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ORIGINAL PAPER

Sustainable urban drainage systems: examining the potential for green infrastructure-based stormwater management for Sub-Saharan cities

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Abstract Green infrastructure (GI)-based approaches to urban drainage such as sustainable urban drainage systems (SUDS) could provide Sub-Saharan cities with an opportunity to address projected climate change impacts and existing deficits in their drainage infrastructure, even more so due to the synergies between an enhanced green infrastructure stock and sustainable urban development. The objective of this paper was to assess the theoretical value of using green infrastructure for stormwater management as an alternative and supplement to conventional pipe-based stormwater management systems. A SWOT analysis is performed to assess the potential that SUDS hold if adopted and implemented in Sub-Saharan cities. This analysis is based on a review of sustainable stormwater management as well as urban planning and governance literature. Results show that despite seemingly significant barriers to the adoption of SUDS in Sub-Saharan cities such as low prioritization on the urban agenda and lack of data among others, the concept may hold valuable potential for flood risk reduction, even more so due to its multi-functionality and synergies with urban agriculture, amenity and water supply. In the light of the existing threats and weaknesses, it is recommended that GI-based SUDS may be best approached initially as experiments at a local community scale.

Keywords Green infrastructure · Stormwater management · SUDS · SWOT analysis · Sub-Saharan cities

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1 Introduction

Sub-Saharan cities are confronted with two major imminent challenges: the so-called second wave of urbanization and the impending "climate departure" heralding historically unprecedented climate (UN 2012; Mora et al. 2013). The UN predicts that between 2011 and 2050 the world population will increase from 7 billion people to 9.3 billion people. Most of the population growth will be concentrated in cities of the developing world, i.e. Asian and African cities. African cities will experience the highest growth rates, with urban populations likely to treble due to natural increase and migration (UN 2012: 12), further intensifying rapid urbanization and its attendant problems of deficits in infrastructure and unplanned expansion already plaguing these cities (Jha et al. 2011; Parkinson and Mark 2005).

The move from recent climate variability towards a "climate with no modern precedents" (climate departure) is also expected to occur earlier in the tropics (see Mora et al. 2013: 183), which are where most low-income countries lie. This could further worsen the problems in cities in low-income countries. Depending on the carbon emissions scenario[1] used, this means that between 1 and 5 billion people currently live in areas where climate is likely to exceed historical bounds by 2050 (ibid). Projected climate change impacts such as increased incidence of droughts, more intense precipitation and rising sea levels suggest that human welfare will be adversely impacted through changes in food and water supply as well through increased flood risk among other impacts (Jha et al. 2005; Mora et al. 2013). Although local climate change projections for individual cities may still be uncertain, if they are coupled with the projections for a new wave of urbanization, they begin to highlight the vulnerability of urban populations and infrastructure in Sub-Saharan cities to climate change impacts. This further underscores the need for robust adaptation options (Jha et al. 2011) that simultaneously support sustainable urban development goals while helping increase the resilience of urban systems to climate change.

It is being increasingly asserted that one such adaptation option could be the use of the green infrastructure (GI) in the urban landscape to manage stormwater in what is seen as a departure from the conventional pipe-based (also known as grey infrastructure) approach to urban drainage (Kitha and Lyth 2011; Van de Meene et al. 2011). Such approaches are known as sustainable urban drainage systems (SUDS), landscape-based stormwater management (LSM), best management practices (BMPs), low impact development (LID) and water-sensitive urban design (WSUD) among other terms (Fletcher et al. 2014). They consist of "soft" or "green" elements, e.g. green roofs, rain gardens and swales, all of which depend on the natural processes of infiltration, evapotranspiration, conveyance, retention and detention of stormwater using the urban landscape (Fryd et al. 2012). In this article, the term SUDS is used.

Over the past three decades, much research has gone into exploring the applicability of SUDS to cities in developed countries, i.e. USA, Australia and Europe, directed at the biophysical processes, technological aspects, aesthetics, transdisciplinarity, decision-making and institutional aspects of SUDS (see Fryd et al. 2012: 866). There is, however, a growing recognition that SUDS might present a viable adaptation and stormwater management option for cities in the developing world as well (Armitage 2011; Reed 2004). More research therefore needs to be directed towards exploring the theoretical applicability

[1] Representative concentration pathways (RCP) represent contrasting mitigation efforts between a "concerted rapid carbon dioxide mitigation" scenario (RCP 45) and a "business-as-usual" scenario (RCP85) (see Mora et al. 2013: 183).

of SUDS in contexts that may be characterized by drainage infrastructure deficits, burgeoning populations, informality and poor service delivery.

Exploring the value that GI-based approaches like SUDS could offer Sub-Saharan cities may contribute valuable insights to ongoing research on the potential SUDS possess as a no-regrets adaptation option to climate change impacts. It may also widen the scope of appeal of SUDS from being just an urban drainage and adaptation option to include SUDS as an opportunity for cities in the developing world to harness the second wave of urbanization through land-use policies that support the development of a comprehensive GI. Such an opportunity brings with it a possibility of reconstructing this wave of urbanization into a transformation of Sub-Saharan cities from cities of crisis towards resilient cities of the future that are based on an alternative, and possibly more sustainable, paradigm of "watercentric urbanism"[2] (Novotny et al. 2010: 71).

