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Status and Potential of Green Infrastructure to Support Urban Resilience in Zomba City, Malawi

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By

Patrick Jeremy LIKONGWE

Student No: 18L5274

https://orcid.org/0000-0002-9555-2195

Supervisors
Prof. Charlie Shackleton – Rhodes University, South Africa
Prof. Sosten Chiotha – LEAD SEA, Zomba, Malawi

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Abstract

Small and medium towns with less than one million inhabitants are regarded to be the fastest growing urban centres globally, absorbing the bulk of the urban population growth. This urban growth drives the diminishing natural capital within the urban settings, resulting in compromised ecosystem services delivery, thereby rendering urban dwellers and systems less resilient to hazards and shocks. It is known that urban resilience discourse is rooted in robust, empirical assessments of the nature, composition and distribution of urban green infrastructure. Using the concept of green infrastructure, a mechanism for the delivery of ecosystem services that are multi-functional, well connected, and that integrate the grey-green infrastructure while providing room for social inclusion, anchored the research in a small city of Zomba, Malawi, which is a fast-growing city facing natural resource and ecosystem service degradation. The research therefore was set to understand the status of urban green infrastructure in Zomba over space and time as the basis for enhancing urban resilience. This was facilitated by an understanding of the spatial and temporal quantity, quality, diversity and distribution of urban greenspaces and the composition, structure, diversity and distributional differences of urban trees within different urban greenspace classes. Further to this was an investigation on the perceptions of and preferences for urban greenspaces among the different socio-demographic groups and finally the role of residents, institutions and institutional frameworks in building urban resilience through the delivery of ecosystem services.

To achieve these objectives, the study used a suite of methods. First was geographical information system and remote sensing to understand the spatial and temporal changes in greenspaces within the city in terms of quantity and distribution. Ecological methods of assessing the tree species composition, diversity, population structure and distribution were also employed. To gauge the perceptions of and preferences for urban greenspaces, a survey was done, targeting users found within the urban greenspaces plus residents that claimed to have patronised the urban greenspaces. Finally, to understand the role of nature and the relevant urban ecosystem services provided towards building urban resilience, remote sensing and key informant interviews were done to enrich the literature searches on a case study of urban community efforts involved in managing Sadzi hill to reverse ecosystem disservices versus Chiperoni hill that was not managed.

A general impression of declining urban green infrastructure was verified through the study. The city has indeed lost 14 % tree cover between 1998 and 2018 due to increased housing and creation of agricultural land to support the growing urban population. The city has 168 tree species with 65 % of them being indigenous. Residential areas were dominated by exotic trees, mainly due to the abundance of exotic fruit trees like *Mangifera indica*. Generally, the city has a good tree diversity score but unequally distributed, with the formal residential areas, where the colonial masters settled, having more trees than the mixed and informal residential areas. Nine urban greenspace types were identified, but there was a low per capita urban greenspace area of 11.6 m^2 per person, slightly above the minimum standard set by World Health Organisation. From the preferences for and perceptions of urban greenspaces, patronage to these greenspaces (treated as parks) was highest among the educated youth, a majority being from the high housing density areas where there are no urban parks. Walking to the nearest urban greenspace took more than 10 minutes for 85 % of the respondents. With the available by-laws in support for the governance of greenspaces within the city and the role of residents towards the same, restoration efforts that targeted Sadzi hill yielded positive results through reversing ecosystem disservices that were being experienced by the community members around the hill. The community enjoys several ecosystem services that have also contributed towards building their resilience to climatic and environmental hazards.

The results of this study have unveiled several green infrastructure attributes that can contribute towards building urban social ecological resilience like the presence of high proportion of indigenous tree species, healthy urban forest, high proportion of fruit trees, high diversity scores, unparalleled demand for urban greenspaces for cultural and regulatory ecosystem services, the willingness to pay and work towards managing and conserving greenspaces and the social capital available from the urban communities. However, the study also unveiled several green infrastructure related attributes that if not checked will continue to undermine efforts towards building urban resilience. These included the continued drop in tree and greenspace cover, poor governance of the available public greenspaces, unequal distribution of trees and urban greenspaces, poor management of greenspaces, bare river banks, lack of park amenities and a lack of a clear strategy, policy or an urban plan that clearly outlines green infrastructure. Efforts towards addressing these will mean acknowledging the role of green infrastructure in supporting urban social ecological resilience.

Declaration

I, **Patrick Jeremy LIKONGWE,** hereby declare that this thesis is my own original work, and that all the sources consulted have been duly acknowledged within text and list of references. The thesis is submitted in fulfilment of the requirements for the degree of Doctor of Philosophy at Rhodes University and has not been submitted for any degree or under examination at any other university.

Signature: ………………………………………………………… Date: 30th Aug 2023

Dedication

This work is dedicated to my daughter Sindisiwe, the youngest of the four children, who together with her brothers and sisters, and my dear wife Patricia, missed me for a greater part of this work.

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I am so thankful to God almighty for availing this opportunity through AFRICITY (**A**daptability, **F**ood security, **Ri**sk and the **Ri**ght to the **City** in SSA: Towards Sustainable Livelihoods and Green Infrastructure) project which provided the funds for the studies at Rhodes University. Further appreciation goes to LEAD for further funding support all the way to the end of my studies after the project came to an end while the PhD was not yet completed.

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List of Abbreviations and Acronyms

AFRICITY	Adaptability, Food security, Risk and the Right to the City in sub-Saharan Africa: Towards Sustainable Livelihoods and Green Infrastructure
DBH	Diameter at breast height
EDS	Ecosystem disservices
EI	Ecological infrastructure
ES	Ecosystem services
FIVI	Family importance value index
FRIM	Forestry Research Institute of Malawi
GI	Green infrastructure
GIS	Geographical information system
GN	Global North
GS	Global South
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IUCN	International Union for the Conservation of Nature
IVI	Importance value index
LCBCCAP	Lake Chilwa Basin Climate Change Adaptation Programme
LDC	Least developed country
LEAD	Leadership for Environment and Development
NbS	Nature-based solutions
NDVI	Normalised difference vegetation index
NGOs	Non-Governmental Organisations
NUA	New urban agenda
RD	Relative density
RDo	Relative dominance
RF	Relative frequency
SDGs	Sustainable development goals
SDII	Simple daily intensity index
SES	Social ecological systems
SSA	Sub-Saharan Africa
SUDS	Sustainable urban drainage systems
UGI	Urban green infrastructure

UGS	Urban greenspace
UHI	Urban heat island
UN	United Nations
UP	Urban park
USA	United States of America
WHO	World Health Organisation
WTP	Willingness to pay
WTW	Willingness to work

Publication from the PhD thesis

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Roles: Patrick conceptualized the study, reviewed literature, formulated the methodology, did the formal data analysis, investigations, writing, reviewing, editing, visualisation, field supervision, and project administration. Frank Chimaimba supported in conceptualising, methodology, investigation, review and editing, while Treaser Mandevu and Lois Kamuyango supported in GIS software, methods, and mapping. Hesekia Garekae assisted in reviewing and editing the paper while Sosten Chiotha supervised the work, reviewing, editing, and acquisition of funds. All authors read and agreed to the published version of the manuscript. On average, my overall contribution accounted to 90 %.

1 INTRODUCTION: GREEN INFRASTRUCTURE IN SUPPORTING URBAN RESILIENCE

‘As cities have grown rapidly across the nation, many have neglected infrastructure projects and paved over greenspaces that once absorbed rainwater’ — Charles Duhigg, 1974 – date

1.1 Introduction

The African continent is experiencing high urbanisation rates. The population is expected to reach 60 % urban by 2030 and 70 % by 2050 (United Nations, 2016, 2018). Sub-Saharan African (SSA) countries will account for 52 % of the additional two billion people to be added to the global total by 2050 (United Nations, 2019a). Furthermore, smaller cities with less than one million inhabitants are generally regarded as the fastest growing the world over, at an annual average of 4.1 %, against a world average of 2 % (United Nations, 2014), absorbing the bulk (75 %) of the urban population growth (Baeumler et al., 2021). This projected population increase is likely to cause a loss of natural ecosystems and their associated ecosystem services (ES) due to degradation of the urban and peri-urban environment (Seto et al., 2012) and transformation to urban land uses (Ghofrani et al., 2020). The focus on the urban environment is well outlined in three international agreements, namely: The Agenda 2030 (2015), The Paris Agreement (2016) and The New Urban Agenda (2016). In all these agreements, the urban environment and its inhabitants are targeted in three domains, i.e., social, economic, and environmental, which is echoed in the widely recognised concept of urban green infrastructure (UGI) (Lindley et al., 2018).

Urban GI is a concept that spans ecology, biodiversity conservation, and urban planning and design for the provision of multiple ecosystem services (ES). This study draws on Benedict & McMahon (2006, 2001) and Schäffler & Swilling, (2013) in defining UGI as an interconnected network of natural and human-made ecological systems, greenspaces and landscape features that are designed and managed for the contribution of multi-functional and multi-scale ES for urban communities. Some of the multi-scale ES include food production, stormwater mitigation, urban heat island mitigation, air and water purification, reduced surface runoff, improved physical and mental human health, and sewer water management (Wolch et al., 2014). Despite the broad and crucial roles that UGI provides, many cities in SSA lack adequate UGI (Mensah, 2014). The success of effectively providing urban greenspaces (UGS) however depends on the type of benefit residents want from such UGS even though requirements can change over time (du Toit et al., 2018). Allied to the inadequate UGI in most SSA cities, many urban areas in developing countries are rapidly expanding and UGI planning and ecosystem research is in its infancy (Hansen & Pauleit, 2014; Pauleit et al., 2017), resulting in poor understanding and dissemination of the UGI concepts and principles (Shackleton et al., 2018).

Authorities in Malawian cities also face the same challenge of not knowing the number and extent of UGS they have and the ES that they provide. This is exacerbated due to the constraints within urban planning which include incapacitation of the institutions in terms of human and technological capacity to achieve modernism as they are marred by bureaucracy, cumbersome procedures, inefficiency, corruption, and poor enforcement of the available master plans (Edwin et al., 2020; Mwathunga & Donaldson, 2018). These constraints were also echoed by the director of planning and development (personal communication) for Zomba (the study city of this thesis), citing the major challenge as unplanned city development. This is mostly caused by institutional failures that require harmonisation and forward planning. Further to that, is the issue of inadequate resources, no master plan to guide city development, and under collection and improper disposal of waste. Most of the unplanned areas are not serviced and the drainage and stream channels have become waste dumping sites. There is also environmental degradation due to pressure on trees and land resources. With these constraints, UGI planning is far-fetched, but it is worth noting that the current development agenda, Malawi Vision 2063, puts focus on creation of world class urban centres and the creation of secondary cities that will have UGS such as parks, sports fields, and vegetation, as a key element in integrated urban planning (Government of Malawi, 2020). This is an entry point for the study as it will help to guide planning for UGI in line with the ES needs of the urban residents.

For cities to be sustainable, they need to ‘balance the immediate needs of today while not compromising on the needs of tomorrow’ (Keeble, 2007). Therefore, a sustainable city is an environmentally, economically, and socially healthy place where people can comfortably live, work and interact for centuries to come. Included in the environmental component, a sustainable city takes pride in its UGI network that includes connected parks, formal and informal UGS, a diversity of biodiversity, habitats and ecological systems, wildlife rehabilitation and forest conservation areas (Anastasiadis & Metaxas, 2013). Apart from sustainability, a city must be safe from and resilient to undesirable changes and stresses. According to Krüger (2013), a lack of resilience and now ‘resourcefulness’ in a city is linked to governance patterns that ignore the importance of social inclusiveness and common, public spaces. The role of UGI in contributing cost-effectively to urban sustainability and resilience is therefore gaining credence (Austin, 2014; Mell, 2016).

Despite increasing pressure to plan for sustainability, there is now recognition to also plan for resilience (Ahern, 2011; Davoudi et al., 2012). The expansion of UGI is a major strategy for enhancing both the sustainability as well as resilience and resourcefulness of cities and communities in general (Lennon & Scott, 2014). Resourcefulness focuses attention upon the uneven distribution of resources within and between communities and maintains an openness to the possibilities of community self-determination through local skills and 'folk' knowledge (MacKinnon & Derickson, 2013). Resourcefulness works towards cultivating conditions in which communities can develop alternative visions of social relations and structures.

This study therefore focused on the status and potential of UGI to support urban resilience in Zomba, Malawi. It is inspired by the concepts of ES from UGI through understanding the status of formal and informal urban forests and UGS as a subset of UGI. It is believed that healthy urban forests and UGS do provide a myriad of ecosystem services, some of which positively contribute to urban resilience. The interactions between the formal and informal UGS and the urban communities within a socio-ecological systems setup was understood to provide a guide for practice and policy in a small city like Zomba. This introductory chapter further provides a snapshot of the key terms, theories and concepts used in this study and analyses the underlying research problem, outlines the aim and objectives, guiding research questions, conceptual framework and research philosophy. Finally, it introduces the case study city along with the historical perspectives inclined towards the natural environment or UGI, the social, economic, and environmental profiles, and the challenges the city is facing.

1.2 Key terms, theories and concepts in the context of this study

The key terms and concepts that this research hinges on are defined below:

ES: nature's contributions to humanity, in the form of services and disservices (Pascual et al., 2017), an upgrade from the direct and indirect contributions of ecosystems to human well-being (TEEB, 2010). The concept of 'ecosystem goods and services' is synonymous with ES. When the location of these ES is in the city, then they are defined as urban ES.

Formal greenspaces: are designated, accessible, and usable open spaces in urban ecosystems characterised by the presence of vegetation and managed by city authorities to serve primarily for cultural ES, such as recreation, socialisation, and other community purposes (Farahani & Maller, 2018).

Green infrastructure: an interconnected network of natural and human-made ecological systems, greenspaces and landscape features that are designed and managed for the contribution of multi-functional and multi-scale ES for urban communities (Benedict & McMahon, 2006, 2001; Schäffler & Swilling, 2013). The concept is based on the principle that nature and natural processes are deliberately integrated into spatial planning and urban development to promote and enhance the delivery of ES and therefore social, economic, and environmental benefits, including better food security and involvement of residents in shaping the city (Herslund et al., 2018; Mell, 2017; Schäffler & Swilling, 2013).

Greenspaces: all the partly and fully vegetated areas that occur in urban environments, commonly referred to as urban greenspaces, including formal parks, natural areas, forest reserves and other informal open greenspaces (Taylor & Hochuli, 2017).

Informal greenspaces: are accessible and usable open greenspaces in urban ecosystems characterised by the presence of vegetation but are not managed by the city authorities for recreation, socialisation, and other community purposes (Rupprecht & Byrne, 2014).

Social-ecological systems (SES): are complex, adaptive systems in which social and biophysical components are interacting at multiple temporal and spatial scales (Liu et al., 2007), where social systems can be viewed as a hierarchy of systems interconnected by cross-scale interactions from global to local (Chapin et al., 2006), while biophysical components influence ecosystem properties across temporal and spatial scales in a hierarchical way (Bailey, 2009).

Urban resilience: the capacity of urban systems, measured along economy, society, governance, and environment, to absorb disturbance and to re-organise while undergoing a change to retain similar function, structure, identity, and feedbacks (The Rockefeller Foundation, 2016; Walker et al., 2004).

1.3 Statement of the research problem and justification

The potential of UGI in contributing cost-effectively towards sustainability and resilience of urban livelihoods has gained credence from the late 1990s (Shackleton et al., 2018). Fostering urban resilience requires a social-ecological systems approach that considers the ecological and social dimensions of and interactions in cities. The quantity, quality, diversity, and distribution of UGI in a city determines the ES that underpin resilience of the city and its dwellers. The 'resilient and resourceful city' is a just city providing sufficient means to sustain the livelihoods and well-being of all citizens and enabling them to be aware of their living environment, and to actively shape their urban environment in the way they deem necessary or preferable, and to buffer and mitigate increasing external climate change related threats (MacKinnon & Derickson, 2013). Conversely, a city lacking in resilience and resourcefulness will most likely also be marked by governance patterns that ignore the importance of social inclusiveness and common, public spaces (Pedrosa et al., 2021). These assertions will be analysed through the lens of UGI, focusing on the multi-functionality of trees and greenspaces as a concept for the shaping of urban spaces and lifeworlds through the provision of the various urban ES in Zomba, Malawi.

The need to know the status of UGI within a city is emphasised by several authors although most city authorities, especially in Africa, do not know the quantity, quality, density and distribution of public greenspaces and trees under their jurisdiction, making it almost impossible to plan, manage and appreciate their value and functions (Chishaleshale et al., 2015; Shackleton, 2012; Shackleton et al., 2014). However, a few other cities from other developing countries elsewhere and in SSA did studies to know the quantity, quality, density and distribution of UGS for planning purposes like in the suburbs of Shanghai (Ta et al., 2021), from 111 urban areas in Southeast Asia (Richards et al., 2017), in Kumasi, Ghana (Nero et al., 2018; Nero, 2016b), in Cairo, Egypt (Aly & Dimitrijevic, 2022), urban trees in Nairobi, Kenya (Nyambane et al., 2016) and three cities from Nigeria (Agbelade, Onyekwelu, & Oyun, 2016; Dangulla et al., 2020). The Zomba City Resilience Plan (2016-2026) outlines five priority actions to reinforce the city's resilience; the top two being to reduce and mitigate floods and to improve the drainage system. However, in its short, medium and long-term interventions in response to these two priority actions, there is no mention of the role of UGI interventions to help in building resilience to floods, like the use of sustainable urban drainage systems (SUDS) such as swales, filter trench/strips, infiltration pits, detention and retention ponds, rain gardens, ponds and wetlands to reduce surface water runoff as well as clean the water before it enters rivers and other natural water storage facilities. These have become a mainstream concept for the expression of values assigned by people to various functions of healthy ecosystems (IUCN, 2016).

However, Bennett et al. (2015) note that even though there is much research on ES for human well-being, there is insufficient use of the knowledge for sustainable resource use. Schäffler and Swilling (2013) and Bennett et al. (2015) agree that urban resilience discourse is rooted in robust, empirical assessments of the nature, composition and distribution of urban green networks and understanding the ‘state’ of UGI. Therefore, knowledge of the urban resilience discourse can help in questioning how ES are co-produced by social-ecological systems (SES), who benefits from the provision of ES and what are the best governance mechanisms for ES to enhance resilience and resourcefulness of people and nature in urban environments.

1.4 Research aim and objectives

Within this context, the aim of this study was to understand the status of UGI over space and time to support urban resilience in Zomba, Malawi. To achieve this aim, the study was guided by four research objectives, namely:

1. Understand the composition, structure, diversity, and distribution of urban trees within designated greenspace classes in Zomba, Malawi.
2. Analyse the spatial and temporal changes in the quantity, quality, diversity, and distribution of urban greenspaces in Zomba, Malawi.
3. Analyse perceptions of and preferences for urban parks by different social-demographic groups in Zomba, Malawi.
4. Examine the role of residents, institutions, and institutional frameworks in building urban social-ecological resilience through the delivery of urban ES in Zomba, Malawi.

1.4.1 Research questions

This study was set to understand the status of UGI in Zomba with a focus on the formal and informal urban greenspaces and trees. According to Rupprecht & Byrne (2014), informal urban greenspaces (informal UGS) are explicitly social-ecological entities, rather than solely cultural or biological. Informal UGS are neither formally recognised by governing institutions or property owners as greenspace designated for agriculture, forestry, gardening, recreation (either as parks or gardens) or for environmental protection. Their use for recreational, cultural, and provisioning purposes is informal and transitional. Informal UGS are mostly influenced by factors of human origin and ecological conditions and not management. Formal UGS on the other hand, are those that are planned, managed, and modified by the city authorities, including urban parks, gardens, and conservation areas, and influenced by management mainly for human and ecological well-being (Farahani & Maller, 2018; Rupprecht & Byrne, 2014). Assessing the status of both the formal and informal UGS and trees in Zomba was guided by four research questions, namely:

a. What is the composition, structure, diversity, and distribution of urban trees in the different greenspace types in Zomba?
b. What is the quantity, quality, diversity, and distribution of formal and informal greenspaces in the city of Zomba over space and time?
c. What are the perceptions of and preferences for urban parks amongst the different social-demographic groups in Zomba?
d. What is the role of residents, institutions, and institutional frameworks in building urban social-ecological resilience through the delivery of urban ES in Zomba?

1.5 Conceptual framework

This study was motivated by the concepts of ES and UGI applied in a social-ecological system framework. It sought to understand the status and potential of the available UGI within the city to support urban social-ecological resilience while providing the basis for urban planning. The concept of ES as 'nature's contribution to people (NCP)' as recoined by Pascual et al. (2017) encompassed the notion of ecosystem disservices (EDS), changing the meaning of ES from nature's 'benefits' to nature's 'contribution' to people. The concept of ES finds its roots in the 1970s when ecosystem functions beneficial to humans were referred to as 'services' in a drive to bring awareness of biodiversity conservation (Sterling et al., 2010). This followed a global assessment of ES to policy makers by the United Nations' Millennium Ecosystem Assessment team in 2005, who defined ES as 'the benefits ecosystems provide to humans.' This was developed upon the realisation that the benefits humans derive from nature are not sufficiently reflected, if at all, in conventional economics (Sterling et al., 2010). ES were divided into four categories of (i) provisioning, (ii) regulatory, (iii) cultural and (iv) supporting services.

The provisioning services are the goods such as food, fresh water, wood, timber, non-timber forest products, that urban and peri-urban natural environments provide (Finlayson et al., 2005). The regulatory services include flood protection and water purification as provided by healthy natural systems like wetlands, reduction of temperatures and air pollution by trees, just to mention a few (Finlayson et al., 2005). The cultural services are the intangible benefits such as recreation and aesthetics, sense of home, cultural identity and spiritual experience related to natural environments (Finlayson et al., 2005). Finally, supporting services are the basic processes and functions like soil formation, nutrient cycling, habitat for wildlife, which are critical to the provisioning of the first three categories (TEEB, 2010). This study also focused on cultural ES to appreciate the perceptions of and preferences for urban parks as one way of understanding the views of park users towards recreation. This was against the background that most studies focused on the first two ES of provisioning and regulatory, at least from 20 out of 53 SSA countries as reviewed by du Toit et al. (2018). Nonetheless, the other ES were also understood from the residents within the urban setting.

Since the ES concept was adopted in the late 1990s, many research studies have been done, mostly from the Global North (Rigolon et al., 2018). One economic recommendation from Elmqvist et al. (2013) was that the benefits of active investment in restoring rivers, lakes, woodlands, and forests in urban areas is not only ecologically and socially desirable, but also economically advantageous. Another conclusion was that the concept of ES has a significant role in reconnecting cities to the biosphere and in reducing the ecological footprint of cities while enhancing health, quality of life and resilience (Gómez-Baggethun et al., 2013). Despite this positive depiction about ES, it should also be noted that ecosystems also generate ecosystem disservices. According to Shackleton et al. (2016), these are 'the ecosystem generated functions, processes and attributes that result in perceived or actual negative impacts on human well-being.' These would include, for instance, a snake bite as a direct effect on human well-being or pollen allergies as an impact of an ecosystem process;

another example would be diminished flow of ES following an EDS episode e.g., crop pests and finally could be wildfire which would impair the supporting or regulating service of an ecosystem. The latter being a case in the study area and Malawi in general where wildfires have distorted flows of ES in forest ecosystems (Pullanikkatil et al., 2016; UN-Habitat, 2016). The ES normally comes from healthy ecosystems and other parcels of greenspaces at a regional or local scale. Studies have mapped ES within urban environments, but managing them sustainably involves a cross-section of stakeholders in different fields (Maes et al., 2019). This has seen the evocation of the concept of UGI to reinforce the ES concept in urban planning.

The concept of UGI, as one of the major components of sustainable cities, has attention from academia, practice, and policy planning circles since it emerged in the late 1990s. However, the first term that used ecosystems as infrastructure was 'ecological infrastructure' (EI), proposed by 59 scientists from 24 countries participating in a United Nations Educational, Scientific and Cultural Organisations (UNESCO) Man and Biosphere (MAB) Programme on urban planning in 1984 (Ishwaran, 2012). This original concept was explained as using 'natural landscape and natural areas as the framework for spatially organizing the city', and traces back to urban parks in the 1850s in Europe and USA (Ishwaran, 2012; Sun et al., 2020). This concept of UGI reinforced the EI concept in the sense that UGI focused on connectivity and multi-functionality of the ES providing units. UGI is however perceived differently in line with the context in which it is used (Benedict & McMahon, 2006). To some, it may be engineered structures for stormwater management or may involve natural areas and ecosystems that provide ES (Benedict & McMahon, 2006; Matthews et al., 2015), the latter being the case for this study.

The core principles guiding UGI planning include multi-functionality, connectivity, green-grey integration, and social inclusiveness (Benedict & McMahon, 2006; Lindley et al., 2018). Multi-functionality is about the combination of a whole set of functions and benefits from UGI and their ecological, social, and economic aspects in a particular area (Monteiro et al., 2020). Connectivity considers the structural and functional connections between different greenspaces at different levels and perspectives like biodiversity, urban climate, stormwater, recreation, etc. (Benedict & McMahon, 2006; Lindley et al., 2018; Monteiro et al., 2020). The principle of integration is about coordination and combination of urban greenspaces with other urban infrastructure in a physical and functional sense. Social inclusion on the other hand, involves the wide range of social groups with emphasis to the groups that are vulnerable and disadvantaged when it comes to decision making (Pauleit et al., 2017). The concepts of ES and UGI have the potential to improve environmental planning in urban areas but lack application-oriented frameworks that can support mainstreaming these in planning practice (Tzoulas et al., 2021).

