implementation strategies and variables commonly used to assess environmental justice as well as characteristics of disadvantaged communities that have been shown in the literature to influence engagement in community-based programmes to improve environmental or public health. The following paragraphs review the results of the analysis presented in Table 3.

When viewed from a programmatic level, the first row representing all GSI projects implemented, Philadelphia's GSI programme appears to be inequitably distributed. Specifically, the results indicate that census tracts with higher levels of Minority, Hispanic, and Single-parent household populations

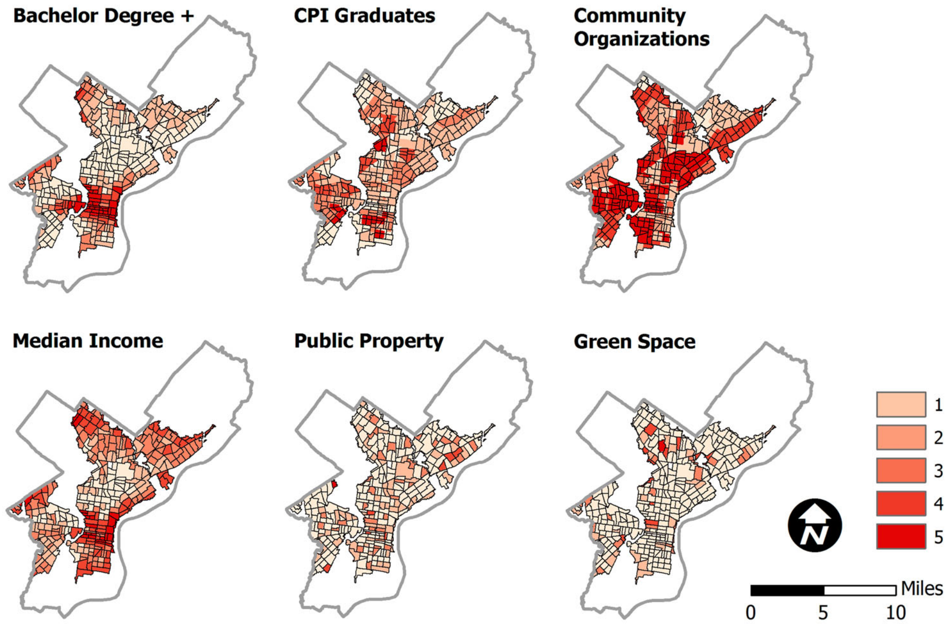

Figure 3. Capacity variables – Ordinal Ranks of Census tracts.

experience lower rates of GSI implementation. It is interesting to note that not one of the policy approaches indicates significant negative correlation with Hispanic populations, but at the programmatic level it becomes a relationship of environmental justice concern. Also worth noting is the positive correlation with Vacant. While vacant land signifies long-term disinvestment in a community, it exhibits a positive correlation in this study because vacant lands and buildings present opportunities for new development, which is required by law to include GSI. Lastly, the positive correlation with Income Inequality is explained below in the discussion of the results for the Private Regulatory policy, which appears to drive this outcome.

Philadelphia's private sector approaches to GSI implementation are leaving minority populations and urban poor underserved, as demonstrated in the second and third rows in Table 3. As noted earlier, Private Regulatory refers to mandated investments in GSI for new development and significant rehabilitations. Private Voluntary refers to a set of programmes that incentivise private property owners to invest in GSI. Both private sector policies are shown to drive the programme's inequitable distribution in census tracts with higher Minority populations. While both private sector strategies have statistically significant negative correlations with Black populations, this relationship is not shown to be significant at the programme level. This suggests that public sector investments moderate this inequitable outcome, although the correlation is not statistically significant. The Private Voluntary has positive correlation with Asian populations and is difficult to explain by the results of this study; however, results from a study on environmental activism suggest that this outcome can be explained by Asian populations having a propensity to have the highest level of policy support and intentions to act in comparison to other minority groups (Lubell *et al*. 2006). The negative correlation between the variables Private Voluntary and Poverty is best explained by Nik Heynen and colleagues (2006) who claim that voluntary implementation is not a successful policy approach in low-income neighbourhoods because property owners are reluctant to invest in upgrades beyond the bare minimum especially in the poorest neighbourhoods that have been impacted most by the process of disinvestment and decay.

Moving further to the right on Table 3 and into the set of additional context variables, both private sector policy correlations are largely consistent with the programme level outcomes. Violent Crime,

Table 3. Context and implementation correlations.