The aim of this paper is to offer a preliminary analysis of the possible value of SUDS to cities in the developing world (mainly Sub-Saharan cities), an analysis which may be useful to urban managers and practitioners concerned with enhancing the resilience of their cities to climate change while still addressing the pressing issues of managing rapidly urbanizing cities. Such a preliminary analysis may form part of the basis for land-use policy engagement and experimentation with SUDS in cities in the developing world. Hence, the main objective of this paper is to assess the theoretical value of using green infrastructure as an alternative to conventional stormwater management in the context of Sub-Saharan cities.

To this end, we perform a literature review of the SUDS concept as presented in sustainable stormwater management literature and then proceed with a SWOT analysis of SUDS, presenting the possible strengths, weaknesses, opportunities and threats to the approach from the perspective of cities in the developing world. The SWOT analysis is based partly on a review of urban planning and governance literature mainly concerned with Sub-Saharan cities as well as sustainable stormwater management literature, illustrated with examples from Sub-Saharan cities such as Dar es Salaam, Accra, Johannesburg and others. The article concludes with recommendations on how SUDS may be approached in such contexts as well as the different issues that need to be taken into consideration when thinking about the possible value that SUDS may hold for Sub-Saharan cities.

2 Using green infrastructure for stormwater management: the concept of SUDS

Urbanization and the resultant process of increasingly impervious surfaces alter the hydrological cycle of an area and lead to increased surface run-off (Butler and Davies 2011: 3). As such, one of the main objectives of urban drainage is to provide flood protection through stormwater management (Chocat et al. 2007). Conventional stormwater drainage, whose main purpose is the rapid removal of all stormwater from the urban landscape, has been found to have some undesirable effects on the urban environment such as lowering the water quality of receiving water bodies due to increased sediment yields and related contaminant fluxes, a decrease in hydrological amenity and an increase in flood risk (Charlesworth et al. 2003: 99). Moreover, conventional stormwater drainage is said to

[2] According to Novotny et al (2010: 71), "water centric urbanism" considers urban waters to be the lifeline of cities, a lifeline that must be managed, kept and restored with hydrological and ecological sustainability as the main goal.

be expensive in terms of the costs of developing and maintaining the infrastructure, while its overall effectiveness as a flood risk management option has also been questioned (Kitha and Lyth 2011).

SUDS are stormwater management systems that are designed to mimic the natural hydrological cycle process by using the natural processes of infiltration, storage, detention, retention, evapotranspiration, conveyance and treatment of stormwater in the green infrastructure of the urban landscape (Fryd et al. 2012; Poleto and Tassi 2012). The SUDS concept has three wide-ranging aims of: 1. reducing the *quantity* of run-off through source control and slowing the velocity of run-off; 2. improving the *quality* of stormwater by providing passive treatment of collected surface water before discharge onto land or a watercourse; and 3. enhancing *amenity* and maintaining *biodiversity* (Charlesworth et al. 2003: 100; Ashley et al. 2011).

As can be seen in the description of SUDS above, green infrastructure (GI) is an integral part of SUDS. GI is defined as "… an interconnected network of green space that conserves natural ecosystem values and functions […] providing related benefits to human populations", flora and fauna (Benedict and McMahon 2005: 5). Unlike the open space planning hitherto used to provide green spaces in urban areas, the GI concept is centred on providing a hydrological/drainage network that compliments and links green space with built infrastructure (Ahern 2007: 267). Furthermore, GI has to be functionally and physically contiguous emphasizing connectivity (ibid; Kitha and Lyth 2011). GI is seen as one way of approaching the sustainability goals of urban areas (Benedict and McMahon 2005) due to the ecosystem services it offers such as the "…moderation of climatic extremes, cycling of nutrients, detoxifying of wastes, maintenance of biodiversity […] and the purification of water and air" (Ahern 2007: 268; Gill et al. 2007). Nonetheless, the reader should note that "…not all SUDS are GI nor are all GI amenable to SUDS" although in general all GI are valuable to the management of the water cycle (Ashley et al. 2011: 16).

What then do SUDS consist of? To achieve the three broad aims of SUDS listed above, SUDS employs four hydrological processes also identified hitherto namely: temporary storage, infiltration into the soil, evaporation into the air and conveyance of the water, as well as treatment of the water (Jensen et al., forthcoming). All SUDS structural elements are thus based on the four hydrological processes. Besides the structural elements that make up SUDS, a very important part of SUDS is that of non-structural elements that are not based on GI, i.e. pre-treatment of the stormwater to minimize the release of pollutants like pesticides, solid waste into the environment (Ashley et al. 2011; Armitage et al. 2012). SUDS structural elements are individually designed to be attached to existing developments, thus complimenting the existing hard infrastructure of the sewer system in what is also known as "retrofitting" (Charlesworth et al. 2003: 100). SUDS elements can also be established in new developments (ibid), thus bypassing the need to provide hard infrastructure for stormwater management in such areas.

