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Thorn, J. P.R., Biancardi Aleu, R., Wijesinghe, A. et al. (3 more authors) (2021) Mainstreaming nature-based solutions for climate resilient infrastructure in peri-urban sub-Saharan Africa. Landscape and urban planning. 104235. ISSN 0169-2046

https://doi.org/10.1016/j.landurbplan.2021.104235

Landscape and Urban Planning 216 (2021) 104235

Contents lists available at ScienceDirect

Landscape and Urban Planning

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

Research Paper

Mainstreaming nature-based solutions for climate resilient infrastructure in peri-urban sub-Saharan Africa

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HIGHLIGHTS

- Developed eight-part framework of barriers distinct to peri-urban UGI implementation.
- 832 households surveyed and 118 key informants interviewed.
- 18 forms of green infrastructure and 47 derived ecosystem services determined.
- Scale up co-designed restoration, monitoring, coordination, and cost-benefit analyses.
- Limit ecosystem disservices by managing waste, faecal contamination, and crime.

GRAPHICAL ABSTRACT

1. Introduction

Peri-urban informal settlements house an estimated 59% of the sub-Saharan African population and are expected to grow three-fold by 2050 (UN-HABITAT, 2019). Here, peri-urban informal settlements are defined as areas located at the interface between rural and urban areas. Residents' lack access one or more of the following: clean water; improved sanitation; uncrowded sufficient living area; durable housing; or secure tenure (UN-Habitat, 2016a in Roy, Shemdoe, Hulme, Mwageni, & Gough, 2018). Peri-urban exposure to risk from increasingly variable and extreme climatic conditions is higher, and adaptive capacity levels are generally lower than residents living in formal urban areas (Lindley, Pauleit, Yeshitela, Cilliers, & Shackleton, 2018; Roy et al., 2018). This is particularly the case for people living along riparian zones susceptible to flooding and water supply shortages (IPCC, 2018). However, in the last two decades many sub-Saharan African municipalities are increasingly recognising the role that urban green infrastructure (UGI) can play in just urban transitions towards resilience, by reducing ecological scarcities, social inequalities, and increasing wellbeing (Breuste, Artmann, Li, & Xie, 2015; Pelling, O'Brien, & Matyas, 2015).

UGI, often used interchangeably with ecological infrastructure in the sub-Saharan African context (Cumming et al., 2017), is an umbrella term for all urban areas covered by vegetation (green space) or water (blue space) (Mensah, 2014). UGI predominantly consists of unsealed,

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https://doi.org/10.1016/j.landurbplan.2021.104235
Received 14 January 2021; Received in revised form 25 August 2021; Accepted 26 August 2021
Available online 16 September 2021

permeable, 'soft' surfaces (e.g., soil, grass, shrubs, trees, cemeteries, parks, play areas, other green spaces), whether they are publicly accessible or managed, intended for recreational use or with other origins and purposes (du Toit et al., 2018, Roy et al., 2018). UGI is closely associated with the concepts of ecosystem-based adaptation (Lo, 2016), eco-disaster risk reduction (Renaud, Sudmeier-Rieux, & Estrella, 2013), and nature-based solutions (Kabisch et al., 2016). UGI's operationalisation can range from site-specific interventions like swales, to national ecological networks (Lindley et al., 2018). UGI supports well-functioning ecosystems that provide a range of ecosystem services that can buffer against risks arising from droughts and floods, reduce the loss of lives, assets and infrastructure, and aid in nutrition security. UGI are thus critical for prevention and recovery from extreme events (Douglas, 2018; du Toit et al., 2018).

Processes of urban sprawl and densification fragment green space, reduce permeable surfaces and aggregate buildings – which when combined with the intensification of seasonal variability of rainfall and land use change, can increase the likelihood of water runoff and flooding. However, the rehabilitation of vegetation on slopes, terracing, and agroforestry along rivers can help to restore hydrometeorological functions – by reducing erosion, filtering grey water, reducing sedimentation of downstream water, and attenuating floods through infiltration, canopy interception, and evaporation. UGI restoration can capture stormwater and recharge groundwater supplies to be then extracted for other purposes such as landscaping and irrigation (Martinez et al., 2018). Maintaining or restoring UGI can complement or substitute for more expensive infrastructure investments that may not be tailored to meet local needs. Minimal input, maintenance, and technical simplicity hold the promise for both scalability and replicability. Low-income residents greatly value having access to UGI close to their homes, indicating the importance of shade, temperature regulation, windbreaks, aesthetic and recreational value, and provisioning services, but often trade-offs may occur between services (e.g., clearing trees for fuelwood, which increases flood risk) (du Toit et al., 2018; Roy et al., 2018).

Recent discourse on UGI has shifted emphasis, from focusing mainly on spatial planning, beautification, and recreation (Diep, Dodman, & Parikh, 2019), to consider the multiple ecosystem services derived from UGI (du Toit et al., 2018). Previously published reviews pertaining to the topic in Anglo-American (Wolch, Byrne, & Newell, 2014) and South African contexts (Cilliers, 2019; Venter, Shackleton, Van Staden, Selomane, & Masterson, 2020) argue that distributional access to green space varies across affluence and racial lines and presents an issue of environmental justice. Most studies are conducted in the northern hemisphere (Brink et al., 2016), while the role that UGI can play in sub-Saharan Africa remains understudied (Shackleton et al., 2018; Guenat, Dougill, Kunin, & Dallimer, 2019). For instance, the urban poor's access to ecosystem services has rarely been studied (Roy et al., 2018), and empirical comparative analyses of the barriers and enablers to maintaining and restoring UGI are lacking (Wangai, Burkhard, & Müller, 2016; Abo-El-Wafa et al., 2018). Concurrently, continued informal occupancy of vacant, often hazardous, land exposes households to routine flooding, diffuse pollution, and water-borne pathogens (Weber & Mendelsohn, 2017). Consequently, in densely populated, unplanned areas, green space increasingly is being diminished and sealed by built-up areas (Lindley et al., 2015; McPhearson et al., 2016).

Maintaining UGI in peri-urban settlements is challenging, because settlements are often the product of unresponsive or inappropriate financial, political or governance systems, dysfunctional land markets, and inadequate policy implementation (Roy et al., 2018). Meanwhile, decision makers across all sectors continue to act on an insufficient understanding of the synergies and trade-offs of UGI for risk reduction pathways (Sarabi, Han, Romme, de Vries, & Wendling, 2019). UGI is rarely accounted for in planning, design, construction, or monitoring, while 'hard' infrastructure requiring large investments are favoured. Consequently, strategies tend to be ill-informed, scarce financial resources are often misused, and opportunities that could deliver multiple benefits fit for purpose are lost. Moreover, those who directly depend on ecosystem services, or are not buffered against slow- and rapid-onset disasters, are further marginalised (Pasquini & Enqvist, 2019). While there are numerous analytical frameworks to guide thinking in the complex, transdisciplinary arena of UGI (Lindley et al., 2018), none exist that accommodate multiple perspectives for barriers to approaches and processes in peri-urban areas. Barriers relate to limits that can be restrictive and unresolved within a given time horizon, or those that can only be overcome 'with concerted effort, creative management, change of thinking, prioritisation, and related shifts in resources, land uses, and institutions' (Moser & Ekstrom, 2010: 2; IPCC, 2018).

In this paper, we address the following two questions: (1) What are the barriers to the mainstreaming of approaches and processes that ensure the maintenance and rehabilitation of UGI in peri-urban areas? (2) What are the enablers to overcome barriers and increase the implementation of UGI solutions? To address these questions, we employed an empirical comparative in-depth case study research design juxtaposing drought-prone Windhoek, Namibia with flood-prone Dar es Salaam, Tanzania. First, based on a review of the literature, we identify eight common barriers to the implementation and uptake of UGI globally to develop an analytical framework. Second, we apply this framework to analyse empirical data from our two study sites, comparing similarities and differences. We conclude by discussing enablers for urban planners, municipal authorities, policy makers, and others in the Global South, which can be used to develop, prioritise, monitor, and evaluate practical strategies to scale UGI given each context.

2. Development of analytical framework to guide our analysis

To develop an analytical framework of barriers to mainstreaming approaches and processes of UGI in peri-urban settlements, we reviewed peer reviewed and grey literature searching in the bibliographic database Thomson Reuter's (formally ISI) Web of Science, key international journals (e.g., Landscape and Urban Planning, Environmental Planning and Management, International Sustainable Built Environment), and Google Scholar. We then applied the Boolean operator search terms and wildcards: "urban green infrastructure*", "ecological infrastructure*", "ecosystem-based adaptation*", "nature-based solution*", "urban forest*", "urban park*", "informal settlement*", "peri-urban", "slum*", "shack*", "barrier*", "constraint*", "trade-off*", "hinder*", and "enabler*". Altogether, 155 studies were screened at title, abstract, and full text level to discern if they met the following inclusion criterion: reported data on barriers or enablers to UGI; focused on urban systems facing single- and multi-scalar, multisectoral challenges; were published in English; used quantitative or qualitative data; were available in electronic format; had no publication date limit; and were published up to July 2020. Finally, 29 studies in 24 countries internationally were reviewed. The eight categories of our analytical framework were derived from analysing each paper to identify the most common themes, as follows (Table 1).