The concepts of ES and UGI have different frameworks, notably the ones presented by Finlayson et al. (2005), Haines-Young & Potschin (2018), and (Pascual et al., 2017). These have evolved over time and now contribute towards nature-based solutions (NbS), an umbrella concept which has an ecosystems approach and UGI as the tools to deliver the much-needed ES, mostly used in policy (Pauleit et al., 2017). The ecosystem approach was defined by the Convention on Biodiversity Conservation (CBD) (2004) as a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. While NbS are defined as 'actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits' (IUCN, 2016). The concept of NbS echoes UGI with regard to multi-functionality on top of being conservational and additional as it focuses broadly on building natural capital which contributes to overall resilience of the landscape. NbS is also integrative and governance-based in creation and management as it is not top-down but participatory, involving the principles of co-design, co-creation and co-management and is action-oriented (Pauleit et al., 2017).

The concept of social-ecological systems (SES) regards resilience as one of its important goals when sustainability thinking is considered. Wu (2014) acknowledged cities as 'coupled social-ecological systems, with an increasing emphasis on the relationship between ES and human well-being in urban areas.' Shackleton et al. (2021) underscored the need for tailor made SES studies in the Global South (GS), mindful of the fact that many SES studies have been done in the Global North (GN), which is different from the GS in many regards. One such difference in line with this study is that GS cities have a diversity of belief systems on human–nature relationships which needs to be understood as to why and how particular groups of people view, use and value nature and the type of nature they require, to be included in urban planning.

It is against this background that the conceptual framing for this study (Figure 1-1) intends to analyse 1) the quantity, quality, diversity, and distribution of urban greenspaces 2) the composition, structure, diversity, and distribution of urban trees 3) perceptions of and preferences for urban parks, and 4) the roles of residents and institutions in the provision and management of UGI in Zomba. This will be analysed within the urban landscape which is subjected to different stressors like climate change, environmental degradation, and urbanisation, resulting in land use and land cover changes. The concepts from UGI that support building urban resilience and sustainability are focused on the much-sought after ES. These ES are influenced by the dynamics in the presence or absence of trees and UGS within the city scape in space and time. The analysis within these concepts will support in understanding the status of UGS and trees within the city of Zomba to inform policy and practice action plus further research that will contribute knowledge towards building urban resilience and sustainability now and in the years to come. Much as the past cannot determine or define the future, knowledge in spatial and temporal trends of UGS and trees would reveal what can be enhanced and what needs to be changed if UGI is to contribute to building a resilient and sustainable city.

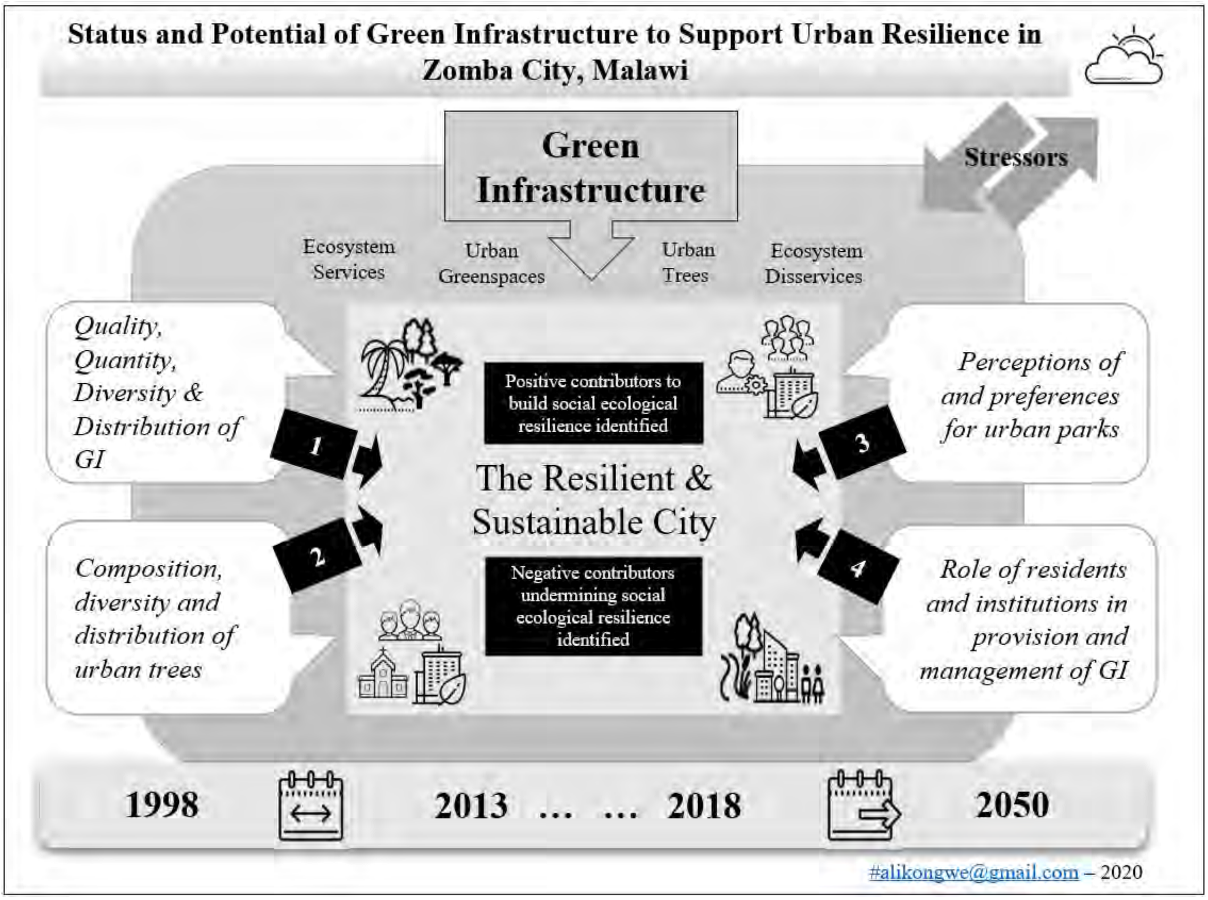


Figure 1-1: The conceptual framing for the research study (Source: Researcher).

1.6 Research philosophy

This research took the pragmatism worldview, a bridge between the two extremes, that of positivism (quantitative scientific method) and interpretivism (qualitative methods) (Creswell, 2013; Creswell & Plano Clark, 2011). Pragmatism is identified with consequences of actions, problem solving, pluralistic and real-world practice oriented (Creswell, 2014). Instead of focusing on methods, researchers emphasize on the research problem and use all approaches available to understand it. A major underpinning of pragmatist epistemology is that knowledge is always based on experience and that one's perceptions of the world are influenced by our social experiences (Creswell, 2014). The three pragmatism principles of 1) an emphasis on actionable knowledge, 2) recognition of the interconnectedness between experience, knowing and acting and 3) a view of inquiry as an experiential process provides the philosophical link to this study (Kelly & Cordeiro, 2020).

The principle of actionable knowledge anchored the research through knowledge gained in quality, quantity and distribution of UGS, composition, structure, diversity and distribution of trees within the city and the experiences of respondents as outlined in perceptions of and preferences for UGS. The second principle anchored the roles of residents and institutions in the provision and management of UGI. This helped to identify information-rich respondents most likely to provide useful practice-based knowledge while ensuring that the sampling process uncovered a range of perspectives. Finally, the third principle on experiential processes clarified the role of the researcher in triangulating quantitative and qualitative results to combine macro- and micro-level perspectives within the study. Pragmatism allowed for a research process that was flexible and adaptive through the use of the mixed-methods approach as summarised in Figure 1-2, which further outlines the type of the philosophical worldview, the abductive research approach as the research category and its related strategies of inquiry and research methods involved in the studies. Quantitative methods in the scientific realm included use of tree inventory data, GIS and remote sensing, and use of related indices in the analysis. Qualitative methods included use of questionnaires in survey with both open- and close-ended questions, key informant interviews and their related thematic analysis. Each empirical chapter therefore explains the research methods employed to answer the research questions, outlines data collection methods and tools, data analysis, interpretation and validation and synthesised in the final chapter with recommendations for research, policy and practice.

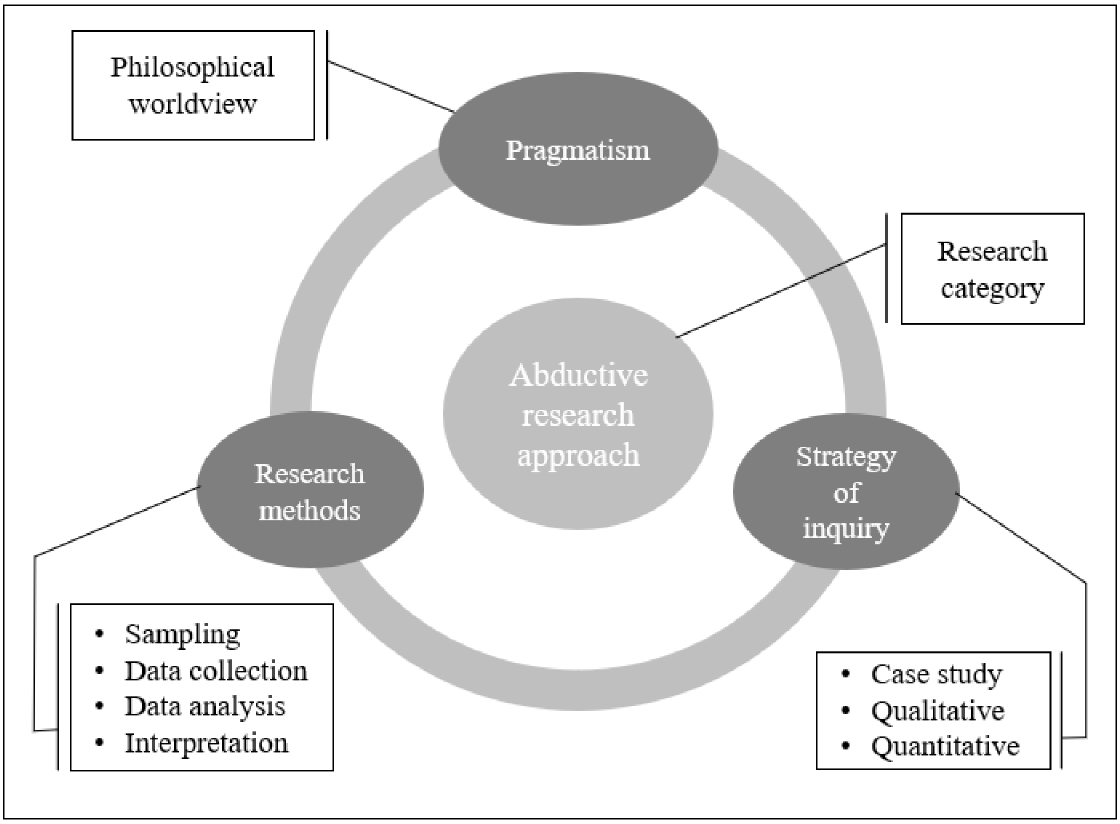


Figure 1-2: Schematic outline of the research philosophy, ontology, epistemology and methods underpinning the research (adapted from Creswell, 2014).

1.7 Introduction to Zomba city

This study was done in Zomba, the fourth largest city in Malawi after Blantyre, Lilongwe and Mzuzu. It covers an area of 42 km^2, located at the foot of the Zomba Plateau, which is 2,085 m above sea level. The city is made up of one constituency, called Zomba Central, with ten wards (Figure 1-3) and 25 neighbourhoods. These host the central government and business zone, public and private institutions and residential areas which have a mix of planned and unplanned settlements that are further categorised into low, medium, and high population density. The governance structure of the city puts the mayor as the most senior administrative officer with support from service committees and the town and country planning committee. Below them is the council secretariat, manned by a Chief Executive Officer, who reports to the mayor but works hand in hand with several directors from administration, planning and development, engineering services, finance, health and social services, education, parks and recreation, and trade and commerce. At ward level, ward development committees facilitate development while neighbourhood committees facilitate development at neighbourhood level.

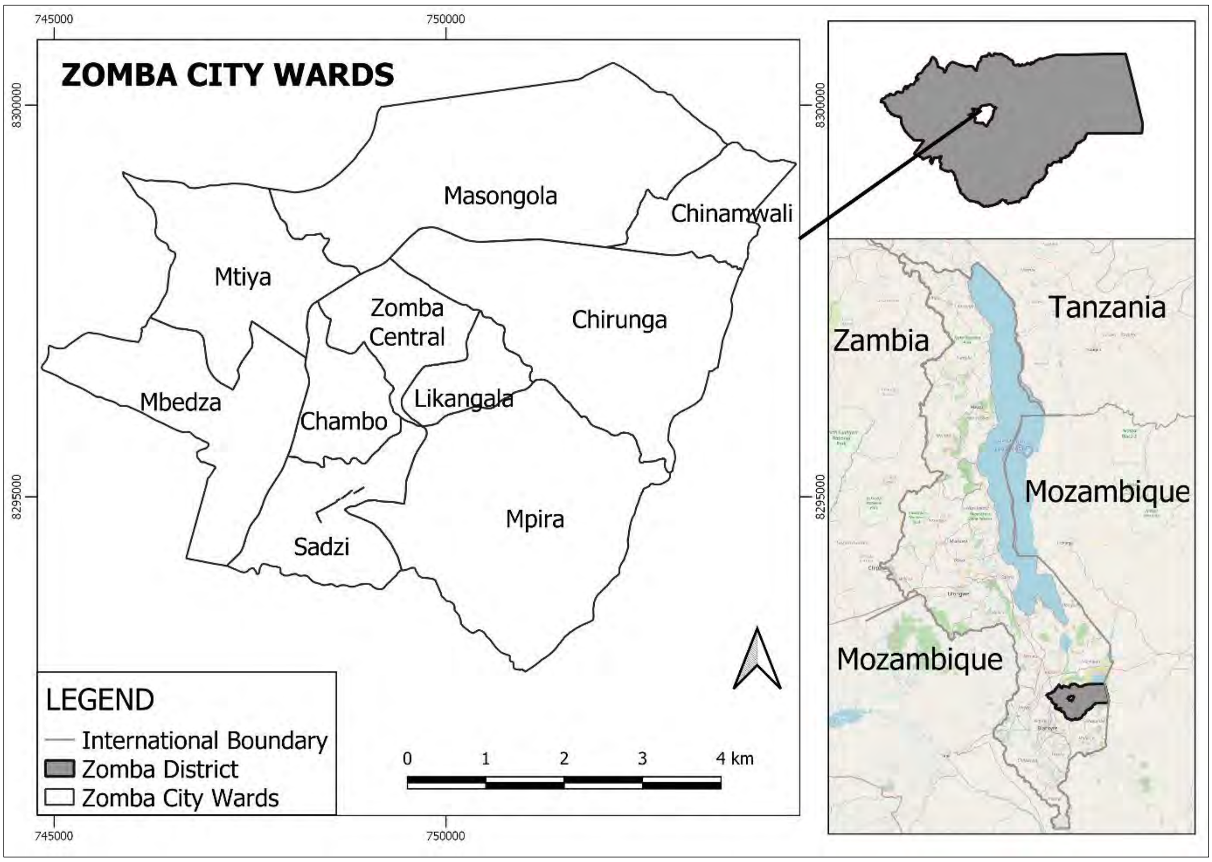


Figure 1-3: The location of Zomba and the city's ten wards (Source: Researcher).

1.7.1 Historical perspective of the city

The story of Zomba was orchestrated by the Livingstonia Mission when they sent John Buchanan, the mission's horticulturist, and gardener, to establish the Church of Central African Presbyterian (CCAP) mission in Zomba in 1876 (Stahl, 2010). Buchanan, who arrived at the base of Zomba Mountain, was struck by its beauty as Zomba was situated in a valley and covered with evergreen forests and grasslands. The church mission represented the British control until 1884. In 1885, the whole of southern Malawi was formerly under the British Foreign Office who declared it a British Authority to protect the growing number of British settlers who were mandated to guard British commercial interests (Stahl, 2010). Zomba was then declared as the seat of the British Authority in the same year, calling for the construction of buildings to suit the British administration.

The first consul was Captain Foot after who consul A.G. Hawes arrived in 1885 to take over leadership. He appointed Buchanan as the Vice consul. It was this time when the first building was erected, the residence for the consul. It was built on a 40 ha piece of land, bought from Chief Malemia (Roy, 1984). The residence comprised two, one-storey houses, built in a style permitting easy fortification in time of trouble as the administration then was engaged in eradicating the slave trade. The house was given a native name *Masongola*, meaning ‘the points’ from which the hexagonal towers had window slits at either end of the main structure (Roy, 1984).

Buchanan also bought land for the garden located in front of the residency and together with Alexander Whyte, a fellow of the Zoological Society and a practical botanist, established the residency gardens by 1900 (Stahl, 2010). This garden was later transformed into the first Botanic Garden in the British Central Africa, now the present Zomba botanical gardens (Stahl, 2010). The botanical gardens were established to serve various functions which included the introduction and screening of exotics, especially those of economic importance; collection and classification of indigenous species, especially useful trees and shrubs, herbs and medicinal plants; to distribute plants, seeds and seedlings; to demonstrate the uses for which plants were suitable – economic, decoration, shade, foliage and flowers; to educate the public to recognise the various trees and plants and their uses and finally to provide relaxation and pleasure (Gann & Duignan, 1981). The National Herbarium and Botanic Gardens of Malawi was established by an Act of Parliament in 1987 with the objective of developing botanic gardens and herbaria. The Zomba Botanic Garden houses the headquarters with other botanical gardens present in Lilongwe and Mzuzu.

In 1889, Buchanan (considered as the father of Zomba) declared it as the seat of the British Central African Protectorate over the British Authority covering Malawi and in 1891, Sir Harry Johnstone became the first commissioner (Stahl, 2010). Zomba was known as the greenest capital of the British Empire. By 1896, a gymkhana club had been started, with a tennis court, a cricket ground and golf links (Stahl, 2010), with the government conveying some land to the club for playing fields and ceremonial parades (Mathews, 1964). In 1897, Zomba’s population was estimated at 150 (British Central Africa, 1904). Due to its growing population, infrastructure, and prestige, it was later declared a township in September 1900 and the first secretariat was established in 1901 (Stahl, 2010). It was declared a planning area in 1955 with its first Outline Zoning Scheme (Urban Structure Plan) published in 1958. When the country became independent in 1964, Zomba was the first capital city until 1975, after which the capital moved to Lilongwe. Zomba then retained a municipal status and was later established as a Local Authority and District Administration under the 1998 Local Government (Urban Councils) Act, Cap 22.01 of the Laws of Malawi (Government of Malawi, 1998) and was later granted the city status in 2008 till now.

1.7.2 Social profile

Before colonisation, the Zomba area was dominated by the Amang'anja and Yao tribes (Stahl, 2010). Currently, the city has a heterogeneous population composed of different ethnic groups, cultures, and languages, with about 85 % of the city population comprised of the Lomwe, Yao, Chewa, Ngoni, and Nyanja tribes, while the rest are from Mang'anja, Tumbuka, Sena, Tonga, and others (National Statistics Office, 2019a). From the initial known population of 150 in 1897, the city had a population of 105,013 people (representing a density of 2,500 people per km^2) in 2018 (Figure 1-4), and the average annual growth rate has been 2.5 % over the last decade (National Statistics Office, 2019a). The current population density of Zomba city was similar to that of Lagos city, Nigeria, at 2,594 people per square km as of 2013 (Dipeolu et al., 2021). There was a slight increase in population between 1966 and 1977 following the relocation of the capital city to Lilongwe in 1975. The population increase in the preceding years corresponds to an increase in built up area, more especially in residential property. Plans are underway to extend the city boundaries further.

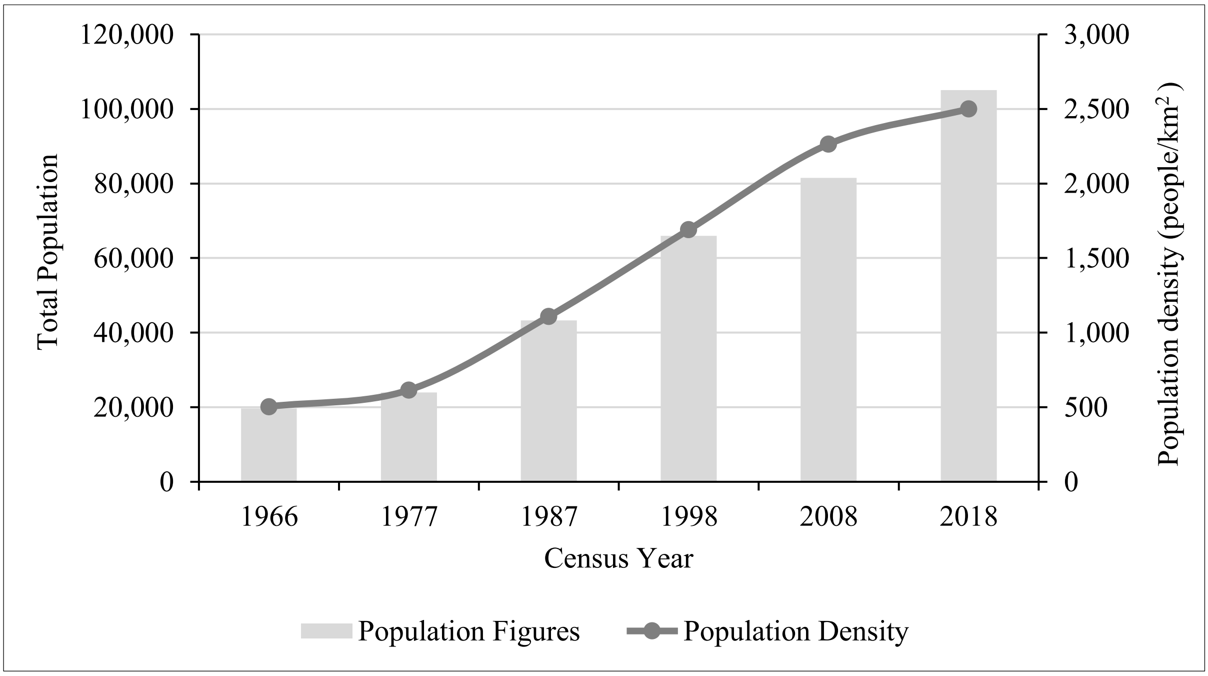


Figure 1-4: Population growth in Zomba city since independence in 1964 (Source: Researcher).

The National Statistical Office (2008) indicates that 66 % of the population of Zomba lack basic urban services, social infrastructure and reside in informal settlements. Transport facilities are mostly provided by minibus, taxi, motorcycles, and bicycles, with buses offering long transportation services. The city is yet to provide footpaths and bicycle paths to reduce the growing challenges of congestion and conflicts between road users such as cyclists, pedestrians, and drivers (UN-Habitat, 2011b). The city is expanding into the rural surroundings and agricultural land outside the city periphery, being absorbed and developed for commercial and residential urban use, with rivers that are polluted (Zomba District Council, 2017). Culturally, the city has a rich heritage which complements the district's natural beauty with tourists who come to see historical relics. The Malawi Housing Corporation owns many of the housing units in the city as one of the major landlords, complemented by private housing units.

1.7.3 Economic profile

There are numerous economic opportunities, especially in agro-processing industries. The city is dominated by informal income generating activities from small and medium enterprises, with the most important local economic development activities being retail trade, construction, manufacturing, transport, marketing, finance, social services, and public administration. Small enterprises like hawkers, vendors, taxi, and minibus operators represent 93 % of the economy, while medium-scale activities contribute 6 % and large-scale 1 % (Zomba District Council, 2017). The city has about 27 % economically inactive population (UN-Habitat, 2011b, 2016), 15 % unemployed and 58 % employed, all in the age group of 15 – 64 years (National Statistics Office, 2019b). Employment activities include agriculture and small-scale mining, manufacturing, construction, marketing, finance, and social services. Very few enterprises have access to bank loans due to lack of knowledge as well as unsuitable terms and conditions attached to these loans despite having several commercial banks (Zomba District Council, 2017). On average, Zomba residents have a mean annual consumption of MK421,789 per person, second to Blantyre city at MK760,778 per person (National Statistics Office, 2019b). The highest quantile consume almost eight times that of the lowest quantile, however on average, the richest consumes about MK590, 440 per annum with the poorest consuming about MK71, 002 per annum ($1 = MK 729.50 based on 2018 average - https://www.exchangerates.org.uk/USD-MWK-spot-exchange-rates-history-2018.html). In the Malawi Poverty Report (2018), the National Statistics Office uses consumption expenditure as a welfare indicator as it is a more accurate measure of living standards than income, and it is preferred more in developing countries like Malawi (National Statistics Office, 2019b).

The informal sector is vibrant, with many informal settlement residents working in the informal sector. The high dependence on small and medium enterprises, rapid population growth and unemployment contributes to the 16 % poverty in the city, with 4 % being ultra-poor as of 2018 (National Statistics Office, 2019b), down from the 2010 poverty level of 29 % poor and 12 % ultra-poor (UN-Habitat, 2011b). The Zomba City Resilience Plan (2016-2026) further mentions that many of the social and economic activities plied within the city, like timber trading, moulding, and firing of bricks, large-scale sand mining and small-scale quarrying, among others, increase the threats of environmental disasters with potential human health and social implications. The city is accessed by a main road that connects it to the neighbouring commercial city of Blantyre. It is served by Chileka International Airport in Blantyre, about 100 km away. According to the National Statistics Office (2018), literacy level within the city of Zomba is 90% after Mzuzu city at 91 % for those aged 5 years and above who were able to read and write a simple sentence in any language.