SUDS elements, both structural and non-structural, are arranged in a treatment/management train (Ashley et al. 2011; Armitage et al. 2012). The first part of the train is largely non-structural element of prevention or *good house-keeping*, e.g. good solid waste disposal, avoidance of harmful pesticides and recycling of waste water for reuse. The second stage of the train are the *source controls* which try to manage run-off close to its source, e.g. rainwater harvesting, green roofs and permeable pavements. The third stage of the train are the *local controls* which manage water within a local area, e.g. bioretention areas, grassed swales and infiltration trenches. Lastly, *regional controls* handle combined stormwater run-off from several developments, e.g. constructed wetlands, retention and detention ponds. For more details on the individual green infrastructure elements of SUDS, the reader is advised to see Ashley et al. (2011); Armitage et al. (2012).

Inherent in GI-based approaches such as SUDS is the desire to address multiple objectives of economic, environmental and social sustainability (Fryd et al. 2012). The implementation of SUDS requires an understanding, not only of the technical aspects of drainage, but of socio-political, institutional and biophysical contexts of the area in which they are to be implemented (Fryd et al. 2012: 866; Chocat et al. 2007). As such, in order to unlock the full potential of GI-based approaches like SUDS in any context, a highly transdisciplinary approach is essential (Ahern 2007), drawing on professionals from urban planning, civil engineering, hydrology, ecology, landscape architecture and social scientists among others (Fryd et al. 2012). Besides the professionals, who will plan for, design, implement and manage the SUDS, the clients or "locals" are very important actors. This is because they (the larger public) are the end-users of the product; thus, how they view and interact with the SUDS elements is a very important aspect of the implementation and maintenance aspects of any SUDS.

How then should the implementation and management of SUDS be approached? Fryd et al. (2010) suggest that city-wide SUDS retrofits could be best approached through a top-down process with the planning arm of the municipal level taking the lead, while the public is brought in at a later stage or engages in niche-level SUDS experiments. Under such a top-down approach, Ahern (2007): 274–276 suggests that the city could articulate a GI-based spatial and drainage vision for adaptation and urban development. Secondly, those planning and managing the city could employ strategic thinking, seeking ways to integrate SUDS into the city by protecting and using existing as well as new GI for SUDS.

For increased sustainability, Ahern (2007) suggests that GI should be multifunctional enabling varied uses at different times or simultaneously, i.e. implementation of SUDS options suitable for amenity, food production, recreation and water supply. Most importantly, since GI-based approaches like SUDS do not possess the security of empirical evidence that more than 150 years of existence has granted conventional drainage systems, Ahern (2007), Bulkeley and Broto (2012) and Ashley et al. (2012) suggest a learning-by-doing approach that embraces experimentation, knowledge and mutual learning and appreciating the possibility of success or failure. The following section presents the urban water management context in Sub-Saharan cities and how SUDS could be more applicable to such cities than conventional drainage systems have been thus far.

3 The context: urban water management in the developing world

This section presents the context within which urban water management is found in Sub-Saharan cities. Such a contextualization should aid in the assessment of the theoretical value that SUDS may hold for these cities. Although the modern urban drainage system as we know it has been around for at least 150 years (Fryd et al. 2012; Sørensen et al. 2006) in cities in the developed world, cities in the developing world have been struggling to adequately provide urban drainage based on this hard/grey infrastructure paradigm. While many cities in the developing world were first established during colonial times based on the assumption that they would develop in a similar trajectory as those of the developed world, this has proved to be misestimation as third world cities experience a rapid mode of urbanization that is unlike any experienced in the developed world (Watson 2009).

The *rapid urbanization-without-development* (Cheru 2005: 2) that developing cities have experienced has meant that where developed cities were able to provide urban drainage infrastructure that was commensurate with the pace of urban development; Sub-Saharan cities have struggled to keep up with the pace of urban growth (Pastore 2015). This has led to the prevalence of an infrastructure deficit in Sub-Saharan cities that is characterized by an ageing infrastructure that is inadequate in its coverage and unlikely to be renewed and improved adequately in the near future. This situation is so prevalent that some view the most visible manifestation of an urban crisis in the developing world to be the lack of access to urban sanitation and drainage services of the urban poor (Cheru 2005).

As rapid urbanization continues, local governments have continually failed to meet these growing needs due to institutional fragmentation and lack of institutional capacity (UN-HABITAT 2011). As a result, the number of actors in urban governance and development in Sub-Saharan cities has also grown as community and individual household initiatives at the local scale seek to fill in governance gaps by playing vital roles in infrastructure provision, job creation and food security (Lindell 2008; Pastore 2015). This has meant that in many Sub-Saharan cities there are *multiple sites of governance*, at different scales of the city, displaying various modes of power and contestation (Lindell 2008: 1879). It should be noted, however, that when it comes to urban water management and the potential for transition towards such approaches as SUDS, the problem of poor governance seems to be a worldwide phenomenon, i.e. Pahl-Wostl et al. (2010) suggest that in general many problems with the management of water are a result of governance failures.

