Anthropocene 29 (2020) 100227

Contents lists available at ScienceDirect

Anthropocene

journal homepage: www.elsevier.com/locate/ancene

Hybrid infrastructures, hybrid governance: New evidence from Nairobi (Kenya) on green-blue-grey infrastructure in informal settlements "Urban hydroclimatic risks in the 21st century: Integrating engineering, natural, physical and social sciences to build resilience”

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A R T I C L E I N F O

Article history:
Received 7 February 2019
Received in revised form 25 September 2019
Accepted 27 September 2019
Available online 10 October 2019

Keywords:
Green infrastructure
Urban drainage
Hybrid infrastructure
Governance
Participation
Climate vulnerability
Informal settlements
Community leadership

A B S T R A C T

In expanding informal neighborhoods of cities in sub-Saharan Africa, sustainable management of storm and wastewater drainage is fundamental to improving living conditions. Planners debate the optimal combination between "green" or natural infrastructure, traditional "grey" infrastructure, and "blue" infrastructure, which mimics natural solutions using artificial materials. Many advocate for small-scale, niche experiments with these approaches in informal settings, in order to learn how to navigate the intrinsic constraints of space, contested land tenure, participation, and local maintenance. This paper reports the benefits and limitations of implementing and managing local green, blue and grey infrastructure solutions in an urban informal setting. We studied ten completed public space projects that featured urban drainage infrastructure in the informal neighborhood of Kibera, Nairobi. The analysis drew from ten surveys with project designers and seven semi-structured interviews with site managers. The studied spaces featured different combinations of green, grey, and blue drainage infrastructure that have evolved over years of operation, maintenance, and change in the settlement. All projects featured participation in design, mixed design methods, hybrid infrastructure, and community governance models with potential to interact successfully with municipal actors. Results show that involvement in the co-development of small-scale green infrastructure changed people's valuation, perception, and stewardship of nature-based systems and ecosystem services. These results have implications for the larger scale adoption, integration, and management of urban drainage infrastructure. They also suggest that hybrid systems of infrastructure and governance constitute a resilient approach to incremental and inclusive upgrading.

1. Introduction

Cities in sub-Saharan Africa (sSA) face the intersecting challenges of rapid urbanization (UN-Habitat, 2014), high levels of informality and poverty (Kessides, 2006; Smit et al., 2017; Hove et al., 2013), poor planning (Lusugga Kironde, 2006), loss of green space (Mensah and Roji, 2014), and the impacts of climate change (Cook and Vizy, 2013; Shongwe et al., 2011). However, with around two-thirds of the projected urban area in 2050 yet to be built (Fragkias et al., 2013), these cities have a window of opportunity to address these intertwined urban challenges. Green infrastructure (GI) is a global movement to improve multiple dimensions of urban sustainability (Kabish et al., 2017) which may represent a potential strategic approach (Mguni et al., 2016; Du Toit et al., 2018). Challenges nonetheless include cost (Depietri and McPhearson, 2017), potential ecosystem disservices (Döhren and Haase, 2015),

Abbreviations: CBO, Community-Based Organization; GI, Green Infrastructure; KDI, Kounkuey Design Initiative; KPSP, Kibera Public Space Project; sSA, sub-Saharan Africa; SUDS, Sustainable Urban Drainage Systems.

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http://dx.doi.org/10.1016/j.ancene.2019.100227
2213-3054/

spatial constraints (Ashley et al., 2015), limited cooperation between stakeholders (Wamsler, 2015), and planning and governance boundaries (Mell, 2014).

All cities already have extensive traditional "grey" (or piped) drainage infrastructure, and more is planned. As such, it is critical to understand how GI can interact and integrate with these existing systems (Palmer et al., 2015). Urbanists increasingly recognize the importance of "hybrid infrastructure" as both a practical and financial reality, and as an effective and more comprehensive strategy for climate change adaptation (Muller et al., 2015; Depietri and McPhearson, 2017). Hybrid infrastructure encompasses both green and grey approaches, as well as "blue" infrastructure, which mimics natural systems using artificial materials.

In urban informal areas, managing storm and wastewater drainage is especially important because of high flood exposure and public health impacts, but inadequate governance in these areas presents a significant barrier (Reed, 2004; Armitage, 2011; Mguni et al., 2015; Douglas, 2016; Du Toit et al., 2018). While many have attempted to implement GI in informal contexts, few have successfully navigated the inherent constraints of space, contested land tenure, and the need for local maintenance (Haase et al., 2014; Mguni et al., 2015; Charlesworth et al., 2017). Mguni et al. (2015 and 2016) make the case for starting with "niche experiments" at the "local community scale" by non-governmental actors to demonstrate how GI can work in the informal context. But can such "niche experiments" sustain themselves? Do they inform or influence larger-scale planning and design (Herslund et al., 2017; Diep et al., 2019)?

In this paper, we address this knowledge gap by evaluating ten constructed public spaces in the informal neighborhood of Kibera, Nairobi. Each public space incorporates green-blue-grey drainage infrastructures at the "local community scale". The projects studied are all "community-managed" but also demonstrate political interactions with municipal government bodies, as well as integration with municipal urban drainage infrastructure in certain cases. We interview the designers and managers of these public spaces to understand the benefits and limitations of these community-scale approaches as well as how these local projects interacted with and influenced larger-scale planning and design processes.

The following section outlines the status of research in nature-based solutions for urban drainage and their potential applications in informal settlements as the basis for further defining the research questions laid out in Section 3 and addressed throughout this paper.

2. Conceptual framework: green infrastructure, sustainable urban drainage, and informal settlements

2.1. Sustainable urban drainage and green-blue-grey infrastructures

In a comprehensive overview of drainage taxonomy, Fletcher et al. (2015) establish a relationship between Sustainable Urban Drainage Systems (SUDS), green infrastructure (GI), and other nature-influenced drainage concepts on a spectrum of "Principles" and "Scale" (see Fig. 1), which positions SUDS as set of specific techniques nested within the broader framework and principles of GI. These concepts have recently gained traction in many cities and countries: SUDS have been mandatory in most new developments in Scotland since 2003 (Water Environment and Water Services Act, 2003); South Africa launched its "Guidelines for Sustainable

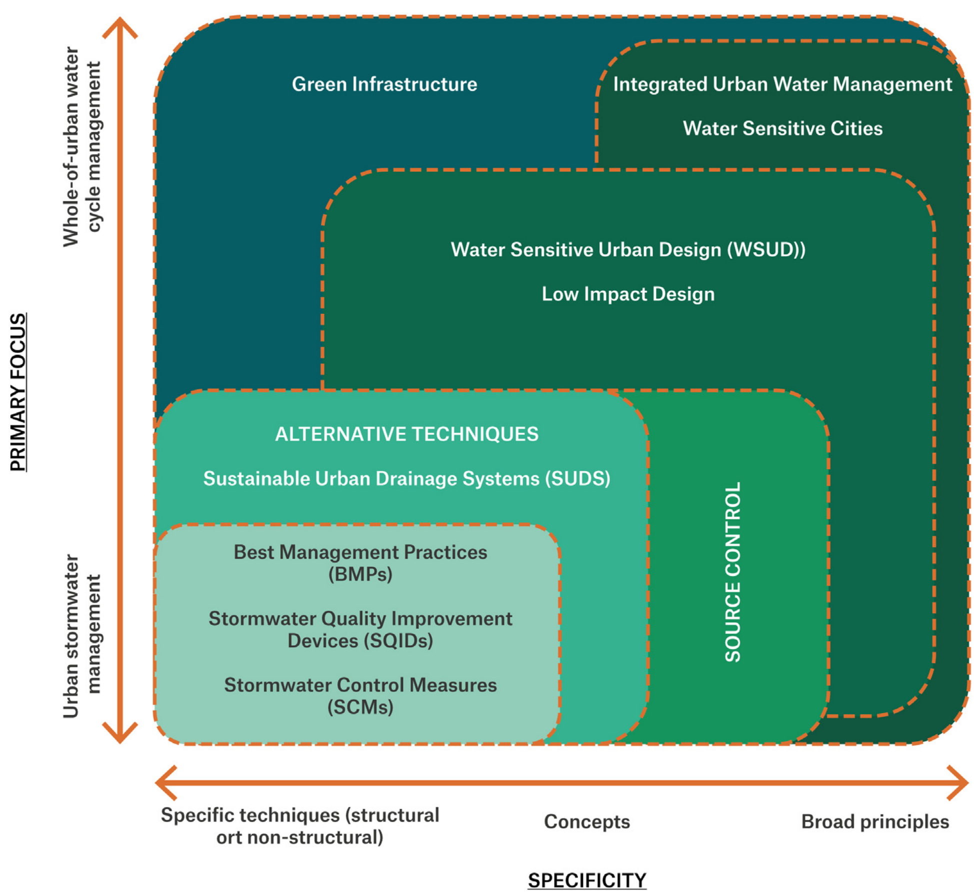


Fig. 1. Relationship between SUDS, GI, and other drainage concepts on a spectrum of "Principles" and "Scale" replicated from Fletcher et al. (2015).

Drainage Systems" in 2013 (Armitage et al., 2013); and many US jurisdictions promote and monitor Best Management Practices (BMPs) to address storm and wastewater pollution (Clary et al., 2002).