2.1. Design, performance, and maintenance barriers

A widely cited barrier to scaling UGI is a lack of data availability, including design and performance data, foresight information, and tools to support urban planning (e.g., use of climate forecasts). This is connected to inadequate verifiable data that is up to date, accessible, affordable, and at an appropriate scale (Staddon et al., 2018). Connected to this, is an absence of globally acknowledged, standardised UGI design principles and guidelines that can be tailored to local contexts (Baptiste et al., 2015). Previous studies have linked this informational absence to infrastructural and technological deficits, for instance in Namibia (Davies et al., 2019), Ghana, Uganda, Burkina Faso (Douglas, 2018), China, and the US (Staddon et al., 2018).

Table 1
Analytical framework of barriers to mainstreaming of approaches and processes of UGI in peri-urban settlements. Categories are unbounded, non-exclusive, and interconnected.

Barriers	Subcategories	References
Design, performance, and maintenance	Low data availability and lack of standardisation Limited technical capacity Poor long term maintenance	Abo-El-Wafa et al., 2018; Mensah, 2017; O'Donnell et al., 2017; Douglas, 2018; du Toit et al., 2018; Staddon et al., 2018
Legal and institutional barriers	Pro-grey infrastructure path dependence Outdated policies and ineffective master plans Land regularisation and ownership rights Limited social inclusion and public participation Poor implementation and enforcement	Kabisch et al., 2016; Van Ham & Klimmek, 2017; O'Donnell et al., 2017; Douglas, 2018; Mensah, 2017; Herslund et al., 2018; Titz & Chiotha, 2019; Davies et al., 2019
Financial barriers	Inadequate financial resources and short-term project cycles Lack of monetary and nonmonetary valuation of UGI Privatisation of land and water Inadequate transparent financial management	Muderere, 2011; Pelling et al., 2015; Ampaire et al., 2016; Sarabi et al., 2019; Davies et al., 2019
Complementarity and integration barriers	Lack of coordination and cooperation between and within institutions Absence of strong communication strategies for citizen engagement Hindered innovation, experimentation, and forward-looking strategies	Spires et al., 2014; Ampaire et al., 2016; Dhakal & Chevalier, 2016; Van Ham & Klimmek, 2017; Herslund et al., 2018; Pasquini & Enqvist, 2019; Titz & Chiotha, 2019
Ecosystem disservices	Exposure to physical risks Perceptions of low aesthetic value and health hazards	Cilliers & Cilliers, 2015; Kabisch et al., 2016; du Toit et al., 2018; Cilliers, 2019; Pasquini & Enqvist, 2019
Land use change and spatial trade-offs	Lack of multifunctionality and land use trade-offs Land degradation Biodiversity loss and limited connectivity	du Toit et al., 2018; Titz & Chiotha, 2019
Climate change	Disproportionate exposure to climate-induced hazards	Parnell & Walawege, 2011; Wang, Lee, & Kim, 2019
Socio-cultural values, traditions, and perceptions	Lack of household awareness regarding UGI Cultural and religious beliefs Paternalism	Mensah, 2014; Cilliers & Cilliers, 2015; Pelling et al., 2015; Wangai et al., 2016; O'Donnell et al., 2017; du Toit et al., 2018; Lindley et al., 2018; Roy et al., 2018; Lange et al., 2016; Davies et al., 2019

Even when there is data, there remains limited technical capacity and educational training of decision makers to use this data in the planning, design, implementation, operation, maintenance, and evaluation of UGI (Zuniga-Teran et al., 2020). Many new investments serve to counter the small remnants of nature, and urban ecosystem disservices are generally better understood than services (Kronenberg, 2015).

Poor long term maintenance is another barrier in peri-urban areas as UGI are often contaminated and used as spaces to hide criminal activity. A lack of technology transfer and follow-up actions to already-implemented UGI has shown to lead to the decline of green spaces. For instance, Mensah (2017) found that poor irrigation of green spaces in Kumasi, Ghana caused their excessive desiccation, and eventual disappearance.

2.2. Legal and institutional barriers

Most municipalities are reluctant to integrate UGI into their infrastructure upgrading projects due to the perception of higher capital costs, low return on investment, historical preference, or relative ease (Sarabi et al., 2019; O'Donnell, Lamond, & Thorne, 2017). However, most cost benefit analyses do not recognise avoided costs from conventional approaches nor account for multiple ecosystem services, which are greatly valued across low income areas. Policy makers, planners, and civil servants are often resistant to change due to pro-grey infrastructure path-dependence and make decisions based on recent past experiences (also a cognitive barrier) (Sarabi et al., 2019; O'Donnell et al., 2017).

In some developing country contexts, inefficient urban planning can be linked to outdated regulations and policies which do not promote UGI (Roy et al., 2018). Many legal frameworks and institutions with the potential to scale UGI implementation are scattered, outdated, ambiguous or conflictual with peri-urban areas (Sarabi et al., 2019). Some urban policies remain anchored in the 'modernist fundamentals of apartheid', in the sense that spatial segregation influences access to green spaces (Davies et al., 2019; Delgado, Muller, Mabakeng, & Namupala, 2020: 178). Similarly, many governments continue to work within the constraints of inefficient master planning and inherited legislation, which struggles to cope with the rapid pace of urbanisation, deforestation, and bush encroachment (Herslund et al., 2018, Roy et al., 2018).

Land regularisation and ownership rights dynamics stifle individual and community incentives to ameliorate green spaces, and make monitoring challenging (du Toit et al., 2018; O'Donnell et al., 2017) as shown in a study based on peri-urban settlements in Kumasi, Ghana (Mensah, 2017). Connected to informal property rights is the fact that many peri-urban residents feel there is limited social inclusion and public participation in decision making processes related to UGI. Even where appropriate laws and policies exist, implementation and enforcement capacity can limit the uptake of UGI (Dhakal & Chevalier, 2016).

2.3. Financial barriers

There is limited funding budgeted for the development, rehabilitation, and maintenance of UGI (Davies et al., 2019), while public private partnerships, and monetisation of UGI assets needed to facilitate direct and indirect financial investments remain largely untapped (Staddon et al., 2018). Moreover, the disbursement of financial resources by governments tends to be short term and dependent on the political cycle (Kabisch et al., 2016; Davies et al., 2019). This is a challenge for the long

term continuous management required for UGI.

Monetary and nonmonetary valuation is particularly challenging because all UGI cannot be commoditised, nor are all the benefits tangible (e.g., identity value, human wellbeing). While the economic case for investing in ecosystem services derived from UGI is sound, and methodologies do exist (e.g., The Economics of Ecosystems and Biodiversity), municipal departments typically lack methodologies that value UGI in a routine way that is comparable to other types of infrastructure.

Privatisation of land and water in peri-urban settlements hinders access to UGI. This is because privatised water systems disincentives residents to pay for water to cultivate food, plant trees, harvest water, or engage in new economic activities which could benefit the ecosystem (Mitlin & Walnycki, 2020). In a similar way, land development is often led by private corporate agencies (SHLC, 2018) – which has increased the costs of access to basic public services and put important areas for biodiversity and ecosystem functioning at risk.

Another barrier relates to a lack of transparent financial management in the management of public spaces. For example, Muderere (2011) showed how in Zimbabwe attempts to integrate wildlife in the design and planning of cities were hampered by mismanagement of funds and political interference, despite the well-developed national policy and regulatory system for urban development. Corruption has the potential to be higher in peri-urban areas compared to other contexts, due to lower levels of accountability and transparency, with sometimes opaque institutional processes (Nuhu & Mpambije, 2017).

2.4. Complementarity and integration barriers

Limited coordinated management and cooperation between and within institutions is pervasive across the urban governance domain (Davies et al., 2019) – and is particularly challenging in managing UGI due to its multi-dimensional nature (Lindley et al., 2018). Government departments managing UGI often operate in sectoral silos or institutional fragments (Spires, Shackleton, & Cundill, 2014). A persistent lack of integrated management across scales (vertically, from national to local), and inter-agency coordination (horizontally) hinders a change of practices (O'Donnell et al., 2017). Unclear institutional mandates cause confusion over who should operate and maintain UGI projects in the long term (Titz & Chiotha, 2019). For example, in Addis Ababa the lack of cooperation, coordination, and knowledge-sharing between agencies regarding who was responsible for green space stalled the implementation of the 2003–2013 structure plan, which designated 22,000 ha to green spaces (Herslund et al., 2018).

The absence of strong communication strategies for citizen engagement runs the risk of urban plans being ill-suited to local needs, creating antagonism towards the state, and at worst positively undermining those needs and reflecting ideals that resonate with colonial pasts (Hossain, Sholz, & Baumgart, 2018).

The third barrier in this category relates to the fact that civil servants are often constrained by a strong institutionalisation of traditional planning technologies, instead of having opportunities to innovate through local experimental practices. Hindered forward-looking strategies in rigid government institutional structures inhibits UGI mainstreaming (Pasquini & Enqvist, 2019).

2.5. Ecosystem disservices

A common concern among residents in Sub-Saharan African cities is that ecosystem disservices arise from UGI (du Toit et al., 2018). In the long term, the lack of maintenance, and poor sanitary conditions of UGI leads to greater fire, safety or drowning risks, or the presence of wild animals (Guenat et al., 2019; Gómez-Baggethun & Barton, 2013). This varies depending on severity of risk, frequency of exposure, and negative past experiences (IPCC 2018). Barriers aforementioned can furthermore lead to low aesthetic value health hazards through increased proximity to zoonotic diseases and contamination (Guenat et al., 2019; Gómez-Baggethun & Barton, 2013). Accordingly, Cilliers and Cilliers (2015) found that in five South African residential areas (in Potchefstroom, the North West province), such perceptions of risk lowered the house price of properties located adjacent to green spaces.