	Environmental justice variables					Additional context variables			
	Minority	Black_AA	Asian	Hispanic	Poverty	Violent crime	Vacant	Single parent	Income inequality
All GSI	−.136*	−.072	.024	−.159**	.037	.031	.169**	−.222**	.162**
	.018	.211	.679	.005	.520	.590	.003	.000	.005
	303	303	303	303	303	303	303	303	303
Private Regulatory	−.153**	−.131*	.079	−.053	.107	−.037	.246**	−.206**	.214**
	.008	.023	.170	.358	.062	.520	.000	.000	.000
	303	303	303	303	303	303	303	303	303
Private Voluntary	−.208**	−.166**	.128*	−.072	−.135*	−.047	−.043	−.282**	.048
	.000	.004	.026	.213	.019	.414	.455	.000	.407
	303	303	303	303	303	303	303	303	303
Public	.058	.087	−.137*	−.096	.050	.094	.125*	.045	.011
	.318	.129	.017	.097	.382	.102	.030	.438	.850
	303	303	303	303	303	303	303	303	303

*Correlation is significant at the .05 level (two-tailed).
**Correlation is significant at the .01 level (two-tailed).

an indicator of social disorder due to long-term disinvestment (Foster-Fishman *et al*. 2007), is not shown to influence private sector implementation. While vacancy also is associated with long-term disinvestment in a community, vacant buildings and land present opportunities for reinvestment in the form of new development and rehabilitation. There are roughly 40,000 vacant lots and buildings in Philadelphia, 70% of which are privately owned (PHILADELPHIA, C.O.). The results in Table 3 reflect the impacts of recent regulatory mandates (Philadelphia Water Department 2006) to include GSI facilities to reduce stormwater run-off in all new development and major rehabilitations. Tracts with higher populations of Single-parent households appear to be marginalised with respect to implementation of GSI projects and the associated benefits. This result is similar to an earlier study on the distribution of green spaces in East Tampa, Florida, which found single-parent households experienced marginalised access (Wendel *et al*. 2011).

The last variable assessed is Income Inequality, which exhibits a positive relationship with Private Regulatory. The variable Income Inequality is included in the study as an indicator of disadvantaged communities and a potential indicator of census tracts undergoing gentrification. This study employs a similar definition as used by Hwang and Sampson (2014) who defined gentrification as reinvestment that attracts the in-migration of wealthier residents and does not include displacement. A comparison of development patterns and assessments of gentrification in Philadelphia indicate that new development and gentrification are occurring in the same neighbourhoods on the fringe of previously gentrified neighbourhoods and within a two-mile radius of the central business district (Ding *et al*. 2015, Macaig 2015).

The negative correlations observed in relationship to the PWD's policies that mandate private sector investment in GSI appear to be subject to historic and current economic forces that shape inequities in the built environment. Several studies by Nik Heynen and colleagues (Heynen 2006, Heynen *et al*. 2006) point to a Marxist urban political ecology for the production of uneven urban landscapes that "epitomize past and present structural processes inherent in the urban political economy … " (2006). Philadelphia is not immune to these influences. Philadelphia is commonly referred to as a city of neighbourhoods, which is a moniker that hides the harsh reality that it is a city with a history of ethnic, racial, and economic segregation. Patterns of segregation between 1850 and the 1950s showed that immigrants established ethnic villages or "ghettos of opportunity" close to their work places and black communities tended to be "ghettos of last resort" (Adams *et al*. 1991). These patterns persist today, whether it be through external forces of real estate agents, developers, and political institutions or internal forces of residents such as how they identify with neighbourhoods (Hwang 2015). In addition, the post-industrial decline in the manufacturing economy had a harsher impact on black household incomes than whites and created larger concentrations of urban poor (Adams *et al*. 1991). While there have been ongoing attempts to revitalise Philadelphia's economy and redevelop housing, the successes tend to cluster around the central business district with limited impacts in the neediest neighbourhoods (Adams *et al*. 1991, Econsult Corporation 2006).