An important feature of SUDS is their ability to function within and as complements of other infrastructure systems. Davis and Naumann (2017) present SUDS as a nature-based solution to urban flooding that can be used alongside grey infrastructure. Grimm et al. (2016) describe SUDS as a "hybrid or mixed approach" and Depietri and McPhearson (2017) as "based on ecosystem functions but complemented by engineered infrastructure". This important distinction acknowledges that SUDS may mimic natural systems, but do not necessarily have "green" or nature-based components (e.g. rainwater harvesting mimics natural processes by attenuating flows, but does not include any soil or planting). For Stephenson (2013), such SUDS techniques are "blue infrastructure", i.e. "man-made water bodies and manufactured drainage features". Andoh (2014) sees blue infrastructure as a way to connect the benefits of green and grey infrastructure: especially practical in challenging redevelopment environments such as tightly spaced urban areas. These categories of green-blue-grey are used throughout the paper and data collection.

Challenges facing the wider uptake of SUDS are well documented, with maintenance arrangements and financing, land take, and the role of regulation being most prominent (Fletcher et al., 2015; Ashley et al., 2015). Davis and Naumann (2017) see the need for promoting pilot and demonstration projects of SUDS as nature-based solutions, as well as making the lessons learned and data gathered from existing cases more widely available. Each of these challenges has specific dimensions in the context of African cities.

2.2. Green infrastructure and sustainable urban drainage systems in sub-Saharan Africa

The unprecedented pace and scale of the urban transition in many developing countries outstrips the capacity of local governments to provide the necessary housing, infrastructure, and amenities (Farrell, 2018). In particular, urban green spaces in Africa are rarely prioritized in planning and development processes, and are disappearing at unprecedented rates (Mensah, 2014). At the same time, many recognize that there is a unique opportunity for cities to harness the current wave of urbanization through land-use policies that support the development of a comprehensive "GI approach" (Mguni et al., 2016; Du Toit et al., 2018) and embrace the role of biodiversity (Anderson et al., 2013). Nonetheless, Muller et al. (2015) warn that in the "Global South", "green idealism", often emanating from Northern climes, must be tempered and integrated with the fundamental need for grey infrastructure to promote water security and socio-economic development.

Research into GI in sub-Saharan Africa (sSA) is nascent and varied. Du Toit et al. (2018) produced a comprehensive analysis of 68 reviewed papers, spanning 20 African countries and 74 urban areas, to consolidate research undertaken into urban GI and the associated ecosystem services. Table 1 presents the seven overarching challenges to the sustainable delivery of GI and ecosystem services emerging from the study. While many of the barriers are consistent with studies of GI in other geographies, some of the elements make them specific to cities in sSA–in particular, high levels of informality, rapid loss of urban green space, and shifting and incomplete governance structures. The study also notes the regional and geographical differences across multiple countries and the hydro-climatic conditions within sSA, as well as quite different anecdotal experiences in the formal literature. The additional complexities of urban drainage in informal areas (which make up a large part of these cities) are discussed below.

2.3. Sustainable urban drainage systems in informal areas

The future of global urban development is closely linked to the future of informal settlements, or "slums". Projections show that the 400 million urban dwellers currently in Africa will triple by 2050 (UN-Habitat, 2014). SSA continues to have the highest

Table 1
Seven overarching challenges to the sustainable delivery of GI and ecosystem services in urban sub-Saharan Africa emerging from Du Toit et al. (2018).

Seven Overarching Barriers - Du Toit et al. (2018)	Key Issues in Urban sSA
i Socio-cultural values, traditions and perceptions	• Lack of relevant local (non-monetary) valuation of Ecosystem Services (Du Toit et al., 2018). • Residents have insufficient understanding of the function and value of wetlands and rivers which are often highly degraded (Schuyt, 2005; Suri et al., 2017)
ii Lack of capacity	• Pervasive lack of capacity and expertise for identifying and managing urban GI (Du Toit et al., 2018). • Financial limitations (e.g. Bobbins and Culwick, 2015; Chishaleshale et al., 2015) and this extends into a lack of technological capacity (e.g. Anchang et al., 2016), institutional capacity (e.g. Udoh, 2016) and a deficiency of infrastructure (e.g. Di Leo et al., 2016; Shackleton et al., 2015).
iii Governance, urban planning and social inequality	• Weak systems of formal government and planning (Wilkinson et al., 2013). • Lack of coordination and cooperation at multiple scales: among stakeholder groups, management levels, and institutions (Bobbins and Culwick, 2015; Esmail and Geneletti, 2017; Jorgensen et al., 2015; Sutherland et al., 2016). • Disparities in the availability of green space between established wealthy suburbs, poor suburbs, and new housing program areas (e.g. McConnachie and Shackleton, 2010 in South Africa).
iv Lack of data and/or case studies	• A lack of baseline data on the current provision of ES precludes the establishment of targets and subsequent monitoring of GI projects (Du Toit et al., 2018).
v Ecosystem disservices;	• Perception that urban GI can negatively impact safety (e.g. Richardson and Shackleton, 2014; Shackleton et al., 2015), green spaces present a fire risk (Munien et al., 2015) or sustainable urban drainage systems (SUDS) provide a drowning risk (Mguni et al., 2016).
vi Spatial trade-offs and conflicts	• Population growth, urbanization and limited space cause ever increasing pressure on land, manifesting into trade-off decisions about land use (Du Toit et al., 2018).
vii Climate change	• Poor communities will be the most vulnerable due to their lower adaptive capacity (Bele et al., 2014).

prevalence of slum conditions globally, with the majority of new city dwellers expected to live in slums (UN-DESA, 2015)[1] .

Slums often form on public land along natural drainage paths in many cities, creating a correspondence between levels of poverty and informality, and flood exposure and vulnerability (Lusugga Kironde, 2006; Parikh et al., 2012). The density, imperviousness, and lack of sanitation services in these neighborhoods creates hotspots of local riverine and coastal flooding and related public health risks, while leaving little physical or political space to maneuver (Mulligan and Bukachi, 2017). In future climate change scenarios, potential urban in-migration is likely to increase the already high levels of urban risk, especially flooding (Pelling and Leck, 2018).

Life in informal settlements varies greatly from place to place, as do national government policies and local practices that affect squatters' rights and development strategies (Mitlin and Satterthwaite, 2004). There is a growing international consensus that slums can best serve citizens and nations if treated not as outlaw places to be eradicated, but as emergent communities to be supported through incremental, in-situ slum upgrading processes (Cities Alliance, 2014).

The public health implications of poor storm and wastewater management require that upgrading drainage systems is fundamental to any serious effort to improve wellbeing in informal settlements (Armitage, 2011; Charlesworth et al., 2017). However, the high density of structures, lack of open space, ambiguous legal status, complex social and political dynamics, and limited available resources present major challenges to the development of sustainable drainage systems (Pegram et al., 1999) whether they are green, blue, or grey. Charlesworth et al. (2017) make an explicit connection between stormwater and wastewater drainage in "challenged environments" (informal settlements and refugee camps) and argue for considering drainage alongside the traditional Water, Sanitation, and Hygiene (WASH) programs to create "WASH'D". Many papers and practitioners point towards the potential of SUDS in the specific context of informal settlements (see for e.g. Parkinson, 2002; Reed, 2004, Charlesworth, 2010; Armitage, 2011; Mguni et al., 2016; Charlesworth et al., 2017; Reed, 2017). Parikh et al. (2012) demonstrate the value of nature-sensitive solutions following natural drainage paths to provide water management for slums in India. The residents of informal settlements are encouraged to be proactive and install measures themselves in the absence of government action (Charlesworth et al., 2017), though the financial and technical means for them to do this are not always clear (Mulligan and Bukachi, 2017). Jiusto and Kenney (2016) argue that drainage strategies designed explicitly for informal settlements need to take various upgrading contexts, including community-led, ad-hoc, and systematic upgrading, into particular consideration. Hamann and April (2013) and Mguni et al. (2015 and 2016) emphasize the importance of resident engagement and the role of intermediary organizations in adapting solutions to local context and promoting local stakeholder participation in the design, implementation, and maintenance processes.

2.4. Navigating governance scales: starting small, thinking big

While the evidence base for SUDS is growing globally, challenges to wider uptake remain (Fletcher et al., 2015). In contexts characterized by drainage infrastructure deficits, burgeoning populations, informality, and poor service delivery, researchers point toward the need for more research and practical examples (Mguni et al., 2016). Armitage (2011) cites a lack of skills, holistic design, and funding as the major barriers, but concludes that non-governmental organizations can be a considerable asset in mediating drainage solutions while supporting local authority capacity building.

Lindell (2008) sees the "multiple sites of governance" in sub-Saharan cities as an advantage for experimentation. Indeed, Hamann and April (2013) propose the adoption and implementation of SUDS at a sub-city level, while Mguni et al. (2015 and 2016) make a case for delivering SUDS at a "local community scale": working within local governance boundaries and partnering with intermediary organizations to demonstrate how SUDS can work in informal contexts and build the case for larger-scale interventions. Jiusto and Kenney (2016) suggest the current lack of evidence requires new "partnerships for applied research in different informal settings, and the development of guidance illustrating options, costs, and other social and technical considerations in formats accessible to each stakeholder group".