2.6. Land use change and spatial trade-offs

Land use changes and unsustainable land management leads to a lack of UGI multifunctionality (Pauleit, Zölch, Hansen, Randrup, & Konijnendijk van den Bosch, 2017). Increasing pressure on land can manifest into decisions about land use trade-offs (e.g., the allocation of land for agricultural production at the expense of flood regulation). Land degradation, particularly deforestation, erosion, and industrial pollution, can negatively impact the delivery of other ecosystem services from UGI (Vlek et al., 2017). Habitat loss and fragmentation can lead to biodiversity loss by reducing the size of wildlife populations. Fragmentation also hinders individuals' movement between increasingly isolated populations, threatening their long term viability (Pauleit et al., 2017).

2.7. Climate change

Climate change has been put forward as the most challenging barrier to the implementation of UGI (Parnell & Walawege, 2011; Dobson, 2017). This is because climate change deteriorates UGI's physical state, and negatively affects residents' perception of it, instead of highlighting its role as an adaptation tool (du Toit et al., 2018). The existing vulnerabilities of African cities, with their rapidly growing populations, means climatic changes are likely to have critical implications for peri-urban residents – who are disproportionately exposed to climate-induced hazards (Bele et al., 2014). Heightened vulnerability to climate change can indirectly reduce ecosystem services or increase ecosystem disservices (Roy et al., 2018).

2.8. Socio-cultural values, traditions, and perceptions

Socio-cultural values, traditions, and perceptions relate to all barriers associated with local appreciation and knowledge of UGI. A lack of household awareness regarding UGI can, in some cases, deter the use of UGI or constrain the adoption of bottom-up initiatives. Cultural and religious beliefs can influence the overall adaptability of communities and delivery of ecosystem services both positively (e.g., conserving sacred heritage) and negatively (e.g., the reliance on God instead of meteorological climate information to help minimise the effects of natural hazards) (Davies et al., 2019). Another barrier is a one of paternalism, where communities rescind individual responsibility to restore UGI, and believe it is the responsibility of the state (Lange, Pirzer, Dunow, & Schelchen, 2016, Douglas, 2018; Muderere, 2011). Such considerations can underpin uncooperative attitudes from residents to maintain UGI (Mensah, 2014).

3. Methodology

3.1. Study area

We studied Namibia and Tanzania because these countries represent a gradient of likely hydroclimatic risks predicted to increase in many sub-Saharan African cities in the face of climate change. Both cities of Windhoek and Dar es Salaam are characterised by fast growing economies and urbanisation, strong rural–urban linkages, and water-related UGI. Case studies offer broad regional coverage, a range of population sizes, inland *vs* coastal locations, and growth rates. These characteristics provide rationale for generalising and scaling up place-based results which, in turn, will provide a needed baseline for quantitative longitudinal monitoring.

We selected study locations through expert consultations, previous

Fig. 1. Images of case study area. (a) Structures in Northwest Windhoek are typically constructed of corrugated iron sheets. (b) Peri-urban settlements in Kinondoni and Ilala municipality in Dar es Salaam are typically built with concrete homes, and many people farm subsistence and cash crops along riverbanks. (c) Informal settlements in Windhoek encroach flood zones where waste collection and open defecation are challenges. (d) A home in a residential areas Mchikichini, Dar es Salaam has been abandoned due to flooding.

community risk mapping surveys (i.e., Rumani Huria; Community Land Information Programme), and field visits, following the criteria of: (i) located along river systems; (ii) regular occurrence of floods or drought; (iii) existence of UGI; (iv) highest concentration of unplanned settlements in the city; and (v) local partners have long term community engagements. In Dar es Salaam seven settlements were surveyed in Ilala (6.9276° S, 39.1336° E), and Kinondoni (6.7053° S, 39.1127° E) districts, while in Windhoek, nine wards were surveyed in Tobias Hainyeko (22.5061° S, 17.0339° W), Moses |Garoëb (22.5038° S, 17.0185° W), and Samora Machel (22.5187° S, 17.0371° W) constituencies (Figs. 1, 2).

Both cities lack affordable housing and financing schemes. Approximately 70% and 32% of Dar es Salaam's and Windhoek's populations live in peri-urban settlements, respectively (Weber & Mendelsohn, 2017; Izar & Mtwangi Limbumba, 2020). Since Namibia's independence from South Africa, Windhoek has been a landing-point for rural–urban migrants, signalling the shift from a predominantly rural to urban society from 27.7 to 51% between 1990 and 2019 (World Bank, 2020a). Today, Windhoek accounts for 42% (411,508) of Namibia's small population, exhibiting peri-urban growth rates of 10–11% yr^{-1} compared to 3–4.5% yr^{-1} in formal areas. Between 2001 and 2011, the number of temporary structures increased by 92% (Weber & Mendelsohn, 2017). Comparatively, Dar es Salaam accounts for 27% (6,702,000) of Tanzania's much larger population and is one of the fastest growing cities in sub-Saharan Africa. Between 1990 and 2019, the urban population grew from 18.9 to 34.5% (World Bank, 2020b), and today Dar es Salaam accounts for 30% of Tanzania's urban population, growing at 5.8% yr^{-1} (URT, 2013).

Each city is prone to climate-related natural disasters associated with water, with the highlands in Windhoek affected by an ongoing multiple year drought, and low-lying areas in Dar es Salaam affected by perennial flooding of up to three months yr^{-1}. In Windhoek in the last four decades (1980–2021), nine droughts lasting up to four years occurred, causing severe shortages, and the drying of the main water supply of the Von Bach Dam (EM-DAT, 2021; van Rensburg & Tortajada, 2021). In Dar es Salaam in the last decade, two major floods occurred lasting between 12 and 15 days (EMDAT, 2021), while daily rainfall reached 420.1 mm in 2009, 321.1 mm in 2012, and 444.5 mm in 2017- surpassing by far the threshold for heavy rainfall (≤50 mm) as defined by the Severe Forecasting Demonstration Project East Africa (Mafuru & Guirong, 2018).

Encroachment into green spaces such as river valleys, farms, or under electricity lines is common, as land demand is high and in such areas rental or occupation is affordable. For historical reasons, including apartheid in Windhoek and colonisation in Dar es Salaam, UGI is unevenly distributed amongst people of differing affluence and ethnicity (Giombini & Thorn, 2021). By around 2050, development gains are likely to be threatened by climate change, particularly through displacement of rural populations (Rigaud, de Sherbinin, Jones, Bergmann, Clement, Ober, Schewe, Adamo, McCusker, Heuser, & Midgley, 2018). In Namibia, projections suggest that there will be warmer temperatures, higher evaporation rates from surface reservoirs, more frequent droughts, and a decline in average rainfall. In Tanzania, projections suggest intensified flooding during wet seasons (IPCC, 2018).

3.2. Household interviews

Due to the complex nature of climate adaptation, we used a combinatorial approach that brings to bear different forms of evidence, disciplinary perspectives, worldviews, and methods.

After obtaining consent and input into the research design by local government officials (*Mitaa*/chief, ward, municipal levels), data were collected in four field visits in January and July corresponding to the dry and wet seasons, between November 2018 and January 2020. To