1.7.4 Environmental profile

The city experiences a tropical climate with three main seasons, i.e., cold-dry, hot-dry, and hot-wet from April-July, August-October, and November-March, respectively. The average maximum temperatures in the hottest months of September-November range between 28 ºC and 31 ºC, with maximum temperatures of over 36 ºC. Minimum temperatures are experienced in June and July, with readings as low as 10 ºC. It is also noted that the number of days annually with maximum temperatures above 30 ºC are increasing, while those with less than 10 ºC are decreasing (Figure 1-5), an indication of the warming up within the city environment.

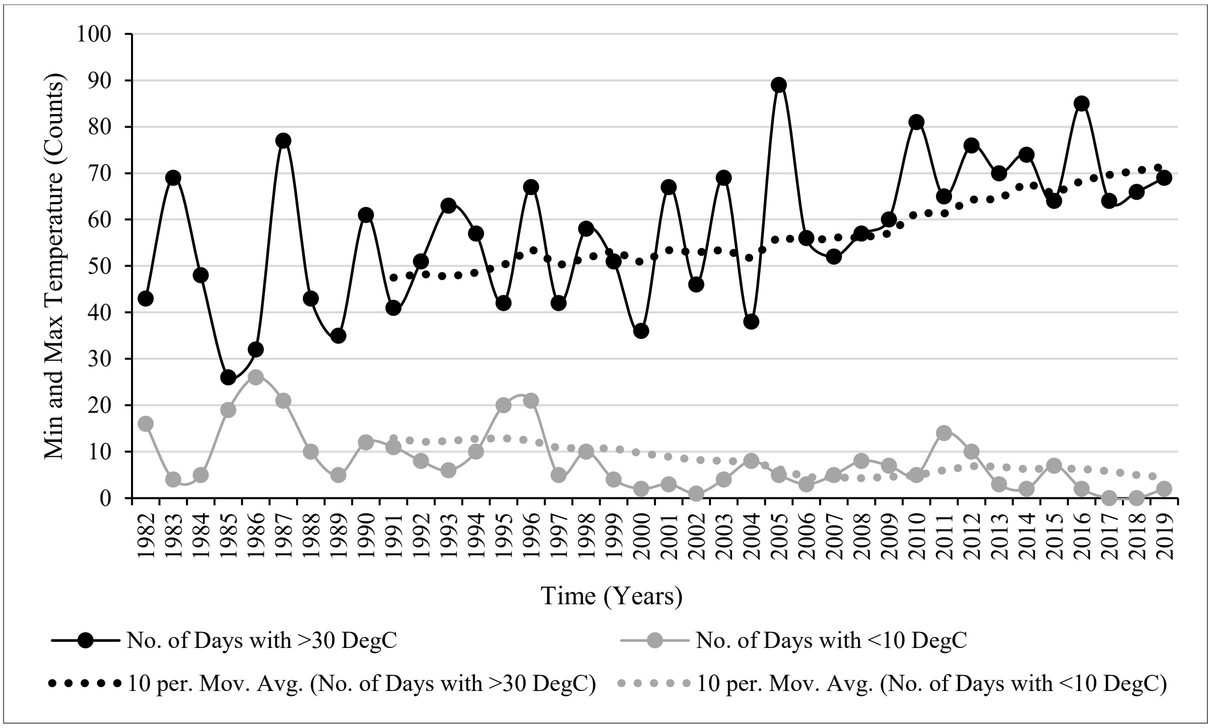


Figure 1-5: Counts of number of days with maximum temperatures above 30 ºC and minimum temperatures of below 10 ºC per year for Zomba (Data source: Chancellor College).

Annual rainfall ranges between 500 mm and 1,800 mm, as recorded from Chancellor College weather station between 1978/79 and 2018/19. However, there was an observed decrease in annual rainfall from 1985 to 2015, but the Mann-Kendall trend showed no statistically significant trend (Ngongondo et al., 2018). There was also an increase in Simple Daily Intensity Index (SDII) though it showed no statistically significant trends. However, the increase in SDII was an indication that most of the annual rainfall total is accumulated through few but intense events in a season, resulting in no change in total annual rainfall. The increase in SDII supported the unprecedented January 2015 floods due to heavy rainfall that fell over a few days, claiming lives, destroying infrastructure, and washing away crops and livestock (Rudari et al., 2016). The 2015 flood was the most devastating to date in terms of spatial coverage, the severity of damage and extent of loss (UN-Habitat, 2016). The heavy rains and flood episodes, strong winds destroying roofs and dangerous tree falls, earth tremors and landslides are of late becoming a more common occurrence in the city and Malawi in general (Chiotha et al., 2021).

In terms of biodiversity, there are trees in many household gardens, along some of the streets, rivers and other areas. Currently, there is Chirunga Forest, an urban forest of 70 ha, re-established by the University of Malawi, Chancellor College and Leadership for Environment and Development (LEAD). Chirunga forest was re-established as part of greening the campus, provision of a research site and learning in all aspects of tree-planting and management, as well as mainstreaming environment and sustainability in the university (Chiotha, 2010). However, throughout the city, most of the trees along the riverbanks and hill slopes have been cut down due to a high demand for charcoal, firewood, and timber for construction, resulting in frequent landslides, soil erosion and degradation of water catchment areas (UN-Habitat, 2011b). The main road passing through the city used to have street trees all along it, but no more except in a few stretches. Further to that, the city has several avenues which are mostly treeless. Avenues are typically defined as straight paths or roads with a line of trees or large shrubs along each side (Woodsman Staff, 2015).

Most households (62 %) rely on electricity for lighting followed by 14 % relying on batteries, 11 % on candles with the remaining 13 % relying on solar, paraffin, firewood, grass/straw, and others (National Statistics Office, 2019b). For cooking energy, 86 % of the urban population rely on biomass energy (about 67 % on charcoal and 19 % on firewood), 13 % on electricity and the remaining 1 % rely on gas, solar, paraffin, grass/straw, and others (National Statistics Office, 2019b). As a result of the high reliance on charcoal as a source of cooking energy, there is a corresponding high demand for charcoal production which is reinforced by frequent power outages and rising electricity tariffs, making use of electricity very expensive. Charcoal is seen as a quick alternative source of energy to electricity which is perceived as expensive by the residents and the suppliers take charcoal as a quick money spinner in view of the market demand. This reliance on biomass energy contributes to the high deforestation rates within the city and surrounding areas which is blamed for contributing towards the frequent flooding in the city.

Waste is collected mainly from the formal settlements and institutions at regular intervals, but the city is yet to provide the same services to informal urban settlers (UN-Habitat, 2016). Waste dumping by the city council leads to pollution, especially at the landfill site at ‘Four Miles’, along the Zomba-Blantyre Road, a location that belongs to the district council. There is limited collaboration between the district council and the city council in handling issues or challenges that are common to both, like environmental degradation and urban development sprawl over into the district (Zomba District Council, 2017). Zomba has several rivers that pass through it with the major ones being Likangala and Mulunguzi. Most of the informal settlements are close to these rivers and waste disposal is high, negatively affecting the quality of water and sanitation around the homesteads. Zomba, like the other cities in Malawi, has off-site sewage systems which experience regular breakdowns at treatment plants and blockages due to poor maintenance attributed to improper designs of some sections, lack of public awareness and lack of spare parts (http://www.sdnp.org.mw/enviro/soe_report/chapter_8.html).

1.8 Structure of the thesis

This thesis is organised into seven chapters, with chapters 3 – 6 presenting the empirical results of the study, written in paper-based format. Each of the four empirical result chapters constitute a standalone manuscript, comprising of the following sections: Introduction, Methods, Results, Discussion, and Conclusion. References for all chapters are presented at the very end of chapter 7 under section 7.6. With this format, there is some repetition and overlaps to a certain extent between the first chapter on general introduction and the introduction and methods sections of the empirical chapters. However, the format and style of all empirical result chapters were harmonised to maintain uniformity of the thesis. One empirical chapter (Chapter 6) has been published in *Land* in a special issue of: *What is next for urban landscape ecology?*

Chapter 1 introduces the subject area with global trends in aspects of UGI. This goes on to a problem analysis, the aim, and objectives of the study with relevant research questions. A conceptual framework of the study, relating the concepts of UGI, ES and social-ecological systems to the status and potential of the available UGS and trees to support urban resilience and an introduction to the study area is presented, covering the historical perspective, social, economic, and environmental profiles of Zomba.

Chapter 2 is a review of literature on UGI, urban greenspaces, trees in the city and urban resilience. This was the basis for the objectives and approach, realised after scaling down to SSA, while focusing on the small city of Zomba.

Chapter 3 understands the urban tree species composition, structure, diversity, and distribution from the different greenspace types. This is discussed in line with the status of tree composition, structure, diversity, and distribution from other cities within SSA and elsewhere.

Chapter 4 maps the spatial and temporal coverage of greenspaces within the city between 1998 and 2018 and then all the formal and informal greenspaces between 2010 and 2018. The study further analysed the spatial and temporal changes in quality of UGS through use of NDVI. Since the study was interested in the distribution of these greenspaces in space and time, their status is also discussed from two decades ago to the current state. It further analyses the current quantity, quality and spatial distribution of the urban greenspaces available in the city.

Chapters 5 examines community perceptions of and preferences for urban parks. This chapter understands how residents in Zomba perceive the urban parks available in the city regardless of their social-economic and demographic differences. What they prefer and their perceptions over urban parks is not significantly different amongst the different social classes and that the same applies across other Global South cities.

Chapter 6 deals with urban resilience through a case study where one urban community reversed the ecosystem disservices and started enjoying the resulting ES from afforestation and natural regeneration. An insight into this goes further to compare UGS in terms of tree abundance, species diversity and related diversity indices, spatial temporal changes within a period of eight years and resultant ES, all changes attributed to the impact of the communities' natural resource management efforts.

Chapter 7 synthesises the status of UGI within the social-ecological system of Zomba in terms of spatial temporal changes in greenspaces, urban tree abundance and species diversity from selected land uses, preferences for and perceptions of the available urban parks within the city and resilience from ecosystem disservices using the UGI approach. These culminate to some policy and practice pointers on the importance of UGI in supporting social-ecological resilience within urban settings in an era where urban population is on the rise, more especially in small- and medium-sized cities like Zomba.

2 GREEN INFRASTRUCTURE, GREENSPACES, URBAN TREES, AND THEIR LINK TO URBAN RESILIENCE

‘The trees in our cities help to cool our urban landscapes and if we don't have them, the city is going to be hotter, it's going to be harsher, and it's going to be a real problem under climate change’ – Prof. Stephen Livesley (2019)

2.1 Introduction

Zomba, like many other small cities in SSA, puts much focus on grey infrastructure for the delivery of services. Much as grey infrastructure is extremely important, the natural ‘green’ infrastructure calls for equal or more attention. On top of reducing the risks to grey infrastructure from hazards like floods, green infrastructure is meant to be multi-functional, a critical attribute that makes it particularly good at improving urban resilience (Haruna et al., 2018). This chapter considers what green infrastructure is, its components and their importance, trees as a major component of green infrastructure in urban settings, and how urban resilience is linked to green infrastructure.

2.2 Green infrastructure

The (UN-Habitat, 2011a) characterises infrastructure as essentially public goods, providing in principle, non-exclusive goods accessible to all, having considerable variation in earning power capacity and sensitive to corruption and political shifts. It can be either hard or soft, with hard referring to the physical structures that support the economy while soft are the non-tangibles like policy, national frameworks, governance mechanisms, and social networks (Bhattachryay, 2009). The UN-Habitat (2011a) further acknowledges that there are two generally accepted categories of infrastructure, namely economic and social. Economic infrastructure is part of an economy’s capital stock used to facilitate economic production, or serve as inputs to production, while social infrastructure, also referred to as human-social infrastructure, is ‘a complex system of facilities, programs, and social networks that aim to improve the quality of life’ (Yhee et al., 2021) and includes educational, medical, cultural, and sports facilities that are essential for the everyday life of citizens. These broad categories also include grey and UGI. Grey infrastructure refers to human-engineered solutions that use concrete and steel, typically designed for a single purpose or function like sewer systems, water pipelines, and roads. UGI, on the other hand, is regarded as natural, multi-functional, life-support systems to sustain ecosystem functions within a network of natural and open spaces (Benedict & McMahon, 2006). The difference between the two is that grey is a constructed asset while green is a natural asset, but both occupy land and benefit humankind, green is multi-functional while much of grey is not, green is networked while much of grey is not, with the best achieved through a hybrid system where both green-blue-grey are featured and integrated (Mulligan et al., 2020).

UGI comes in different forms, including urban parks, wilderness, conservation areas, planted and indigenous trees, street trees, gardens, woodlands, green corridors, permeable paver parking lots, bio-swales, forests, servitudes, road verges, green roofs, wetlands, and stream buffers. Benedict & McMahon (2006, 2001) broadly defined UGI as an 'interconnected network or strategically planned and managed network of greenspace or green assets that conserves natural ecosystem values and functions and contributes to health and quality of life and other associated benefits to human populations.' This was refined to include 'all of the open space, woodlands, wildlife habitat, parks, and other natural areas that sustain clean air, water, and natural resources, and enrich our quality of life' (Benedict & McMahon, 2006). Weber et al. (2006) simply defined UGI as the abundance and distribution of natural features in the landscape which, in addition to supporting ecological processes, also contribute to human health and well-being. In the following year, Kambites & Owen (2007) defined UGI as 'the connected network of multi-functional, predominantly un-built space that supports both ecological and social activities and processes.' Some years later, Allen (2012) understood UGI as the 'strategic use of networks of natural lands, working landscapes, and other open spaces to conserve ecosystem values and functions and provide associated benefits to human populations', while Schäffler & Swilling (2013) defined UGI as the interconnected set of natural and human-made ecological systems, greenspaces, and other landscape features. This recognises the human involvement and the large contribution that UGI makes to urban ES (EU, 2013) unlike its original reference to natural ecosystems in and around urban areas and the corridors that connect them (Hostetler et al., 2011; Weber & Wolf, 2000). Literature suggests that UGI comprises 'all natural, semi-natural, and artificial networks of multi-functional ecological systems within, around, and between areas, at all spatial scales' (http://www.thesolutionsjournal.com). Recently, Mell (2017) defined UGI as an evolving and complex concept, with the key principles of connectivity, multi-functionality, interrelated and supportive benefits of natural and ecological systems and a strategic approach to landscape management. This research therefore defines UGI as the interconnected set of natural, semi-natural and human-made ecological systems, greenspaces and other natural landscape features that are designed and managed to provide multi-functional and multi-scale ES for urban communities.

Most of the authors above define UGI with a focus on ecology, planning, social activities, and processes that benefit humankind. Key features in the concept of UGI, as discussed above are (i) the UGS network, (ii) that they are interconnected or networked strategically and (iii) that they are multi-functional. The multi-functional and multi-scale aspects of UGI are that they have the capacity to supply multiple ES (Hansen & Pauleit, 2014) and are intended to strengthen connections between different types of greenspaces as well as with the grey urban infrastructures (Benedict & McMahon, 2001; Kambites & Owen, 2007). UGI provides space for habitat and biodiversity, which in turn deliver services to the urban environment and people that do not benefit directly through grey infrastructure (Harrison et al., 2014). On top of space for habitat and biodiversity, UGI also provides ecosystem services from stormwater culverts, water filtration, rain gardens, constructed wetlands and others, making the delivery of services the most important aspect (Rizzo et al., 2020).

To achieve multi-functional and multi-scale ecosystem services, UGI initiatives should be designed holistically, planned comprehensively, laid out strategically, planned and implemented publicly, grounded in the principles and practises of diverse professionals and communities, and funded up-front (Benedict & McMahon, 2001). Further to this, UGI planning should consider all scales: from the household to the community, regional, state-wide, and inter-state scales. At the household level, this could mean designing homes and businesses around greenspace. At the community level, this could mean creating greenways to link existing parks. And at the state-wide and inter-state level, this could mean reconnecting existing natural areas, for instance through wildlife corridors or stepping-stones and eco-bridges, as well as improving the general ecological quality of the wider environment to be more friendly and permeable to wildlife (Benedict & McMahon, 2001). For instance, Jones et al. (2012) note that there is a general decline in wildlife corridors which are increasingly important for maintaining ecological and genetic connectivity and exploring restoration options has become a priority conservation goal since the early 2000s. Another decline of potential key corridors was noted since the 1990's in the southwestern part of China, but addition of four stepping-stones in the Menghai County, which has five towns, improved the quality of key corridors in the southern part between 1990 and 2015 (Shiliang et al., 2021).

GI planning has advanced within the last two decades. Mell (2017) outlines the three phases, i.e. Exploration (1998–2008), Expansion (post-2008 - ?) and Consolidation (2014 – onwards). UGI is synonymous with other terms previously referred to as greenways planning or greenspace management. The exploration phase was extended by Parris Glendening's 1999 call to use GI to optimise the ways in which landscapes are developed, planned, and managed (Mell, 2016). Following that call, Benedict & McMahon (2000) linked GI use to the smart conservation movement in North America through one of the first papers to consider using GI as a contemporary term. Their paper catalysed expansion of debate around GI (Mell, 2017). The GI terminology was later used more in research and practitioner reports, mostly in framing conservation discussions at local and regional scales (Mcdonald et al., 2005). Over time, an acceptance of the terminology, and the ways in which it could be applied to landscape planning became increasingly visible (Benedict & McMahon, 2006). The uptake of the concept and philosophy also steadily engaged European academics and practitioners. Work by England's Community Forests (2004), and Country In and Around Towns (CIAT) programmes of the Countryside Agency and Groundwork (2005) focused GI discussions on to a number of key ideas: connectivity, multi-functionality, interrelated and supportive benefits and a systematic or strategic approach to landscape management. This stage was more of creating a greater level of consensus amongst UGI advocates regarding its guiding principles (Beer, 2010).

After exploration, the expansion phase was reflected in an increase in the number of academics, government agencies and practitioners working with GI concepts and plans, plus a burgeoning discussion of the principles and values, policy guidance and research projects examining its benefits (Mell, 2017). The Regional Spatial Strategy (RSS) process in England strongly included GI where advocates used a growing body of research to relate its values to regional government (Horwood, 2011; Thomas & Littlewood, 2010) and later brought together a diverse range of partners to discuss the evolving concept which was framed by the work of the Community Forest Network and their landscape renewal programmes. The East of England, North-West and the North-East were the proactive advocates of investment in GI, with some success (Llausàs & Roe, 2012; Mell, 2017). Similar strides in advancing the GI agenda were also witnessed in the USA with the continued influence of conservationists alongside the release of Benedict and McMahon's seminal GI book (Benedict & McMahon, 2006), which ensured that the concept remained visible in landscape debates.

The US Environmental Protection Agency (EPA) has mainstreamed GI debates within North America since 2010, supporting UGI through a series of memoranda outlining how GI should be used to manage water resources (EPA, 2016). The expansion phase also saw a growing regional development with the number of GI strategies increasing in the UK with similar growth processes being witnessed across the USA where major cities, including New York, Chicago, and Philadelphia, started to explore the possibilities of investing in UGI as an effective approach to urban land management (Mell, 2014). Lafortezza et al. (2009) and Llausàs & Roe (2012) also presented examples of Spanish, Scandinavian and Italian explorations of UGI utility which addressed climatic, functionality and administrative differences in its use across Europe. This period witnessed the beginnings of a more refined approach to UGI, examining its value as a planning process and framed with more nuanced interpretations, leading to the current consolidation phase where UGI research is gaining momentum.

While the UGI expansion phase assessed how, where, and why it could be seen as a relevant form of investment, the transition towards consolidation developed more detailed, grounded, and robust evidence to support its use, suggesting a more refined approach to policymaking while drawing on a decade of UGI evidence (Mell, 2017). This was influenced by the growing realisation of the economic, ecological, and social values that UGI can deliver (Summer & Barchfield, 2018). Summer & Barchfield (2018) and (Merk et al., 2012) provided further guidance by reflecting on the opportunities for UGI investment in Asia and examining the added value of greener and more sustainable cities. There is a consensus that UGI is now seen as a more appropriate approach to the delivery of multi-functional urban landscapes compared to other forms of urban development (Mell, 2017; Mell & Clement, 2019). Indeed, some scholars argue that the concept of UGI should promote multi-functional greenspaces and their integration into the grey infrastructure (Hansen & Pauleit, 2014).

Multi-functionality can also be considered as the capacity of UGI to supply multiple ES (Hansen & Pauleit, 2014). Thus, UGI is being linked to greener, smarter, and more efficient methods of urban development (Austin, 2014; Hansen & Pauleit, 2014; Jones & Somper, 2014). Another aspect of UGI thinking is the consideration of its context specificity in the investment form. For policy focus, a small number of UGI principles are being discussed extensively within the more established UGI arenas (the UK, the USA and Europe) where several policy objectives can be identified as central to 'promote natural solutions where possible and can offer the best alternative to grey infrastructure through complementarity of versatility of approach' (European Commission, 2013).

Schäffler & Swilling (2013) note that there is a growing realisation by governments that alternative solutions to climate change and urban expansion are needed if landscapes are to be planned sustainably. This realisation is evident using UGI in UK, USA, and Europe, but also in the expanding economies of the BRICS countries (Brazil, Russia, India, China, and South Africa), with most SSA countries lagging (Schäffler & Swilling, 2013). UGI offers a suite of options that can, and have demonstrated the capacity to mitigate climate change, alleviate flood risk, improve public health, and promote economic viability (FAO, 2016a; Gill et al., 2007; Weber et al., 2006). UGI, therefore, needs to be considered in landscape planning and management globally (Mell et al., 2013).

Once incorporated into urban planning, the concept of UGI can provide several benefits spanning social-cultural, economic, and environmental. Social-cultural benefits are encompassed in moral, spiritual, aesthetic, ethics and values associated with biodiversity and ES (Finlayson et al., 2005). This can include emotional and symbolic values. Economic benefits are direct or indirect monetary values, for instance, costs avoided for property damage because of environmental extremes (Gill et al., 2007; Li et al., 2020). Environmental benefits are UGI outputs that have value for human beings, some good examples include biodiversity, moderation of climate and water cycle and air quality (Andersson, 2006; Haq, 2011; Kim & Song, 2019; Sandstrom, 2009).

Botkin & Beveridge (1997) outline that 'in more than 2000 years of city planning, those who have written about cities have agreed on three main points: (1) cities are centres of innovation and creativity in civilisation, (2) the more pleasant a city is the more likely it is that residents will be innovative and creative and (3) vegetation is the key to making cities pleasant.' Focusing on the third point where UGI plays a great role, significant research has been done. In their special issue on UGI for urban sustainability, Breuste et al. (2015) concluded that there is a need for science and practice to reposition UGI from a passive, urbanisation-affected role to an active, stable paradigm steering cities towards sustainable development. Sustainability is important in the context of climate change coupled with urbanisation. Gill et al. (2007) discussed the role of UGI in adapting cities to climate change, using Greater Manchester (UK) as a case study. They presented outputs from energy exchange and hydrological models showing surface temperature and surface runoff in relation to UGI under current and future scenarios. Further to this, Davies et al. (2006) and Roe & Mell (2007) raised the profile of UGI benefits and aided its implementation into national documents. What was needed then was for researchers, policy makers and practitioners to do further research on issue-specific topics such as climate change responses, urban regeneration, or health. Developed countries increasingly have policies on UGI (Lawrence et al., 2013) while on the other hand, few developing countries have such policies (Lindley et al., 2018).

2.3 Urban greenspaces

Urban greenspaces are recognised as a core element of urban ecosystems (Gairola & Noresah, 2010) and a central component of UGI (WHO, 2017). Greenspace has been used as two words, *green* and *space*, where the adjective green describes the space. This study will concentrate on the one-word compound to be explicit about the focus on the modern use of the term 'greenspace.' According to Kendal et al. (2016), greenspaces are all the vegetated areas that occur in cities, commonly referred to as urban greenspaces (UGS). Many greenspace inventories are commonly categorised by land use, distinguishing areas used for public recreation, biodiversity conservation, residential dwellings, transport corridors, undeveloped lands, and remnant lands. They can also be further categorised by the land cover such as trees, shrubs, lawn, or native vegetation. In their brief, the WHO (2017) defined urban greenspace as all urban land covered by vegetation of any kind, on private and public grounds, irrespective of size and function, including small water bodies such as ponds, lakes or streams which are also referred to as 'blue spaces.' Much as Kendal et al. (2016) attach function which distinguishes different greenspaces, the WHO (2017) disregards that and generalises on just vegetation cover regardless of size and function. Taylor & Hochuli (2017) noted this difference and highlighted that there are six different definitions of greenspace with basically two broad interpretations used, that of being synonymous with nature and that of being explicitly urban vegetation.

A systematic review of the word 'greenspace' by Taylor & Hochuli (2017) identified 367 publications that were published between 1975 and 2014. The publications covered a wide range of disciplines including health and medical sciences, urban design and planning, ecology, and several social sciences. Across the disciplines, Taylor & Hochuli (2017) realised that there are two possible interpretations of greenspace that could provide a more functional understanding of its definition within and between disciplines. The first being that greenspace refers to bodies of water or areas of vegetation such as forests and wilderness areas, street trees and parks, gardens and backyards, farmland, coastal areas, and food crops. The second interpretation represents urban vegetation, including parks, gardens, yards, urban forests, and urban farms – usually relating to a vegetated variant of open space. The first is a macro understanding of greenspaces and could be a synonym for nature and antonym of urbanisation, where the general land cover is a dichotomy of either urban or natural areas (McIntyre et al., 2008). The latter is described as a subset of the overarching concept of greenspace that is confined to the urban environment. It is a subset of open space, largely describing land use that requires human involvement and planning for it to be successful, even if only to ensure its conservation (Kumar et al., 2009). Considering open space as a subset, the EPA (2016) defined open space as an open piece of land that is undeveloped with no buildings or built structures and is accessible to the public and it can include greenspace which is a piece of land that is partly or completely covered with grass, trees, shrubs, or other vegetation, including parks, community gardens, and cemeteries; schoolyards; playgrounds; public seating areas; public plazas and vacant plots. Within this debate, Taylor & Hochuli (2017) argued that researchers should provide a meaningful definition of greenspace that both qualifies and quantifies what the term means, with further publications employing clearer operational definitions based on measurable criteria to advance greenspace research. Table 2-1 clearly outlines both the qualitative and quantitative understanding in defining greenspace across the several disciplines and in different contexts.