Herslund et al. (2017) apply a Multi-Level Perspective (MLP) of nested systems (see Geels, 2011) to study GI in sub-Saharan Africa, arguing that transitions toward sustainability can take the form of "regime shifts" driven by "niche innovations [that build] internal momentum to challenge the regime". Pelling and Leck (2018) point to the emergence of multi-level governance arrangements, where highly networked civil society organizations act in concert with local and city authorities as a specific strategy for risk reduction in sSA. At the same time, these multiple sites of governance can lead to confusion and waste. Douglas (2016) identifies three scales of governance and intervention in African cities that are rarely coordinated: i) municipal drainage and floodplain clearance plans; ii) international non-governmental organization (INGO) and consultant-led schemes; and iii) community-based small-scale actions (often for immediate relief and protection). This calls for further investigation on if and how these "niche innovations" and "community-based small-scale actions" can sustain and potentially influence other scales of governance and intervention.

3. Research questions and methodology

3.1. Research questions and hypothesis

Based on the gaps identified in the literature above, this paper aims to address the following research questions:

RQ1: What are the benefits and limitations of implementing nature-based drainage solutions at the "local community scale" in an urban informal setting to navigate the inherent constraints of space, land tenure, maintenance, and participation?

RQ2: What are the implications of "community-managed" and nature-based urban drainage in terms of interaction with municipal governance systems, and for the larger scale adoption, integration, and management of green-blue-grey infrastructure?

Based on anecdotal evidence from the authors' experience and from the literature outlined above, our hypothesis is that there are significant practical benefits of nature-based drainage solutions at the "local community scale" in terms of creating control, ownership, and innovation. However, we also hypothesize that there are limitations, including the need to develop technical capacity among community managers and the costs of maintenance. The methods used to test these research questions and hypotheses are described below.

[1] The terms "slum" and "informal settlement" are used interchangeably in this paper to mean the physical and spatial manifestation of urban poverty and intra-city inequality (following UN-Habitat (United Nations – Human Settlements Programme), 2010). A recent and nuanced exposition of the concept of slums in the African context is given in Smit et al. (2017).

3.2. Overview of methods

This paper addresses the above research questions by analyzing the urban drainage components of ten built projects at various locations in the large informal settlement of Kibera, which together make up the “Kibera Public Space Project” (KPSP). The multiple-case study methodology is based on an embedded approach, with several different cases analyzed through the same structure in the survey and in interviews (after Yin, 2009).

The analysis of the KPSP sites is based on three sets of data: i) ten detailed online surveys completed by six designers ("D1-6") involved in the design and implementation of eight KPSP sites; ii) semi-structured interviews with seven site managers ("M1-7") from five completed projects; and iii) a walk-over survey of all sites to establish the status of urban drainage at that point in time. All data collection was completed between 24th October 2018 and 19th January 2019.

The results, analysis, and discussion in this paper include simple statistics (where multiple respondents responded to a yes/no question) from the surveys, and direct quotes from the surveys and interviews. The codes used to attribute the different surveys and interviews in the text are given in Table 2.

Questions in both survey and interviews were structured according to the seven overarching barriers to green infrastructure (GI) and Ecosystem Services in sub-Saharan Africa (sSA) cities from Du Toit et al. (2018) (and introduced in Section 2.2 and Table 1 of this paper) to elicit responses across the spectrum of issues identified from the cross-section of experiences in urban GI in sSA.

Further detail on the cases, and the methods used in data collection and analysis is given in the subsequent sections.

3.3. Case background

The case projects are all part of the KPSP and located in the informal settlement of Kibera, which is one of the largest informal settlements in Nairobi (KNBS, 2009). Residents of Kibera face many challenges including unemployment, poverty, insufficient water and sanitation infrastructure, poor housing, and high rates of crime and insecurity (Mitra et al., 2017). Fig. 2 shows the location of Kibera with respect to other informal settlements in Nairobi.

The KPSP was developed by the non-governmental design and community development organization Kounkuey Design Initiative (KDI), founded in 2006. Odbert and Mulligan (2015) describe the KPSP as a process of actively involving multiple stakeholders (residents and local authorities) in the creation of integrated projects that activate the latent potential of informal neighborhoods to address some of Nairobi’s most vexing conditions. In a study of bottom-up resilience approaches in Manilla, Nairobi, and Cape Town, Borie et al. (2019) highlight KDI’s “Productive Public Space” model as a means of “combining expert and lay knowledges” for urban development.

The project is also raised in the literature as an example of navigating social and technical constraints in small-scale public space, flood management, and drainage infrastructure. In a study of the potential of GI for flood management in four intertropical African cities, Douglas (2016) highlights the KPSP as a means of creating multi-functional green space while bringing local voices to the fore. Diep et al. (2019) describe the KPSP as a “GI network of micro-interventions” and an opportunity to create momentum for the larger scale development of GI to benefit wider hydrological systems.

At the time of the research, the KPSP comprised ten built spaces (including one in construction) and various combinations of urban drainage infrastructure at various scales (with sites between 100 and 1000 m^2). Nine out of ten are near major watercourses and all are in flood prone areas. The sites have been co-designed by residents and KDI and are all “community-managed” at the time of the research. The development of the projects required collaboration with local and municipal government bodies, and certain sites have connected to municipal infrastructure.

Fig. 3 shows the location of these sites in Kibera and with respect to the Ngong River and its tributaries, and in relation to central Nairobi. Fig. 4 shows pictorial examples of the green, blue, and grey infrastructures from a few of the sites.

3.4. Designers’ survey

The authors issued a web-based survey in October 2018 using the ONA.io survey tool and server to collect information from designers. The target respondents were eight different designers centrally involved in the design of the KPSP projects, going back to 2006. Six of the eight designers responded between October 2018 and January 2019. In some cases, one designer had been responsible for more than one KPSP site and submitted a separate survey for each, and in two cases, two different designers submitted responses for the same site. In total, ten complete survey responses were uploaded, covering eight of the KPSP sites.

Respondents included current and past employees of KDI, as well as previous volunteers and consultants, based in Kenya and internationally. The authors of this paper have all been involved in the KPSP at different times and in different capacities (as volunteers, designers, and employees of KDI). The research is based on inputs provided by designers other than the authors, as well as from the current managers of the spaces (all Kibera residents).

The survey comprised three main sections: i. intent and proposed use of the survey and request for consent; ii) description of the projects and their urban drainage infrastructure components, as well as the stages at which the designer was engaged; and iii) discussion of the challenges and opportunities around Sustainable Urban Drainage Systems (SUDS), with questions structured around Du Toit et al’s seven overarching barriers to GI in sSA cities (2018).

Submissions and results were anonymized. The full survey can be accessed at Enketo (2019).

Table 2
Codes used to attribute the different surveys and interviews to the KPSP sites and in the text.

KPSP Site (in dataset)	1. Designer Surveys	2. Manager Interviews	3. Walk Over Survey	Latitude (degrees)	Longitude (degrees)
1 and 6	D1	M1 + M2	Yes	−1.317387	36.8008243
2	D2	–	Yes	−1.3126749	36.7917223
3	–	–	Yes	−1.3174326	36.7806266
4	D3	–	Yes	−1.3134914	36.7942107
5	D4 and D5	M3	Yes	−1.3164049	36.7836052
7	D6 and D7	M4	Yes	−1.3138253	36.7903242
8	D8	M5	Yes	−1.3142999	36.7933973
9	D9 and D10	–	Yes	−1.3138253	36.784084
10	–	M6 + M7	Yes	−1.3184308	36.7938057