The results for public sector investment, last row in Table 3, are less remarkable for their statistical significance; however, as noted above, efforts by the public sector to implement GSI projects appear to moderate some of the inequity resulting from private sector investments. The one ethnic group experiencing lower public investment in GSI as its population density rises is Asian. Prior research on the equitable distribution of green space in Philadelphia, including vacant parcels greened by the Pennsylvania Horticultural Society, a PWD partner for GSI implementation on vacant land, revealed that Asian households have less access to traditional green space and significantly less access to greened vacant lands (Heckert 2013). Negative correlations between the variables Asian and Vacant (not shown) also suggest that there is limited vacant land for public sector GSI projects in tracts with higher Asian populations. On the other hand, the positive relationship with Public and Vacant land reflects the PWD's long history of partnering with the Pennsylvania Horticultural Society and community-based organisations to clean up and green vacant land to enhance neighbourhood stabilisation and to improve stormwater management (Mandarano 2011).

In summary, the overall pattern of GSI investment in Philadelphia suggests that public GSI investment moderates the inequitable distribution of GSI projects resulting from private sector investment. Regulations mandating private sector investment in GSI prompt the inclusion of GSI projects in development, but do not shift the location of development. Thus, development continues to occur in the neighbourhoods in which the private sector sees opportunities for the highest return on investment. In Philadelphia, this is the geography around the central business district where neighbourhoods have experienced prolonged disinvestment and a recent rapid resurgence (Hwang 2015). However, this pattern of investment does not benefit all populations equally. Without a change in policy that directs private sector investment into the more disadvantaged neighbourhoods – tracts with higher levels of Minority, Black, Asian, Hispanic, Poverty, and Single-parent households – strategic public sector investment is needed to establish a more equitable distribution. A framework to guide public sector investment in GSI to achieve more equitable outcomes is presented herein.

Community capacity and implementation

The relationships between indicators of community capacity and implementation of GSI shed light on the community capitals associated with positive neighbourhood change in the form of GSI projects. The results discussed below are shown in Table 4.

At a programmatic level, the first row in Table 4, Human, Cultural, and Political capitals exhibit positive correlations with implementation. However, as noted with the analysis presented earlier, there are important variations in these relationships when viewed from each policy level.

The Privately Regulatory policy approach is shown to have positive correlations with Human and Political capitals. These correlations appear to stem from Philadelphia's development review process, which requires developers to meet with community stakeholder groups under the Civic Design Review for certain types of development. Interpreting the results from this context suggests that residents with higher levels of education are more active in the development review meetings run by local community organisations and more successful in pressuring private developers to provide public amenities such as GSI features. The literature on the community capacity building and engagement supports this interpretation with frameworks that demonstrate how both Human and Political capital are indicators of collective agency to bring about positive change (Chaskin 2001, Emery and Flora 2006, Mandarano 2015). In these studies, increased knowledge and skills enabled community members to become effective problem solvers and leaders, while increased political capital facilitated community change through improved access to resources and influential stakeholders in decision-

Table 4. Capacity and implementation correlations.

	Human	Cultural	Political	Financial	Built	Natural
	Bachelor degree+	CPI graduates	Community organisations	Median income	Public property	Green space
All GSI	**.162****	**.215****	**.171****	.000	.094	.101
	.005	.000	.003	.999	.102	.080
	303	303	303	303	303	303
Private Regulatory	**.132***	.037	**.125***	−.029	.078	−.021
	.021	.521	.029	.616	.175	.714
	303	303	303	303	303	303
Private Voluntary	**.296****	**.237****	.083	**.157****	−.053	.054
	.000	.000	.150	.006	.360	.348
	303	303	303	303	303	303
Public	−.080	**.136***	.088	−.066	**.171****	**.151****
	.164	.018	.125	.249	.003	.008
	303	303	303	303	303	303

*Correlation is significant at the .05 level (two-tailed).
**Correlation is significant at the .01 level (two-tailed).

making processes. Educational attainment, in particular, is a strong predictor of civic engagement (Putnam 2000, Kegler *et al*. 2010, Hays 2015). With respect to Political capital, communities with more informal and formal organisations are engaged in more effective collective action because community-based organisations represent assets community members can easily access such as venues for gathering, leadership, funding resources, and connections beyond the local community including influential decision makers (Homan 1993, Hyman 2002, Emery and Flora 2006). A possible alternative explanation of the positive correlations with Human capital could be new development with GSI leads to gentrification – in-migration of new residents with bachelor degrees, which has recently been identified as an indicator of a gentrification in Philadelphia (Ding *et al*. 2015).