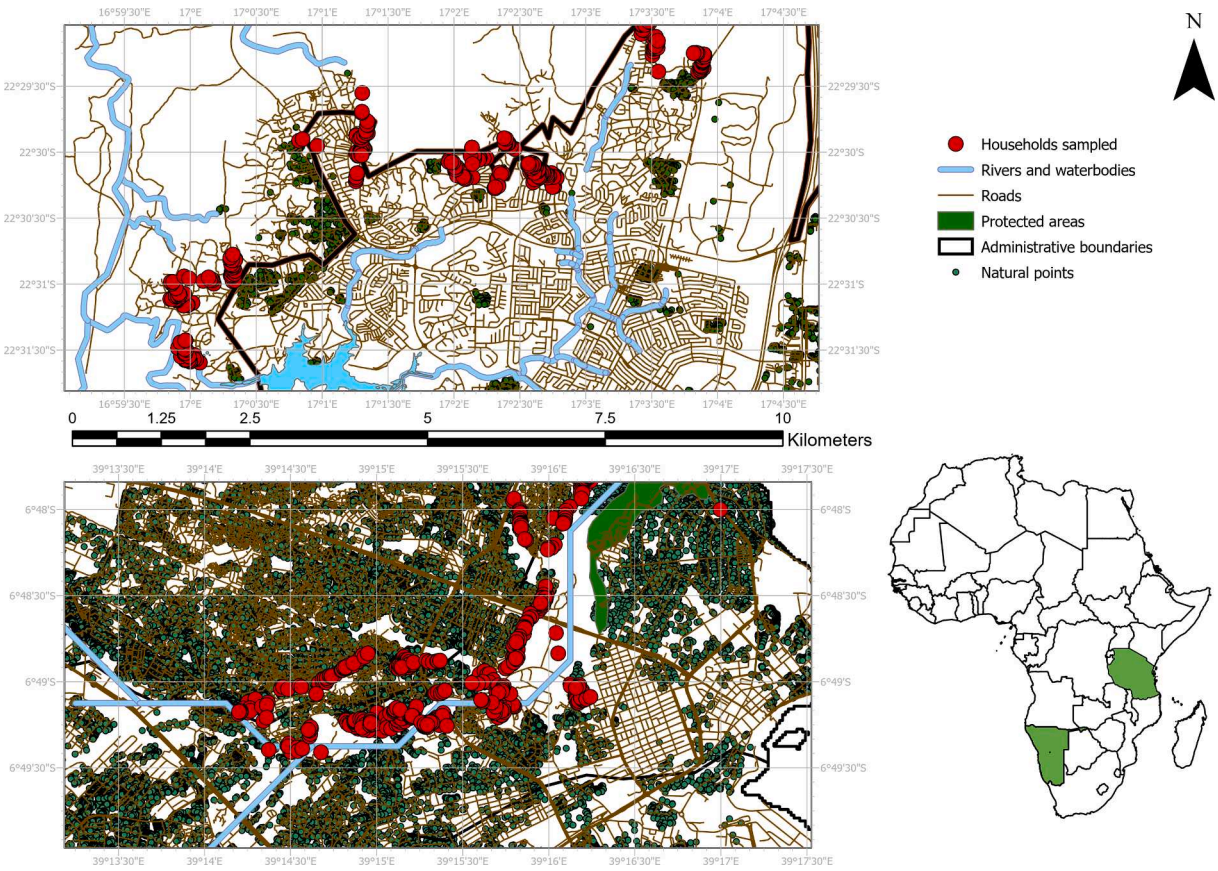

Fig. 2. Map of study area. We studied younger settlements in arid northwest Windhoek, Namibia (top) and older settlements in tropical Dar es Salaam, Tanzania (bottom) along the Msimbazi valley. The mean annual precipitation in Windhoek is 360 mm yr^{-1}, temperature min/max 2–8/28–32 °C and elevation 1636 masl. The mean annual precipitation in Dar es Salaam is 1056.6 mm yr^{-1}, temperature min/max 19–29.5/24–32.5 °C and elevation 24 masl. Given these climatic differences, there is more access to green spaces in Dar es Salaam than Windhoek. Windhoek's settlements are on the boundary of the city encroach into surrounding vegetation, farms, and mountains, while in Dar es Salaam peri-urban settlements are closer to the city centre. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

understand the local context, we conducted 19 transect walks in settlements located in low lying zones. A household survey was then piloted and adjusted in each city. A lead surveyor supervised, and quality checked two trained enumerators to ensure precision and consistency in sampling, data collection, and entry.

The survey consisted of 66 questions (Supplementary data 1), and data was collected using Qualtrics in English, Oshiwambo or Kiswahili. The survey covered socio-demographic data (gender, education, origin, ethnic identity, literacy levels, land ownership, health, and access to services of water, sanitation, and energy); ecosystem services provided by UGI (provisioning, supporting, regulating, and cultural); and how residents define UGI or green and blue space. We asked about the condition of UGI, causes of contamination, what activities people undertake to conserve the local green and blue spaces; access, responsibilities and overall satisfaction of the maintenance of UGI, and climatic-environmental and socio-economic risks. Finally, we asked about barriers and enablers to approaches and processes of restoring or maintaining UGI.

In Dar es Salaam, we administered 502 surveys. Here, the female: male distribution of the sample was 54:47, averaging 36.9 ± 0.5 years (mean, SE) and 28 ethnic groups – with the largest group being Zaramo (9.2%). In Windhoek, we administered 330 surveys, representing a female: male ratio of 57:43, age of 41.3 ± 0.6 years and 27 ethnic groups - mostly Omuwambo (68.8%). The study population in Dar es Salaam was generally more employed (D 35.5%; W 7.4%) and educated (e.g., secondary schooling) (D 44.7%; W 15.3%), and had better services (e.g., running water close to homes) (D 31%; W 0%). Interviews were conducted with residents, community leaders, community groups, religious leaders, business owners, municipal workers, amongst others. Respondents were selected using stratified sampling where the population was divided into gender strata. Percentages reported are non-exclusive.

3.3. Key informant interviews

We conducted in-depth semi-structured key informant interviews in Dar es Salaam ($n = 48$) and Windhoek ($n = 70$) in respondents' workplace (Supplementary Data B). Interviews were centred around barriers and enablers to approaches and processes of restoring or maintaining UGI. Utilising a purposive peer referral sampling approach (i.e., 'snowballing'), stakeholders were selected based on their knowledge and involvement in environmental management, urban planning, climate change, disaster risk reduction, education, public administration, economic development, health, parks, gender, and vocational training – with the goal of engaging a diversity of participants who represent different constituencies in Windhoek. Interviews were conducted across local and national government (e.g., City of Windhoek), NGOs (e.g., Namibian Housing Action Group), CBOs (e.g., Greenspace), shack dweller federations, universities (Namibian University of Science and Technology), traditional or political authorities (e.g., constituency counsellors), multilateral agencies (e.g., UNDP, GTZ) and private sectors (e.g., architects, town planners) (Supplementary data C). We validated insights from secondary sources when reference was made to master plans and legislation.

3.4. Participatory dialogue validation workshops

Finally, we held a concluding one-day dialogue with 30 stakeholders in each city, including community representatives, to validate and refine initial findings. Stakeholders represented diverse sectors and scales of influence, from local to international, including ward and constituency counsellors; municipal divisions for environment, human settlements, health, parks, and disaster risk reduction; NGOs working on land, housing, biodiversity, and conservation; businesses; vocational youth training centres; community representatives; ministries for environment and land reform; research agencies; universities; donors and consultancies.

3.5. Analysis

Interviews were transcribed and anonymised. Using NVIVO 12 qualitative software, we then deductively analysed the extent to which transcribed data corresponded to our eight categories of UGI barriers. Data from the household survey and key informant interviews were then broken down into nodes at household, community, local authority, and national levels, where each parent node of barriers had the four categories of levels as child nodes. Barriers were ranked in terms of frequency reported in surveys and interviews. Data were analysed using descriptive statistics in R Studio V.1.3.959 (R Development Core Team, 2020) (Fig. 3). Maps were generated in ArcGIS Pro.

4. Results

Peri-urban residents in Windhoek and Dar es Salaam indicated 18 forms of UGI and 47 derived ecosystem services. Key forms of green and blue infrastructure are shown in Fig. 4a, b.

Across scales and study sites, when adjusting for the number of respondents in the household survey and key informants, the greatest obstacle preventing uptake and implementation of UGI in peri-urban settlements reported was financial (40.8%); legal and institutional barriers (35.8%); followed by land use change and spatial trade-offs (33%); ecosystem disservices (30.6%); design, performance, and maintenance barriers (20.6%); complementarity and integration barriers (18.5%); and socio-cultural values, traditions and perceptions (12.4%). Interestingly, while being reported as an important risk to society, climate

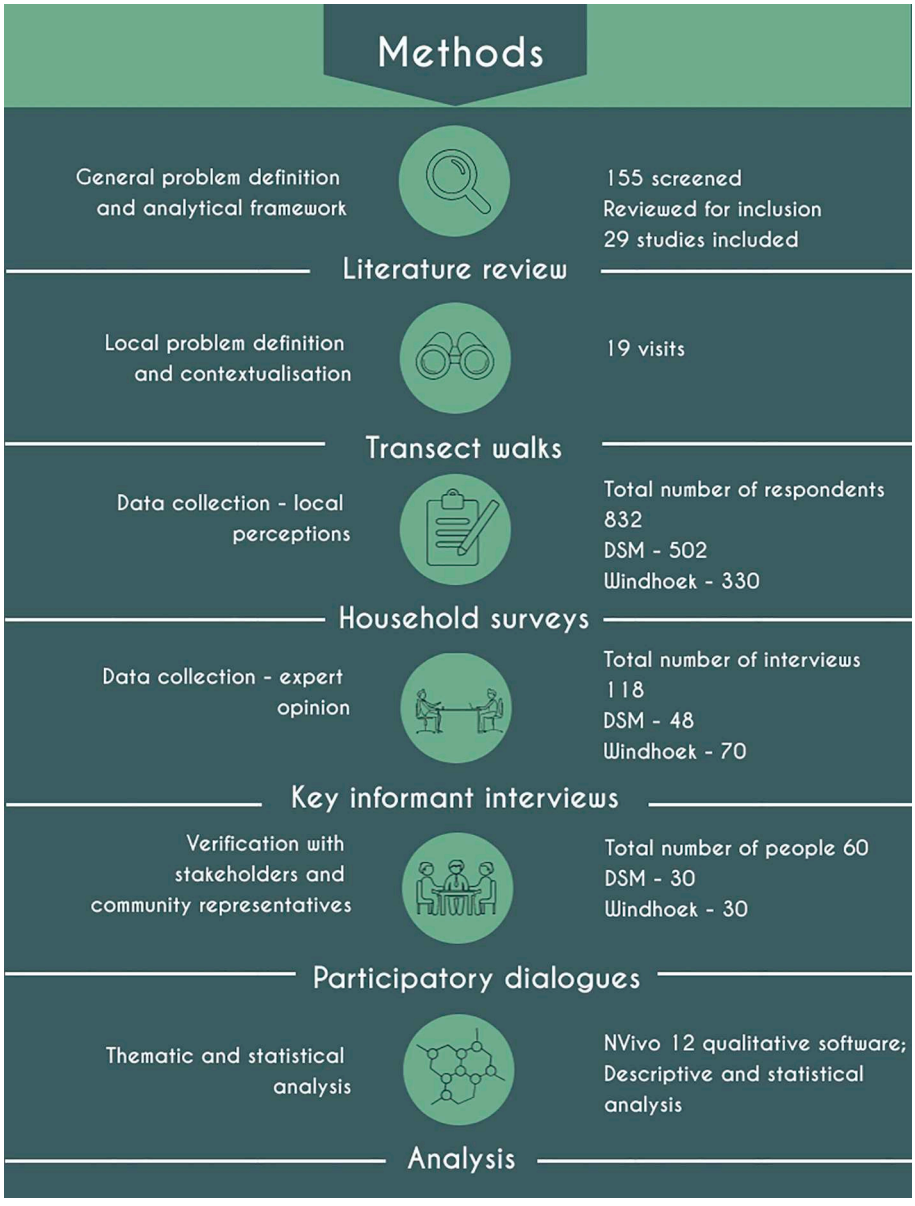

Fig. 3. This figure outlines the methodology including the processes, scale, data input type, and analysis (DSM: Dar es Salaam).