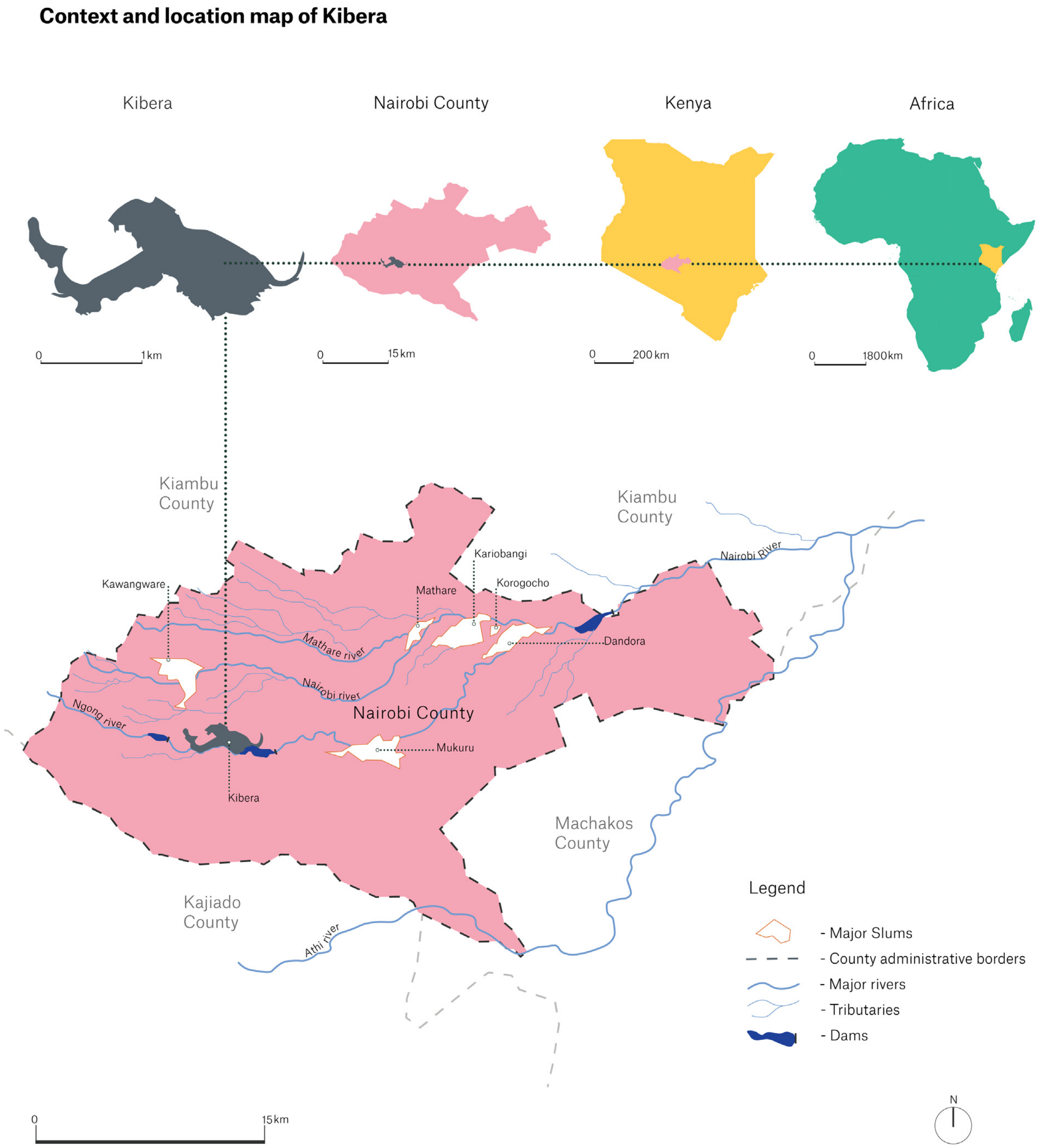


Fig. 2. Location of Kibera Public Space Project sites in Kibera and with respect to the Ngong River and its tributaries, and in relation to central Nairobi.

3.5. Managers' interviews

The second wave of data collection was based on semi-structured interviews with seven managers of five completed KPSP sites. Each of the site managers is a resident of Kibera and a member of the Community-Based Organization (CBO) responsible for maintenance and management of each public space, including on-site infrastructure and drainage systems. Site managers were all involved in the design and construction of the sites.

Like the designer's survey, the interviews were structured around the Du Toit et al. (2018) challenges, though with more flexibility considering the semi-structured format. Interviews were conducted in a mix of English and Kiswahili by two KDI employees in Nairobi between 25th October and 10th December 2018, including one of the authors. Consent was requested after the intent and use of the interview had been explained, and each interview was recorded and transcribed.

3.6. Walk-over survey

In December 2018, the Nairobi-based study authors also undertook walk-over surveys of the sites not included in the managers' interviews to verify the current status of the urban drainage features there.

3.7. Defining green, blue, and grey infrastructure for the study

The following definitions of green, blue, and grey infrastructure (based on the literature in Section 2) were introduced in the survey

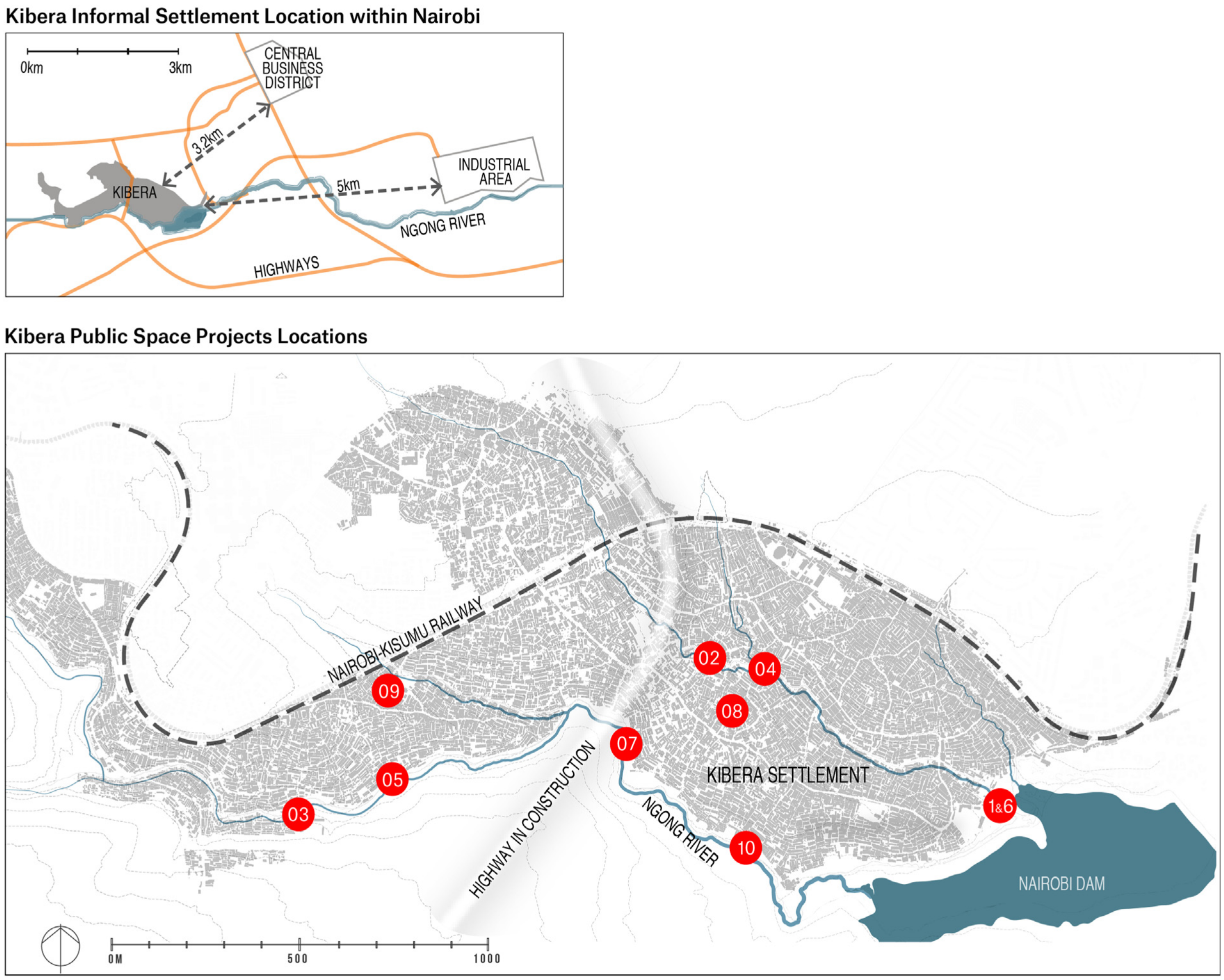


Fig. 3. Location of Kibera Public Space Project sites in Kibera and with respect to the Ngong River and its tributaries, and in relation to central Nairobi (for interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

to guide designers in their classification of the techniques used in the KPSP sites:

> GREEN INFRASTRUCTURE (GI) is an evolving and complex concept, though with the key principles of connectivity, multi-functionality, interrelated and supportive benefits of green (natural and ecological systems), and a systematic (i.e. strategic) approach to landscape management (Mell, 2017). Examples related to Urban Drainage could include: bio-filtration, wetlands, rain gardens, and other natural land and plant-based ecological treatment systems and processes (CIRIA, 2007).
>
> The concept of BLUE INFRASTRUCTURE includes natural watercourses, lakes and ponds, as well as people-made water bodies and manufactured drainage features (Stephenson, 2013). Manufactured drainage features might include the use of small-footprint, high-efficiency devices installed and retrofitted within existing collection systems (Andoh, 2014). These systems often mimic natural processes, though not necessarily including plants (Stephenson, 2013).
> GREY INFRASTRUCTURE comprises conventional piped drainage and water treatment systems. Examples include channeled drainage, piped sewerage, and concrete/stone riverbank protection (Stephenson, 2013).

Table 3 shows a menu of infrastructure techniques given as options in the survey which were derived from the above references. The survey included the option for designers and site managers to add any additional techniques not captured here.

The remainder of this paper refers to GI to capture the breadth of nature-based urban drainage and SUDS approaches.

4. Results

4.1. Principal results of the survey and interviews

We have organized the principal qualitative results from the designer surveys and manager interviews in Table 4. Results are organized vertically per Du Toit et al.'s (2018) overarching barriers to green infrastructure (GI), and horizontally by the research questions. Research Question 1 is split into two columns: one for "benefits" and one for "limitations".

4.2. Urban drainage features in the Kibera Public Space Project

Fig. 5 and Table 5 gives an overview of the urban drainage features (i) selected at concept design, (ii) as built, (from the designers survey) and (iii) as they stood at the time of the interviews and walkover survey in late 2018. We define each technique as one of three typologies - (discharge) point, (soakage) area, or linear (conveyance) - following CIRIA's (2007) definition of Sustainable Urban Drainage Systems (SUDS).

Fig. 4. Examples of the green, blue, and grey infrastructures from KPSP01, 07, and 08.

Table 3
List of drainage techniques delineated as green, blue, grey for the purposes of the survey and interviews.