Table 2-1: Multiple criteria used to define greenspace (adapted from Taylor & Hochuli, 2017).

Examples of criteria	**Examples of how the criteria might be defined**	**Category of criteria**	**Example of discipline**
Definition	Greenspace refers to urban parks and wetlands that comprise some vegetation.	Qualitative	Urban ecology
Examples	Greenspace refers to small urban parks, including public parks, street verges, cemeteries, and sports grounds.	Qualitative	Urban planning
Size	The greenspaces had an area of 2 ha or less.	Quantitative	Public health
Ownership	The greenspace is located on public land that is maintained by the local government or council.	Qualitative	Geography
Landscape	The greenspace is calculated across the full extent of the city, as defined by the GIS boundaries and zonal statistics.	Qualitative and Quantitative	Landscape planning
Ecological information	All greenspaces had a minimum biodiversity of at least 10 different tree species, 8 shrub species, lawn, and 5 bird species had been counted there during one site visit.	Quantitative	Ecology
Access	All greenspaces were located within 10 km of the participants' homes.	Quantitative	Public health
Amenities	Greenspaces were chosen because they had amenities that made them accessible to low-mobility residents, requiring paths, flat surfaces, and numerous benches for frequent rests.	Qualitative	Sociology
Tree cover	In order to reduce urban heat island, greenspace considered in this study includes vegetated land comprised of >40 % mature tree cover.	Quantitative	Environmental quality

In terms of the status of urban greenspaces across the world, the recommended *minimum* per capita public greenspace, which is only suitable if the greenery is reachable, safe, and usable is 9 m^2 according to the WHO (2017) and 30 m^2 by the United Nations, (2015). However, the ideal amount of greenspace per capita is 50 m^2 (WHO, 2017). In developed countries, normally, they advocate for more than 20 m^2 greenspace per city dweller to meet the ecological balance for human well-being (Wang, 2009), compared to cities in developing countries which often fall below the minimum standard set by WHO. For example, cities in China have an average of 6.5 m^2 of greenspace per person (Wang, 2009) while Asansol city in West Bengal was negligible at 0.27 m^2 of greenspace per person (Siddiq et al., 2022).

However, average values do not reflect distribution and accessibility. Harrison et al. (2014) noted the uneven share of greenspace in Gauteng, South Africa, which fuelled the drive to address the disparities that were inherited from the apartheid era. The best way of addressing the disparity was through UGI planning to not only provide an opportunity to equalise the access to greenspaces across the province but also create an opportunity to serve those who had been historically under-served by ES. In this way, green assets were linked to the discourse on the rights to services and the inequality in infrastructure coverage. The obligation to improve access to UGS for all in Gauteng, therefore, generated strategic dialogues about relative shares of UGS for a particular population group and standards for maximising access (Schäffler & Swilling, 2013). However, Shackleton et al. (2014) noted that the most recent government low-income housing schemes (also called RDP suburbs in South Africa) are largely devoid of UGS, missing an opportunity to improve overall urban sustainability and liveability, and the situation has worsened over the past two decades (Venter et al., 2020). Similar disparities in UGS distribution and amount have been reported in Germany where district level access showed that almost every resident (target achieved of >95%) from eight districts had access to public UGS within 300 m, while in four districts less than 50% of dwellers had access to urban greenery for daily or leisure-time recreation near to residential areas (Artmann et al., 2017).

Apart from Germany, a BBC online review by Pataki (2013) indicated that London, whose current greenspaces occupy 47% of the city space, plans to increase them to 50 % by 2050 and could become the world's first 'national park city' by the year 2019 as set out by the city's mayor. This will be made possible by protecting and increasing the number of parks and greenspaces, ensuring that developments have more green roofs and walls while protecting and increasing wildlife habitats. They also plan to tackle air pollution and make London a 'zero-carbon' city by 2050. However, this is yet to be tested as some analysts indicate that this idea could face many challenges, one being the huge demand for new housing which is also targeting the same land for increasing the greenspace area. According to National Park City Foundation (2022), past 2019 targets, current statistics indeed show that London is an ecological city with 3.8 million gardens, 8.3 million trees for a population of 8.6 million people.

In Kumasi, Ghana, UGS currently occupy about 33% of the city's land area, though declining fourfold faster in recent years (2009-2014) than previously (1986-2002), with the majority located in the urban periphery (Nero, 2016). This is common in many developing countries where urbanisation plays a greater role. Through all-inclusive planning in urban development and sustainability, it is possible to ensure that diverse demands and preferences of urban residents for UGS are met by providing a variety of greenspaces with various functions (Gondwe et al., 2011; Kabisch et al., 2016). Quality of life in European cities centres on addressing four issues: people satisfied with their cities, people's views of their city, environment, and people's personal situation. A survey of 79 European cities revealed that Europeans living in urban areas were particularly concerned about health services, unemployment, education, and safety (European Commission, 2013) which can also be addressed through availability of UGS and the relevant ecosystem services they can provide.

For cities to be sustainable, there is need to introduce inner-city gardens, urban agriculture, forests and wilderness areas, street trees, whilst simultaneously using the city for food supply (Anastasiadis & Metaxas, 2013). This is against the backdrop that 19th century UGS focused on urban aesthetic needs, whereas the 21st century UGS are tasked to do more than that (Pataki, 2013), including systems dealing with surface water runoff and pollution control to green corridors, and increased urban food production (Schewenius et al., 2014) There is need to maximise the resilience of urban ecosystems through urban landscapes that mitigate the 'urban heat island' (UHI) effect, using plants for air purification and urban cooling (Anastasiadis & Metaxas, 2013; Puchol-Salort et al., 2021; Schewenius et al., 2014; Turner-Skoff & Cavender, 2019). Further, the narrowing of roads, which calms traffic and lowers the UHI effect, allows for more all-important tree planting. In all urban planning, there is need to maintain and protect the existing ecosystems that store carbon and plan for the creation of new carbon storage sites by increasing tree planting in all areas and new developments (Anastasiadis & Metaxas, 2013). The urban parks of the future will be designed and engineered for functionality as well as for beauty based on empirical data and state of the art simulations for the multi-functional aspects that urban greenspaces provide (Pataki, 2013). Greenspaces as nature's assets provide favourable economic returns for the entire community if they are well planned and managed (Wolf, 2004).

2.4 Trees in the city

Trees are the oldest living things in the world. Nadel (1977) highlight the four basic concepts about the trees in the city. The first is that trees play an essential role in humans' urban life. Second, people must become aware of the environmental, aesthetic, social and political importance of trees. Third, trees need to be integrated with the pattern and function of urban activity. The last is that the design, placement, and maintenance of trees on city streets are the responsibility of everyone in the community. Olmsted described trees as ‘the lungs of a city’, an expression which shows how trees and other UGS are valuable to the liveability of cities (Jennings et al., 2012). This outlook, however, contrasts with the attitudes in many contexts that trees and UGS are discretionary spending items and are of low priority when measured against other municipal needs that are assumed to address human health, safety, and welfare more directly (Gwedla & Shackleton, 2015).

Since time immemorial, trees have provided benefits to both the environment and people in terms of habitat and resources for flora and fauna, improving human health and well-being, increasing local economic prosperity and real-estate values and, of late, advocated in climate change adaptation and mitigation (Garden & Ryan, 2016). Urban trees have the capacity to reduce stormwater runoff, hence reducing flooding and related damage to urban property (FAO, 2016a; Sulaiman et al., 2016; Ziter et al., 2019). Being an important element in UGS in residential and commercial areas, trees play a great role in recreation (Tyrväinen et al., 2007). Though the benefits of trees and associated UGI elements are not new, only recently has their importance been actively recognised and calls made to enhance communication and networking among practitioners like urban planners, scientists, and decision-makers to optimise the potential of trees in contributing to the sustainable development goals (Borelli et al., 2018). There is now a rapidly growing impetus at local government level in many regions to increase UGI as an adaptation strategy. However, justifying and advocating for more trees has proven difficult in many urban areas where competition for land and financial resources is high (Dobbs et al., 2014; Gwedla & Shackleton, 2015).

Despite the difficulties, several studies have illustrated the importance of urban trees by quantifying the value of the services they provide. For instance, Fazio (2010) indicated that the urban forest can reduce annual runoff by 2 – 7 %, and that as much as 65 % of storm runoff can be reduced in residential developments when trees are combined with other natural landscape features, and sometimes 100 % of the rainfall can be retained on site. Large trees deliver up to eight times the benefits of small trees (United States Forest Service, 2004). McPherson et al. (2003) reported that net annual benefits generated by a large tree was US$ 40, a medium-sized tree was US$ 30, and a small tree was US$ 16. Ajuntament de Barcelona

(2017) estimated that the city trees in Barcelona, Spain, removed about 5 000 net tonnes of CO_2 and more than 305 tonnes of pollutant compounds on an annual basis. In the City of Tshwane in South Africa, 115 200 trees planted from 2002 – 2008 were estimated to store 200 492 tonnes of carbon, sequestering an equivalent of about 54 630 tonnes of CO_2. This amount of CO_2 reduction was valued at US$ 3 million per annum (Stoffberg et al., 2010). A review of 34 published studies on the costs and benefits of urban trees showed that benefits of trees outweigh their costs though focused on carbon regulation, air quality and shading with aesthetic and amenity values being less studied (Song et al., 2018).

Though it is generally understood that the more trees in a city the better, the important parameters are the canopy cover and the species diversity. The tree canopy supports thermal regulation, capture volatile organic compounds and other air pollutants, carbon sequestration, and oxygen production, improving human health and reducing other complex air-quality problems in the process (Calaza et al., 2018; Nowak et al., 2006). For instance, Barcelona published its Urban Forest Master Plan 2017 – 2037 which aims to increase the tree canopy cover that will achieve an urban forest cover of 30 % in the city (Calaza et al., 2018). Various studies from the United States indicated that a 40 % tree canopy cover in urban areas is feasible and can provide a substantial reduction in stormwater runoff as well as other benefits (Baptista et al., 2020; Selbig et al., 2022; Ziter et al., 2019). However, Ziter et al. (2019) indicated realistic baseline targets of 40-60 % urban tree canopy in forested cities, 20 % in grassland cities and 15 % in desert cities. But with prioritisation and greater investment, higher percentages are possible.

With respect to species diversity, Sjöman et al. (2012) hint that a high diversity of species and genera is needed to have a healthy and sustainable urban tree population that offers multiple ES. The need for diverse, resilient, and multi-functional urban tree resource dates to 1990 when Santamour first proposed the often cited 10-20-30 guide. This guide states that a single species should not comprise more than 10 % of the trees in a specified area, a single tree genus no more than 20 % and a family no more than 30 %. This approach results in more diverse use of tree species. However, Sjöman et al. (2012) realised that the maximum level of 10 % was too high when they assessed urban tree diversity and distribution in major Nordic cities. This is related to what (Stahl 2010) indicated that no species should exceed 5 % and that no genus should exceed 10 % of the urban tree population to be more feasible and sustainable. This agreed to the revised proposition reported by Galle et al. (2021) where a revised 5-10-20 urban forest composition benchmark was adopted by the City of Poland, Oregon, USA in 2015 and later a new benchmark of 5-10-15 was proposed by the Morton Arboretum in 2018. However, this new benchmark was not met by several studies like in 12 urban forests from Great Britain (Monteiro et al., 2019), street trees from Bangalore, India (Nagendra & Gopal, 2010), and a bit closer in Bangkok, Thailand, where none of the species exceeded 7 % (Thaiutsa et al., 2008).

Urban trees can be isolated individuals or in a forest patch to be rightly referred to as an urban forest. Despite a growing demand for urban forests as a component of UGI, there is also a global campaign to have edible UGI or urban food forests and trees which can help address a range of problems caused by rapid urbanisation, such as food scarcity, poverty, the deterioration of human health and well-being, air pollution and biodiversity loss (FAO, 2016a). Tree-based edible landscapes have been developed since the ancient times in Egyptian and Persian gardens, through to medieval monastic gardens, and Renaissance estates until the Industrial Revolution in the nineteenth century when edible elements in urban landscapes were replaced by ornamental vegetation (Castro et al., 2018). Most urban landscapes today are largely devoid of edible components or restricted to undeveloped remnant lands (Shackleton et al., 2017) and instead feature traditional shade trees, lawns, and other soil-cover plantings, missing the multi-functional aspect of UGI and trees.

Urban trees are also influenced by history, social-economic circumstances, ethnicity, and other factors. For instance, in Berlin, Germany, the estimated fruit-tree density is still significantly higher in the eastern part of the city than in the west (8.6 trees/ha versus 1.6 trees/ha). This is because domestic fruit production remained important in the east for domestic use and retail trade. Contrary to the west, domestic food production reduced after the World War II and fruit tree density differences are still there even after reunification over 25 years ago (Larondelle & Strohbach, 2016). In South Africa, the apartheid system also influenced tree density and composition (Shackleton & Gwedla, 2021). For example, Schäffler & Swilling (2013) reported that Johannesburg’s historically wealthy suburbs have a forest cover of approximately 24 % of the total area of Johannesburg, while tree cover in the poorer southern quadrant is approximately 6.7 %. In similar studies on inequalities in the distributions of street trees in South Africa, Gwedla & Shackleton (2017) found that there were disparities in the distribution of trees both within and between the different suburbs in the 15 towns studied in Eastern Cape due to the apartheid legacy. McConnachie &

Shackleton (2010) examined greenspace inequality in nine small towns from the poorer Eastern Cape, South Africa, and revealed marked disparities in availability of greenspaces between the wealthy suburbs previously reserved for whites, and the poor suburbs and the newly built low-cost housing areas (RDP suburbs) mainly for black South Africans. The RDP suburbs were found to be poorly endowed with UGS, and the poor economic status of residents limited their ability to travel outside their suburb to access UGS elsewhere.

Such differences are also reflected in Kumasi, Ghana, where a Gini coefficient of 0.26 emphasised the uneven distribution of tree cover and greenspaces within the city (Nero, 2016). Approximately, 25 % of the population in Kumasi is associated with 10 % of the UGS while 50 % of the greenspaces or tree cover is associated with 67 % of the population. In Abuja, Nigeria, the centre has more tree families (27) compared to the peri-urban centre (Lugbe) with 12 families and having a pooled total of 69 and 20 species in Abuja and Lugbe, respectively. Nero (2016) further highlights that Abuja is a well landscaped city which considered biodiversity alongside infrastructural development in a win-win situation. More studies on urban tree diversity have been done in the developed countries, with some recommendations. For instance, Sjöman et al. (2012) recommended exploitation of rare indigenous tree species available from local urban tree databases for their recruitment as street trees in the Nordic cities. While in Los Angeles, California, Avolio et al. (2020) recommended a need for further rare indigenous tree species evaluation to include additional data like age, DBH and tree height. In Changzhou, China, Wang et al. (2021) highlighted the important role of tree species diversity in mitigating the urban heat island effect in that greenspaces with a higher diversity of tree species had a higher cooling effect than ones with low tree species diversity.

2.5 Urban resilience and resourcefulness

Urban resilience is the capacity of a system to absorb disturbance and to re-organise while undergoing a change to retain similar function, structure, identity, and feedbacks (Walker et al., 2004). In a detailed context, The Rockefeller Foundation (2016) definition of urban resilience largely stems from earlier conceptualisations of social vulnerability and sustainable rural livelihoods (Krüger, 2013). Despite the current popularity of the concept, which (in theory) includes adaptability and inclusiveness as important qualities of cities and actor collectives to tackle stresses and crises, there has been an increasing critique of the definition in recent years as the ‘paradigm shift from vulnerability to strength’ (Almedom & Tumwine, 2008).

Bolund & Hunhammar (1999) argue that key resilience challenges faced by cities are locally generated and can be dealt via locally based solutions that offset the impacts in situ. Alternatively, these can be addressed through the adoption of an ecosystems approach and implementation of UGI (Harrison et al., 2014) which allows for urban problems to be addressed in situ and allows for the uptake of all key design principles for building urban resilience and addressing resilience challenges. Ahern (2011) outlines the design principles to include multi-functionality, redundancy and modularisation, biological and social diversity, multi-scale networks and connectivity, and adaptive planning and design. Based on these resilience principles, Ahern (2011) further notes that urban infrastructure is more vulnerable and likely to fail when a function or service is provided by a central entity. However, when the same function is provided by a distributed or decentralised system it becomes more resistant to shocks or changes.

The centralised system is more of a top-down governance which is counter to resilience building, which is now moving to resourcefulness. Bruneau et al. (2017) developed a 4R’s Resilience Framework which is based on metrics, dividing resilience into four performance criteria, namely robustness, redundancy, resourcefulness, and rapidity. Resourcefulness in this case is ‘the capacity to identify problems, establishing priorities, and mobilising resources when conditions exist that threaten to disrupt some element.’ The 4R’s Resilience Framework was later followed by a City Resilience (The Rockefeller Foundation & ARUP International, 2014) where urban resilience was characterised by seven qualities which are reflective, robust, redundant, flexible, resourceful, inclusive, and integrated. In this case, resourcefulness ‘implies that people and institutions can rapidly find different ways to achieve their goals or meet their needs during a shock or when under stress’, a showcase of decentralised systems.

However, according to MacKinnon & Derickson (2013), resourcefulness means ‘to problematize both the uneven distribution of material resources and the associated inability of disadvantaged groups and communities to access the levers of social change.’ MacKinnon & Derickson (2013) argue that the concept of resilience is conservative when applied to social relations, it is externally defined by state agencies and expert knowledge and that resilience of places is misplaced in terms of spatial scale as the processes which shape resilience operate primarily at the scale of capitalist social relations. The authors therefore advocate for resourcefulness, which is ‘the capacity of communities to engage in genuinely deliberative democratic dialogue to develop contestable alternative agendas and work in ways that meaningfully challenge existing power relations.’ This is reflected again in the governance issues within the cityscape where lack of resilience and resourcefulness is marked by governance patterns that ignore the importance of social inclusiveness and common public spaces (Haferburg & Krüger, 2014).

In this study, one such decentralised system is that of UGI which spreads the risks across geographical areas, time, and multiple systems as it provides room for redundancy and modularisation. This is a result of the social, ecological, and economic diversity of UGI which forms part of an effective strategy for supporting urban resilience (Ahern, 2011). In most cities globally, services provided by UGI remain poorly connected to urban planning, design, and management for resilience (Scarlett & Boyd, 2015). Cities need to plan and manage UGI for an enduring supply of ES in dynamic urban systems that are continually affected by global environmental change. McPhearson et al. (2015) therefore proposed that ES and resilience are related in two ways: First, resilience can be fostered by incorporating the concept of ES in urban planning, design, and management of urban social-ecological systems. Second, cities need to safeguard the resilient supply of ES in the long-term to ensure urban human well-being (Figure 2-1).

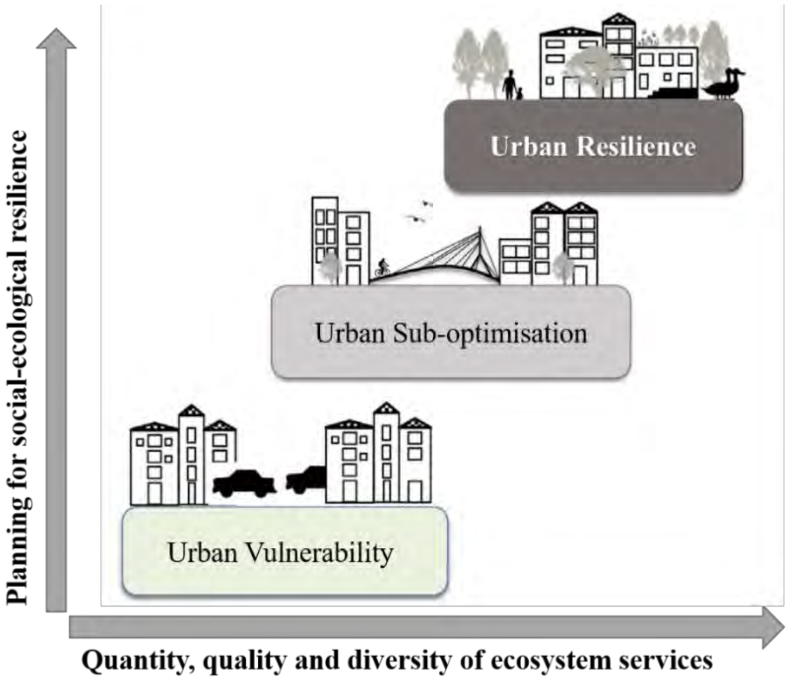


Figure 2-1: Urban resilience can be fostered by incorporating urban ES in the planning, design and management of urban social-ecological systems (SES). (Source: McPherson et al., 2014).

The links between urban resilience and the role of ES from the UGI are further expressed in these examples. Despite the wider infrastructural challenges in Johannesburg, the city's trees and ecological networks provide a set of ES that uniquely showcases the potential of UGI. The trees provide phytoremediation functions on acid water emanating from Johannesburg’s old mines into sewer systems, wastewater treatment works and natural systems (McCarthy, 2010). Trees also regulate water flow and stormwater runoff (Kirnbauer et al., 2009; Selbig et al., 2022), enhancing resilience to erosion damage. The green assets and vegetation from the forest constructed during the gold-mining boom significantly improved air quality (McPherson et al., 1997) and the urban forest is often said to contribute a sense of calm and ‘quality of life’ to an otherwise busy city (Schäffler & Swilling, 2013).

Apart from South Africa, efforts to use UGI in building urban resilience are being witnessed in Beira, Mozambique, where regular flooding follows severe rains, leading to siltation around the fishing port and Chiveve River. They are rehabilitating the Chiveve riverbed and riparian vegetation to restore the drainage function of the tidal river, an additional precaution against flooding (World Bank, 2016b). Further to this is creation of a 3.5 km walking and biking pathway through the mangrove vegetation along the length of the river, along with other landscape investments that will help improve and expand the tree coverage, creating basic urban amenities that also help define the area available for public use and under environmental protection (World Bank, 2016b). While in Kibera, Kenya, Mulligan et al. (2020) working in an informal area on green-blue-grey infrastructure concluded that UGI techniques can function effectively while adding societal and ecological benefits in dense, urban, and low-income areas. It was further appreciated that this could be a starting point for introducing such into larger discussions about the sustainability of informal areas through engaging green-blue-grey infrastructure techniques.

According to Schewenius et al. (2014), foundation of UGI planning lies in the valued and systematic planning of ES alongside the services produced by grey infrastructure thereby contributing to society's everyday functioning and building urban resilience. Such a mix of ES and grey infrastructure is manifested in a combined green-grey approach which is a specialist form of engineering infrastructure that replaces conventional elements for green assets, using a UGI approach. Natural and engineered UGI solutions can create unprecedented opportunities for building resilient cities for the future. For instance, blue-green infrastructure design solutions when combined with sustainable urban form and sustainable construction principles delivers a suite of urban ES. These urban ES include flood mitigation and stormwater management, urban heat island mitigation, air quality, water quality, resources efficiency, aesthetics, recreation and well-being, biodiversity, water supply and urban agriculture, all these available from parks and open spaces when well planned (Puchol-Salort et al., 2021). Examples of engineered stormwater controls include bioswales, rain gardens and retention ponds, while other engineered UGI approaches include blue and green roofs, green facades, parks and open spaces, ponds and water-ways, and urban gardens (Kabisch et al., 2017; Keeler et al., 2019).

2.6 Conclusion

Is it evident that cities should consider how UGI can help mitigate effects of climate change or create spaces that will increase the cities' existing adaptive capacity. The benefits from nature are diverse and with UGI planning like in planning for other city infrastructure, city authorities should be able to put more focus on promoting resilience. As climate change impacts increase and more people move to cities, the importance of UGI cannot be overemphasised. ES from UGI and trees in urban environments, like urban heat mitigation in the face of increased heat waves, amelioration of air quality, and promotion on healthy physical activity, reduced incidence of diseases, food provision, and stormwater runoff regulation, amongst many other benefits, need to be sustained within urban environments. These and other benefits are amongst the very many social, environmental, and economic benefits that UGI can bring to its residents that not only builds resilience but also supports the quest for urban sustainability and liveability.

3 URBAN TREE SPECIES COMPOSITION, DIVERSITY AND DISTRIBUTION

'The materials of city planning are sky, space, ***trees****, steel and cement; in that order and that hierarchy.'* – Le Corbusier, 1922

3.1 Introduction

Urban forests, defined as all trees in the urban realm, in private and public spaces, along linear routes and waterways and in amenity areas (Urban Forestry and Woodlands Advisory Committees Network, 2016), contribute to urban green infrastructure (UGI) and the wider urban ecosystem. Urban forestry was first formerly defined in 1970 as 'management of trees for their present and potential contributions to the physiological, sociological and economic well-being of urban society, which include the overall ameliorating effects of trees on their environment, as well as their recreational and general amenity value' (Jorgensen, 1970). However, its history dates back to 1894 when urban forestry was coined in the USA but later used broadly from the 1960s as the role and benefits of trees became more widely understood in urban areas (Davies et al., 2017). The focus on trees as a component of UGI is based on four scale-based elements, namely isolated trees, lines of trees, clusters of trees (<0.5 ha) and woodlands/forests (>0.5 ha) which anchor the definition on greenspaces (Davies et al., 2017).