The rapid mode of urbanization in the context of high unemployment, poor governance and service delivery, as well as weak public institutions has also produced a specific characteristic of *informality* in Sub-Saharan cities (Lindell 2008; Cheru 2005; Watson 2009; Roy 2005). Informality is the outcome when increasing socio-economic inequality confronts the "techno-managerial and marketized" (Watson 2009: 2260) systems of urban governance, thus highlighting the "multiple rationalities" of formal urban planning and management versus informality at work in Sub-Saharan cities (Harrison 2006; Watson 2006, 2009: 2267). In more practical terms, this informality has come about as the urban poor in Sub-Saharan cities pursue a suite of survival strategies in sectors outside the formal structures that govern cities, so as to fill in the service and governance gap. Informality is therefore a major aspect of the urban economy, housing among other aspects of negotiating life in the city; it is the norm in most of the cities in the developing world (Watson 2009; Roy 2005).

As a result of rapid urbanization and the informality identified above, urban development in most Sub-Saharan cities has been uncontrolled as most existing laws are not followed while policies and urban plans do not materialize (Lindell 2008). This has led to widespread settlement on environmentally fragile areas such as flood plains and wetlands, especially by the poor (Kiunsi et al. 2009). There has also been extensive *environmental degradation* as the green infrastructure stock is appropriated for energy supply in informal areas with no formal power supply, while solid waste presents a pollution problem of massive proportions (Dodman et al. 2009; START 2011; Goldenfum et al. 2007). Such settlement patterns coupled with the associated environmental degradation and pollution serve as multipliers of vulnerability to climate change impacts.

It is no surprise then that the appropriateness of conventional pipe-based stormwater management in such contexts has been questioned, especially in the light of the techno-institutional and socio-economic obstacles prevalent in such cities (Kitha and Lyth 2011:

251). In such a scenario, a more sustainable solution to a problem such as urban drainage would need to address multiple goals at once. The following section presents an SWOT analysis of the theoretical potential a GI-based approach to urban drainage such as SUDS could have in the context of Sub-Saharan cities where rapid urbanization, poor governance, informality, environmental degradation and imminent climate departure define urban realities and futures dissimilar to those in the developed world where the approach has so far been employed.

4 Results: a SWOT analysis of the of the theoretical potential SUDS holds in Sub-Saharan cities

In this section, we perform an analysis of the strengths, weaknesses, opportunities and possible threats to the potential that SUDS possesses as a GI-based stormwater management approach in Sub-Saharan cities (see Table 1). This analysis is based mainly on insights pooled from sustainable stormwater management, urban planning and governance literature that has been reviewed. A SWOT analysis is a useful strategic planning tool for mapping and analysing the prospects of an organization or policy (Panagiotou 2003; Helms and Nixon 2010) and in our case, the unit of analysis is the SUDS approach to stormwater drainage. A SWOT analysis of the theoretical value of SUDS in the context of Sub-Saharan cities could provide policy makers and urban management professionals with more accessible knowledge on the possible merits and demerits of SUDS, thus making SUDS a more visible alternative to conventional stormwater drainage as well as supporting initial policy engagement with SUDS.

Table 1 Summary of SWOT analysis of the potential SUDS hold in Sub-Saharan cities in comparison to conventional stormwater management systems based on literature review

Strengths	Weaknesses	Opportunities	Threats
Viable flood risk management option	Difficulty in quantifying performance of SUDS	Augmentation of water supply	Lower prioritization on urban agenda and poor solid waste management
Address triple goals of controlling quantity and quality of run-off and support biodiversity	Operation and maintenance may be costly and require new skills	Support for urban agriculture	Difficulty in convincing decision-makers and lack of data on existing GI, drainage systems
Predicted to be cheaper in the long run	Requires multi-stakeholder decision-making and coordination	May be part of infrastructure upgrading programmes	May become health and safety threats if unmaintained
More adaptive option	Relatively untested approach compared to conventional systems	Opportunity for more inclusive decision-making	Gentrification based on SUDS may lead to displacement of urban poor
Allows for total urban water cycle management	May require large open spaces of land		Multiple rationalities may preclude consensus

4.1 Strengths of GI-based SUDS

Within a SWOT analysis of SUDS, the strengths are the internal advantages SUDS as an approach possesses over the conventional stormwater management approach. A reading of current guides, manuals and sustainable water management literature suggests that there are six main strengths that GI-based approaches such as SUDS possess which give it an advantage over pipe-based systems. One of the main strengths of SUDS is their ability to reduce flood risk as an ecosystem service of GI. Unlike conventional stormwater management systems which seek to remove water as quickly as possible from urban areas, SUDS elements contribute to flood hazard mitigation by reducing and/or delaying surface run-off through storage in the ground or elsewhere, thus ensuring lower flood peaks (Green 2010). According to a simulation carried out for a 12-ha Eastside development in Birmingham, UK, in 2007, green roofs, porous pavements and infiltration trenches may yield an overall run-off flow reduction of 30 % depending on their size, placement and the duration of the rain event (Viavattene and Ellis 2013). While this reduction is modest, it is argued that the highest flood management benefits of SUDS are most likely to accrue if differing combinations of SUDS treatment trains are strategically woven into a wider GI framework within a catchment (Ellis 2013).