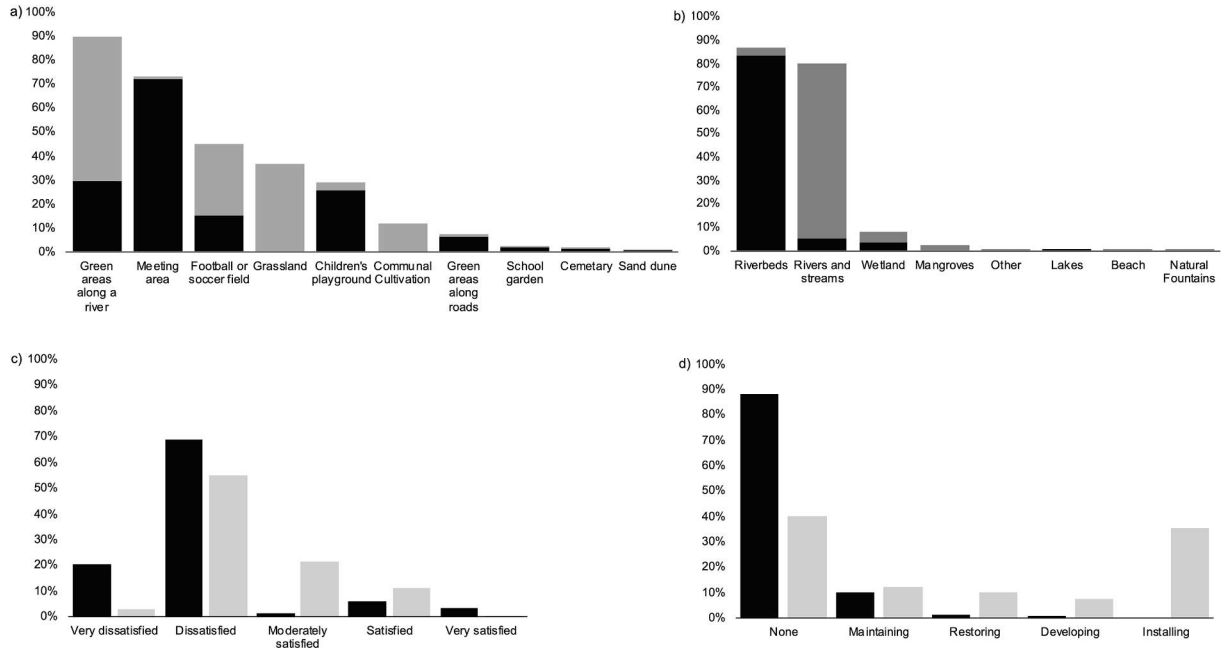

Fig. 4. (a) Peri-urban residents' perceptions of what constitutes UGI in green and (b) blue spaces. (c) Satisfaction with the maintenance of UGI in settlements. (d) Activities being undertaken by people in the community to conserve UGI. Black denotes Windhoek, while grey denotes Dar es Salaam. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

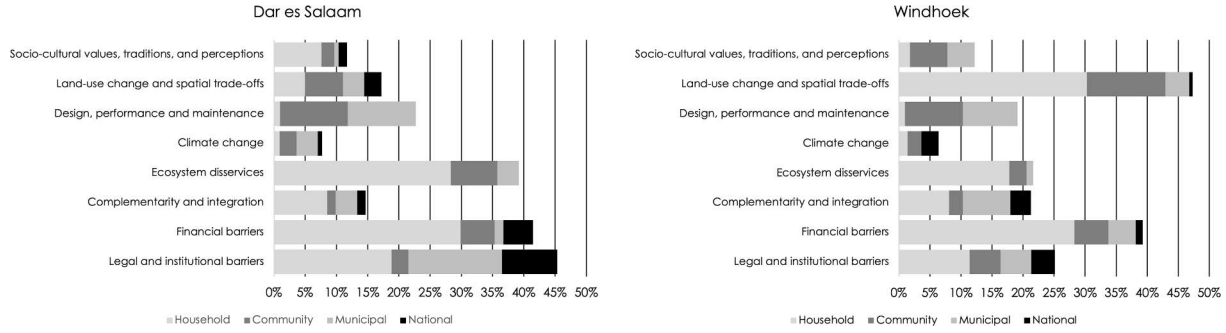

Fig. 5. Comparison of prioritised barriers across study sites, differentiated by institutional level. Percentages reported are non-exclusive.

Table 2
Household perceptions of barriers to implementation of UGI.

Categories	Dar es Salaam		Windhoek	
	n	%	n	%
Design, performance, and maintenance	22	1.0%	39	0.9%
Legal and institutional barriers	434	18.8%	474	11.4%
Financial barriers	690	29.0%	1175	28.3%
Complementarity and integration	197	8.5%	336	8.1%
Ecosystem disservices	653	28.3%	740	17.8%
Land use change and spatial trade-offs	114	4.9%	1259	30.3%
Climate change	21	0.9%	59	1.4%
Socio-cultural values, traditions, and perceptions	176	7.6%	74	1.8%
Total	2307	100.0%	4156	100.0%

change was ranked as the lowest barrier (7.2%) (Fig. 5). Comparing flood-prone and drought-prone cities, the highest ranked barrier in Dar es Salaam was legal and institutional (22.7%); financial (20.7%); and ecosystem disservices (19.6%), whereas in Windhoek, the highest ranked barrier was land use change and spatial trade-offs (24.4%); financial barriers (20.1%); and legal and institutional barriers (13.1%). A key difference identified was that ecosystem disservices were a greater concern in Dar es Salaam (19.6%) than in Windhoek (11%). At the household level, the main barrier to UGI implementation was financial (29.1%) followed by ecosystem disservices (23.6%) (Table 2). At community and municipal levels, the main barrier was design, performance, and maintenance; while at the national level, the main barriers were legal and institutional (Table 3).

4.1. Design, performance, and maintenance barriers

Despite growing awareness of the importance of ecosystem services, UGI is still widely misconceived as unused urban land – as described by a Windhoek municipal official: "*Many people tell you they need a place to build housing. They don't understand that we need to protect open green spaces.*" Municipalities do not have access to up to date, fine resolution standardised data - required for the sustainable management of UGI. Data deficiencies include, *inter alia*, information about costs, localised climate risk, ecosystem value, and the extent of peri-urban areas.

At local authority and national levels, technical knowledge gaps remain (e.g., sustainable urban drainage, best practices). A Dar es Salaam community member described that many "*leaders see issues pertaining to the environment like derailing, complicating, or blocking development*" - suggesting risks are better understood than benefits. Generally, motivations of peri-urban residents are poorly understood or

Table 3
Key informant perceptions of barriers to implementation of UGI across scales.