Urban forests provide habitat, food, and protection to fauna within a city (FAO, 2016a; Shanahan et al., 2015), improve air quality and aesthetic quality of the urban environment (Nowak et al., 2013), improve human health and well-being (Canetti et al., 2018; Koo et al., 2013), increase local economic prosperity and real-estate property values, and of late help in climate change adaptation and mitigation (Garden & Ryan, 2016). FAO (2016a) further indicates that strategic placement of urban trees can reduce temperatures by 2 – 8 °C, as well as reducing building air conditioning needs by 30 % and saving energy used for heating by 20 – 50 %. Being an important element of greenspaces in residential and commercial areas, trees also play a great role in recreation (Sulaiman et al., 2016). Mature urban trees have the capacity to provide other ecosystem services which include regulating water flow, improving water quality and reducing stormwater runoff, resulting in reduced flooding and related damage to urban property in the process (FAO, 2016a; Kirnbauer et al., 2009; Sulaiman et al., 2016). Urban trees further provide other social benefits like sense of place or identity (Quinton et al., 2019), better social cohesion (Kaźmierczak, 2013), crime reduction, and reported better general health (Guenat et al., 2021; Shanahan et al., 2015). Turner-Skoff & Cavender (2019) summarised the benefits of trees into five categories, namely health and social well-being, cognitive development and education, economy and resources, climate change mitigation and habitat and finally that trees are important forms of UGI in support of stormwater management and that these benefits can help cities and countries achieve 15 of the 17 UN SDGs.

Knowledge of the benefits of trees and associated UGI elements are not new. However, justifying and advocating for more trees has proven difficult in many urban areas where competition for land and financial resources is high (Dobbs et al., 2014; Gwedla & Shackleton, 2015), daunted with inadequate equipment, public involvement and weak or inadequate policies (Murtala & Manaf, 2019). Several other factors that affect advocacy for more trees in urban settings include insufficient operation of urban planning regulations, pressure of urbanisation, social-economic and political challenges, and loss in UGS in most developing countries (Mensah, 2014). The same was echoed in Kumasi, Ghana, where UGS shrunk from 0.1 ha per 1,000 people in 2000 to less than 0.02 ha in 2019 due to institutional failures in developing, protecting, and managing parks (Narh et al., 2020). Similarly, loss of UGS was observed in Harare, Zimbabwe, between 1994 and 2017 (Kowe et al., 2020), in Windhoek, Namibia (Thorn et al., 2021), and of late in Cairo, Egypt (Aly & Dimitrijevic, 2022). As the UGS are being lost, so is tree biodiversity lost in the process, obscuring the pivotal role UGS and trees provide in keeping the cities liveable (Gulsrud et al., 2013). Gwedla & Shackleton (2017) further noted that the pressure of urbanisation resulting from high population growth leaves town planning and development in Africa and other developing countries focused on supply of basic infrastructure and services while neglecting urban forests that facilitate recreation, and urban sustainability and liveability.

Despite the continued loss in UGS and trees, the importance of urban trees and forests have been actively recognised, resulting in calls made to enhance communication and networking among practitioners like urban planners, researchers, and decision-makers to optimise the potential of trees in contributing to the sustainable development goals (Borelli et al., 2018). Despite these calls, involvement of the citizenry in urban tree management is limited in most towns and cities in Africa, with weak or non-existent tree planting schedules (Chishaleshale et al., 2015; Murtala & Manaf, 2019). Planned tree planting schedules were followed in only a few South African municipalities (Chishaleshale et al., 2015), while in

Lagos, Nigeria, Soladoye & Oromakinde (2013) reported poor support, management, and maintenance of urban trees. South Africa, Nigeria and Ghana dominate urban tree and forestry research on the African continent (with about 73 % of the publications between 2012 and 2017) with the rest coming from Kenya, Rwanda, Ethiopia, Burundi, Niger, and Zimbabwe, with none from Malawi (Murtala & Manaf, 2019). In particular, studies on urban tree species composition, structure, diversity and distribution have been done in SSA by several researchers in Democratic Republic of Congo, Ghana, Kenya, Nigeria, Togo, South Africa among others (Agbelade, Onyekwelu, & Apogbona, 2016; Agbelade, Onyekwelu, & Oyun, 2016; Kuruneri-Chitepo & Shackleton, 2011; B. Nero et al., 2018; Nyambane et al., 2016; Raoufou et al., 2011; Shackleton & Mograbi, 2020; Sikuzani et al., 2019).

Urban GS and trees play a significant role in addressing several urban challenges that societies face, including climate change, food security, economic competitiveness, sustainable and resilient cities and building social cohesion (Lafortezza et al., 2018). Furthermore, understanding the dynamics and status of tree species diversity in urban areas facilitates informed decision-making with respect to biodiversity conservation, the promotion of nature in urban areas, tree selection and optimisation for context specific tree benefits for human well-being (Nagendra & Gopal, 2010). There is therefore a need for increased research on urban tree composition and diversity to contribute to sustainable planning of cities (Dangulla et al., 2020). Consequently, the objective of this chapter was to assess the status of urban tree composition, structure, diversity, and distribution within UGS in the city of Zomba. To date, no study has assessed the urban tree composition, structure, diversity, and distribution based on the different UGS types in Malawi, Zomba inclusive. Only tree diversity and the carbon storage contribution from different land use types was done in Zomba (Chimaimba et al., 2020).

3.2 Methods and materials

3.2.1 Data collection

Multi-stage stratified cluster sampling of urban trees was done based on the strata from the nine designated UGS types namely, cemeteries, conservation areas, hills, formal and informal residential areas, parks, public and private institutions and streets. Stratified sampling was done in six of the UGS except in hills, parks and cemetery. In each stratum and sub-stratum, a random sample was taken to select the locations to be sampled. This random sampling was possible for the parks, hills, cemeteries, residential areas, institutions and streets only. From the residential area, samples were drawn from households within the sub-stratum of low, medium, and high housing density areas while the institutions as per the 2010 Zomba land use map. Leasehold land housed formal residents from all the three categories whereas informal residents were from mixed land use, mostly from the medium and high housing density areas. Within the residential areas, data was collected from every other 10^{th} house, counting from both the left and right side of the main ring road within the area. As for the public and private institutions, random samples were drawn from schools, lodges, churches, and office complexes, where tree inventory data was collected within the plots in the sampled UGS.

In all non-linear greenspaces, different size square quadrats were randomly sampled depending on the size of the UGS sampled. In small greenspaces, like cemeteries, 10 m by 10 m (100 m^2) plots were sampled. In each cemetery sampled, depending on its size, a minimum of one and a maximum of three plots were measured in five of the sampled cemeteries. At least 30 to 50 % of the known greenspace type were sampled where plots were demarcated to collect the tree inventory data. The same plot size was used for woodlands in public and private institutions, like at Chancellor College and Masuku Lodge as they had smaller UGS. For bigger UGS like parks and hills, plots measuring 20 m by 20 m (400 m^2) were randomly sampled in transects that were 50 m apart between the plots. In both the formal and informal residential areas, private and public institutional areas (except for the two above), the size of the property was measured and an inventory of all the trees within it was done. For linear greenspaces like roads, belt transects 20 m long with different width of the road reserve or buffer zone, ranging from 0 – 60 m, were sampled at regular intervals of 500 m. All data was collected between March and May 2018. A total of 175 samples were enumerated from different greenspaces using different sampling techniques as outlined in Table 3-1.

GPS coordinates were taken in each plot or transect sampled using a Garmin 62sc. Tree inventory records included number of trees, species, origin classified as either indigenous or exotic, height (m), and tree diameter (cm) taken at breast height (DBH) as outlined in the data collection form in Appendix 8-1. The DBH was taken from trees that were ≥ 5 cm taken at 1.3 m from the ground and from ≥ 1.5 m tall trees. A diameter tape was used for measuring the DBH while a hypsometer was used for measuring tree height in metres (m). Plots or transects were demarcated with the help of a distance tape measure and ranging poles except for those in households and other private and public institutions, where the entire area of the property was surveyed. Species identification and origin was done with the help of tree experts from the National Herbarium and Botanical Gardens (NHBG) and Forestry Research Institute of Malawi (FRIM).

Table 3-1: Greenspace types, sampling techniques used, number of sampled plots and area.

Greenspace	Sampling technique	No. of plots /households /transects	Area sampled (m^2)	Number of trees sampled
Cemetery	Random	13	1,300	59
Conservation area	Random	16	5,800	285
Formal residential	Random	40	39,374	746
Hill	Transect	26	10,400	450
Informal residential	Random	19	10,924	184
Park	Random	11	4,400	184
Private institution	Random	11	24,007	268
Public institution	Random	10	63,634	412
Street	Transect	29	9,670	228
Total		**175**	**169,509**	**2,816**

3.2.2 Data analysis

From the raw data, computations on tree composition, structure, diversity, and distribution were done. Tree composition was on species origin, structure was on size-class profile, diversity was on abundance and richness (or the number of species) and use of diversity rules (Santamour and The Morton Arboretum), then evenness (or equality in the number of individuals for every species), while distribution was more on tree availability in the formal and informal residential greenspaces. The indicators used were Chao1 for estimated species richness, Shannon-Weiner index for tree diversity, Pielou's index for evenness and Lorenz curve and Gini coefficient for tree distribution.

Species richness was expressed as the number of observed species in each UGS type and for the entire city, while Chao1 was used to estimate the potential species richness for each greenspace type and the entire city (Equation 3-1). Chao1 is the simplest nonparametric estimator.

$$Sest = Sobs + \frac{a^2}{2b} \qquad \text{Equation 3-1}$$

where Sest is the estimated total number of species found by adding a term that only depends on the number of observed singletons (a) and doubletons (b) to the number of species observed (Sobs). Singletons are all species that are represented by a single individual while doubletons are species that are represented by exactly two individuals each (Chao et al., 2006).

Tree diversity was computed using the Shannon-Weiner diversity index (Equation 3-2) whose values are generally between 1.5 and 3.5 and increases as both richness and evenness of the community increases. Use of diversity indices provides a more compact method of comparing diversity (Oksanen et al., 2019). Hutcheson t-test, a modified version of the classic t-test which considers the variation of the Shannon index, was used to compare if there are any statistical differences between the Shannon-Weiner diversity indexes of the greenspaces (Hutcheson, 1970).

$$H' = -\sum_{i=1}^{S} P_i \, In\,(P_i) \qquad \text{Equation 3-2}$$

where S is the total number of species in the community; P_i is the proportion of S made up in the i^{th} species and *In* is the natural logarithm of this proportion (*lnPi*). The resulting product was summed across species, and multiplied by -1. Pielou's evenness (J) for tree species evenness (equitability) was determined using Equation 3-3.

$$J = \frac{H'}{In(S)} \qquad \text{Equation 3-3}$$

Taxonomic tree diversity was also assessed using two diversity rules: the 10-20-30 rule (Santamour, 1990) and the Morton arboretum 5-10-15 stricter rule. These two are well accepted and commonly used by urban forestry practitioners despite that they are not established based on scientific evidence (Leff, 2016). The 5-10-15 rule is mostly promoted in

USA to manage the spread of pests and diseases whereas a similar rule for managing urban forest in Britain was a recent topic according to (Doick et al., 2017).

For distribution, the Lorenz curve and Gini coefficient (Equation 3-4) was used as a measure of inequalities in tree distribution across the differently sampled housing density. The Gini coefficient ranges between 0 and 1, with 0 representing perfect equality and 1 perfect inequality and it was used in the context of UGS provision by Kabisch & Haase, 2014.

$$G_{Site} = 1 - \sum_{n=1}^{N_{Site}} \frac{P_n}{P_{Site}} * (\theta_n^{green} + \theta_{n-1}^{green}) \qquad \text{Equation 3-4}$$

with $\theta_n^{green} = \frac{x_n^{green}}{x_{site}^{green}}$ where x^{green} is the absolute amount of coverage in a 1,000 m buffer around grid cell *n* as the dependent variable. Each grid cell is weighted by its population *p*. Further to this distribution, tree canopy cover from the linear greenspace types, mainly the main street and major rivers passing through the city, were followed on Google Earth where transects of tree cover were traced and estimated in meters using the inbuilt measurement tool.

R Studio, version 1.2.1335, was used for computing Equations 3.2, 3.3, and 3.4 using 'vegan' package (R Development Core Team, 2019). Microsoft Excel 2013 was used for organising the data, checking for normality of the data, analysing the Hutcheson t-test and Gini coefficient. Microsoft Excel 2013 was further used for preliminary computations like tree density and summary tables and graphs. Tree density was calculated per hectare by extrapolating the number of trees recorded from each plot (Ortega-Álvarez et al., 2011). The composition of the trees was presented as summaries in tables for the plant families and species, while origin was presented by greenspace type distribution histograms. Structure was analysed through use of size-class profiles per greenspace type. Trees were categorised into seven diameter classes of 5-15 cm, 15.1-30 cm, 30.1-45 cm, 45.1-60 cm, 60.1-75 cm, 75.1-90 cm and >90 cm (Nyambane et al., 2016). Height was categorised into six classes of 5.1-10 m, 10.1-15 m, 15.1-20 m, 20.1-25 m, 25.1-30 m and >30 m (Ajibola et al., 2013). Data from DBH, height of the trees and density were not normally distributed despite removing some outliers. Differences in DBH, height and density between the nine UGS types were determined by a Kruskal-Wallis H test (KWH test), a non-parametric test used for comparing two or more independent samples of equal or different sample sizes, the case of the nine types of UGS. Dunn's test was run for pairwise comparisons of all possible pairs of median ranks to identify where there are significant differences at 0.05 significance level.

3.3 Results

3.3.1 Tree composition

From the different formal and informal greenspaces surveyed, out of 2,816 trees sampled and recorded, a total of 2,769 trees were considered in the analysis after removing 47 observations that had either DBH, height or both values missing. These belonged to 47 families, 118 genera and 168 species. The 20 most abundant families, genera and species contributed 94 %, 64 % and 56 %, respectively, to the total. The Fabaceae family was most common (25 %), followed by Anacardiaceae (15 %). There were 22 families that had only one species, whereas other families were composed of two or more tree species (Table 3-2). The conservation and formal residential areas had each 29 families, followed by the private institutions (22) and public institutions (21) with the least number of families in the cemetery (Figure 3-1). Top ten families constituted 79 % of all the trees sampled, an equivalent of 47 tree species sampled.

Table 3-2: Families with more than one tree species

No.	No. of Species	Family (Number of species in brackets where applicable)
1	≥ 10	Fabaceae (39), Moraceae (10)
2	8 – 9	Myrtaceae (9)
3	7	Anarcardiaceae, Bignoniaceae, Malvaceae, Phyllanthaceae
4	6	Apocynnaceae, Combretaceae, Euphorbiaceae, Meliaceae
5	4 – 5	Annonaceae (5)
6	3	Lamiaceae, Rubiaceae, Asparagaceae, Cannabaceae, Chrysobalanaceae, Hypericaceae,
7	2	Laganiaceae, Proteaceae, Rhamnaceae, Rosaceae, Rutaceae, Salicaceae, Sapindaceae

From the 168 species, the formal residential gardens, conservation areas and private institution gardens had the highest number of tree species, at 66, 57 and 55 tree species, respectively, with the least being found in the cemetery at 23 (Figure 3-1). Only *Bridelia micrantha* (indigenous species) and *Toona ciliata* (exotic species) were present in all nine greenspace types. Table 3-3 provides a list of the five most common tree species in each greenspace type. In terms of origin, about 65 % of the 168 species were indigenous. The highest indigenous tree species contribution was 86 % from the hills, while the conservation had 84 % followed by cemetery at 79 %, with the formal settlements registering the least (11 %). Despite the hills commanding more indigenous tree species, the total number of tree species recorded was lower than the formal settlements, conservation areas, and private institutions (Figure 3-2).

Table 3-3: Five most common species in each greenspace type

UGS	**Species name**
Cemetery	*Bauhinia petersiana, Bridelia micrantha*, *Diplorhynchus condylocarpon, Parinari curatellifolia, Toona ciliata*
Conservation	*Bridelia micrantha, Cupressus lustanica, Newtonia buchananii, Uapaca kirkiana, Shirakiopsis ellipticus*
Formal residential	*Carica papaya, Cascabela thevetia, Mangifera indica, Persea americana, Psidium guajava*
Hills	*Bauhinia petersiana, Dalbergia boehmii, Diplorhynchus condylocarpon, Eucalyptus saligna, Pterocarpus angolensis*
Informal residential	*Carica papaya, Eucalyptus tereticornis, Mangifera indica, Persea americana, Prunus persica*
Park	*Anthocleista grandiflora, Cupressus lustanica, Khaya anthotheca, Shirakiopsis ellipticus, Toona ciliata*
Private institution	*Dalbergia nitidula, Mangifera indica, Senna siamea, Terminalia ivorensis, Thuja orientalis*
Public institution	*Bauhinia petersiana, Bridelia micrantha, Delonix regia, Dracaena steudneri, Jacaranda mimosifolia*
Streets	*Albizia procera, Jacaranda mimosifolia, Khaya anthotheca, Mangifera indica, Psidium guajava*

From the ten most abundant tree species that comprise 39 % of all stems sampled, six are exotic (of which four species are fruit trees) and four are indigenous. Of the top ten, the most abundant tree species were *Mangifera indica* (14 %) followed by *Persea americana* (4 %), both exotic fruit trees. Both formal and informal home gardens were dominated by fruit trees at an average of 66 %. The fruit trees were present in all UGS types, representing 36 % of all trees sampled, with 23 % of this being from the residential areas which were dominated with higher fruit tree proportions than the other UGS types. Comparing the formal and informal residential areas separately, there were more exotic fruit trees in the informal (70 %) than the formal (59 %) residential setup, with more exotic non-fruit trees in the formal (30 %) than the informal (17 %) settlement (Figure 3-2).

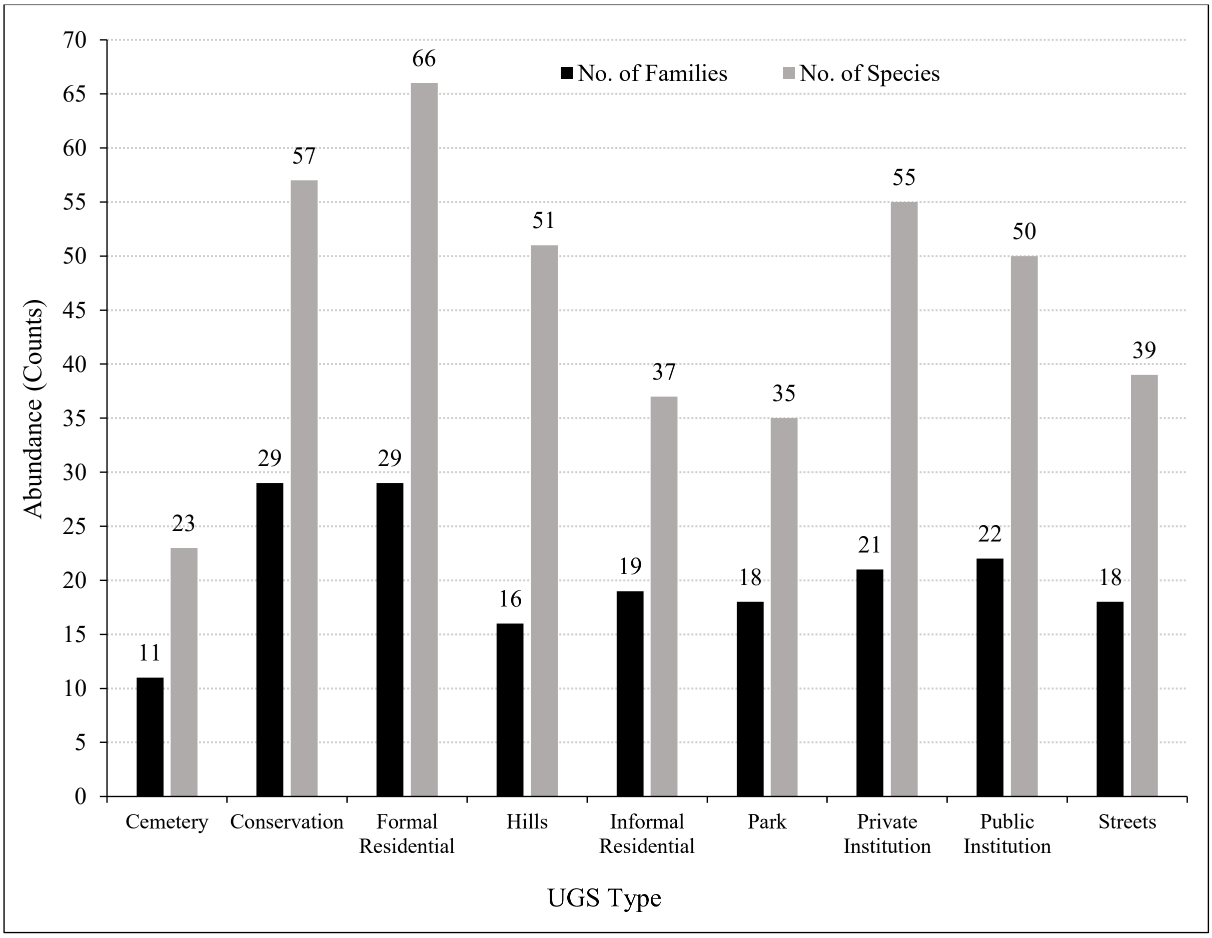


Figure 3-1: Composition of families and species within the different UGS types.

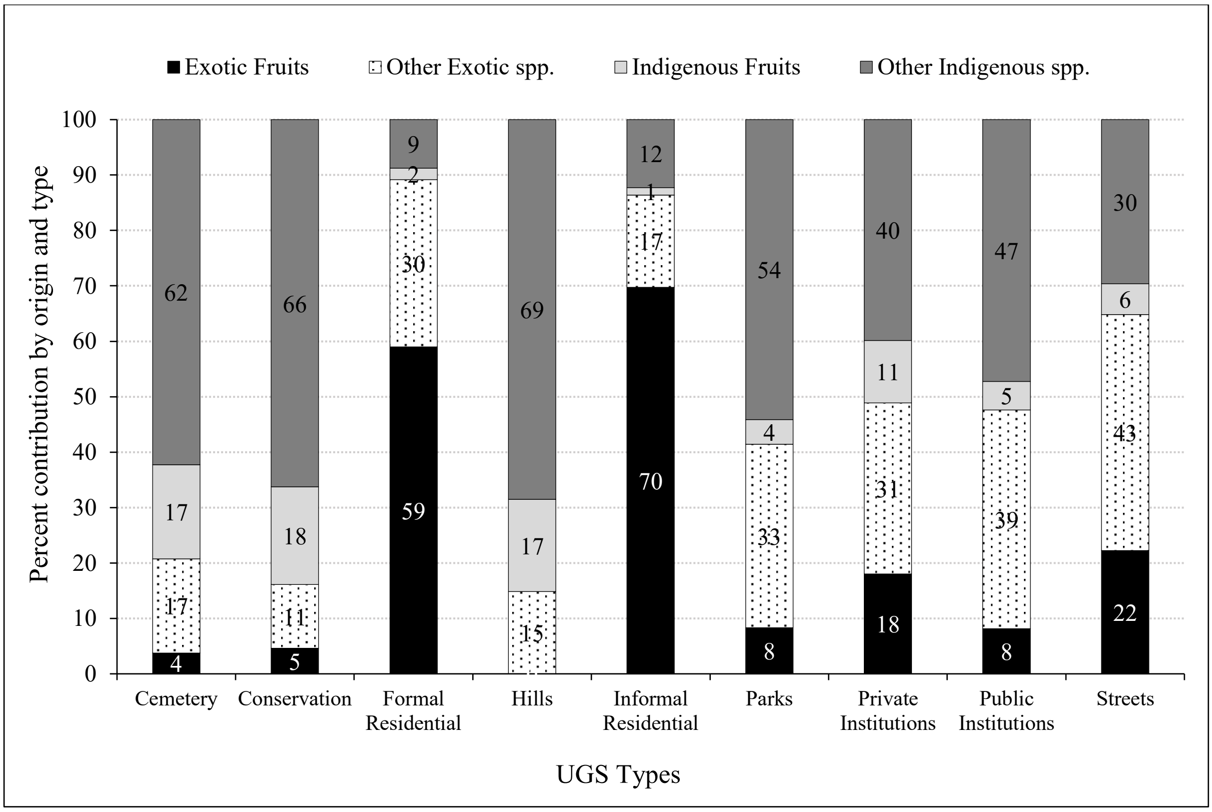


Figure 3-2: Proportional contribution from origin and type of tree species (fruit and non-fruit trees) within the different UGS types.