The correlations between community capacity and Private Voluntary GSI implementation indicate positive associations between Human, Cultural, and Financial capitals. Education and income are paired indicators of knowledge, wealth, power, and status and are generally associated with positive environmental quality (Locke and Baine 2015), so it is not surprising to see that both of these variables are associated with voluntary implementation of GSI on privately owned properties. The positive relationship between Human capital could translate into these individuals having developed better knowledge of PWD's incentive programmes for voluntary implementation through better access to the PWD's online resources (e.g. programme websites, social media). In fact, educational attainment is one of the strongest predictors of internet access, use, and skills and a key challenge to digital equality (Department of Commerce 2000, DiMaggio *et al*. 2001, Reddick 2005, Van Deursen and Dijk 2009). Although the PWD also promotes its programme at community meetings, this does not appear to be relevant. Regardless of how Philadelphia properties owners learned about the PWD's initiatives, educational attainment is a strong indicator of demand for green amenities in several studies of investment in tree canopy (Heynen *et al*. 2006, Locke and Baine 2015) and conversion of vacant land to community gardens (Park and Ciorici 2013). Cultural capital, a sense of commitment to improve the community, is measured by the number of graduates from the City's Citizen Planning Institute (CPI) and exhibits a strong correlation with Voluntary implementation. The Philadelphia City Planning Commission initiated the CPI in conjunction with the civic engagement process to update the Comprehensive Plan. CPI is a voluntary 7-week educational programme covering planning, zoning, the development review process, etc., with an elective module on the PWD's GSI programme and incentives available to private property owners. Research on the citizen academy model (Mandarano 2015) shows that graduates of these programmes have a propensity to take actions to improve the community's capacity to take collective action. Individual graduates reported becoming more active in neighbourhood groups, posting flyers about events, cleaning a vacant lot, etc. Actions taken related to green infrastructure improvements included greening a vacant lot and planning to landscape a traffic triangle (Mandarano 2015). This evidence linking planning academy graduates to community action is a logical explanation of the positive association between Cultural and Private Voluntary implementation. Finally, the positive correlation with Financial capital indicates that Voluntary GSI implementation by private property owners, both residential and commercial, is more prevalent in neighbourhoods where household incomes facilitate investment in environmental amenities, non-essential property upgrades.

The PWD's collaborative approach to implementation (see the row Public in Table 4) exhibits strong correlations with Cultural, Built, and Natural capitals. Cultural capital appears to facilitate collaborations with the PWD to implement GSI on public properties. As described earlier, Philadelphians are encouraged to suggest schools, parks, and other public properties they would like to see greened on the PWD's Community Input website. Thus, it is not surprising to see correlations with CPI graduates because they likely learned about this website or other opportunities to collaborate with the PWD to bring GSI into their neighbourhoods. In addition, individuals with stronger sense of community commitments are engaged in advocacy, collaborations, and bringing more services to the community (Chaskin 2001, Mandarano 2015) and through community engagement act as norm setters generating a spill-over effect – a sense of community and duty in others to do something to improve the community – that increases collective capacity (Goodman *et al*. 1998, Lelieveldt 2004). The positive relationships with publically owned property (Built) and green space (Natural) most likely are driven by rules that the limit city agency expenditures to improvements on publicly owned buildings and lands only. To this end, the PWD has developed collaborative programmes to partner with other city agencies and community groups to implement GSI and to use these projects as demonstration sites to educate others of the benefits of greening similar properties throughout the city.

This analysis demonstrates that all six measures of community capacity are related to higher levels of GSI implementation. After reviewing these results, the authors decided to determine how to use levels of community capacity to guide public investment in GSI in disadvantaged communities to achieve more equitable outcomes.

A framework for equitable GSI implementation

Building on the earlier finding that public GSI implementation tends to moderate inequities resulting from market-driven forces, this section presents a framework to guide public sector investment to achieve a more equitable distribution of GSI projects and associated benefits in Philadelphia's neighbourhoods. A strategy that targets communities based on the level of disadvantage alone has limitations because communities have variable levels of capacity to serve as effective community partners for Philadelphia's collaborative approaches to public sector investments in GSI. To address this concern, public sector investment should be guided by both community context and capacity. Herein, we present the foundations of a community capacity-based framework that stratifies disadvantaged communities by levels of capacity and suggests strategies for public sector investment according to level of capacity. Recommendations for capacity building approaches for communities with lower levels of capacity also are outlined in this section.

We propose the three-step framework to prioritise areas for public investment in GSI. This framework is flexible and transferrable to other cities facing similar challenges.