Green	Blue	Grey
Constructed Wetlands (stormwater)	Rainwater Harvesting (RWH)	Concrete Revetment
Constructed Wetlands (wastewater)	Spring Water Collection	Gabion Baskets
Pervious Paving	Underground Detention/Infiltration	Concrete Channels
Planted Infiltration Pits		Lined Channels
Planted Revetment		City Sewer Connection (wastewater)
Recycled and Planted Tires		Chanelled Overland Flow
Swales		
Vegetated Open Areas		
Tree Planting		
Urban Agriculture		
Soil remediation		
Rain Gardens		
Bamboo Planting (for erosion control)		
Composting Toilet (wastewater)		

4.3. Classification of the scales of governance and municipal interactions

Respondents (both designers and managers) agreed unanimously that the land on which all the projects were developed is "government-owned", and yet that all the projects themselves are "community-managed".

From the responses given to surveys and interviews, we identified three typologies of community-led urban drainage governance represented in the sites investigated:

1 Community Decentralized: Fully community-managed with distinct boundaries
2 Community to Community: Community-managed with inter-site connections
3 Community to City: Community-managed with municipal connections

These typologies are further illustrated in Table 6 and referred to within the analysis and discussion. Fig. 6 gives examples from the Kibera Public Space Project (KPSP) sites that demonstrate these typologies.

The "Community Decentralized" and "Community to Community" governance typologies provide evidence for RQ1 on the benefits and limitations of implementing community-managed and nature-based solutions, and whether such governance models help address the inherent constraints and challenges of the informal context. The "Community to Community" and especially "Community to City" governance typologies provide evidence on RQ2 about the scalability of nature-based solutions and how they might integrate with municipal systems.

Results presented in Tables 4, 5 and 6 and Figs. 5 and 6 are discussed further below with respect to the research questions and wider literature.

5. Discussion

5.1. Research question 1: Benefits and limitations of implementing nature-based drainage urban drainage at the "local community scale"

5.1.1. Green infrastructure stewardship within clear management boundaries

"Kibera is full of shanty buildings. But here we have shady trees. Fresh air in the entire area. A good site for viewing." (M2)

Table 4
Principal results from designer survey and manager interviews, organized according to the Research Questions, and the Du Toit et al. (2018) "seven overarching barriers".

Barrier (from Du Toit et al., 2018)	RQ1 – Benefits	RQ1 – Limitations	RQ2 – Integration
Socio-cultural values, traditions and perceptions	• 5 out of 10 of the designer survey responses selected that community stakeholders had "an understanding of the value and function of wetlands and rivers (natural systems) in general". • Manager 1 (M1): "The bamboo was given us because it is good for the riverbanks. That part where there is bamboo, you can see, that the river bank is good." • M5: "I try to understand the soak pit – it's to avoid flooding and put less water in the drains".	• Seven out of the ten designers thought that there was "a preference among the community for Grey Infrastructure for managing Stormwater". • Reasons given for community preference for Grey Infrastructure from community were 'familiarity' (4 designers), "space" (2 designers), and "ease of maintenance" (1 designer). • Designers 1 and 4 (D1 and D4) felt there was "not enough internal design team knowledge to deliver (green) systems". • D4: "Not only in sanitation but in general, I have found that when given an option, 'bricks and mortar' always wins in community consultations". • D4: "Despite spending many hours explaining, demonstrating, debating and visiting sites of alternative (green) sanitation options, the community still pushed towards grey options. I believe the biggest reason the community rejected a green solution was for fear of having to deal closely with the 'mafi' (waste)". • M6 felt that Green Infrastructure solutions were perceived as being "outside" ideas. • M1 and M2 (from KSP01/06) stated a preference for infrastructure that provided services with a clear revenue return (e.g. water and sanitation).	• In one site (KPSP07) a positive reason was established for the transition from green to grey solutions: "the installation of a new municipal sewer that allowed for a sewer connection rather than a composting solution" (D6).
Capacity	• Six of the designers detailed ways in which "the capacity of local stakeholders with regards to Green Infrastructure management was developed through the design/implementation process". • D4 found that following sensitization during the design process (workshops and project visits) "most community members agreed that the GI systems were helpful and a step in the right direction".	• M1, M2, M3 pointed to the failure of green infrastructure systems on their sites which may have been related to design as well as maintenance. • There was one example from M3 where "green" solutions have been costly to maintain and were subsequently abandoned (the greenhouse at KPSP05). • At KPSP01, D1 stated the lack of "reliable maintenance strategy in place" as a reason for not pursuing a particular GI solution. • With respect to the wetlands for urine treatment at KPSP06 M1 stated "There have been problems but the soil needs to be dug and it can work again."	• The solutions were connected (with approval) to municipal services, but municipal utilities did not maintain the systems post-connection, forcing the community to take over management and maintenance (D3, D7). • At KPSP08, a major blockage in the city-connected sewerage was cleared and a new inspection chamber installed in late 2018, but required technical and financial inputs from KDI to succeed, demonstrating how intermediary support may still required in the absence of municipal maintenance.
Governance, urban planning and social inequality	• It was not feasible to connect the solutions to municipal services. Community members and designers chose decentralized infrastructure instead, and management was also decentralized (D1, D2, D4, D6).	• All seven managers raised the costs of maintenance. • M1 and M2 highlighted the responsibilities and challenges of maintenance, with respect to rainwater: "When the rain stops the tanks empty soon. The gutters need cleaning"; composting toilets: "when we need to clean it can spill"; green open spaces: "the park/gardens need management, the grass has been killed by the floods", and planting: "the bamboo takes the space and needs management to stop it from taking all the land". • At KPSP05, M3 stated: "There were challenges with the greenhouse from the community. It was hard to get the community to contribute [. . .]. We couldn't afford to have security personnel and that was a challenge." • Also M3: "The main costs are to the community. There is maintenance and repairs all the time (sic)." • M7 stated: "It will be costly once the construction is completed. Previously we did some repairs on the drainage, since people were getting hurt from the slope". • D1 suggested that the actual mode of drainage governance was "unmanaged" since routine maintenance was too costly and time consuming. • M1 at KPSP01 (in operation for 8 years) stated: "the water tank will be (sic) the best, this is because it's an income generating activity". The M2 from the same site stated: "the toilet (compost-based) is the best for sanitation and income".	• Designers and managers were unanimous on government ownership of land. • Multiple managers emphasised the precariousness of the arrangement. • Designers were unanimous in saying that the urban drainage systems were managed by the community as opposed to the government or private resident. • M2: "We have been talking with local governments when anything is being done on our site." • M6: "We informed the local administration, like the chief and the member of local assembly, representing this area."
Lack of data and/or case studies	• According to D4 and D6 community members from two sites (KPSP05 and 07) were supported to go and visit to other sites in Nairobi and more widely in Kenya with proposed green solutions.	• D4 stated that technical guidance on green infrastructure was used in KPSP05 from the UK and the US, and D6 in KPSP07 from Kenya and the UK.	• One manager gave the example of a government planting program with limited maintenance provisions: "There was a tree planting project where 10,000 trees were planted. Only 10 are surviving. There has been poor management" (M6).

Ecosystem disservices	• M1: "Bamboo is not a hiding place in our area. They are scattered so it is not our problem."	• D4 and D6 (for KPSP05 and 07) found that there was "a perception among stakeholders that the Green Infrastructure systems proposed could cause problems". The perceived issues were "public health" and "security" respectively. • M3 at KPSP05 raised public health concerns around some of the sanitation options discussed during design: "the safety of some of the sanitation options e.g. composting toilets". Also at KPSP05, evacuation of the selected wastewater septic and wetland system was not maintained, "so going straight into the river was the only option" (M3). • M2 at KPSP06 was concerned about the green infra planting solution at their site: "the bamboo can catch fire easily and can destroy our properties."	
Spatial trade-offs and conflicts	• The infiltration pit at KPSP08 was understood by the M5 to "avoid flooding and put less water in the drains - this avoids conflict with our neighbors". • The design of KPSP09 also emphasized "landscaping the ground to manage localized flooding" (D9). • At KPSP07, where there was slightly more space (300m2), a planted revetment gabion matt was used which, according to one of the designers, "made the site more attractive" (D7).	• Designers of the smaller area sites (KPSP05, 07, and 08) stated that space was a constraint, in particular for selection of sanitation options (at KPSP05). • Designers at KPSP05, KPSP07, KPSP08 and KPSP09 stated that cost was the bigger constraint. • At KPSP01 there was a dispute in 2016 when a part of the site that housed a playground was re-appropriated by the local chieftaincy for a series of buildings. • At KPSP05 (a relatively small site of 200m^2), there was a "lack of space to accommodate proposed solution" and "the community rejected the green concept" (M3). • At KPSP04 (one of the tightest sites – 100m^2), "grey" infrastructure (in this case gabion baskets) was seen by the designer as the only way. "Initially, KPSP04 was completely and consistently flooded. Without our 'grey infrastructure' flood protection solution, there would have been no land to build on at all" (D3). • The "limits of space" and "density of activity" raised by the designer were also factors at KPSP05.	• At KPSP05 and 07, the community and KDI managed to negotiate with the Water Services Board and contractor to re-align the right of way of a new government trunk sewerage line. • At KPSP05, the potential to connect was welcomed given ongoing issues with the existing septic and "green" wetland system: "The group wants to connect to the sewer line. The sewage is currently going into the river" (M3). • At KPSP03, the main structures and green elements were removed during excavation for the same government trunk sewer, and the community is still awaiting compensation.
Climate Change	• M4 and M6 highlighted the value of urban drainage solutions in general (irrespective of type) with respect to flood protection.	• All nine designers reported "local drainage flooding" to be a climate risk on the sites, and seven reported "riverine flooding" as a risk.	