3.3.2 Stand structure

The hills had the lowest mean DBH (6.7 ± 3.2 cm), while the streets (48.4 ± 46.5 cm), parks (42.1 ± 39.6 cm), cemetery (32.7 ± 25.8 cm) and formal settlements (30.1 ± 23.2 cm) recorded the highest averages of above 30 cm for the indigenous species (Figure 3-3). An ANOVA run on DBH from the different UGS showed that there were significant differences in mean DBH from the different UGS types ($F = 68.705$, $p<0.001$), and Kruskal-Wallis H (KWH) test for post-hoc analysis showed the UGS that had significantly different mean DBH (Figure 3-3). The overall modal DBH across the different greenspace types was 5.5 cm as the DBH class of 5-15 cm contributed 49.9 % of the total stems sampled. The lowest DBH contribution was from the class of 75.1-90 cm at 1.2 %, having only 33 stems, lower than DBH of >90 cm at 2.5 % (69 stems). The overall average DBH was 22.7 ± 22.2 cm with several trees (2 %) being larger than 100 cm, while the largest DBH was from *Khaya anthotheca* (199.3 cm) from the streets (Figure 3-4). The biggest tree species with ≥100 cm DBH were *Albizia procera, Eucalyptus camaldulensis, Eucalyptus saligna, Ficus vallis-choudae, Jacaranda mimosifolia, Khaya anthotheca, Spathodea campanulata, Toona ciliata* and *Ziziphus mauritianus*. Of these, *Khaya anthotheca* comprised of 62 % of all large DBH trees from the park and streets, followed by the *Euclyptus* species at 18 % from the same greenspace types plus one from the formal residential area. Plotted data from these two large diameter tree genera of *Khaya* and *Eucalyptus* between the number of individuals and the mid-point of the size classes on the reverse J-curve model gave two different slopes. There was a positive slope from the log-transformed data when a regression was fitted for *Khaya* while that of *Eucalyptus* was negative (Figure 3-5).

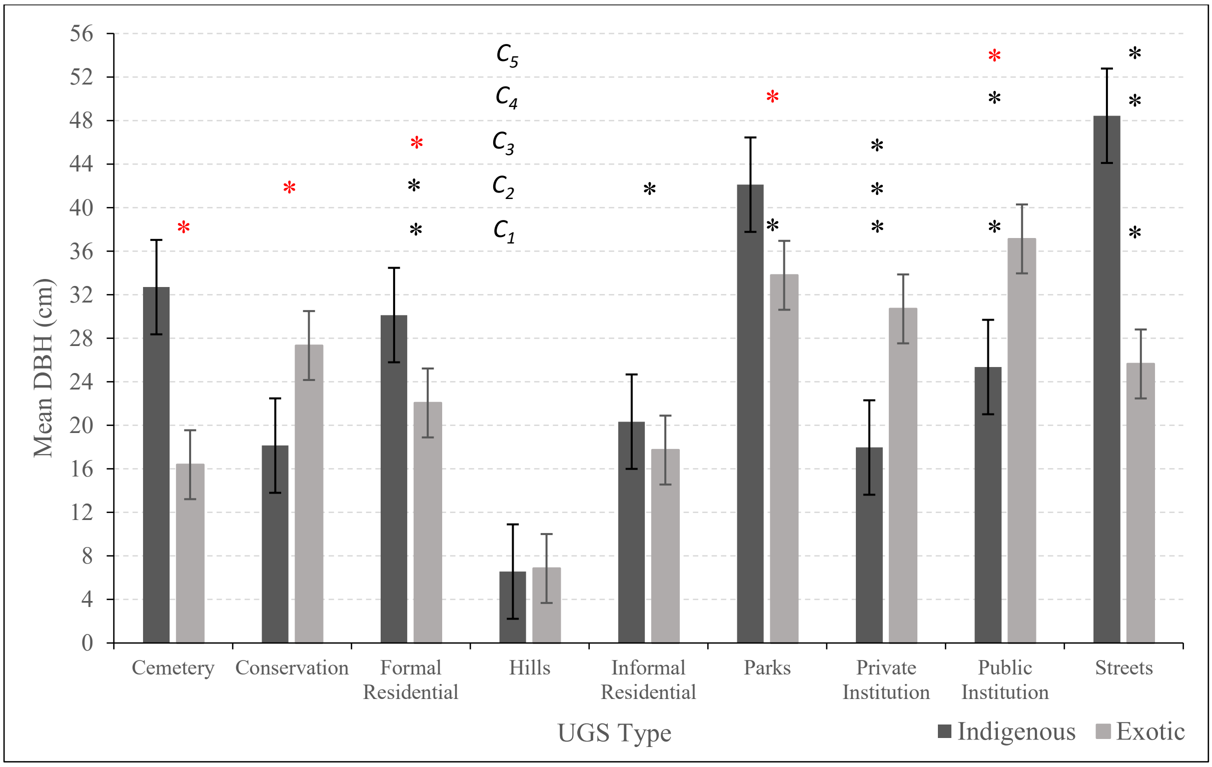


Figure 3-3: Average DBH distribution of indiginous and exotic tree species within different greenspace types in Zomba.

(Note: * denotes a reference UGS for the Tukeys HSD post-hoc tests with other UGS. The overall mean DBH of trees within the UGS types sharing an * within the same horizontal line (C1, C2, …, C5) are not significantly different from each other but significantly different from those without an * at 0.05 significance level. This is presented so in order to declutter the multiple comparisons which are many when the significant comparisons mode are to be shown).

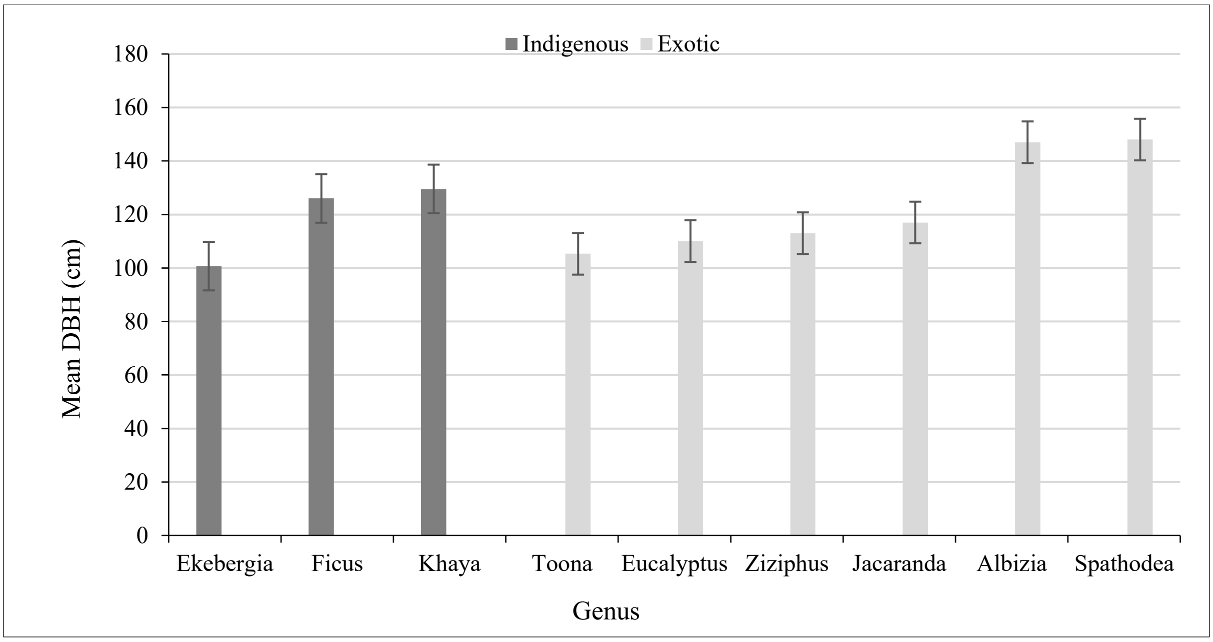


Figure 3-4: Average DBH distribution for genera with big trees above 100 cm from the different greenspace types in Zomba.

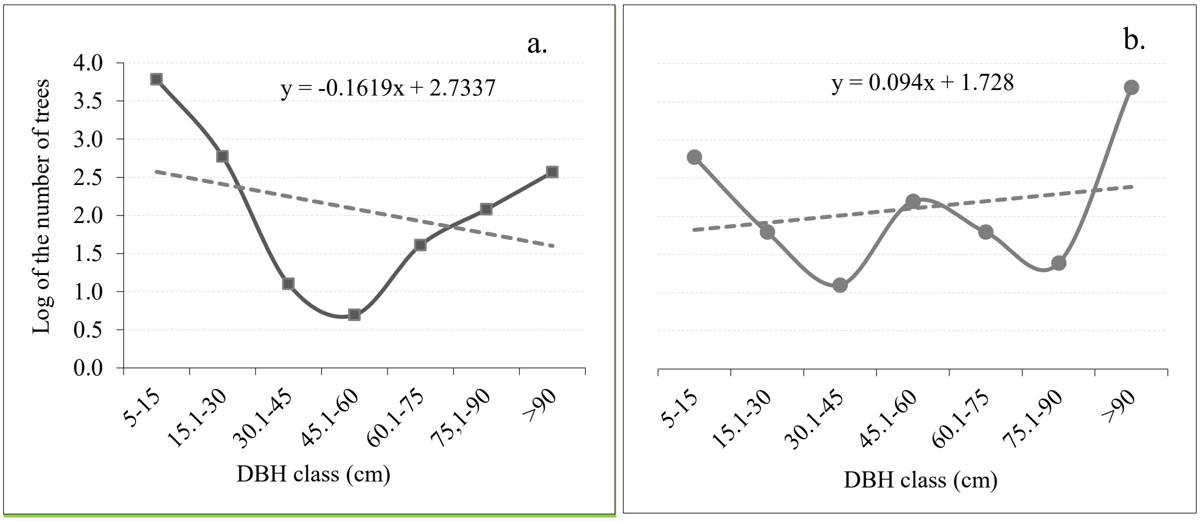


Figure 3-5: Log transformed data trends of the top two big diameter trees (a) *Eucalyptus* and (b) *Khaya*.

The tree height also varied between the different greenspaces, with an overall mean height of 9.8 ± 7.2 m. The lowest height was from a *Mangifera indica* at 1.3 m from the conservation site, with the tallest being *Khaya anthotheca* at 55.4 m from a park. The mode was registered at 5.0 m, from the height class of 5-10 m which commanded the greatest share of 59.1 % of all stems sampled. The least contribution was from height class of 25.1-30 m at 2.5 % with 55 stems, whereas those above >30 m contributed 3.5 % (76 stems). The hills had the shortest trees compared to the parks and streets that had the tallest trees (Figure 3-6). An

ANOVA run on tree height from the different UGS showed that there were significant differences in mean tree height from the different UGS types (F = 68.705, p<0.001), and a Kruskal-Wallis H (KWH) test for post-hoc analysis showed the UGS that have significantly different mean tree height (Figure 3-6). The overall tree stand structure within the city is expressed as a reverse-J shape for both DBH and height (Figure 3-7). However, this pattern was absent in the stand structure from the hills and informal residential sites as the hills were dominated with the first DBH class (5-15 cm – 98.8 %), while the informal residential was dominated by the first two classes that commanded 88.7 % with the highest DBH being in the 45.1-60 cm class. More details of the stand structure in terms of abundance and number of tree species, with mean height per DBH class in each of the UGS is outlined in Appendix 8-2.

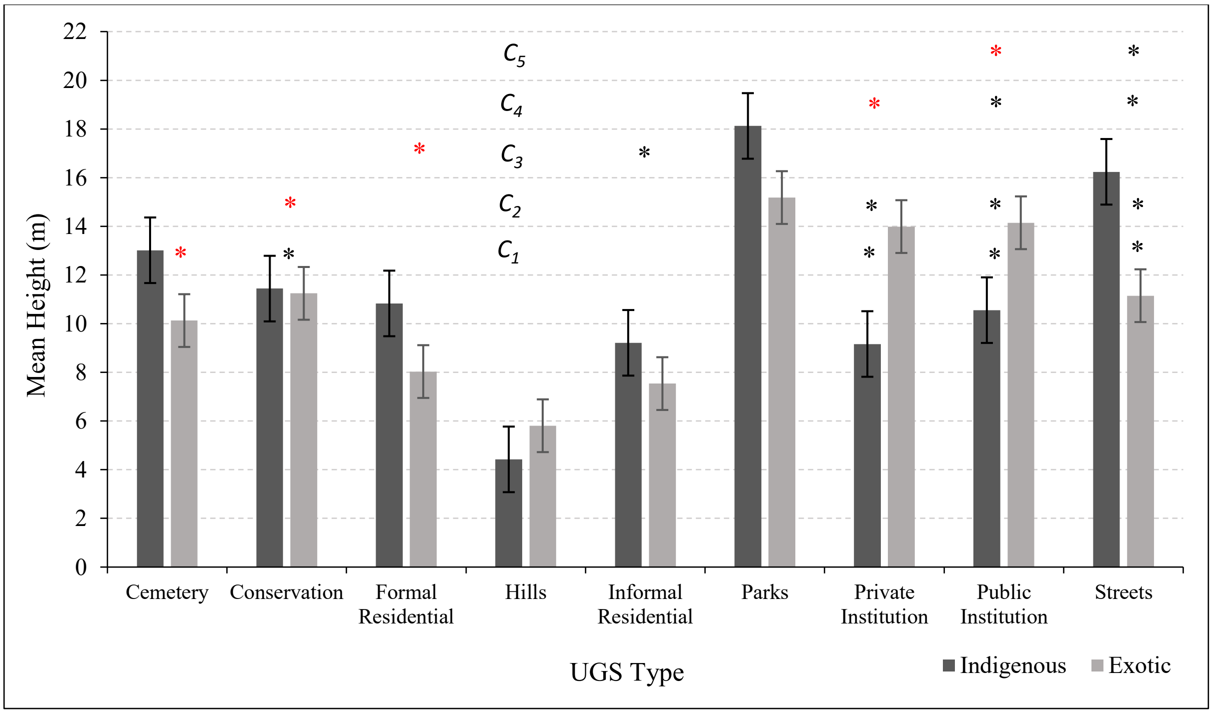


Figure 3-6: Tree height distribution of indigenous and exotic trees for different greenspace types in Zomba.

(Note: * denotes a reference UGS for the Tukeys HSD post-hoc tests with other UGS. The overall mean height of trees in the UGS type sharing an * within the same horizontal line (C1, C2, …, C5) are not significantly different from each other but significantly different from those without an * at 0.05 significance level. This is presented so in order to declutter the multiple comparisons which are many when the significant comparisons mode are to be shown).

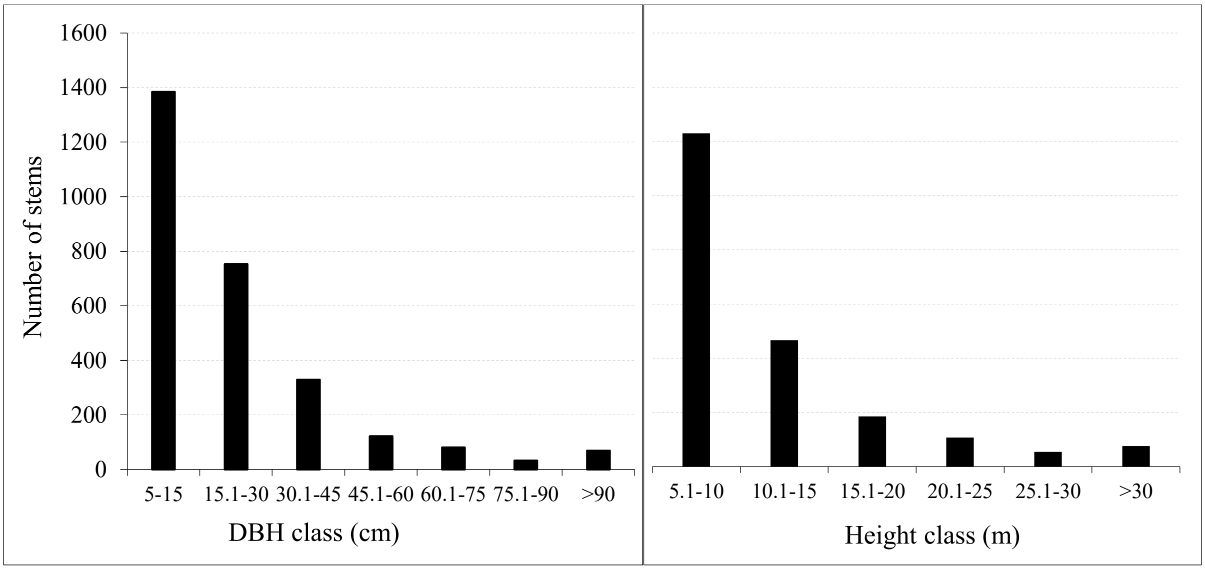


Figure 3-7: Size-class distribution of urban trees in terms of DBH and height.

The overall differences in mean stem characteristics (DBH, height and density) amongst the greenspace types are presented in Table 3-4. The biggest mean DBH was observed in the parks, 38.9 ± 36.8 cm, with the tallest mean height of 17.0 ± 13.4 m. The highest tree density was observed in private institutions (810.5 trees/ha) with the lowest tree density observed in the public institutions (91.0 trees/ha). Results of Kruskal-Wallis H (KWH) ANOVA test (Table 3-4) showed that there were significant differences amongst the different greenspaces in the mean DBH, mean height and mean tree density. Notable significant differences between the pairs are that hills were significantly different to all other greenspace pair comparisons on DBH and height, but not tree density.

Table 3-4: Structural attributes (DBH, height and tree density (Mean ± SD)) from the different greenspace types

Greenspace Type	DBH (cm)	Height (m)	Density (trees/ha)
Cemetery	29.3 ± 24.6^{a}	12.4 ± 8.4^{a}	453.8 ± 330.7^{a}
Conservation	19.5 ± 17.9^{b}	11.4 ± 7.7^{ab}	478.7 ± 358.0^{ab}
Formal Residential	23.0 ± 17.4^{abc}	8.3 ± 4.0^{c}	183.9 ± 181.8^{c}
Hills	6.6 ± 3.2^{f}	4.6 ± 1.2^{f}	451.0 ± 352.8^{abd}
Informal Residential	18.1 ± 10.1^{bc}	7.8 ± 4.0^{c}	264.2 ± 139.3^{abd}
Park	38.9 ± 36.8^{d}	17.0 ± 13.4^{g}	111.1 ± 114.5^{ce}
Private Institution	24.2 ± 18.0^{abc}	11.5 ± 6.6^{abd}	111.6 ± 1001.1^{abd}
Public Institution	31.2 ± 22.0^{ae}	12.3 ± 6.6^{abde}	56.9 ± 333.6^{e}
Streets	33.8 ± 34.3^{ade}	13.0 ± 9.0^{abde}	225.8 ± 189.0^{c}
Mean	22.7 ± 22.2	9.8 ± 7.2	259.7 ± 333.4
X^2 test value (H (0.95, 8)	917.0	782.9	71.7
X^2 tabulated value	15.5	15.5	15.5
Significance (0.05)	$p<0.001$	$p<0.001$	$p<0.001$

Note: Columns sharing the same superscript letter are not significantly different from each other at $p = 0.05$. The first superscript letter is a reference point for comparison with other UGS type within the column.

3.3.3 Tree diversity

Informal residential sites had the lowest diversity (2.65), whereas private institutions had the highest (3.56), followed by conservation area (3.48). Six greenspace types had diversity index scores of greater than 3.0, and three greenspace types (residential, cemetery and parks) were below 3.0 (Table 3-5). However, in terms of evenness, the cemetery showed the highest (0.92), followed by the private institutions (0.89), whereas the least evenness was found in the formal residential areas (0.72).

Table 3-5: Tree diversity indices from the different greenspace types within Zomba

Greenspace	No. of stems	Species richness	Estimated richness	Shannon-Weiner	Pielou's Evenness
Cemetery	53	23	59	2.89^{a}	0.92
Conservation area	285	57	65	3.48^{b}	0.86
Formal Residential	783	66	95	3.00^{c}	0.72
Hills	445	51	54	3.44^{bd}	0.87
Informal Residential	231	37	56	2.65^{a}	0.73
Park	196	35	56	2.98^{a}	0.84
Private Institutions	267	55	67	3.56^{b}	0.89
Public Institutions	288	50	78	3.45^{b}	0.87
Streets	221	39	46	3.13^{c}	0.85
Totals/Overall	**2 769**	**168**	**187**	**4.22**	

Note: Shannon-Weiner index values from the UGS types sharing the same superscript is not significantly different in diversity score (Shannon-Weiner scores sharing the same superscript letter are not significantly different at $p = 0.05$).

3.3.4 Distribution of urban trees

There is a significant difference in the mean size of homesteads between the formal and informal households, being 955.5 ± 774.3 m^2 and 576.7 ± 221.5 m^2 (T-test = 23.610, $p < 0.001$), respectively. A Lorenz curve showed that there is some inequality in terms of urban tree distribution between the high, medium and low housing density areas (Figure 3-8). Gini coefficient value of 0.62 was found with respect to number of trees per household across the social economic divide. That is about 60 % of the population, mostly from the high and medium housing density, is associated with about 15 % of the trees found in homesteads. The remaining 40 % of the population, mostly from the low and part of the medium housing density, is associated with 85 % of the trees. From the linear greenspaces (such as streets and rivers), neither were completely lined with trees. Of the 10 km main road passing through the city, only 10.5 % of the road stretch had trees along it. The three major rivers passing through the city had a combined stretch of 20.7 km with Likangala contributing half of this followed by Mulunguzi and lastly Mponda. Of these rivers, Mulunguzi had a higher linear tree cover of 64 %, seconded by Mponda at 57.1 %, while Likangala had only 6.5 %.

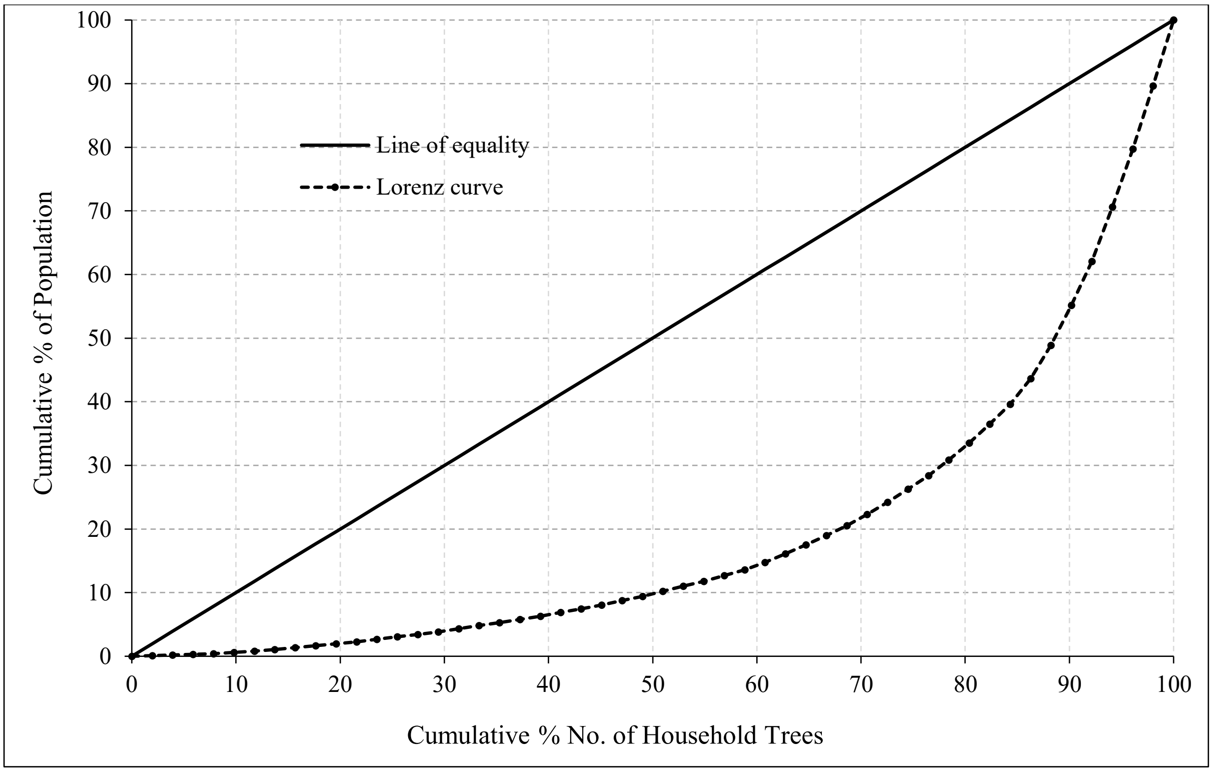


Figure 3-8: A Lorenz curve of average number of trees from high, medium and low housing density areas.

3.4 Discussion

3.4.1 Composition of trees in urban greenspaces in Zomba

The Fabaceae and Anacardiaceae families dominated the cityscape (40 %), as was also observed in several studies in other African cities like Abuja, Nigeria (Agbelade et al., 2016), and Lubumbashi, Democratic Republic of Congo (Sikuzani et al., 2019). The Fabaceae family tops the list of traditional African medicine in SSA alongside Malvaceae, Rubiaceae, Annonaceae and Cucurbitaceae families as a result of historical or cultural preferences and also presence of biologically active terpenoids, alkaloids, and volatile compounds (van Wyk, 2020). This could also explain the dominance of the two families within the residential areas followed by institutions within Zomba city. The Anacardiaceae family, on the other hand, is an ecologically and economically important plant family with diverse leaf architecture and morphology, valuable for global market of fruit and seed crops like cashews, mangoes, and pistachios, with a great potential value in its medicinal properties (Mitchell et al., 2022; Turner-Skoff & Cavender, 2019). Additionally, the high percentage of indigenous tree species (> 80 %) from the hills, cemetery and conservation areas is not different from other cities within Africa. For instance, a city park and two other urban forests had over 80 % indigenous tree species in Nairobi city (Nyambane et al., 2016). The composition also revealed that 36 % were fruit trees, of which 27 % were indigenous. Nyanga et al. (2013) lists some of the most utilised indigenous fruit bearing trees in Africa which are *Adansonia digitata, Uapaca kirkiana, Sclerocarya birrea, Strychnos cocculoides* and *Ziziphus mauritania* which were also found in Zomba except for *Strychnos cocculoide* but other *Strychnos* spp. like *S. innocua* and *S. spinosa.* The composition of fruit trees in the city calls for a consideration towards the potential for an urban food forest, an emerging frontier in edible landscaping (Park et al., 2018). Urban food forests have a potential to match food production to ecological restoration with possibilities of providing different social-cultural benefits like improving social cohesion, strengthening community and environmental education (McLain et al., 2012). Urban food forests are understood as 'multiple perennial and annual food-producing species in multi-storied arrangements, providing canopy cover while at the same time addressing resident needs such as food security and health' (Clark & Nicholas, 2013).