First, identify tracts based on level of disadvantage. Using the same data as used in the prior analysis, the community context variables were processed to identify only medium to highly disadvantaged census tracts within the CSO watersheds. A census tract was considered to house a medium to highly disadvantage community if any of the context variables were ranked 3, 4, or 5. This eliminated census tracts that could not be characterised as having significant environmental justice or disadvantaged populations according to the set of variables used in this study. The resulting map of census tracts is shown in Figure 4.

Second, identify tracts based on level of capacity. Using the same data as used in the prior analysis, the capacity variables were processed to rank census tracks by overall capacity. In this step, we again used raster overlay analysis and arrived at an equal weight sum of the rankings for all six of the capacity variables. Then we reclassified the values into five classes, 1–5. Figure 5 shows the results of census tracts with overall rankings of low to high capacity.

Third, identify priority census tracts based on high levels of disadvantage and high levels of capacity. Next, we combined these two GIS layers to identify disadvantaged communities by capacity. The results are shown in Figure 6, which highlights the basis for an equitable approach to GSI investment by prioritising census tracts with mid to high levels of disadvantage according to capacity to act as effective partners. The dark grey areas indicate census tracts with mid to high levels of disadvantage with the highest levels of capacity. In contrast, the pale grey areas have comparatively less capacity. The white areas indicate census tracts that were not considered to house a significant population of disadvantaged individuals.

The results highlighted in Figure 6 are useful in developing strategies and policies for public sector and possibly private sector GSI investment to achieve a more equitable distribution of GSI projects and corresponding benefits. Herein, we present preliminary strategies for public sector investments

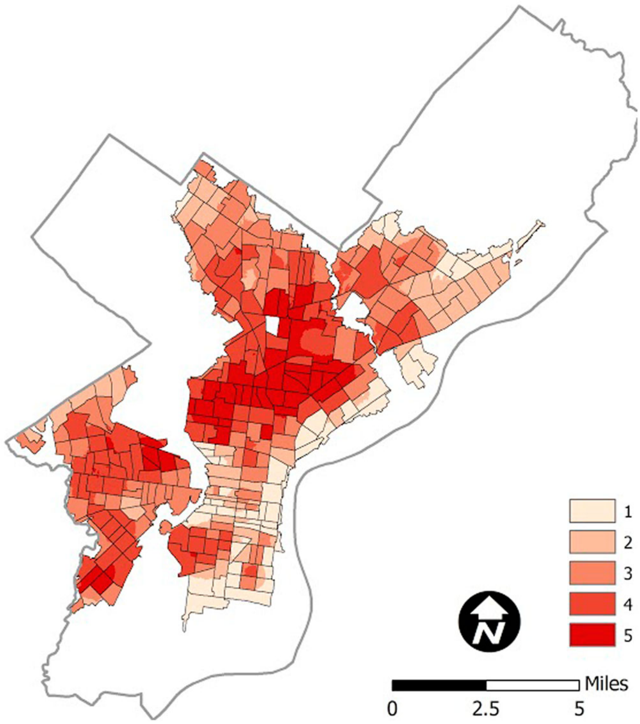

Figure 4. Composite map – context variables.

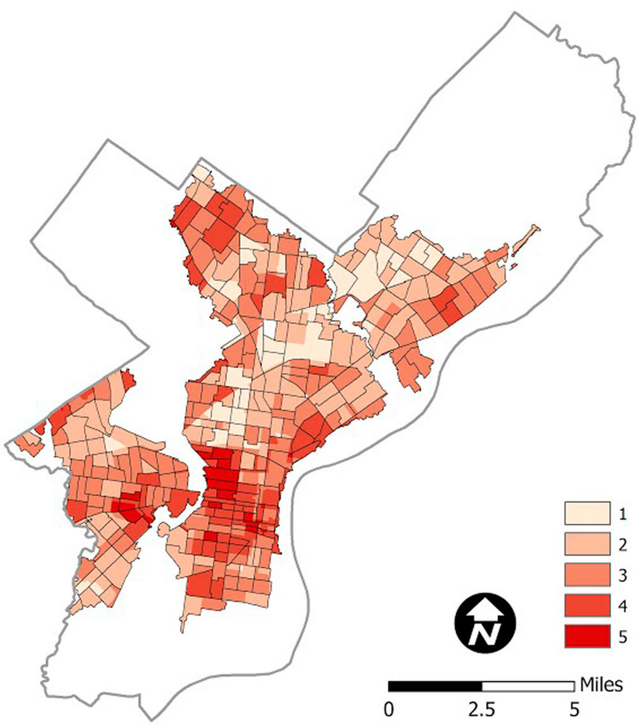

Figure 5. Composite map – capacity variables.