The testimonies of managers from Kibera Public Space Project (KPSP) 01 and 06–the sites with the most "green" elements–clearly illustrate how the group's expertise has developed through managing green infrastructure (GI) over 8 years of operations. Over time, this has led to a trust and appreciation of nature-based approaches:

> "The environment feels like the air is cool, it's green, it gives a good picture of the area." (M1)

At KPSP08, a school and public space for children ages 2 to 14, the school management was already convinced of the value of GI and had a high level of influence over the immediate local boundary, making it possible to test out nature-based solutions:

> "The courtyard gets very dusty and hot so we would like to put pots of plants to cool and reduce dust . . . the kids can have an appreciation of environment." (M5)

The results in Table 4 chime with examples from Andersson et al. (2014) showing how "within-city" GI can offer new opportunities and contexts for people to become stewards of Ecosystem Services. Though the managers at KPSP01 highlight the underlying precariousness of operating in government-owned spaces, there are clearly significant short-to-medium-term benefits to the local community: income generation (in particular from sanitation facilities and urban agriculture); local environmental remediation and risk reduction; improved personal security through controlled landscaping; and lessons for other neighborhoods.

All of the project examples illustrate the importance of clear local governance boundaries in fostering community-managed GI solutions, as well as the crucial role of intermediary organizations that can bring technical expertise. This supports Mguni et al.'s assertion (2016) that creating "spaces of innovation where SUDS [Sustainable Urban Drainage Systems] niche experiments can be done with the active engagement of the local community" can avoid "the barriers that exist at the city government level". At the same time, there is also evidence that these "niche experiments" can influence the city's and government's exposure to SUDS and GI approaches. M1 and M2 reported that KPSP01 and KPSP08 have attracted significant interest and investment from the Ministries of Agriculture and Education respectively. The degree to which they "build internal momentum to challenge the regime" (after Herslund et al., 2017) is not clear. Further work is required to evaluate both the barriers and enabling conditions for these types of niche experiments to create change at a larger scale.

5.1.2. Capacity, maintenance, and internalizing risks

> "The main costs are to the community - there is maintenance and repairs all the time." (M3)

One clear outcome of the community-managed model is that the Community Based Organizations (CBOs) running the sites must internalize management capacity and financial costs related to maintenance. Reflecting the need for maintenance and operations capacity, seven out of ten of the responses from the designers' surveys identified "capacity building among communities for the maintenance of nature-based systems" as "the most important factor" in the successful uptake of explicitly green systems. This is reflected in Bredhauer (2016) who studied the potential of the KPSP to influence transformation and highlights Kounkuey Design Initiative's (KDI) focus on community capacity building and skills transferal through small-scale upgrading measures as the key enabler of local innovations in technology.

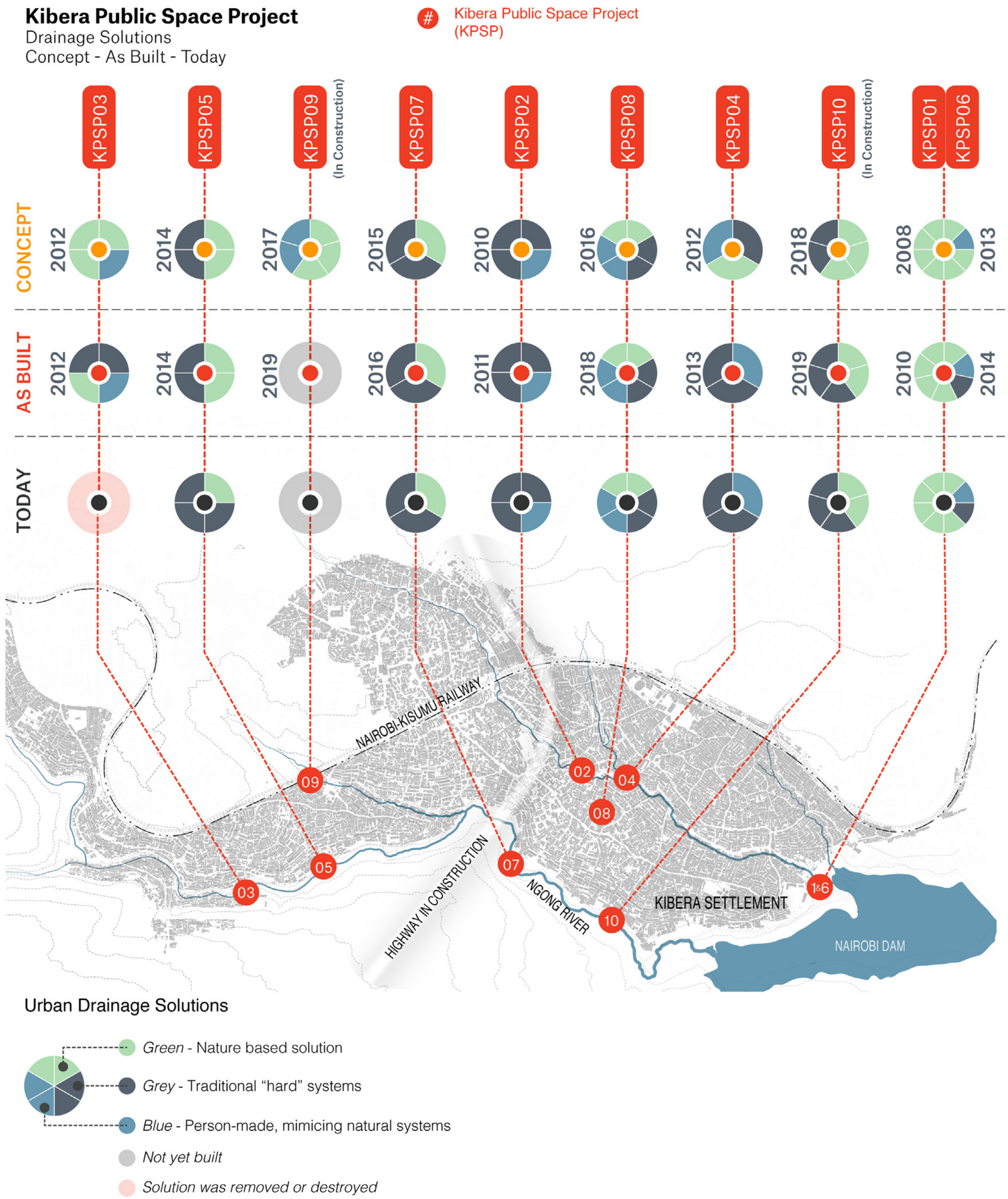


Fig. 5. Overview of the green, blue, and grey urban drainage features based at concept design, as built, and as they stand at the time of the interviews and walk-over in late 2018.

At the same time, all of the interviewed managers mentioned the risks, costs, and burden of maintenance for green systems, with M1 and M3 and (from KPSP01 and KPSP05) noting a number of incidents of failed systems, suggesting a lack of capacity in either design or maintenance. The composting toilet system at KPSP06 in particular was raised as an example of potential public health risk. The significant maintenance requirements of these systems puts a heavy emphasis on the need for extensive and robust capacity development of groups, as well as technical inputs at the design phase. This may not always be replicable which raises limitations to the "community-managed" model in terms of its potential to scale and replicate horizontally.

5.1.3. Green aspirations, grey realities

> "Without our 'grey infrastructure' flood protection solution, there would have been no land to build on at all." (D3)

There is a clear trend from a higher proportion of GI for urban drainage in concept design (48% of proposed drainage features across the sites), to a smaller proportion in the finished, constructed projects (35%), with the still-functioning sites featuring only 33% GI in late 2018. Three out of ten of the designers' survey responses (D1, D4, D7) stated there was a clear movement from emphasizing GI in concept design to choosing grey infrastructure in the final designs and implemented projects (on KPSP01, KPSP05, and KPSP07 respectively).

Table 5
Overview of the green, blue, and grey urban drainage features based at concept design, as built, and as they stand at the time of the interviews and walk-over in late 2018.