The tree inventory data revealed a diverse composition of trees within the city's greenspaces and the residential settings. The five most common species were – *Mangifera indica, Persea americana, Bridelia micrantha, Toona ciliata* and *Khaya anthotheca.* The presence and dominance of *M. indica* is not only common in Zomba as it was also reported in other sub-tropical cities like Zaria, Nigeria (Dangulla et al., 2020); Lumbumbashi, Democratic Republic of Congo (Sikuzani et al., 2019); Dar es Salaam, Tanzania (FAO, 2014) and six urban areas in Brazil and Venezuela (Hunte et al., 2019). It was also common in Harare, Zimbabwe (Muvengwi et al., 2019) and Sokoto, Nigeria (Dangulla et al., 2020). *M. indica* originated from South Asia (Awodoyin et al., 2015), with biodiversity and livelihood benefits like food provision and shade (Sikuzani et al., 2019). *M. indica* is well adapted to the local conditions, and has a high stomata density like *Khaya senegalensis* (Wu et al., 2021). This is a notable character, together with complex leaf shapes, longer persistence to particulate deposition, and totally developed leaf blade were combined characteristics related to higher average potential of $PM_{2.5}$ removal by *M. indica* (Karutz et al., 2019; Sgrigna et al., 2020). Large fruited species, including *M. indica* are much favoured by urban populations throughout Southern Africa (Shackleton & Mograbi, 2020).

Bridelia micrantha and *Khaya anthotheca* are regarded as protected tree species in Malawi, alongside others such as *Afzelia quanzensis, Burkea africana, Pterocarpus* *angolensis,* and *Terminalia sericea* (http://www.sdnp.org.mw/). Apart from conservation sites, the residential areas hosted some of these protected tree species, an indication that they could be a good refuge to protect such tree species. Thus, 8.6 % of the sampled trees are protected species. In contrast, only five species (0.05 %) were invasive, including *Leucaena leucocephala*, *Pinus* spp., *Pittosporum viridiflorum, Psidium guajava,* and *Syzygium cumini* (http://issg.org/).

3.4.2 Stand structure

The DBH and height class distributions revealed the common pattern of a reverse J-curve except in the hills and informal residential settings. The reverse J-curve is interpreted to signify a forest where there is good regeneration amongst the different diameter classes (Kacholi, 2014; Nero et al., 2018). The hills were regenerating as they were dominated by a single size class for DBH and height while the informal residential areas were dominated by a few large trees within the same classes. In the other greenspace types of parks, streets, institutions, formal residentials, conservation areas and cemeteries which had a clear reverse J-curve model, traces of an undisturbed forest structure were visible. However, this model does not describe the structure of all forest types, more especially in urban landscapes where there is a complex mixture of planted and self-established trees, coupled with different levels of exposure to stress that result in unequal mortality amongst the different diameter classes (Nero et al., 2018).

The size class distribution showed about 30 % of the trees were > 30 cm in diameter. Important ecosystem services like carbon storage and air pollution removal by trees in urban areas are mostly associated with larger tree diameters and heights and these have been widely used in developing models for estimating carbon storage and air pollution removal (Kim & Lee, 2016; Motallebi & Kangur, 2016). According to Russo et al. (2016), large diameter trees of > 30 cm generally remove more air pollutants than those with smaller diameters. Worth noting also from the large diameter tree species, only *Khaya anthotheca* showed a positive slope from the log-transformed data when a regression was fitted between the number of individuals and the mid-point of the size classes on the reverse J-curve model. The positive slope is an indication that the species population is decreasing otherwise negative slope indicates that the population is increasing while neutral slopes indicates that the population is stable (O'Connor & Goodall, 2017). The decreasing trend in large diameter trees is not healthy for the city as large urban trees are excellent filters for urban pollutants and fine particulates, with one tree having the capacity to absorb up to 150 kg of CO_2 per year, sequestering carbon and consequently mitigating climate change (FAO, 2016a).

Estimated tree density results indicate that private institutions hold the highest density at 811 trees/ha, compared to public institutions which registered the lowest at 91 trees/ha. However, the overall mean of 485 trees/ha is 36 % greater than that found in the urban centre in Lubumbashi, Democratic Republic of Congo at 356 trees/ha (Sikuzani et al., 2019) and 50 trees/ha in Zaria, Nigeria (Dangulla et al., 2020). The higher overall mean density could be attributed to various social-political reasons coupled with less rigorous governance and management in much of the unbuilt urban land (Shackleton et al., 2015). With comparatively low tree density in the public institutions and informal residential areas, light penetration could support regeneration capacity as competition for light is low (Rissanen et al., 2019) but the nature of the land use practise would not allow that. The city needs spaces that are clearly designated as greenspaces to maintain the high tree density cover. With public spaces having low tree density as compared to private spaces emphasises the need for the city to critically consider how they can promote higher tree density in public spaces in the urban plan.

3.4.3 Diversity of trees in urban greenspaces

The high diversity index scores in Zomba are like those recorded in Kumasi, Ghana of 3.72 (Nero, 2016), Mina (3.08) and Abuja (3.56) in Nigeria (Agbelade et al., 2016). The high species diversity in the greenspace areas of institutions, conservation areas and hills in Zomba is not different from findings elsewhere. For instance, in Kumasi, Ghana, the high species diversity was recorded in natural forests, institutional compounds and public parks (Nero, 2016). High species diversity was also found in institutions in China (Yan & Yang, 2017) and in Turkey (Yilmaz et al., 2010). High urban plant diversity in cities is associated with extensive habitat heterogeneity that provides a broad range of conditions to suit different species requirement (Nitoslawski et al., 2016). Ecologically, Zomba has several natural features such as the botanical garden, conservation areas and afforestation hills which are contributing to the high tree diversity. Being a relatively small city, there is strong opportunity for dispersal of seeds from the rural and peri-urban fringe into the city.

The high diversity scores of above 3.0 in six greenspace types is in line with the intermediate disturbance hypothesis which states that higher species diversity tends to occur in areas of low to moderate level of human disturbance (McKinney, 2008). The high diversity scores in spaces like cemeteries, which are few and small in area, are a rich source of a gene pool as a greater percentage of the trees found in them are indigenous, and undisturbed (Löki et al., 2019). The high species richness and diversity values in Zomba conform with findings by Raoufou et al. (2011) and Agbelade et al. (2016) that cities in Africa support a high tree diversity, even when compared to neighbouring natural forest. Other African cities that registered high species richness include Lome (Togo) with 297 tree species in 48 families and 141 genera (Raoufou et al., 2011). The streets had a medium diversity score compared to other greenspace types, and credit should go to the first local government after the colonialists for their street tree planting efforts which are now being threatened by road construction and renovations, targeting the big mature ones, as also echoed by Yan & Yang (2017). The species richness in the streets of Zomba however is not different from those found in the three towns in Eastern Cape, South Africa (Kuruneri-Chitepo & Shackleton, 2011). As is the case now, most roadsides are not planned in terms of tree planting, but mainly covered with self-established trees. To have a multi-functional greenspace, planning for the types of trees to be planted is essential if the ecosystem services they provide are to be multi-scale and that they can enhance connectivity.

Santamour (1990) proposed a benchmark on the management of urban forests with a 'rule of thumb' that was based on 10-20-30 rule. This rule suggested that an urban forest should aim at having no more than 10 % of any one species, no more than 20 % of any one genus and no more than 30 % of any one single family. This 'rule of thumb' has led to more diverse and resilient urban forests in many cities and empirical evidence has indicated that relative abundance of the most common taxon is a useful predictor of diversity as measured by the Shannon index (Kendal et al., 2014). Within Zomba, this rule yielded 14-14-25 ratio from *M. indica*, *Mangifera* genus and Fabaceae family, a diversion from the 5-10-15 stricter rule by the Morton Arboretum. Practitioners and scholars have of late preferred this stricter rule as it has the ability to mitigate risks associated with mass mortality events and other environmental stressors that can negatively impact on the urban forest (Leff, 2016). However, achieving this stricter rule in practice is difficult due to existing traditions and choices of trees, limited choice of tree seedlings in local nurseries, uncertainty and cost implications in maintaining different species (Morgenroth et al., 2016).

Despite that Zomba is far from the 5-10-15 rule, other studies from tropical areas like Bangalore, India, had 9 % for the dominant street trees (Nagendra & Gopal, 2010) while in

Bangkok, Thailand, the dominant tree species did not exceed 7 % (Thaiutsa et al., 2008). The closer to the 5-10-15 rule is attributed to the larger selection pool of resilient tree species found in tropical climates that increase tropical urban tree diversity (Jim & Liu, 2001; Kjelgren et al., 2011). However, the relative abundance rules have an impact on urban forest use and can help the urban forest managers in managing the urban forest. According to Kendal et al. (2014), advantages of the Santamour rule are that it is easy to calculate the relative abundance if tree inventory data is available. If urban forest managers have an inventory of the trees within their jurisdiction, they can avoid the use of other measures of diversity that require expert knowledge or specialised software to make calculations and interpretations. Another advantage is that relative abundance of the most common taxon is the measure that is closely related to the risks being managed. In essence, this is where the most popular species, genus and family belong and urban forest managers would want to guard these against any loss due to pests, diseases or environmental changes.

3.4.4 Distribution of urban trees

The inequality in urban tree distribution within Zomba is high, differing from a study in Kumasi, Ghana, where 50 % of the tree cover in the city was associated with 67 % of the population (Puo-uureh & Forig, 2017). This inequality could be attributed to two reasons. One reason could be the colonial legacy where the low housing density residential side had more land per household as compared to high housing density residential area for the low social-economic status category whose plots/yards are very small. This was also echoed by Hunte et al. (2019) regarding tree species distribution in the tropical cities of neighbouring Brazil and Venezuela which were highly influenced by the slave trade and British colonial rule. The other reason could be high urban sprawl in the low social-economic category, as also echoed by McConnachie & Shackleton (2010) in South Africa. The distribution of trees in the streets favoured native species (64 %), findings like those from three selected towns in Eastern Cape, South Africa (60 %) (Kuruneri-Chitepo & Shackleton, 2011) and in a street tree study in Bangalore, India (67 %) (Nagendra & Gopal, 2010). The unequal urban tree distribution in Zomba confirms findings by Rigolon et al. (2018) that there is a notable inequality pattern in urban greenspace distribution in the Global South based on their sample of 46 peer-reviewed empirical articles. People with a higher social-economic status were found to live closer to greenspaces, having access to higher quantities of greenspaces and with higher quality of greenspaces than those from the low social-economic status.

Despite the high percentage, tree cover was low from the 10 km road stretch and even lower along Likangala River which passes through neighbourhoods with low household income. Uneven distribution and access to greenspaces has been recognised as an environmental justice issue (Jennings et al., 2012). Wolch et al. (2014) noted that low-income neighbourhoods and communities where public health challenges are high in many cities often have relatively low tree cover let alone greenspaces and well-maintained parks. Measures that would ensure that UGI is explicitly implemented do not only support social-environmental sustainability and justice but are essential for the greenspaces to play a positive role for both people and nature (Chatzimentor et al., 2020). As one way of increasing social-environmental justice, Enssle & Kabisch (2020) highlight the need for urban planning to understand the city as an integrated social-ecological system so that the design and plan of urban greenspaces focuses on providing ES and creation of social networks.

3.5 Conclusion

Understanding tree species composition, structure, diversity, and distribution is key in assessing sustainability of any forest, conservation of species, and management of the ecosystems at large. This study has described the status of urban forest composition, structure, diversity and distribution of tree species within the city of Zomba. The overall composition of 168 tree species favours indigenous species (65 %) though the residential setting is dominated by exotic trees, mainly due to the abundance of exotic fruit trees like *M. indica*. Institutions commanded a greater number of species, while the cemetery scored more on the species evenness. The overall reverse J-shape curve signifies a healthy urban forest. However, many of the bigger trees were from the streets and the parks unlike in the afforestation hills which were dominated by small trees as they are regenerating. Like many other cities, tree diversity is generally good with high diversity scores in greenspace types of both private and public institutions, conservation area and the afforestation hills. There is unequal tree distribution amongst the households, with the formal setup commanding more than the mixed and informal residential settings. The 10-20-30 Santamour rule and later the 5-10-15 by the Morton Arboretum were not met, an indication on the compromised resilience of the urban forest as it is not diverse enough.

This study has provided a starting point where the city can establish a database for all the trees within the city. The status of tree composition, structure, diversity, and distribution should provide baseline information and a basis for decision-making in urban planning regarding green infrastructure in the city. The high diversity scores are an indication that urban forests are very important in biodiversity conservation as they can act as reservoirs for biodiversity, let alone protection of protected or endangered tree species. As the city further develops, deliberate efforts should be put in place to guard against any loss of trees. Further to that, other studies need to quantify and document the environmental, social-economic, and other benefits that people derive from the urban trees. This can further assist urban planners to know which sites need an increase in tree cover in line with the associated benefits from different tree species as dictated by the resident needs.

4. MAPPING THE QUALITY AND QUANTITY OF URBAN GREENSPACES IN SPACE AND TIME

'If scenery was for sale, Nyasaland would be rich' – JP Gunter, 1955

4.1 Introduction

Urban green infrastructure (UGI) is broadly enunciated as being defined by its *multi-functionality*, the *continuous network* between urban greenspace (UGS) and trees, and its *quality*, known globally as an indispensable component of liveable and sustainable cities (Jerome et al., 2019; Lin et al., 2019). UGI is generally understood as a delivery mechanism for ecosystem services and benefits in urban environments, the missing link between ecosystems and human well-being (Stessens et al., 2017). It embraces most vegetated elements in the built environment, bringing together many land uses (for instance parks, nature reserves, cemeteries, surface water), urban design features (like street trees, landscaped parcels) and functional features (e.g., sustainable urban drainage systems, green roofs) operating at the building, neighbourhood, landscape, and city scale (Burgess, 2015). The vegetated elements are the UGS whose quantity and quality have a bearing on the ecosystem services enjoyed by urban residents and visitors. UGI as a concept aims at delivering the range of ecosystem services that the different vegetated elements provide. These are founded on resident's knowledge as they know, understand, perceive, and feel what vegetated elements bring to their well-being.

Quantity of UGS comes from the trees and shrubs (layers of leaves, branches, and stems) that cover the ground, represented as area of lawn, extent of UGS and mostly measured as per capita greenspace (Sexton et al., 2013; Summer & Barchfield, 2018), which typically is delineated using aerial data (Kanniah, 2017). Studies on the quantity of UGS strive to measure the per capita greenspace area (m^2), as an indicator of their abundance. According to the Economist Intelligence Unit who rated 15 African cities to produce an African Green City index which measures their environmental performance, UGS per capita was a quantitative indicator in the land use category which considered the sum of all public parks, recreation areas, greenways, waterways, and other protected areas accessible to the public, expressed per inhabitant (Summer & Barchfield, 2018). The World Health Organisation (WHO) recommends a minimum of 9 m^2 of UGS per individual with an ideal UGS value of 50 m^2 per capita at a societal level, contributing to happier and healthier urban dwellers when these minimums are attained or exceeded (WHO, 2012). The European Union considers a minimum per capita UGS area of 26 m^2, while the United Nations pegs the minimum at 30 m^2 (United Nations, 2015).

Quality on the other hand gets into the finer details of the UGS to complement their importance. However, most studies focused on the presence (or lack) of UGS, overlooking their quality. O'Neil & Gallagher (2014) identified fourteen 'quality categories' of UGI which included quantity of green infrastructure, ability to mitigate flood risk and provide cooling, and provision of management, with the critical categories determining quality indicated as *proximity* to people, *biodiversity,* and *linkage* between UGI features. Proximity is framed in terms of 'ease of access', 'access close to people's homes', or having UGI elements 'within walking distance.' Biodiversity on the other hand is understood as 'habitats that are part of an ecological framework' and 'features for people to experience nature', whereas linkage is seen as 'physical' and 'functional 'connections and opportunities for a 'variety of experiences' within a 'network of spaces and routes' (O'Neil & Gallagher, 2014). Knobel et al. (2019) later summarised specific quality dimensions of greenspace from a systematic review of studies on UGS quality. The quality checklist included surroundings of the UGS themselves, accessibility, availability of facilities that allow for realisation of a specific activity, aesthetics and attractions, amenities that make UGS more comfortable and convenient, incivilities (elements that make the greenspace less enjoyable), safety, usage (suitability for different activities), measures of land cover, policies related to parks and UGS, diversity measures of animal and plant biodiversity. Several methods have been engaged when analysing the quality of UGS and these include Geographical Information System (GIS)-based measures like use of Normalised Vegetation Index (Contreras & Quiroz-Rosas, 2017) or resident surveys to characterise proximity and accessibility to UGS (Smith et al., 2017) or surveys regarding amenities, infrastructure and feelings about UGS (Manyani et al., 2021).

UGS can be private or public. Examples of private UGS include lawns, domestic gardens, vegetable gardens (Munyati & Drummond, 2020), agricultural land, institutional grounds, and water management spaces. Public UGS on the other hand include parks and gardens, outdoors sports facilities, civic and amenity spaces. Public UGS provide a range of benefits that span from social, physical activity, health, biodiversity to multiple ecosystem services (Haines-Young & Potschin, 2018; Kerishnan & Maruthaveeran, 2021). Shrubs, grass, and water are also important components of UGI as they contribute to urban forests as shown by the overlaps in Figure 4-1 (Dobbs et al., 2014). Urban forests consist of the two parts 'urban' and 'forest.' Urban is understood as a spatially heterogenous and complex, adaptive social-ecological system where environmental functionality, social equity and economic viability interact (Wu, 2014). Forest on the other hand is a land area of more than 0.5 ha, with trees that are capable of reaching a height of 5 m in situ, whose tree canopy cover is more than 10 % of the area, and is not primarily under agriculture or other specific non-forest land use (United Nations Convention on Biological Diversity, 2006). Urban forestry is the 'art, science and technology of managing trees and forest resources in and around urban community ecosystems for the physiological, sociological, economic, and aesthetic benefits trees provide' (Konijnendijk et al., 2006), with a focus on the additional services the forest components provide to advance urban liveability and sustainability (Lin et al., 2019). Agricultural and industrial crops are therefore components of green infrastructure but are not part of the urban forest and therefore not the focus of this chapter. The links between the urban forest and the UGI are outlined in Figure 4-1.

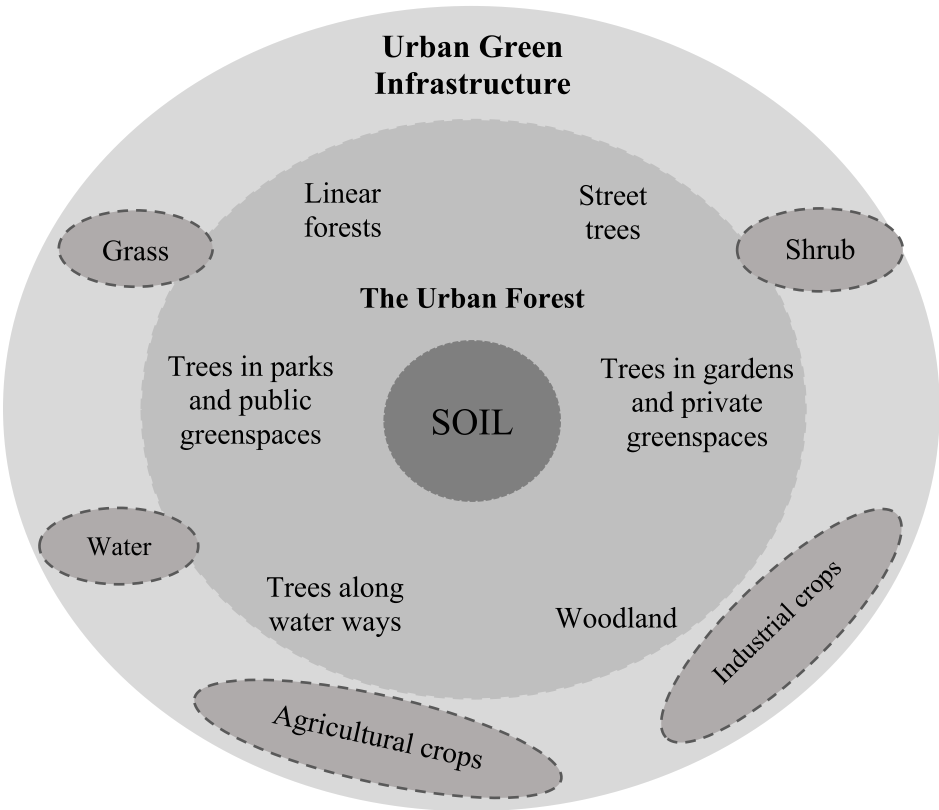


Figure 4-1: The urban forest and its relationship to green infrastructure (adapted from UFWACN (Urban Forestry and Woodlands Advisory Committees Network), 2016).

The components (street trees, woodland, forests etc.) that make up urban forest link up with other vegetation types to make up UGI and these are the focus of this study. There is the dearth of national level examinations of UGS quantity and quality, especially in the Global South (Venter et al., 2020). Although UGS cover is constantly changing, few studies have quantified the quantity and overall change of greenspace cover (du Toit et al., 2018; Schäffler & Swilling, 2013). Malawi is no exception and there has been no study that has mapped the UGS, analysed their quantity, quality, and distribution within cities in the country and Zomba in particular, nor quantified loss or gain in UGS despite having a popular consensus that the city is losing them. Only an assessment of tree diversity and carbon storage from the different land use types within Zomba (Chimaimba, 2019) and Blantyre on urban land use and land cover changes between 1994 and 2018 (Mawenda et al., 2020) were done. Therefore, the main aim of the study was twofold – first was to analyse and map the spatial and temporal changes in quantity and distribution of UGS cover between 1998 and 2018 and changes in quality of UGS between 2013 and 2021. Secondly, the study mapped all the current UGS, with a reference point from the available 2010 land use map to analyse the UGS per capita. This was encompassed in the following research questions:

1. How has the status of UGS transformed over the last two decades?
2. Are there any spatial and temporal changes in quality of UGS within the city?
3. What is the quantity and distribution of the current formal and informal UGS?

4.2 Methods

4.2.1 Data collection

A suite of methods was used to determine the status of quantity, quality, and distribution of UGS in Zomba. These were guided by the research questions outlined in section 4.1 and detailed below.

4.2.1.1 Spatial and temporal changes in UGS cover

The spatial and temporal status of the urban forest was estimated by comparing the 2018 satellite imagery to the one captured twenty years before (1998). The data requirements for this change detection involved acquisition of two cloudless satellite images of the same area, around the same season but from two different time points. The remotely sensed data was used to analyse the land cover change between the two images. For this analysis, a Landsat 5 image from April 1998 and a Sentinel 2 image from April 2018 of Zomba in Malawi were used. The boundary for the maps in the two time periods was the same as delineated by the central government when it was declared a city in 1964 after attaining independence. Data was downloaded from the Copernicus Open Access Hub (https://scihub.copernicus.eu/dhus/#/home), satellite imagery of the European Union Copernicus programme. Sentinel 2 satellite provides high spatial resolution data at a 10 m resolution. The advantage of using Sentinel 2 satellite data is their high resolution, which makes classification more accurate. The disadvantage is that data is only available from June 2015 onwards, meaning that it could not be used for earlier change detection. Furthermore, free Earth Observation browser (EO Browser) contains the full archive of the Landsat missions. The Landsat mission provides satellite data for earlier dates: Landsat 4 since 1982 (until 2001), Landsat 5 since 1984 (until 2013), Landsat 7 since 1999 and Landsat 8 since February 2013 (to date). The disadvantage of Landsat images as compared to Sentinel is that the resolution is lower, meaning that the classification is less precise; Landsat 4, 5, 7 and 8 have a resolution of 30 m, with Landsat 8 having far better spatial resolution than the previous Landsat images. Satellite images that could have gone some 20 years back to understand the tree canopy cover in the years around 1978 were not available.

4.2.1.2 Spatial and temporal changes in quality of UGS

Quality was at the city scale using the Normalised Difference Vegetation Index (NDVI) as a proxy of the state of UGI (Calderón-Contreras & Quiroz-Rosas, 2017). The NDVI uses multispectral data that is transformed into spectral vegetation indexes and has been used as an indicator of the general condition of vegetated surfaces (Creech et al., 2016; Marchetti et al., 2016). Marchetti et al. (2016) further appraises the NDVI as the widely used remote sensing product that analyses and maps differences in vegetation types and plant phenology. To avoid quality differences from the satellite images used for the NDVI analysis, Landsat 8 images for Nov 2013 and Nov 2021 were used to appreciate any spatial and temporal changes in UGS quality (Table 4-1). The comparison for NDVI used Landsat 8 satellite images which were captured from 2013 onwards. Landsat 8 provides scientists with a clearer view, that has better spatial resolution with a greater sensitivity to colour and brightness than the previous Landsat's (Acharya & Yang, 2015). The year 2013 was therefore preferred as that is the oldest time available for Landsat 8 satellite images and this facilitated comparing the two-time spans with the same image quality to reduce on errors that could be attributed to the quality of the satellite images used in the NDVI analysis (Fan & Liu, 2016). A total of three classes (non-vegetation, non-tree vegetation and tree vegetation) were used in the NDVI analysis.