Dar es Salaam, Tanzania							
Categories	Community		Municipal		National		Total
	n	%	n	%	n	%	n
Design, performance, and maintenance	16	10.90%	16	10.90%	0	0.00%	32
Legal and institutional barriers	4	2.70%	22	15.00%	13	8.80%	39
Financial barriers	8	5.40%	2	1.40%	7	4.80%	17
Complementarity and integration	2	1.40%	5	3.40%	2	1.40%	9
Ecosystem disservices	11	7.50%	5	3.40%	0	0.00%	16
Land use change and spatial trade-offs	9	6.10%	5	3.40%	4	2.70%	18
Climate change	4	2.70%	5	3.40%	1	0.70%	10
Socio-cultural values, traditions, and perceptions	3	2.00%	1	0.70%	2	1.40%	6
Total	57	38.80%	61	41.50%	29	19.70%	147
Windhoek, Namibia							
Categories	Community		Municipal		National		Total
	n	%	n	%	n	%	n
Design, performance, and maintenance	17	10.10%	16	9.50%	0	0.00%	33
Legal and institutional barriers	9	5.40%	9	5.40%	7	4.20%	25
Financial barriers	10	6.00%	8	4.80%	2	1.20%	20
Complementarity and integration	4	2.40%	14	8.30%	6	3.60%	24
Ecosystem disservices	5	3.00%	2	1.20%	0	0.00%	7
Land-use change and spatial trade-offs	23	13.70%	7	4.20%	1	0.60%	31
Climate change	4	2.40%	0	0.00%	5	3.00%	9
Socio-cultural values, traditions, and perceptions	11	6.50%	8	4.80%	0	0.00%	19
Total	83	49.40%	64	38.10%	21	12.50%	168

stigmatised by government officials. There furthermore remain limited design considerations in how the spatial reality manifests, as described: *"In Namibia, town planners have no design aspect in their tertiary training. They don't think about how the city will be inhabited."*

While long term maintenance requirements vary by UGI type, and satisfaction of the condition of the UGI is slightly higher in Dar es Salaam than in Windhoek, satisfaction is generally low (Fig. 4c). Almost all respondents in Windhoek (95.8%) and Dar es Salaam (90%) reported the rivers that run through the peri-urban areas are polluted. In Windhoek, residents throw domestic solid waste (97%), dead animals (70.9%) or untreated human effluent (76.4%) in the river system. Residents also burn waste (95.5%). The municipality does not appropriately maintain the sewerage systems (85.2%), which causes leakages. In Dar es Salaam, textile factories and breweries illegally deposit industrial waste into the river (79.7%), and communities throw solid waste and drain grey water waste (68.3%) in the river. Local authorities also poorly maintains sewerage systems (26.3%). A community leader in Windhoek mentioned *"Unfortunately, we don't use the Goreangab Dam at all* (the largest water body adjacent to peri-urban areas). *The water is polluted and it's way too expensive to treat"* (see section on ecosystem disservices).

4.2. Legal and institutional barriers

Both municipalities appear to display a pro-grey infrastructure path dependence - in that officials and planners are reluctant to incorporate UGI as a central element when *in-situ* settlement upgrading processes. For new developments, it is rare that private investors or local municipalities consider the ecosystem services benefits derived from UGI, let alone attribute monetary and non-monetary value (see section on financial barriers). This sentiment was explained by a donor representative in Namibia: "*There is still resistance. When we started working on this* (development project), *there was a concern that Environmental Impact Assessments and managing the environment were too expensive.*" In Dar es Salaam, residents described how public green spaces in Kigogo Kati were sold to private investors who replaced football fields and recreation areas with parking lots.

Importantly, many legal frameworks with the potential to scale UGI in both cities do not explicitly address UGI (Supplementary data E). For example, the Local Authorities Act 1992 of Namibia, which requires new developments or extensions to have a proportion of land set aside as public space, makes no mention of UGI nor climate adaptation. Notably, UGI is not a statutory requirement for municipalities, and often zoning impairs local authorities' ability to implement holistic reforms quickly. For example, not all peri-urban settlements appear on the upgrading plans (Supplementary data F). Spatial segregation legacies persist through the unequal distribution of UGI in socioeconomically differentiated neighbourhoods. Both cities have a history of inefficient, top-down master planning that focused mainly on economic development and was fraught with long bureaucratic processes. Although promise lies in Dar es Salaam's Master Plan of 2012–2032, and Windhoek's overhaul of its master plan, these plans lack financial backing.

A fundamental barrier to implementing UGI remains the lack of distinct land ownership rights and regularisation: 98.8% of respondents lack formal tenure. In Dar es Salaam, land is typically bought through non-contractual agreements outside of a government-mandated system. Agreements usually take place in an *ad hoc* manner (56%), are rented (11.2%) or are owned through customary rights (8%). Middlemen (*madalali*) often facilitate both formal and informal land transfers, even where green areas and informal settlements already exist. In Windhoek, many new migrants coming from rural origins or other more expensive suburbs access land when relatives or leaders indicate that a space is available to erect a structure. People are less willing to add value to their plots if they are temporary or anticipating eviction, especially if benefits take years to accrue (D 14.3%; W 9.7%). Meanwhile, local authorities responsible for maintaining public spaces often do not have the mandate to rehabilitate UGI in peri-urban settlements - as a Windhoek official described: "*We have identified areas where we want to put up family parks, but we cannot because those areas are not proclaimed* (legally recognised)".

Despite recent increased institutionalisation of multi-level and participatory governance approaches in both countries (e.g., Public Participation Policy 1999; Local Authority Act 2003; Tanzanian Urban Planning Act 2007), residents do not feel included or trust the governance of green these spaces, as described by resident of Ombili in Windhoek: *"We really don't know what goes on behind municipality doors. They don't communicate with us*". A lack of public participation and an arising disconnect means community-led innovations in UGI are not mainstreamed or internalised in government processes. In part for the same reason, it means that parks and other forms of UGI are not well-managed (section on complementary and integration barriers).

Poor implementation and enforcement are attributable not only to personnel in municipal offices, but a lack of individual responsibility to maintain UGI and an urban planning sector still characterised by centralised processes that hinder equity and efficiency. However, initiatives are underway to narrow this gap. For example, in Dar es Salaam, the Msimbazi Opportunity Plan completed in 2019 aims to relocate and compensate flooding-exposed communities and install UGI. Similarly, in Namibia, an ongoing partnership between the Freedom Square Shack Dwellers Federation and Gobabis municipality has been forged to upgrade spatial qualities and services, plant UGI along roads, reposition structures, and for residents to ultimately gain tenure security.

4.3. Financial barriers

Fundamentally, municipalities lack collateral to secure loans to scale up pilot UGI initiatives. In Namibia, processes of decentralisation have meant that larger municipalities generate their own revenue, rather than being funded by national sources. This dilemma was described by an official: "*Every municipality listens to where the money is. Activities are usually centred towards high-income apartment blocks where the rates and taxes come from, not urban greening*". A town planner in Kinondoni (Dar es Salaam) went on to explain: "*The decentralisation in Tanzania is not performing well. The local government generates income, but most income is sent to the central government. What they get back is very little, so they are incapable of exercising their duties in informal settlements"*. Connected to this, UGI is often subject to the short term boom and bust cycles characteristic of the disbursement of public funding linked to political cycles. This implies municipalities lack funding for long term maintenance (e.g., fencing), and do not recognise benefits delivered over longer timescales (e.g., ecological succession).

Direct employment (e.g., tourism) or income generating opportunities (e.g., increasing property value) from UGI also remain largely untapped (D 7.6%; W 2.1%). Alternatively, income generation from UGI takes place within the informal economy, which is unrecognised in national accounting systems. Accordingly, one community counsellor expounded: *"The economic potential of UGI and riverbeds has not been well explained to the people, nor fully utilised. City councillors don't really understand the value of green spaces."*

Despite government mandates to protect natural landscapes, many residents perceive that corporate land interests are prioritised above the needs of the poor when local authorities sell off natural spaces to developers to generate income (D 32.5%; W 83.3%). A lack of individual household water supplies (D 71.9%; W 100%) and newly privatised water systems and pricing strategies significantly constrain individual and collective efforts to improve living standards (e.g., sanitation), and benefit from provisioning services (e.g., irrigation).

Residents reported that other important barriers relate to a lack of transparent financial management - whether corruption (D 64.1%; W 45.8%) or delays in accessing government funds (D 16.5%; W 22.4%). In Windhoek, it is common prior to elections for vegetated lands to be informally allocated by politicians for occupation. Similarly, in Dar es Salaam officials have been bribed so residents could continue to occupy UGI along the Msimbazi River Valley.

4.4. Complementarity and integration barriers

Overlapping institutional mandates between and within institutions create confusion over organisational responsibility for maintaining UGI and stall the implementation of well-intended policies and plans. An example is the case of Havana informal settlement. Unclear institutional mandates exist that differentiate responsibilities of the City of Windhoek Parks, Sports and Recreation division, Stormwater division, constituency counsellors, the community, among other actors. Consequently, residents report this to be a reason of why broken sewer pipes and toilets that pollute UGI have not been repaired for several years. There remains no municipal coordination platform for UGI in both cities.

Meanwhile, with an absence of strong communications strategies, residents feel excluded by not bring engaged in development planning processes. An NGO manager described this sentiment: *"The formal part of Windhoek is benefiting from everything, but beyond people are so hungry. Nobody is going to where most of our people are, in the poor and rural areas. They feel like they are left out"*.

Municipalities struggle to keep up to pace with rapid urbanisation demands for public services and have limited capacity to apply strategic foresight to tackle compounding systemic risks. Small scale municipal and community experiments are useful to not only understand what fails and needs readjustment, but also bring to life the co-benefits of UGI for residents and highlight technical deficiencies.

4.5. Ecosystem disservices

Despite the range of services, a common concern among residents is that UGI promotes ecosystem *disservices*. Criminality is a deterrent for people to use UGI, with a higher prevalence in Windhoek than in Dar es Salaam, in the form of vandalism, petty crime, alcohol use, or theft (D 23.5%; W 41.5%), and drug use or trade (D 10.6%; W 83.9%). For example, in Jangwani, Dar es Salaam, some criminals hide in green areas being close to the main market of Kariakoo. Residents also perceive physical risks from wild animals, mostly baboons (only in W 46.7%), snakes (D 24.3%; W 77%), and other reptiles (D 62.6%; W 42.1%); and climate hazards (see section on climate change barriers).