Site	Approx. Site Area	Component	Concept	As Built	Today	Typology (— linear, ○ area, • point)
KPSP 01 & KPSP 06	500m2	Surface Water	Swales	Swales	Swales	—
			Vegetated Open Areas	Vegetated Open Areas	Vegetated Open Areas	○
			RWH	RWH	RWH	•
			Composting Toilet	Composting Toilet	Composting Toilet	•
		River Water	Planted Revetment	Gabions	Gabions	—
			Constructed Wetlands	Bamboo Planting	Bamboo Planting	○
		Urban Green	Urban Agriculture	Urban Agriculture	Urban Agriculture	○
			Tree planting	Tree planting	Tree planting	○
KPSP 02	100m2	Surface Water	Channeled Overland Flow	Channeled Overland Flow	Channeled Overland Flow	—
			RWH	RWH	RWH	•
			City Sewer Connection	City Sewer Connection	City Sewer Connection	—
		River Water	Gabions	Gabions	Gabions	—
KPSP 03	200m2	Drainage	Swale	Lined Channel	Solution removed/destroyed be government project	—
			Spring Water Collection	Spring Water Collection		•
		River Water	Bamboo Planting	Bamboo Planting		○
			Planted Revetment	Gabions		—
KPSP 04	100m2	Site Drainage	Channeled Overland Flow	Channeled Overland Flow	Channeled Overland Flow	—
			City Sewer Connection	City Sewer Connection	City Sewer Connection	—
		River Water	Recycled and Planted	Gabions	Gabions	—
KPSP 05	200m2	Site Drainage	Lined Channel	Lined Channel	Lined Channel	—
			Constructed Wetlands	Constructed Wetlands	City Sewer Connection	•
			Rain Garden	Rain Garden	Rain Garden	•
		River Water	Concrete Revetment	Concrete Revetment	Concrete Revetment	—
KPSP 07	300m2	Site Drainage	Lined Channel	Lined Channel	Lined Channel	—
			Channeled Overland Flow	Channeled Overland Flow	Channeled Overland Flow	—
		River Water	Planted Revetment	Planted Revetment	Planted Revetment	—
KPSP 08	400m2	Site Drainage	RWH	RWH	RWH	•
			Planted Infiltration Pits	Planted Infiltration Pits	Planted Infiltration Pits	•
			Underground detention/	Underground detention/	Underground detention/	•
			Pervious paving	Pervious paving	Pervious paving	○
			Sewer Connection	Sewer Connection	Sewer Connection	—
			Lined Channel	Lined Channel	Lined Channel	—
KPSP 09 (in construction)	500m2	Site Drainage	RWH	TBD		•
			Planted Infiltration Pits			•
			Underground detention/			•
			Pervious paving			○
		River Water	Planted Revetment			—
KPSP 10 (in construction)	150m2	Site Drainage	Lined Channel	Lined Channel		—
			Planted Infiltration Pits	Planted Infiltration Pits		•
			Bamboo Planting	Bamboo Planting		○
			Pervious paving	Chanelled Overland Flow		○
		River Water	Gabions	Gabions		—

Multiple responses from designers highlight the limitations of space and the cost of green systems, shown in Table 4. There is one case where the selected “green” sanitation option (and lack of maintenance) led to a negative ecosystem impact (M3). According to the site manager, the longer-term solution to this was connecting to the “grey” municipal sewer introduced adjacent to the site in 2016.

The above pattern may reflect a common experience in design processes: a move from aspirational thinking to more pragmatic solutions based on constraints of space, time, budget, existing conditions and findings on-site, new adjacent infrastructures, and politics. It may also illustrate how green and blue solutions are not appropriate for groups that do not have the capacity or interest to invest in and manage nature-based approaches, nor when a municipal system connection is available.

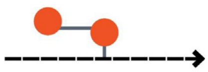
5.2. Research question 2: Interaction with municipal governance systems and the larger scale adoption, integration, and management of green-blue-grey infrastructure

5.2.1. Who governs urban drainage infrastructure in the informal context?

> “For now the management will be the same. In ten years this might change, the government might think of something.” (M1).

Urban drainage infrastructure is typically part of the public realm and traditionally governed by municipal authorities. Summarizing from the perspective of designers, the reasons why the infrastructure systems studied had to be managed by the community fell into two categories:

Table 6
Three typologies of community-led urban drainage governance represented in the sites investigated.

Typology	Governance-model	KPSP Sites (in dataset)	Features
1. Community Decentralised 	Community-managed	1, 2, 6, 10	Distinct local management boundaries.
2. Community to Community 	Community-managed with inter-site drainage connections	4 and 8	Linear infrastructures that expand beyond an immediate local governance boundary - community infrastructure management entity required beyond site boundaries.
3. Community to CITY 	Community-managed with municipal drainage connections	3, 4, 5, 7	Interaction and negotiation with municipal actors required.

1 It was not feasible to connect the solutions to municipal services. Community members and designers chose decentralized infrastructure instead, and management was also decentralized (D1, D2, D4, D6).
2 The solutions were connected (with approval) to municipal services, but municipal utilities did not maintain the systems post-connection, forcing the community to take over management and maintenance (D3, D7).

D4 saw the unreliability of municipal services as a major factor in why "communities wind up managing drainage infrastructure even though they don't technically own it".

A number of the managers emphasized the precariousness of these arrangements: "We are squatters. Anything the government want to do, it is their land" (M3). There was a strong inclination among users to inform local government of their activities, if not to actively involve them. This may reflect the relative lack of government capacity to maintain public infrastructure in informal contexts, as raised in Du Toit et al. (2018). It also suggests a potential pathway for formal "adoption" or acknowledgement of certain infrastructures by local government and municipal authorities through a combination of robust design and community advocacy.

5.2.2. Expanding governance boundaries from the local community scale

The relative scale of the projects and the extent of their connectivity to wider networks of infrastructure delineated the nature of the governance challenges that were experienced – as well as, in some cases, the governance opportunities.

KPSP04 and KPSP08 are examples of linked projects that were community-managed with inter-site drainage connections ("Community to Community" governance typology). This required collaboration between multiple CBOs to manage a linear sewerage infrastructure that links the two sites and multiple residences in-between (see Fig. 6). When the municipal government did not adopt the public and municipally connected system, residents established a community sewer committee to manage the system themselves.

This approach has parallels with that put forward for settlements in South Africa by Jiusto and Kenney (2016), who encourage small-scale experiments that incrementally develop drainage sub-systems, which can then be networked over time as larger-scale resources and planning efforts become available. This incremental networking approach represents an alternative to "raze and replace" upgrading strategies that are more amenable to "standard" drainage practices (Jiusto and Kenney, 2016), and is similar to the "slum-networking" concepts of Parikh and Parikh (2009).

In the KPSP04/08 example, the community cleared a major blockage in the sewerage line and installed a new inspection chamber in late 2018, but this required technical and financial inputs from KDI, demonstrating how intermediary support may still be required in the absence of municipal adoption and maintenance. This highlights the messy realities of networking these physical and governance systems, but also shows the potential for innovation in community-government relationships. Another interpretation is that having one technically and financially able entity responsible for design and maintenance is preferable, and that this cannot necessarily be housed at the community level.

5.2.3. Changing infrastructure landscapes in informal neighborhoods

> "The installation of a new municipal sewer allowed for a sewer connection rather than a composting solution." (D6)

In 2015, the construction of a major sewer trunk line along the Ngong River provided both opportunities and major challenges to completed sites KPSP03 and KPSP05, as well as KPSP07, which was in construction at the time. This provides examples of hybrid green-grey systems as well as multiple intersecting governance models (see Fig. 6).

While M3 at KPSP05 and D6 at KPSP07 saw the value of connecting to the sewer-line (KPSP07 was successful in doing so), the municipality removed the KPSP03 site during excavation for the sewer and neither replaced, nor compensated for it. Anecdotal evidence from managers of adjacent KPSP sites gave reasons such as poor cohesion among community members managing the KPSP03 site and a lack of viable alignment alternatives. This demonstrates the risk of investments in the informal context given shifting land and infrastructure regimes, and the importance of strong and well-situated CBOs if community-managed projects are to sustain and integrate within larger settlement changes.

The flexibility of the systems at KPSP05 and KPSP07 allowed these sites to function in a decentralized way, but also connect to new infrastructure. This is perhaps an example of what Elmqvist et al. (2018) describe as "Urban Tinkering" – the principle of enshrining flexibility in design to accommodate future shifts in function and/or repurposing. While the default approach of government-funded infrastructures may be grey systems, the results show that there are instances when community-managed green systems can connect to and complement larger grey systems.