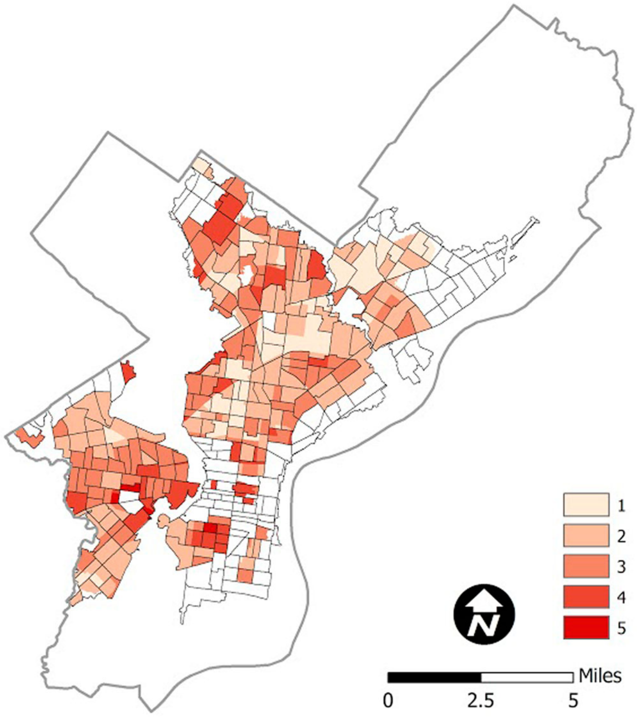

Figure 6. Priority areas for equitable GSI distribution.

that correspond to the capacity of mid- to high-level disadvantaged communities. The strategies outline broad approaches not only to implement GSI but also to build capacity.

- *High capacity*: Public sector organisations should seek to work directly with community leaders in the disadvantaged communities having the highest levels of capacity. The dark grey shades indicate that these disadvantaged populations have the highest levels of capacity based on the variables assessed. This means that these areas of Philadelphia are served by multiple community-based organisations and disadvantaged populations with higher knowledge, wealth, and sense of commitment to improve neighbourhood conditions.
- *Mid capacity*: Communities with mid-range rankings, medium shades of grey, are characterised as not having the inherent capacity to be effective partners with public sector organisations to implement GSI. Thus, it is recommended that the PWD partner with local-community-based organisations and external capacity building organisations already working in these communities to develop strategies that raise the level of capacity specific to implementing GSI projects. For example, this could involve developing CPI programing in these neighbourhoods, with electives relevant to GSI implementation. This is recommended in addition to the current CPI programme that is offered at the Philadelphia City Planning Commission offices located in the central business district.
- *Low capacity*: For the lower ranking capacity communities, lighter shades of grey, the PWD should work with external capacity building organisations to develop general capacity building programming and resources targeted to address other pressing needs. As general capacities grow as will the communities' capacity to take advantage of opportunities to partner with the PWD and others on GSI projects. In addition to the targeted CPI training mentioned above, more general leadership and community capacity building could be developed in partnership with organisations recognised as local leaders in capacity building such as the Philadelphia Association of Community

Development Corporations, which runs a leadership institute. This training would seek to engage local community leaders and volunteers as well as community-based organisations to the extent that they exist.

Conclusion

This work set out to develop a better understanding of factors influencing equity in the distribution of GSI in the City of Philadelphia from the early implementation phase of the city's green approach to comply with CSO mandates. The researchers assessed the distribution of GSI projects through the lens of community context and capacity, which revealed an inequitable distribution. In light of this finding, the researchers developed a framework that prioritises disadvantaged communities for GSI investments in relation to community capacity.