In Windhoek, 90.9% of respondents felt sick when they were in green or blue spaces. A community member in Greenwell C described: "*There is a bad smell, and breathing is hard in these places"*. A case in point was in 2018, during a hepatitis E outbreak, most infections were reported in peri-urban areas - affecting 29.7% of residents, and where 87.6% do not have access to reliable flush latrines. In fact, diarrhoea (D 16.1%; W 20%) from poor hygiene and contaminated UGI is an issue across both sites. Even in Dar es Salaam, where most residents have access to clean water (51%) and a flush latrine (69.7%) in their homes, respondents reported contracting malaria (44%), typhoid (12.2%), and urinary tract infections (8.2%) - connected to contaminated water and blocked drains. If UGI are left unattended or neglected, poor hygiene can exacerbate the spread of these and zoonotic diseases, including SARS-CoV-2.

4.6. Land use change and spatial trade-offs

Critically, increasing land scarcity is putting more pressure on remaining green spaces. Poorer households tend to occupy these spaces due to affordability or availability. A resident of Hannasif, Dar es Salaam explained: "*We are grabbing land because it's our right. It's a never-ending story. If they evict us, others will just come back*". This leads to ecosystem service trade-offs, such as housing at the expense of flood regulation and recreation in Windhoek, and food production at the expense of flood regulation and fibre in Dar es Salaam. Trade-offs fuel land use conflicts, while increased demand for forage, fibre, and forest products is leading to high-quality land consumption and ecosystem service exploitation. Windhoek has seen a recent sharp decline in vegetative cover surrounding the peri-urban areas. This could be due to unmonitored use of locally harvested fuelwood (71.5%), as 97.9% of residents do not have electricity inside their homes, and wood is more affordable than gas, or fodder, with more pastoralists moving to urban centres. In Dar es Salaam, the river flow is obstructed, and mangroves are used for wood. Beyond harvesting wood, peri-urban deforestation for agricultural purposes reduces other ecosystem services (e.g., soil regulation), while increasing biodiversity loss (e.g., mammals) and fragmentation. Predominantly in Dar es Salaam, chemical fertiliser seepage into rivers harms aquatic habitats.

4.7. Climate change

Peri-urban residents are disproportionately exposed to climate-induced hazards. Residents report erosion (D 45.8%; W 80%), flash floods (D 22.7%; W 20.9%), extreme rainfall (D 20.5%; W 10.9%), and riverine or coastal flooding events (D 16.7%; W 1.8%) to be among the most critical hazards. In Windhoek, respondents observed increased temperatures (D 20.9%; W 90.3%), drought (D 0.8%; W 66.4%), and heat waves (D 1%; W 32.1%). Children (D 98.6%; W 98.8%) and the elderly (D 55.8%; 98.5%) are the most vulnerable due to greater susceptibility to diseases, social isolation, reduced mobility, and reliance on carers. In Windhoek, droughts reduce agricultural and livestock production in rural areas increases food costs, remittance responsibilities or seasonal or permanent mobility to peri-urban areas Without rainfall, waste accumulates in riverbeds, which is otherwise washed away. In Dar es Salaam, flooding damages crops and property, disrupts economic

activities, contaminates water systems, increases traffic and sometimes leads to drowning.

4.8. Socio-cultural values, traditions, and perceptions

There appears to be limited household awareness about the concept of UGI or related concepts (D 55%; W 22.1%). For instance, few residents recognise important regulating effects of UGI, such as water purification (D 0.8%; W 4.8%), reducing salinity (D 0%; W 3.9%), and mitigating agricultural runoff (D 6%; W 0.9%). Existing neighbourhood committees often focus on waste collection, but do not actively limit encroachment into green spaces. School curriculums typically do not incorporate education on UGI, although some initiatives to promote UGI awareness exist (e.g., savings groups, or *shirika la uchumi*). On the other hand, some households that do not have formal training on the concept, still act on localised ecological knowledge.

Cultural and religious fatalistic attitudes of predestination sometimes inhibit the adoption of UGI. For example, in Windhoek, urban agriculture is rarely practiced (0.3%) because some consider agriculture to be "*work for the poor*". The reason for this may lie in stigmas associated with non-pastoral labour. One resident described: *"Just green loving, going green, it's not really a part of the Namibian identity. It's not in our culture"*. Comparatively, there appears to be less cultural barriers in Dar es Salaam, where urban agriculture provides the lifeline for 11.4% of peri-urban residents, with a history dating back to government subsidies for riverbank farming in the 1970 s. Nevertheless, cultural, and religious values often foster pro-environmental attitudes (e.g., sacred mangrove forests being places for spiritual experiences).

Paternalistic attitudes towards the state hinder residents' sense of sovereignty. Although we identified some cases of community UGI initiatives, few respondents think individuals and households have the responsibility to maintain UGI (D 12.4%; W 10.3%). Exceptions were activities of de-bushing, rehabilitating space, and providing labour, where in Dar es Salaam 15.4% and in Windhoek, 27% believe households should work in partnership with public bodies. Rather, communities regularly abrogate responsibility to the state to restore natural capital. This approach runs the risk of greater dependence on relief programmes and is aggravated by limited consultation between local authorities and communities.

Fig. 6. Barriers and enablers to mainstreaming of approaches and processes to UGI in peri-urban settlements.

5. Discussion

5.1. Overcoming barriers through effective, practical enablers to scale peri-urban UGI

Although progress is being made, more work is needed to ensure that UGI approaches facilitate inclusivity and are featured with the same consistency as grey infrastructure (Staddon et al., 2018). Especially in an African context, hybrid infrastructures where green and grey work in tandem have wide applicability (Mulligan et al., 2020). Here we discuss some, *inter alia*, effective, enabling pathways we have identified to overcome the barriers revealed in this study and bring local solutions to scale, with potential applicability to other sub-Saharan African peri-urban contexts (Fig. 6).

With regards to design and performance barriers, there is an urgent need for effective engagement of the public on the benefits and costs of UGI. A study by van Rensburg and Tortajada (2021) on the impact of drought in Windhoek showed that awareness raising and contextualising issues for citizens immediately improves local stewardship and participation in co-designing of solutions. This requires a careful balance between technical and political voices, enhancing the credibility of information, and reducing fragmented, conflicting messaging, and inaccurate media reporting. More knowledge and technical skills for UGI can be shared through grassroots capacity building, adult vocational training, and transdisciplinary university modules on the interactions of restoration ecology, urban planning, design, and associated politics of implementation (Dhakal & Chevalier, 2016). Universities can play the role of knowledge brokers in facilitating urban living lab initiatives that bring together residents, authorities, private sector actors, and other players to collaboratively develop solutions (Davies & Swilling, 2018). National education and outreach campaigns of UGI can inspire examples of the long term management of public green spaces, supported by bilateral and multilateral initiatives due to the clear synergies on interrelated development goals (Pasquini & Enqvist, 2019). Knowledge exchanges around UGI best practices, which include both qualitative and quantitative components, are particularly valuable in data poor regions where information sharing is challenging, ecological observations are scarce, institutional mandates for monitoring are ill-defined, and data access is often cost prohibitive.

To overcome legal and institutional barriers, accelerated, simplified land tenure reforms can stimulate phased restoration of UGI. Securing tenure is ever more critical against the broader backdrop of forced land dispossession (Davies et al., 2019). Such reforms could allow the poor to enter the land market with some formal ownership. Tenure security allows poorer residents to have greater individual and collective control of decision making and responsibility of surrounding (semi-)natural areas, and stimulates low-cost, incremental restoration of UGI, as shown in the upgrading process in Freedom Square in Gobabis, Namibia (Delgado et al., 2020). Nevertheless, equitable land policies should ensure that the development of UGI does not increase gentrification, perpetuate historic injustices, and displace the very residents the UGI are designed to benefit (Wolch et al., 2014). The recent Namibian Flexible Land Tenure Act of 2011 and Urban and Regional Planning Bill of 2017 may prove to be instrumental as enabling frameworks for *in-situ* upgrading (Karuaihe & Wandschneider, 2018), as could the land titling process of Tanzania. Moreover, the current perception that peri-urban growth is random, and that governance is in limbo, needs to shift so peri-urban landscapes are recognised as important for other parts of the city (Hedblom, Andersson, & Borgström, 2017). Urban-rural linkages need to be rethought and reframed – where the interdependencies between rural and urban areas are recognised - considering that rural areas supply many ecosystem goods and services consumed in peri-urban areas, and peri-urban areas are increasingly encroaching into rural or agricultural areas (Gebre & Gebremedhin, 2019). Embracing institutional cultures of agile policymaking is essential to transitioning towards a far more inclusive path (Thorn et al., 2021).

New financial instruments and accountability structures that account for formal and informal trade systems are needed (Staddon et al., 2018). Scaling monetary and nonmonetary valuation of UGI can enhance appreciation of natural capital and should be complemented by cultural ecosystem assessments that consider production capacities, cultural practices, and access to markets (Wangai et al., 2016; du Toit et al., 2018). Public sector financing can be sourced through financial mechanisms such as congestion charges and split-rate property tax. However, municipal and national financing alone may not be sufficient. This requires mobilising funds from the private sector. Public private partnerships can help show how UGI can lengthen the life of existing built infrastructure, make areas more attractive for investment, and reduce risk - thereby catalysing a virtuous cycle. Another intervention space for funding comes through national and international commitments, such as Vision 2030 associated with the Sustainable Development Goals 6, 11, 13, and 15. Given the inequitable distribution of UGI due to historical legacies (Venter et al., 2020; Giombini & Thorn, 2021), and the break down of upstream - downstream linkages between poor and affluent neighbourhoods, wealthier citizens should more actively direct funds, and advocate to ensure benefits of greening and restoration projects are shared amongst all citizens.