Another strength is SUDS' simultaneous consideration and promotion of the three goals of water quantity, water quality and amenity/biodiversity (Ashley et al. 2011). With these triple goals in mind, the ecosystem services that are the result of an enhanced GI are particularly important for the urban poor in the developing world who depend on them for adaptive capacity and for their livelihoods (UN-HABITAT 2011). Therefore, by considering these three goals, instead of just one goal of removing water from the surface as quickly as possible, SUDS could provide cities with an opportunity to progress towards environmental, social and economic sustainability and resilience to climate change impacts (Novotny et al. 2010). While not done explicitly as a part of a SUDS approach, an example of this is the widespread practice of planting elephant grass (*pennisetum purpureum*) in Dar es Salaam as a stormwater management practice that not only slows down runoff and promotes infiltration, it is also used to indicate plot boundaries and beautify yards (Herslund et al. forthcoming).

Thirdly, evidence seems to suggest that using GI for stormwater management could be cheaper than conventional stormwater management infrastructure in the long run, even when capital and operating costs are compared (Ashley et al. 2011: 25). Furthermore, if the environmental benefits of ecosystem services provided are monetized, the net present value of GI could highlight it as a more viable investment option climate change adaptation even for developed cities (ibid; CCAP 2011). For example, the City of Copenhagen has estimated in its climate change adaptation plan that instead of expanding the sewer system as a flood risk management option, by investing in a combination SUDS and backwater valves the city will achieve savings equivalent to just over 1 billion USD (CCAP 2011: 22). Fourthly, if the GI on which SUDS are based are multifunctional and connected as Ahern (2007) recommends, then SUDS have the potential to generate urban form (Backhaus and Fryd 2012). This could mean SUDS serves as a departure point for a newer paradigm of "water centric urbanism" where urban water and its related infrastructures serve as the central concept along which Sub-Saharan cities are planned and managed (Novotny et al. 2010: 5).

Another strength of SUDS is that when compared to conventional grey infrastructure systems in the context of Sub-Saharan cities, SUDS seem to be a more adaptable option in relation to avoiding lock-in to old infrastructure technologies that Sub-Saharan cities are now trying to replace (Swilling et al. 2013). This is especially more so for highly informal cities like Dar es Salaam where the majority of residents have no connections to formal piped water systems and instead rely on decentralized or "self-supplied" water, sanitation and stormwater management services (Pastore 2015). The last strength that SUDS has, in comparison with conventional hard infrastructure systems, is that it presents a more holistic way of addressing urban water management and as such provides more opportunities to close the urban water cycle loop (Armitage 2011) through water harvesting and wastewater recycling. The water storage elements of SUDS could help augment water supply and ameliorate water scarcity problems prevalent in many Sub-Saharan cities (Turton 2002).

4.2 Weaknesses of GI-based SUDS in the context of Sub-Saharan cities

In a SWOT analysis of SUDS, the weaknesses are the possible obstacles internal to SUDS, which would need to be avoided or addressed. The use of SUDS as the main stormwater management approach does present several challenges, and these internal weaknesses of SUDS may need to be addressed in relation to the theoretical value SUDS hold for Sub-Saharan cities. The first weakness is the difficulty of precisely quantifying the hydraulic and water quality improvement performances of GI-based SUDS in the management of runoff, especially at a city-wide or catchment-wide scale (Ashley et al. 2011: 18; Goldenfum et al. 2007). Compared to conventional grey/hard infrastructure, the calculation of flow rates and volumes for SUDS is not an exact science and thus a major weakness for the SUDS approach which increases reluctance among practitioners to employ it (Ashley et al. 2011: 18).

The second weakness of the SUDS approach concerns the maintenance level required for some of the elements. According to Charlesworth et al. (2003), surface elements of SUDS such as swales and dry ponds have a high failure rate unless frequently maintained. Furthermore, such maintenance is costly and requires skills which may not be readily available in developing countries (Armitage 2011). For example, one of the barriers to the implementation of SUDS in the City of Johannesburg is frequently said to be the lack of skills and know-how at stormwater management depot level.

A third weakness of SUDS is the increased complexity that stems from the multi-stakeholder decision-making and the transdisciplinary aspects that are essential to SUDS (Fryd et al. 2010; Ashley et al. 2011: 32). Divergent stakeholder interests and parallel professional views could mean that the process of planning for and designing a SUDS retrofit strategy and implementation is a much more intricate and longer undertaking when compared to the fairly linear process of planning and implementing grey/hard infrastructure (Ashley et al. 2011; Fryd et al. 2010). Moreover, the high level of coordination between different institutions that is required to operationalize and manage SUDS at a city-wide level could be a major weakness considering the sometimes highly fragmented and unclear nature of the institutional set-up in many cities in the developing world (Dodman et al. 2009), for example in Dar es Salaam stormwater and flood risk management as well as urban greening fall under different institutional actors each with varying and overlapping responsibilities, i.e. the three municipalities: the Prime Minister's Office, the National Environmental Management Commission and the Tanzania National Roads Agency among others (see Mguni et al. 2015).

The fourth weakness of SUDS relates to the first: SUDS is still a fairly new science; thus, more research still needs to be done on all its aspects (Fryd et al. 2010; Ashley et al. 2011) including its applicability to Sub-Saharan cities. Furthermore, there are still no clear methodologies to measure the "sustainability" of SUDS, or to truly evaluate the full suite of potential added benefits of using SUDS in an urban context (Benzerra et al. 2012: 46; Fryd et al. 2010; Ashley et al. 2011: 25). The last weakness of SUDS is the inherent requirement for large open urban space by some of its elements and even more so if the functionality and contiguity requirement for the GI are to be convincingly achieved. Many Sub-Saharan cities are already densely developed and have little space available to put aside for SUDS elements especially in informal areas (Green 2010; Armitage 2011).