This assessment of GSI practices in Philadelphia yields several contributions that are transferrable to scholars assessing environmental equality in practice and practitioners implementing comprehensive green stormwater management policies as well as other environmental programmes. First, this study contributes to the emerging body of literature on the equitable distribution of environmental amenities including parks, trees, and community gardens (Heynen *et al*. 2006, Wendel *et al*. 2011, Walker 2012, Park and Ciorici 2013, Locke and Baine 2015). While these earlier studies contribute to understanding environmental justice as a lack of access to environmental goods and their benefits, this study examines a broader set of factors, in particular, indicators of community capacity that could influence the variability in placement of green infrastructure. This study reveals that vacant land is an important factor in the distribution of GSI in Philadelphia primarily because it presents an opportunity for new development, which is guided by regulations to include GSI. Moreover, this development is occurring in a fashion that results in environmental inequality as private developers take advantage of the demand for housing adjacent to the central business district, but within neighbourhoods that have experienced decades of disinvestment. This results in lower numbers of GSI projects in neighbourhoods with higher percentages of populations characterised as Minority, Black, Asian, Hispanic, Poverty, and Single-parent households. On the other hand, places with higher levels of capacity are shown to have both higher numbers of private and public sector GSI projects, which suggests that levels of educational attainment, sense of commitment to one's community, and access to community-based organisations influence the effectiveness of individual and collective action to implement green investments.

This study responds to a call for a "revolutionary" approach to implement GSI by targeting investment in the most disadvantaged communities (Dunn 2010). The authors demonstrate how community context and capacity variables can be combined into a framework that prioritises disadvantaged census tracts for GSI investment to achieve a more equitable distribution. The framework enables the prioritisation of disadvantaged populations by levels of community capacity. The framework is based on earlier literature that has indicated community capitals are important to successful community interventions initiated by third parties (Emery and Flora 2006, Monroe *et al*. 2016). As cities adopt and implement this prioritisation framework, the triple bottom line benefits of GSI will enhance the quality of life of residents who tend to have the most compromised accessed to environmental amenities.

To further enhance on-the-ground implementation of GSI, additional research is needed to refine the prioritisation framework and inform implementation strategies. Typically, the planning of GSI projects is based upon the assessment of multiple stormwater management factors such as site characteristics and location as well as GSI performance. Site characteristics may include parcel size, land use, land cover, hydrologic soil group, and land ownership. Location factors tend to include location within a CSO versus non-CSO watershed, nearby impervious surfaces, proximate flood hazard risk, and topography. GSI performance factors may include catchment area, expected stormwater volume detention/reduction, stormwater quality, cost, project lifespan, and degree of vegetation.

Future research should focus on establishing a connection between these traditional stormwater management criteria and the proposed community capacity-based framework to prioritise investment in disadvantaged communities. In addition, the proposed priority framework could be enhanced in future studies. For example, multiple criteria can be used to assess each of the context and capacity variables to develop a richer analysis than this exploratory study. In addition, surveys and interviews could be conducted to assess social capital, which was a limitation of this study due to the funder's restrictions on human subject research.

Notes

1. Non-residential census tracts (2010) excluded from the analysis were identified using the following methods: (1) US Census Tract 9800 series was utilised to identify tracts that encompass a large area and have little or no residential population such as large parks or employment areas (https://www.census.gov/geo/reference/gtc/gtc_ct.html), and (2) Population density less than 500 people per square mile (https://www.census.gov/geo/reference/pdfs/fedreg/fedregv76n164.pdf). The analysis was further refined to just the CSO area of the city as PWD has a greater incentive to implement green stormwater infrastructure in areas of the city on a CSO system. The residential census tracts GIS shape file was clipped to the modified CSO boundary to create the final geographic boundaries for the analysis.
2. Point data were analysed based on a simple count (number of points per tract polygon). Execution of polygon data was done by performing spatial joins with census tract boundaries (clipped to residential CSO area). Five polygons had to be manually assigned to a tract because they were split between two tract boundaries. They were assigned to the tract in which the centroid of the polygon rested.

Acknowledgements

This publication was developed under Assistance Agreement No. 83555701 awarded by the U.S. Environmental Protection Agency. It has not been formally reviewed by EPA. The views expressed in this document are solely those of the authors and do not necessarily reflect those of the Agency. EPA does not endorse any products or commercial services mentioned in this publication. The authors would like to thank Brian Blacker for his contribution to the GIS analysis while a graduate student in the Department of Planning and Community Development programme and research assistant at the Center for Sustainable Communities, Temple University.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This research has been supported by a grant from the U.S. Environmental Protection Agency's [EPA-G2012-STAR-G1] Science to Achieve Results (STAR) programme. This publication was developed under Assistance Agreement No. 83555701 awarded by the U.S. Environmental Protection Agency.

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