To overcome complementarity and integration barriers, more coordination platforms for dialogue are needed, preferably initiated by community hubs, such as nurseries, schools, medical clinics, supported by local authorities. Such platforms can focus on local priorities and experience of UGI and explore integrative policy ambitions (Wijesinghe & Thorn, 2021). An emphasis on spatial planning can make it easier for people to relate theoretical discussions to their specific concerns, and how particular concerns relate to the larger system or other case studies (Hedblom et al., 2017). For instance, although efficacy is currently being assessed in how tools were used – in Lilongwe, the capital of Malawi under the Urban Natural Assets programme, communities and scientists mapped UGI hotspots to guide city infrastructure developments and in turn, planted indigenous, herbaceous vegetation (ICLEI, 2021b). Audit tools can help municipalities collaboratively tackle conflicting ordinances and building codes. Foresight tools can bring citizens, designers, and planners together to reimagine how green corridors can make social-ecological connections (Frantzeskaki, 2019). Moreover, the holistic nature of UGI has the potential to overcome institutional and sectoral silos (Van Ham & Klimmek, 2017), by shifting fragmented spaces to more multifunctional spaces (Pauleit et al., 2017). Collaboration across different sectors is important to realise this potential (Thorn et al., 2021).

To navigate ecosystem disservices, and the clear deterioration of UGI, the importance of long term maintenance cannot be overstated. Security and surveillance measures is a crucial investment in both individual nodes (e.g., parks) and connections (e.g., pedestrian walkways). Actively involving the broader community in the management of urban parks may stimulate more social sanctions if vandalism or theft of public green space occurs, making offenders less inclined to engage in such behaviour (Shackleton & Njwaxu, 2021). Solid waste management reduces ecosystem disservices (e.g., malodours) and generates income. For instance, in Korogocho slum adjacent to the Nairobi River, Kenyan former convicts and street children initiated a community project to transform the polluted river, create and maintain open space, oversee regular clean-ups, and streamline recycling. Local governments should re-examine the impact of cost recovery policies on low-income communities (e.g., for water, storm water drainage, waste services) - considering the need to achieve distributional and procedural equity in service delivery. There are major gains for public health by ensuring access to safe and well-maintained open space (Wolch et al., 2014), and delivering cleaner, more fuel-efficient energy sources.

Climate change deteriorates UGI's physical state and has the potential to negatively affect residents' perception of UGI, instead of highlighting its role as an adaptation tool (du Toit et al., 2018; Parnell & Walawege, 2011). An accumulating body of evidence suggest that UGI can reduce exposure to climate impacts (e.g., Kabisch et al., 2016; Lange et al., 2016; Douglas, 2018). For example, in Kisumu, Kenya the river system was revitalised through peri-urban community cooperation – contributing to flood retention, temperature regulation, and sequestration of biomass and soil organic carbon (ICLEI, 2021a) (see also Cameron & Blanuša, 2016). Yet, application in practice remains limited. An integrated landscape approach provides a basic framework to balance competing demands, manage multiple land uses, and understand connections in a specific area. Working with natural processes involves actions across spatial (e.g., upstream–downstream) and temporal scales (e.g., across seasons).

Finally, to overcome socio-cultural barriers, building mutual trust between residents of peri-urban settlements, local government, more affluent groups, and the professionals who do the planning, building, and infrastructure development is crucial – but is too often neglected (Shackleton & Njwaxu, 2021). If communities are engaged to understand the purpose and value of UGI for their physical and mental well-being and are actively and meaningfully involved in UGI planning and care, it is more likely that poorer neighbourhoods will invest in scarce financial and human resources to maintain UGI. In addition to local buy-in, involving the community in UGI collaborative restoration from the beginning not only has co-benefits of labour, design input and materials, but strengthens residents politically and economically (Pasquini & Enqvist, 2019), builds a shared sense of place, memory, and meaning of UGI, and is ultimately essential for long term sustainability (Sarabi et al., 2019). Shared visioning of future pathways, open dialogue, and a close analysis of assumptions underpinning worldviews, identities, beliefs, and stigmas based on social circumstance can help break path dependence (Santoro et al., 2019). Ongoing communication processes, and peer-to-peer exchanges can help align upgrading design and objectives with local priorities (Steger et al., 2021; Thorn et al., 2021). There is much scope to embed respectful public participation in all phases: from the consultation, design, (re)creation, management, stewardship, and damage prevention of UGI. Equitable partnerships have great potential to foster agency, creativity and more transformative relationships and outcomes (Ziervogel, Cowen, & Ziniades, 2016).

6. Conclusions

Our analysis has explored, using a mixed methods, comparative approach applied across two rapidly developing cities, the key barriers and enablers to UGI rehabilitation and maintenance in peri-urban settlements. We found, overall, the greatest shared barriers to scaling approaches and processes to build UGI across sites include financial, legal, and institutional, and land use change and spatial trade-offs. While all barriers are found in both case studies, we found that ecosystem disservices were more of a barrier in Dar es Salaam compared to Windhoek. Insights can be used to prioritise effective strategies applicable in each context to support local government decision makers to better allocate scarce resources, enabling the delivery, at scale, of integrated socio-economic, health, and environmental gains.

In urbanand peri-urban areas, biophysical, ecological, and climatic conditions affect the growth of vegetation. Divergent ages of settlements, population sizes, institutional, political, infrastructural, and historical context further influence the management of UGI. The comparative study design therefore permitted a more comprehensive picture of how barriers encountered to managing UGI on the fringes of sub-Saharan African cities may play out under different scenarios of climate change - from cooler and wetter, to hotter and drier conditions, as well as different socio-economic scenarios. Consulting with stakeholders across two countries also allowed for more diversity in the sample, while considering similarities and differences.

In the future, UGI will be a critical element needed to secure reliable water sources to these cities with quality and supply–demand constraints – as acknowledged by the UN's Decade on Ecosystem Restoration (Aronson, Goodwin, Orlando, Eisenberg, & Cross, 2020).

The analytical framework and empirical findings from our study encourages further scrutiny of barriers to implementation of UGI in peri-urban settlements, considering the unique challenges faced in sub-Saharan Africa. Doing so is the first step in enhancing the efficiency of urban adaptation planning and meeting national commitments (e.g., Nationally Determined Contributions), international treaties (e.g., African Union Development Agenda), and assessments (e.g., of the International Panel on Biodiversity and Ecosystem Services).

Future research in peri-urban areas should evaluate spatial priorities to concentrate UGI as part of a powerful cascade of hybridised green–blue-grey infrastructure investments. Examinations of traditional ecological knowledge that is retained in peri-urban settlements can illuminate local innovations in restoring UGI. Assessing toxicity levels in river systems arising from the unregulated deposition of industrial, solid, and human waste, can inform the development of effective means to improve human and ecosystem health. Enhancing methods of valuation will go some way to truly reflect the costs and benefits of UGI that will be more important than ever as populations continue to grow, climates continue to change, and peri-urban areas continue to expand, particularly in sub-Saharan Africa.

CRediT authorship contribution statement

J.P.R. Thorn: Conceptualization, Funding acquisition, Investigation, Data curation, Formal analysis, Visualization, Supervision, Project administration, Software, Writing - original draft, Writing - review & editing. **R. Biancardi Aleu:** Formal analysis, Writing - original draft, Writing - review & editing. **A. Wijesinghe:** Investigation, Formal analysis, Data curation, Writing - review & editing. **M. Mdongwe:** Investigation, Writing - review & editing. **R.A. Marchant:** Conceptualization, Methodology, Writing - review & editing. **S. Shackleton:** Methodology, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was conducted under the "Urban Ecolution: Predicting synergies and trade-offs of water-related ecological infrastructure for climate adaptation in peri-urban Sub-Saharan Africa'', supported through the Climate Research for Development Postdoctoral Fellowship (CR4D-19-21) implemented by the African Academy of Sciences in partnership with the UK's Department for International Development, Weather and Climate Information Services for Africa (WISER) programme and the African Climate Policy Center of the United Nations Economic Commission for Africa. This study has also been funded in part by the African Women in Climate Change Science Fellowship supported by the African Institute of Mathematical Sciences Next Einstein Forum and the International Development Research Centre of Canada Aid, the UK's Research and Innovation's Global Challenges Research Fund under the Development Corridors Partnership project (ES/P011500/1), and Lincre College, University of Oxford. Ethics approval was granted by the Faculty of Science at the University of Cape Town and the Department of Environment and Geography at the University of York. We particularly thank all the participants in Windhoek, Namibia and Dar es Salaam, Tanzania, who gave their time, and local partners, namely the Namibian Housing Action Group, Namibian University of Science and Technology, the City of Windhoek, Rumani Huria, University of Dar es Salaam, Ardhi University and the Municipality of Dar es Salaam. Thanks are due to Prof. Mark New, Dr. Steve Cinderby, Dr. Jon Padgham, Dr. Adam Hejnowicz and Saima Haukelo and the anonymous reviewers. Statements made and views expressed in this work are solely the responsibility of the authors.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2021.104235.

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