4.3 Opportunities from GI-based SUDS

From a SWOT analysis perspective, *opportunities* represent the possible external additional benefits that could accrue as a result of the strengths of SUDS. Compared to conventional drainage systems, there are other benefits for urban areas that employ SUDS besides the water management function and ecosystems services that accompany an enhanced GI mentioned above. The possibility of closing the water cycle loop and augmenting water supply is a good opportunity for many cities in the global South, many of which suffer from water scarcity (Turton 2002). As urban populations in Sub-Saharan cities rise, so does the demand for water and other services. This in turn leads to deficits in water supply that are currently difficult to address, and yet such deficits could form the basis for social and political instability if the capacity to adapt to the water scarcity is not cultivated (ibid), while SUDS practices such as rainwater harvesting have the potential to ease the day-to-day difficulties of water supply for informal households during rainy seasons. According to a UNEP report (2005) on the rainwater harvesting potential for 10 African cities, Dar es Salaam has the possibility of harvesting over 5,000,000 m^3 of water per year from buildings alone. Currently, most households in the informal Goba-Kibululu area of Dar es Salaam harvest rainwater yielding between 2 and 12 months' supply of water depending on available technologies (Herslund et al. forthcoming).

The second opportunity that is born out of the possibility of an augmented water supply is the potential support this would have for urban agriculture. Although it is not always legal, most open spaces in Sub-Saharan cities are actually used for urban agriculture, supplying almost half the food consumed in cities like Kampala and Dar es Salaam (Bryld 2003: 79; Simon 2012). In Dar es Salaam, it is estimated that a large proportion of ecosystem service needs are met by field cropping and mixed farming (Lindley et al. 2015). As such, the possibility of a better water supply through SUDS could go a long way in supporting and possibly improving urban agriculture in developing world urban areas where such an activity is a crucial food security and livelihood strategy as well as an integral part of the urban fabric (Schmidt 2012). Urban agriculture could provide an avenue through which to approach and integrate SUDS in Sub-Saharan cities, since it is already a form of keeping GI spaces undeveloped, thus helping with stormwater infiltration and improving biodiversity (de Zeeuw et al. 2011). Conversely, GI-based SUDS retrofits could provide a physical and strategic framework within which to establish urban agriculture in a more comprehensive and physically coherent manner. Urban agriculture could also be supported via other SUDS elements such as green roofs, for example the city of Durban in South Africa has taken the lead in piloting green roof habitats on municipal buildings (van Niekerk et al. 2011), while the City of Johannesburg has piloted three rooftop food gardens in different parts of the city in partnership with other actors.

A third opportunity for SUDS could be the potential it may have for community infrastructure upgrading programs that many Sub-Saharan cities implement in informal areas with the help of non-governmental organizations and other multilateral organizations

(Mguni et al. 2015). Infrastructure upgrading programmes such as the ongoing Dar es Salaam Metropolitan Development Project have planned to use detention ponds in upstream areas to control and reduce stormwater run-off (Bald 2014). Such programmes may afford the opportunity to link SUDS as a solution for drainage issues to the provision of other essential services such as access, solid waste collection and sanitation (Parkinson et al. 2007). Even more so, linking SUDS to these upgrading programmes helps avoid the problem of city administrators seeking specific funds for SUDS projects. Improvements as a result of upgrading based on SUDS could also improve the liveability and the "image" of the informal settlements, thus prompting a possible rise in the value of the land or properties thereof (Parkinson et al. 2007: 140; Ashley et al. 2011).

Lastly, by requiring the involvement of a wider range of stakeholders, SUDS bring the potential for more inclusive decision-making which could be possibly more democratic than the usually linear and narrower (top-down) institutional decision-making required for conventional stormwater systems (Backhaus and Fryd 2012). Such a form of decision-making could be particularly valuable in many Sub-Saharan cities where the informality, poverty and inequality mean that those in informal areas are often outside the decision-making arena and are consequently marginalized.

4.4 Threats to GI-based SUDS

In a SWOT analysis of SUDS, threats represent the possible external obstacles to SUDS that could hinder the applicability of SUDS to Sub-Saharan cities. The first threat to SUDS relates to the way urban service delivery is prioritized in Sub-Saharan cities. Due to the acute housing shortage that plagues many cities, it is likely that stormwater management, and by extension SUDS, could suffer from lower prioritization as the housing provision, water supply and employment are likely to be given more importance. For example, Fisher-Jeffes et al. (2012) highlight that most South African municipalities do not charge for stormwater management, instead stormwater management is financed from property rates and is thus usually under-funded compared to water supply and sanitation.

On the other hand, the lower prioritization of solid waste disposal on the urban management agenda of many cities could also threaten the value that SUDS could have for Sub-Saharan cities. In many Sub-Saharan cities, the poor drainage and flooding problem are aggravated by poor solid waste management as solid waste enters and blocks drains and reduces the hydraulic capacity of the drainage system (START 2011; Parkinson 2003: 120). For example in the municipality of Temeke in Dar es Salaam, it is estimated that only 10–20 % of the solid waste generated in informal areas is disposed of in landfill sites, the rest is either burnt or ends up in rivers and drains (Herslund et al. 2015). It should be noted, however, that the solid waste threat currently affects whatever conventional drainage infrastructure that currently exists in Sub-Saharan cities all the same, so it is not a threat that would make SUDS any less valuable when compared to the conventional drainage system.