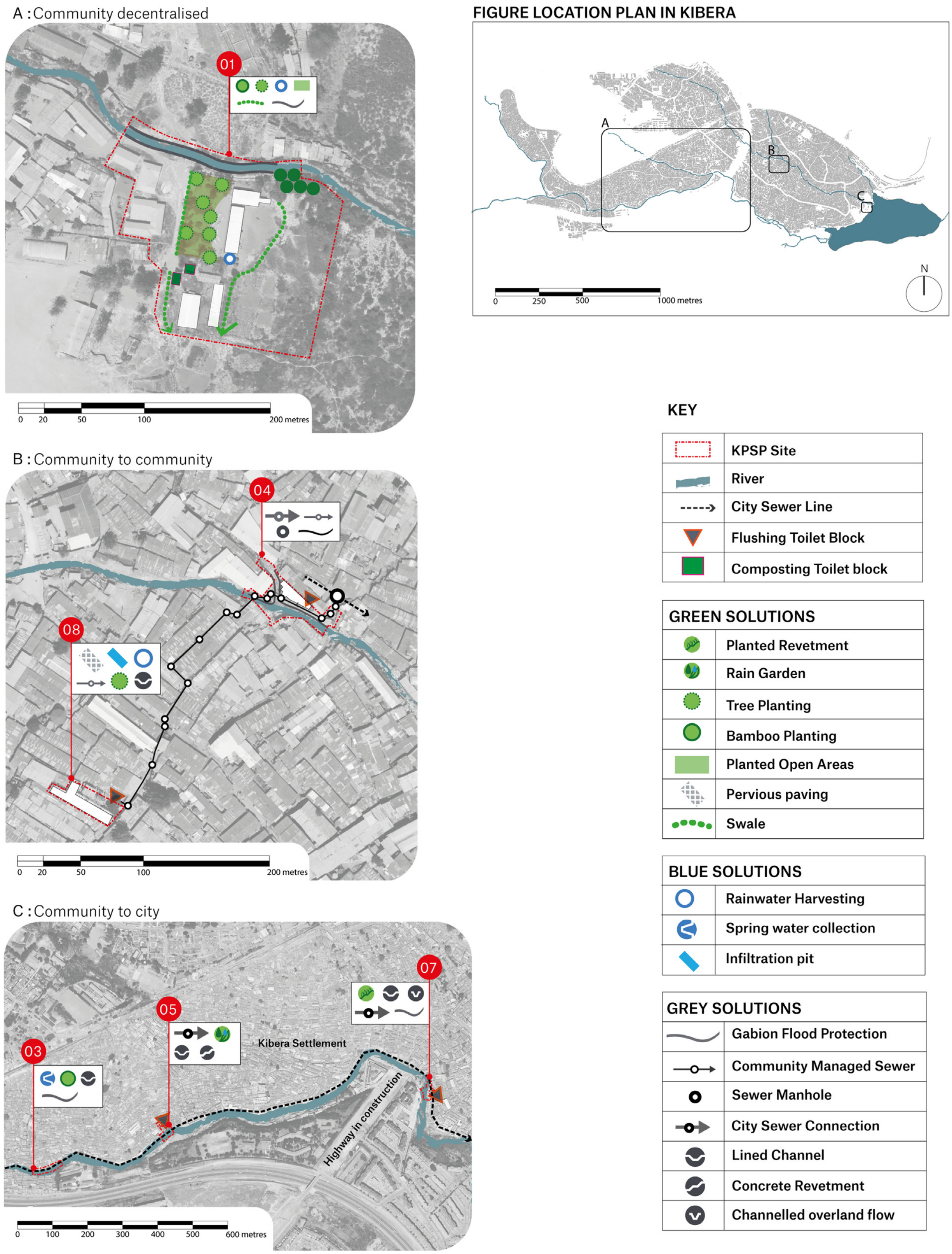


Fig. 6. Typologies of urban drainage infrastructure from different Kibera Public Space Project sites.

The success of these small-scale groups and projects in coordinating with the government points towards a process described by Pelling et al. (2015 and 2018) whereby incremental adjustments can have transformative impacts in urban informal areas. It also corresponds with Lawhon et al.'s (2018) conception of "heterogeneous infrastructure configurations that could nurture a wider urban economy, providing both the context for localised designs to emerge, and to be translated, or exported to be used elsewhere". The case breaks down the idea of "state" separated from "community" and allows for more imaginative and coordinated solutions, reinforcing Sundaresan et al.'s (2017) suggestion that "the governance of complex ecological assets demands a less straightforward relationship between a wide range of social actors in diverse locations of power and capacity".

These changes reflect the increasing pace of municipal infrastructure and service investments in Kibera in recent years, and suggest ways in which local initiatives could intersect with these larger scale processes. Despite its potential to have transformative impact on public health in Kibera, the new sewer trunk line has repeatedly experienced blockages due to flooding as well as questions over its long-term viability. There are issues around its design, planning, and maintenance (see Mitra et al., 2017) as well as the broader need for stormwater drainage and flood risk management to be considered together with wastewater, especially in informal areas (e.g. Winter, 2016; Charlesworth et al., 2017). Emerging examples like the Mukuru Special Planning Area – an integrated resident and government-led upgrading planning process in another large informal neighborhood of Nairobi - point the way toward a holistic consideration of multiple infrastructures and their social, economic, and environmental risk implications (Dodman, 2017; Leck et al., 2018).

5.2.4. Design and maintenance guidance and standards for new systems

"Governance" incorporates design, delivery, regulation, and maintenance of infrastructure (following OECD, 2016). In the context of urban drainage in Nairobi's informal settlements, municipal capacity in all of these phases is sporadic for even conventional "grey" drainage systems. For nature-based systems, it is nonexistent.

Results show how designers of the nature-based systems within the KPSP draw from international guidelines and case studies, alongside design and engineering principles and judgement, to guide their design strategies for urban drainage interventions in specific contexts. This is not an easily transferable process, but could be the first step in considering what standards for adoption of such systems could include. From a municipal perspective, drainage systems must be designed to manage expected rainfall, as well as meet quality standards. Green systems therefore require robust engineering design and monitoring as much as grey systems. Further study could shed light on existing examples of adoption processes for SUDS and other nature-based approaches, considering these in the context of slum and infrastructure upgrading models prevalent in Kenya and other contexts.

5.2.5. Evaluating niche experiments and shifts in large infrastructure planning

To understand the value of these "niche experiments" and to build the case for their larger uptake, careful evaluation before and after the development of test projects could improve trust and knowledge exchange of the piloted systems. Diep et al. (2019) highlight the relevance of an interdisciplinary perspective when evaluating GI interventions, particularly in order to better bridge technical and socio-political factors. Community participation in the planning process for nature-based approaches is key to enabling diversity – and therefore resilience and sustainability – both in the way systems are governed (Wilker et al., 2016), and in the way they adapt to changing functions (Andersson et al., 2017). Evaluating the nature of participation in GI projects in general is important in improving future participation approaches (e.g. Luyet et al., 2012; Wilker et al., 2016). Given the inherent constraints and challenges, the authors consider this particularly important for projects in informal areas and feel it should be built into any evaluation strategy. In particular, understanding how participation influences selection and maintenance of systems, the engagement of municipal actors, and the potential for scaling GI approaches could shed light on how to implement and grow larger hybrid infrastructures.

6. Conclusions

6.1. Conclusions on the research questions and hypothesis

The projects studied in this paper have been successful in building local capacity, appreciation, and stewardship of green infrastructure (GI) at the local scale. Designers and more importantly managers clearly expressed the value of GI, and in many cases, managers transitioned from skepticism to stewardship of GI on their sites. The level of participation in design decision-making (and the transition between different solutions in design and construction) enabled the solutions selected to respond more effectively to community concerns and capacity. Participation in decision-making, as well as building capacity and resources for maintenance of these local drainage infrastructures, has been a factor in their relative longevity and sustainability.

The precarious nature of land tenure in informal contexts limits the long-term benefits of community-managed GI. The relative scale of the projects and the extent of their connectivity to wider networks of infrastructure and governance defined the challenges (and opportunities) experienced. At the scale of full "decentralization" (e.g. Kibera Public Space Project 01), the challenges of green systems revolved around maintenance, revenues, continuity in management, and future precariousness. When projects created linear infrastructures that expanded beyond an immediate governance boundary, questions of wider community engagement and management arose. When the government built major new sewerage infrastructure, there were both challenges and opportunities for adaptation, even transformation, of infrastructure management. The projects demonstrated examples of hybrid green-grey systems, incremental upgrading, and subsequently intersecting governance models.

6.2. Future research and pathways to scale

Much of the literature focuses on the critical need for further interaction between ecologists and landscape designers for creating viable GI (see for e.g. Palazzo and Steiner, 2011; Handel, 2014). We suggest that engineers and community development practitioners are also critical contributors in delivering systems that perform on social, ecological, and technical dimensions, and that convince a wider audience of their robustness. The authors recommend further research and project work to evaluate the effectiveness of specific drainage techniques, which requires setting and evaluating technical performance goals (such as runoff reduction under certain storm scenarios) as well as social and economic outcomes (including the impacts of participatory processes). Overall, there is a need for careful consideration of urban drainage networks within different future scenarios of upgrading, from both a spatial and governance perspective. The networked approaches discussed here suggest the potential for more responsive upgrading approaches that layer drainage, sewerage, access, and public space within existing settlement patterns, rather than a "raze and replace" model. If layers of local knowledge, technical understanding of urban drainage, and integrated planning can be combined with GI as an organizing framework in similar planning processes, the co-benefits of ecological remediation, climate change adaptation, improved services, and local development opportunities could be realized. The efforts of integrated resident and government-led planning processes like the Mukuru Special Planning Area in Nairobi point the way toward realizing these multiple benefits. Demonstrating that GI techniques can function effectively while adding societal and ecological benefits in dense, urban, low-income areas is a starting point for inserting them into larger discussions about the future of informal areas.

Declaration of Competing Interest

The manuscript is an original piece of work and no part of the manuscript has been published before, nor is any part of it under consideration for publication at another journal. There are no conflicts of interest to disclose.

Acknowledgements

Thanks to the designers and managers of the public spaces that contributed surveys and were interviewed for this paper. Special thanks to Amos Wandera and Prisca Okila from the KDI Kenya team for supporting delivery and translation of the managers surveys. Thanks also to Anna Tompsett at Stockholm University and Sara Börgstrom, David Nilsson, and Mattias Höjer at KTH Royal Institute of Technology for highly useful comments and suggestions on the draft paper. Also thanks to Ross Schaffer for graphics support.

Collaboration on the paper was enabled under the Sida and Swedish Research Council funded “Community-Responsive Adaptation” research project in 2017-2019 with Stockholm University, KTH Royal Institute of Technology, Lund University, and KDI. The idea for this paper was sparked at the American Ecological Engineering Society’s 2017 annual meeting in Athens, Georgia.

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