A weakness identified previously, of SUDS being a new science that is in need of further research, may be the basis of another threat. This is the possible difficulty of convincing policy makers of the viability of the SUDS option when compared to the more developed science that supports conventional drainage system. For some cities which may already have functional and established conventional drainage systems, this threat could be exacerbated by path dependencies and dominance of old hard-engineering approaches such as Johannesburg's dependence on inter-basin transfers for water supply (Turton and Meissner 2002).

Even where policy makers may be willing to engage with alternative GI-based approaches like SUDS, most Sub-Saharan cities do not have collated and readily available data that is prerequisite for the implementation of SUDS. For instance, the lack of information on the size and value of existing GI in Johannesburg has been identified as a barrier to the valuation of the city's GI (Schäffler et al. 2013: 172), while stakeholders convened by the SWITCH project to discuss more integrated urban water management in Accra, Ghana identified the lack of baseline documents as a barrier to setting an agenda for more sustainable urban water management and enhanced stakeholder interaction (Howe et al. 2012). As such, it may be necessary to dedicate resources to the gathering of the required data in each city such as the capacity of the existing drainage network before proceeding towards planning, design and implementation of GI-based SUDS (Goldenfum et al. 2007).

The need for high levels of costly maintenance that is characteristic of some elements of SUDS could result in another threat to the value of SUDS' in Sub-Saharan cities in that threat to SUDS. Most Sub-Saharan cities are already facing problems generating income from their small formal tax bases, such that the resources required for maintenance may be unavailable (Armitage 2011; Cheru 2005: 11). This could lead to some SUDS elements becoming health threats if elements are not properly maintained and water is allowed to remain stagnant for long periods. If coupled with the possibility of solid waste that is inappropriately disposed of, stagnant water could become contaminated and become a breeding ground for mosquitoes and diarrhoeal diseases (START 2011: 62).

Another possible threat to SUDS in Sub-Saharan cities concerns the interface between users and SUDS elements (Akrich 1992). There is a risk of unanticipated uses and appropriation of SUDS elements, especially in informal areas which could ultimately lead to SUDS having negative impacts. The possibility of some SUDS elements being large open swathes of flooded land raises practical safety concerns, especially in the light of the risk of drowning and the possibility of them becoming spaces of criminal activities (Charlesworth et al. 2003: 105; Watson 2009). However, this threat could conversely be regarded as an opportunity for the hybridization (Watson 2009) of SUDS by the urban poor to suit local contexts (depending on the nature of the activity concerned) possibly adding to the multifunctionality of SUDS elements. An example of such hybridization are the activities surrounding ponds created to intercept and slow down runoff along the Mbezi river valley by households in the Goba-Kibululu area of Dar es Salaam. One such pond is now used by locals for watering produce, recreation and laundry as it is also fed by a high water table.

An additional threat to the value of SUDS for Sub-Saharan cities is related to the opportunity SUDS may have as part of community upgrading programmes that rehabilitate the image of informal settlements, maybe even up to the point of raising the value of the land these settlements are situated on. Such improvements bring with them the risks of two things happening. Firstly, if upgrading is not accompanied by a commensurate improvement of the socio-economic and legal status of informal settlements inhabitants, SUDS could inadvertently serve as the "aestheticization of poverty", merely painting over deep-rooted problems faced by a majority of the urban populations in Sub-Saharan cities (Roy 2005). Secondly, as land values increase so does the risk of the urban poor being displaced by real estate market forces to make way for what are seen as more desirable developments.

Lastly, in the context of inequality, informality and widespread poverty, the SUDS requirement for inclusive decision-making with multiple stakeholders may not be easy to satisfy when compared to the usually expert-driven and top-down approach to conventional drainage systems. This is because the multiple and sometimes conflicting rationalities often at work in Sub-Saharan cities may preclude consensus-based approaches as those requisite for SUDS (Watson 2009). The reality in many cities of the developing world is that global and local market forces have in some cases resulted in socio-economically, politically and ethnically polarized cities where public interest is at best splintered and differences are large (Watson 2006). In such a context, power thus becomes a very convenient concept to understand and acknowledge, especially when seeking to accommodate the wishes and requirements of the diverse stakeholders (ibid).

4.5 From cities of crisis to cities of the future—discussing the potential for SUDS in Sub-Saharan cities

This section presents a discussion of some of the issues to have in mind when thinking of theoretical value that SUDS may hold for Sub-Saharan cities based on the SWOT analysis performed in the previous section. Firstly, while a scan of the SWOT analysis would seem to reveal seemingly more threats to the value of SUDS than there are opportunities in Sub-Saharan cities, this does not suggest that SUDS would be predestined to fail. What this indicates is that due to the informal mode of urbanization experienced by most Sub-Saharan cities, great care must be taken when approaching any type of urban problem in such contexts. A direct export of ideas like SUDS from developed world cities, without the appropriate scaling and reconfiguration to suit the particular context of each city could produce unintended results which may well be negative. As such, any attempt to engage with SUDS in Sub-Saharan cities should be highly context-specific, designed to take advantage of the socio-economic, political and environmental and physical peculiarities that constitute each city's reality without exacerbating the existing situation, i.e. adding to the difficulties the urban poor face.

Critical to the value that SUDS hold for Sub-Saharan cities is how the informality and infrastructure deficits in these cities are viewed. Contrary to the prevalent conceptualization of developing cities in terms of crisis due to their informal nature (Roy 2005), it may be more practical to view informality and the resultant deficits as providing a specific opportunity for Sub-Saharan cities to develop in a manner that will be relevant to the current projected futures of climate departure and population growth. Informality affords Sub-Saharan cities the opportunity to pursue an urban development trajectory that is possibly more experimental, adaptive and reflexive than can be pursued in developed cities which are already locked-into their existing urban infrastructure systems.

Pursuing a development trajectory that is adaptive implies that Sub-Saharan cities should then actively embrace experimentation, mutual learning and innovation as fundamental components of their governance (Ashley et al. 2012; Bulkeley and Broto 2012). The ability to engage with multiple stakeholders and to learn from how different segments of the population experience the city would help in integrating SUDS into the urban fabric in a manner that is incremental and relevant to the prevailing context. For one, the implementation of SUDS in Sub-Saharan cities implies the reconsideration of what constitutes the modern infrastructure ideal in urban water management in such cities. As the majority of citizens in developing cities cope with burgeoning infrastructure deficits, aspirations towards centralized, pipe-based water systems may not be realistic. Instead, to take advantage of the strengths and opportunities offered by approaches such as SUDS, city governments may have to support practices and technologies previously disqualified as 'rural' such as rainwater harvesting and urban agriculture.

Also, as a way of approaching SUDS implementation most research seems to highlight the importance of the valuation of ecosystem services provided by GI as a key stating point (Cilliers et al. 2013; Simon 2012; Schäffler and Swilling 2013). Furthermore, education of the different stakeholders on the value of ecosystem services offered by SUDS could also help in evading some of the threats to SUDS identified above. To enable a transition towards more sustainable urban water management through the implementation of approaches such as SUDS, another recommendation would be for Sub-Saharan cities to take advantage of the "multiple sites of governance" mentioned before (Lindell 2008) that exist in developing cities and approach the adoption and implementation of SUDS from the sub-city (Hamann and April 2013) or local scale (Mguni et al. 2015). Such an approach is cognizant of the difficulties developing world city governments already face in delivering services as well as the institutional fragmentation that may exist at the city government (top) level.

There are indeed several practical advantages of engaging with the local scale when thinking of the adoption and implementation of SUDS. The local scale allows for the creation of spaces of innovation where SUDS niche experiments can be done with the active engagement of the local community. Lastly, the implementation of SUDS at the local scale may provide opportunities for learning and collaboration between stakeholders which may be difficult to attain were SUDS to be approached in a top-down manner (McCormick et al. 2013). A closer look at the coping strategies of particular local communities and the undertakings of community-based organizations may provide clues as to what form of SUDS experiments may serve the water supply, flood protection as well as amenity and biodiversity needs of the local community best.

5 Conclusions

This article has presented a review of the literature on GI-based SUDS concept, highlighting SUDS' multiple goals of addressing water quality, water quantity, amenity and biodiversity through the elements organized in a treatment/management train. It has also highlighted some of the issues that make up the context of urban water management in many Sub-Saharan cities. These issues include rapid urbanization, informality and numerous sites of governance. Furthermore, a SWOT analysis of the potential value that the SUDS approach may hold for Sub-Saharan cities has been performed. The strengths of SUDS include the stronger viability of GI-based SUDS as an investment option when compared to conventional stormwater management systems, flexibility and the possibility for an augmented water supply. The weaknesses of GI-based SUDS include difficulties in quantifying hydraulic performance and water improvement, the requirement for high levels of maintenance which may also be costly, the need for coordination between stakeholders among others.

The opportunities that accompany GI-based SUDS include possible support for urban agriculture support for ongoing community infrastructure upgrading programmes and a possibility of a more inclusive decision-making. There are likewise numerous possible threats to the potential value that SUDS may hold, and these include low prioritization on the urban development agenda and lack of data among others. In the light of the SWOT analysis, one of the main recommendations has been that SUDS may be best approached from the local community scale, taking advantage of the multiple sites of governance that exist and avoiding the barriers that exist at the city government level. Moreover, however much SUDS may be deemed more sustainable than conventional storm water management systems, their adoption and implementation in Sub-Saharan cities should be approached with a full knowledge of the socio-economic, technical and political context of each particular city.

While GI-based SUDS may not be panacea to all the drainage problems of Sub-Saharan cities, they could potentially offer these cities more in terms of value and function than is currently offered by the sole use of conventional drainage systems. If SUDS and the potential value they hold for Sub-Saharan cities are looked at from a holistic perspective, those concerned with the governance of Sub-Saharan cities may come to a realization that GI-based SUDS (among other approaches to sustainable urban development and transformation as well as adaptation to climate change) could offer their cities a chance to reorient their urban development trajectories towards more sustainable futures.

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