Table 4-1: Details of the Landsat 8 satellite images used in the classification.

Satellite	Sensor ID	Path/row	Date of acquisition	Grid cell size (m)
Landsat 8/9 OLI_TIRS	LC08_L2SP_167071_20131108_20200912_02_T1	167/70	2013-11-08	30
	LC09_L2SP_167070_20211109_20230506_02_T1	167/70	2021-11-09	30

4.2.1.3 GIS mapping for quantity and distribution of the formal and informal UGS

The 2010 land use map for Zomba was used as a benchmark which had public UGS already mapped. The other UGS that were not mapped (cemeteries and other private UGS) were physically identified with relevant officers from the parks and recreation department as the main key informants. These extra formal and informal UGS were then digitised and georeferenced onscreen as either polygons or paths using the 2018 Google Earth image and categorised into greenspace type and status (either formal or informal). This was done within the city boundary and the UGS in question included parks, urban forests, roadside and riverside greenbelts, cemeteries, institutional and residential UGS on public and private land. The polygons and paths were georeferenced using GIS tools in Google Earth Pro, saved in My Places as a .KMZ file for further processing. Google Earth Pro was made free since January 2015, is versatile and supports digitisation and georeferencing as it offers several additional features not available in Google Earth like supporting the import of GIS data, measurement tools for a polygon, circle, 3D path or 3D polygon on top of the path and polygon only available in Google Earth among other features (Eawag Aquatic Research, 2015).

After mapping all the formal and informal UGS, the quantity of the UGS was estimated. This was used to understand the relative amount of greenspace compared to the population demand. Three indicators of quantity were used: UGS per capita (PPC), UGS % (PP), and UGS per urban land (PUL). The latest population figures from the 2018 Population and Housing Census were used to compute the quantity indicators where necessary. The same were also used in the analysis of both formal and informal UGS within the city scape and their distribution across the city.

4.2.2 Data analysis

4.2.2.1 Spatial temporal changes in UGS cover

Using the classified supervision from the April 1998 Landsat image and the April 2018 Sentinel image, the greenspace cover within the city landscape was analysed. The UGS classification and interpretation was performed on-screen using 30 m resolution (moderate resolution) for the 1998 Landsat 5 satellite image and 10 m resolution (high resolution) for the 2018 Sentinel-2B satellite image. Sentinel-2 is a constellation of two satellites launched by the European Space Agency (ESA) on 23 June 2015 and 7 March 2017, respectively. It maps geophysical parameters over land surfaces. The Sentinel satellite image data processing and classification was executed in SNAP 3.0.0 (free software from ESA) and QGIS 3.8 software. Landsat 5 images, acquired from USGS website, were processed, and classified in ESRI ArcGIS Desktop 10 software. A deep green colour was used for high green or tree canopy cover while low green was for non-tree vegetation like grassland and red colour was used for settlements and bare land.

Using a simple settlement-vegetation classification scheme, the vegetation was further divided into tree cover and non-tree vegetation using a maximum likelihood supervised classification. A total of 184 training samples were collected for both the 1998 Landsat and 2018 Sentinel cloud-free images. Sentinel images were downloaded from Sentinel hub, described below, and summarised in Figure 4-2.

Pre-processing of Sentinel-2B product:

1. Resampling image. Sentinel-2 imagery carry a virtually identical decametric resolution multi-spectral imager (MSI) having four bands at 10 m, six bands at 20 m and three bands at 60 m spatial resolution (Djamai & Fernandes, 2018) hence the need to resample to a common resolution of 10 m. The SNAP processor can't handle the data when the dimension of the source bands is different.
2. Subset the area of interest (AOI). AOI, Zomba was clipped using city boundary shapefile.
3. Re-projecting the AOI to WGS84/UTM Zone 36S.

4. Saving the clipped imagery for classification in QGIS 3.8.

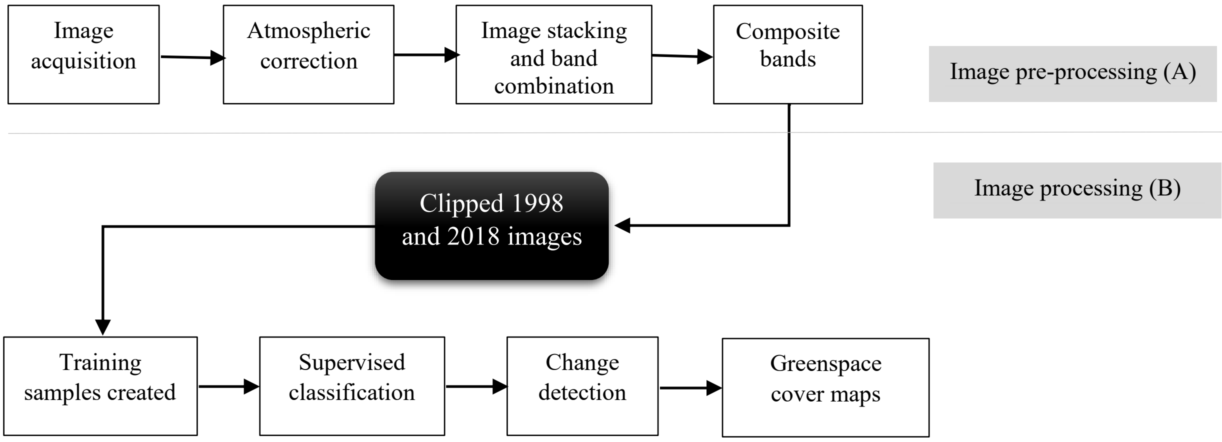


Figure 4-2: Processing spatial temporal greenspace cover in Zomba

4.2.3.2 Spatial and temporal changes in quality of UGS

The quality of UGI was analysed using the NDVI which is based on the relation between the near infrared and red bands. In a Spot image, this corresponds to the band 3 for infrared and 2 for red. This calculates differences in terms of quality of vegetation through the following equation:

$$\frac{NearInfrared_{Band} - Red_{Band}}{NearInfrared_{Band} + Red_{Band}} = \pm 1 \qquad \text{Equation 4-1}$$

NDVI is represented in a scale that ranges between -1.0 and 1.0 where negative values represent highly reflective elements like water or bare soil while positive values closer to 1.0 represent dense vegetation (Astsatryan et al., 2015). The NDVI values for Zomba were deliberately estimated towards the end of the dry season and into the start of the rainfall season as the satellite imagery was available during that time. This helped in avoiding the wet season greenness but actually to capture the perennial greenness from the trees. Accuracy assessment on the three land use land cover classes used in the NDVI analysis was done based on a total of 41 samples that were randomly selected on areas that could be clearly identified on the high resolution Landsat image, Google Earth and Google Map. Accuracy assessment is a quantitative assessment of how effectively the pixels were sampled into the correct land cover classes (Rwanga & Ndambuki, 2017), expressed as number of correct point/total number of points. The accuracy assessment was supported with KAPPA analysis, a discrete multivariate technique that yields a Khat statistic or Kappa coefficient (an estimate of KAPPA) as a measure of agreement or accuracy (Congalton, 1991). The Khat statistic was computed using Equation 4-2.

$$K = \frac{N \sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} (x_i + Xx_{+1})}{N^2 - \sum_{i=1}^{r} (x_{ii} X x_{+1})} \qquad \text{Equation 4-2}$$

where r is the number of rows and columns in error matrix, *N* is the total number of observations (pixels), x_{ii} is the observation in row *i* and column *i*, x_i+ is the marginal total of row *i*, and *x*+*i* is the marginal total of column *i.* A Kappa coefficient equal to 1 means perfect agreement and those close to zero for no better agreement, with five widely referenced categories (Landis & Koch, 1977).

4.2.3.3 GIS mapping of quantity and distribution of the formal and informal UGS

Open source QGIS software 3.8 Zanzibar was used to map the onscreen geo-referenced 2018 formal and informal UGS, using the .KMZ My Places file saved during the georeferencing phase. The UGS were presented on the map as different greenspace types. From the mapped UGS, quantity indicators were computed. The first was per capita UGS (m^2/person) where the total area of UGS was divided by the current city population, based on the 2018 National Statistical Offices' Population and Housing Census results (National Statistics Office, 2019a). The % coverage of UGS was also computed in relation to the city's urban greenspace area (% UGS) followed by a breakdown of proportions of UGS per city ward and their per capita values. The population proportions per city ward were also used in the analysis of UGS quantity distribution with the aid of the Lorenz curve and Gini coefficient (Equation 4-3). The Gini coefficient ranges between 0 and 1, with 0 representing perfect equality and 1 perfect inequality and it was used in the context of UGS provision by Kabisch & Haase, 2014.

$$G_{Site} = 1 - \sum_{n=1}^{N_{Site}} \frac{P_n}{P_{Site}} * (\theta_n^{green} + \theta_{n-1}^{green}) \qquad \text{Equation 4-4}$$

with $\theta_n^{green} = \frac{x_n^{green}}{x_{site}^{green}}$ where x^{green} is the absolute amount of coverage in a 1,000 m buffer around grid cell *n* as the dependent variable. Each grid cell is weighted by its population *p*.

4.3 Results

4.3.1 Spatial and temporal status of UGS cover in the city

UGS cover as represented by tree canopy cover within Zomba city was estimated at 23 % as of April 1998 and this reduced to 9 % as of April 2018, an absolute 14 % drop in 20 years (Figure 4-3), equivalent to 0.7 % per annum. As the tree canopy cover was decreasing, grassland cover slightly increased from 50 % to 55 % over the same period. Therefore, combined high and low green was represented by 73 % in 1998 and reduced to 64 % in 2018, a drop of 9 %, which is translated to an increase in area for settlements from 27 % to 36 % in a space of 20 years.

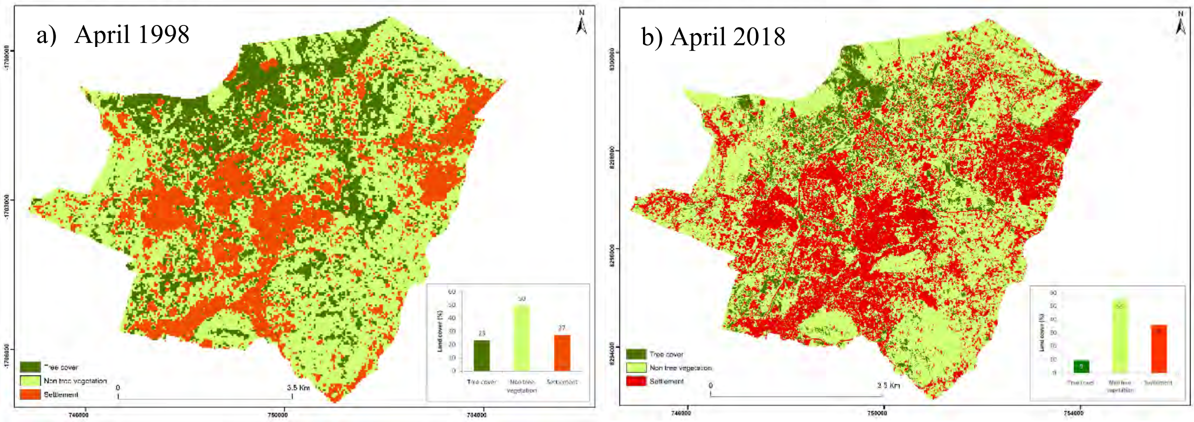


Figure 4-3: Land cover classification for Zomba as of (a) April 1998 and (b) April 2018.

4.3.2 Spatial and temporal changes in quality of UGS

Overall accuracy assessment from the random sampling process for the image was 87.8 %. Users' accuracy ranged from 80 % to 91.6 % while producer's accuracy ranged from 72.7 % to 100 %. An overall Kappa coefficient of 0.812 was obtained, which is rated as almost perfect (0.81 – 1.00), certifying the classified image to be fit for further research. The three land us land cover classes following the accuracy assessment are presented in Figure 4-4 and used for further NDVI analysis, with visible changes in some wards like Mpira and Sadzi. From the almost perfectly classified images, the NDVI analysis gave a higher figure of 0.95 for 2021, up from 0.78 for 2013. From the NDVI map (Figure 4-5), there is a visible increase in the high NDVI values from Mpira, Masongola, Chirunga and Sadzi wards from 2013 to 2021 (Figure 4-5), citing examples of Chirunga forest and Sadzi hill, amongst others, which are gaining good tree cover. Further analysis on the net gains and losses amongst the three classes of no vegetation, non-tree vegetation and tree vegetation shows that Mpira ward had the greatest land use and land cover changes, with a total of 171 ha of no vegetation converted to non-tree (100 ha) and tree vegetation (71 ha). This is seconded by Chirunga ward with a gain in tree vegetation of about 38 ha followed by Sadzi at about 19 ha. Only Masongola and Zomba central registered losses in tree vegetation. Minimal changes in net gains and losses of less than 10 ha were registered in Likangala, Chinamwali and Chambo wards (Figure 4-6). Comparing the NDVI change maps with the population density map revealed a surprising pattern. Wards with high population density (Likangala, Chinamwali and Sadzi – Figure 4-7) were also the ones that registered the minimal net gains and losses in vegetation. Though minimal, Likangala gained tree vegetation by converting no vegetation and non-tree vegetation. On the other hand, Chinamwali gained very little tree vegetation (1 ha) but turned much of the non-tree vegetation (5.8 ha) to no vegetation (4.8 ha). Classified from the NDVI map, overall net gain of 104 ha was observed in tree vegetation and non-tree vegetation (134 ha), both from converting a net loss of 238 ha from no vegetation (Figure 4-6).

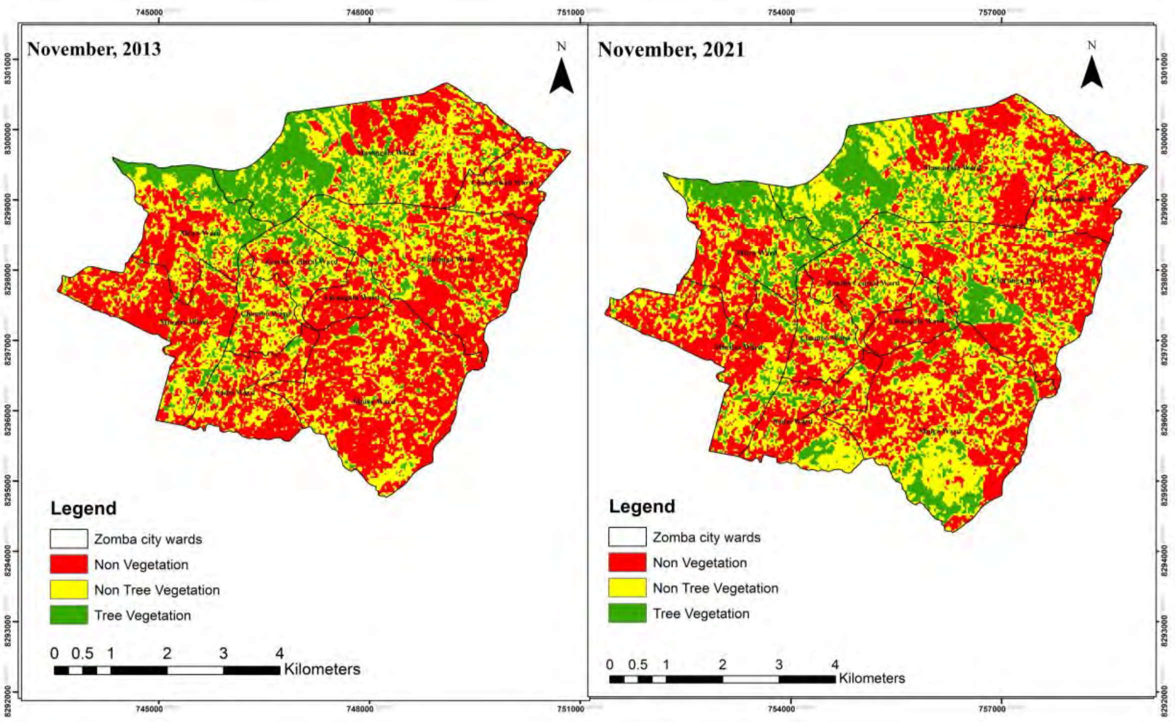


Figure 4-4: Land use land cover changes based on the three classes used in NDVI analysis.

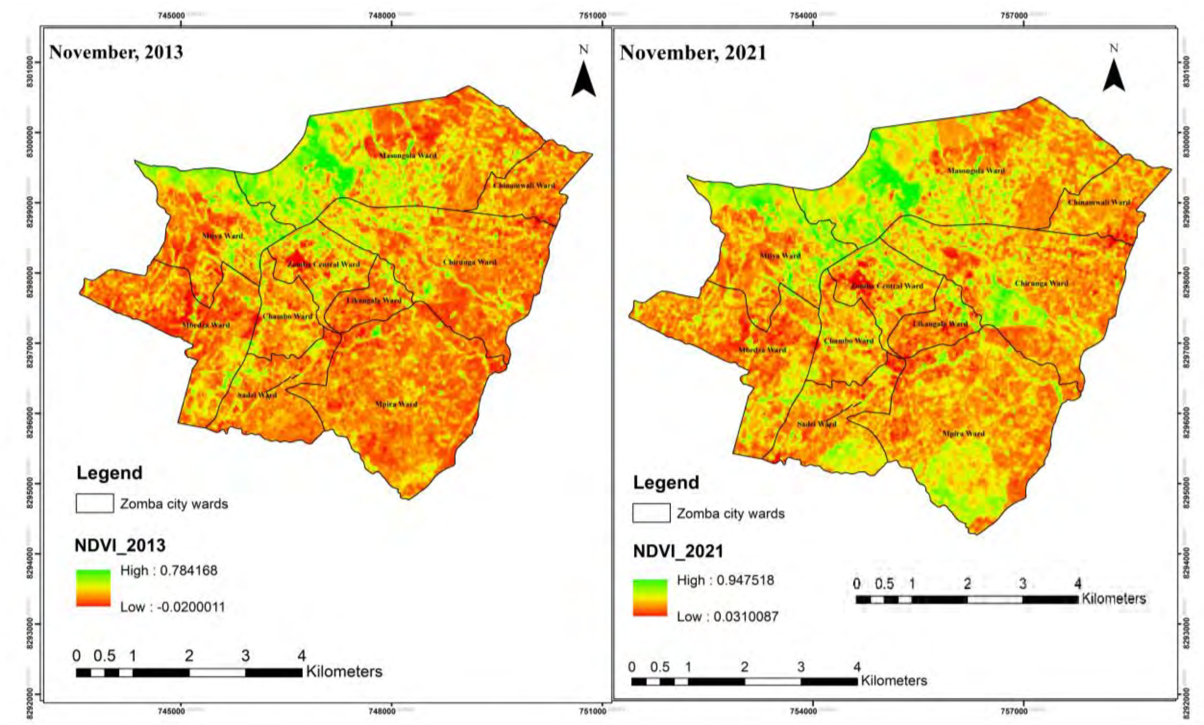
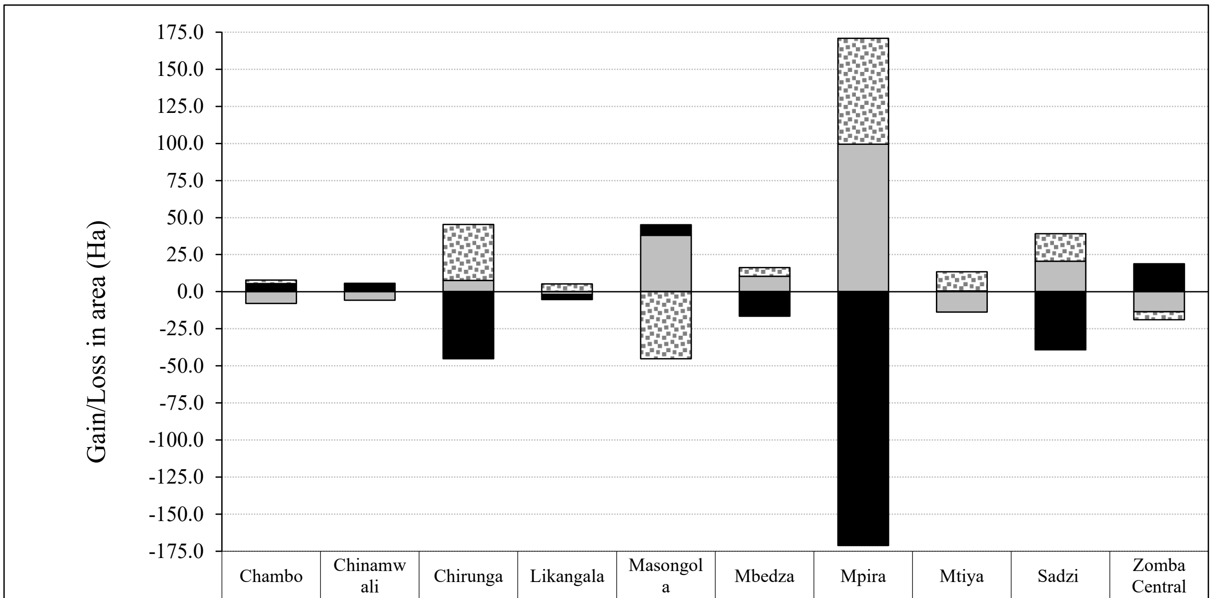


Figure 4-5: Quality of UGS between 2013 and 2021 as measured from NDVI analysis



	Chambo	Chinamwali	Chirunga	Likangala	Masongola	Mbedza	Mpira	Mtiya	Sadzi	Zomba Central
Tree Vegetation	2.3	0.9	37.7	5.3	-45.1	5.9	71.3	12.9	18.6	-5.5
No Vegetation	5.5	4.8	-45.2	-3.4	7.2	-16.5	-171.2	0.6	-39.2	18.9
Non-Tree Vegetation	-7.8	-5.8	7.7	-1.9	37.9	10.5	99.6	-13.7	20.6	-13.4

Figure 4-6: A distribution of net gains (+) and losses (-) in vegetation between 2013 and 2021 across the ten city wards.

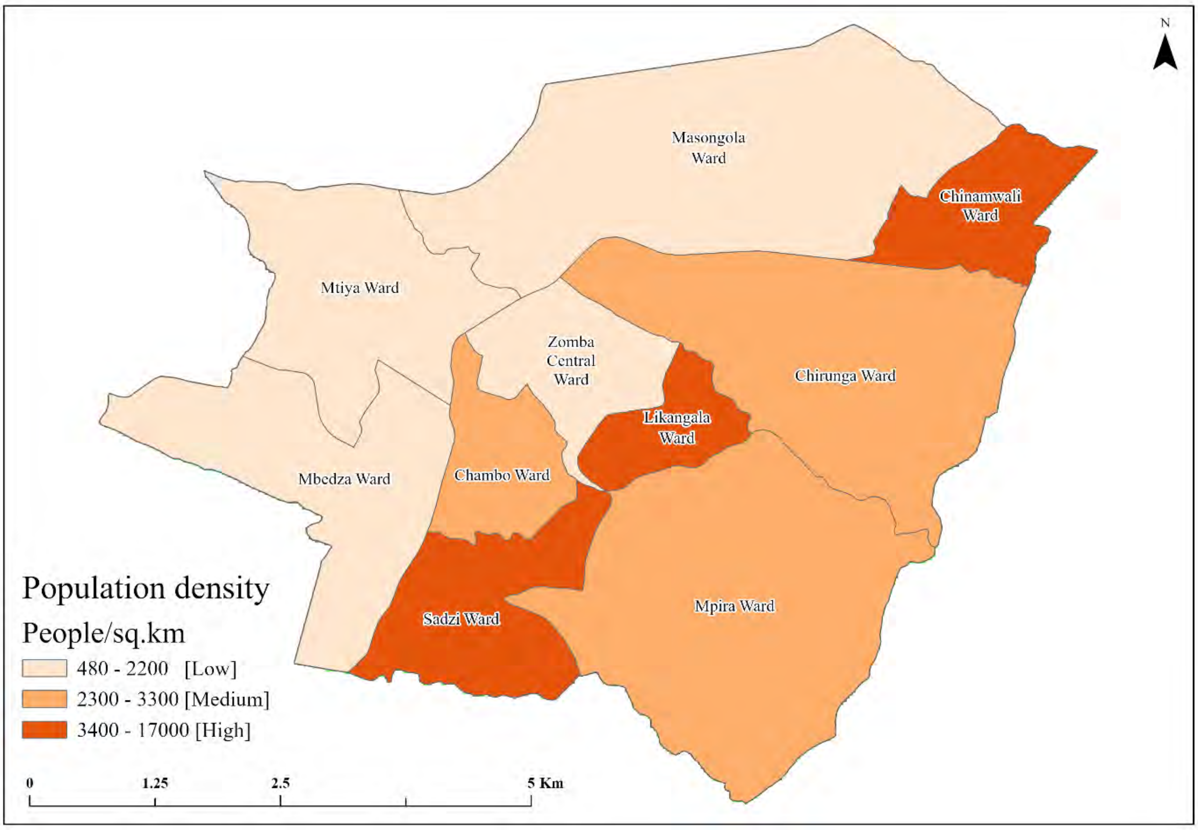


Figure 4-7: A distribution of population density across the ten city wards.

The quality aspect reflected in an increase in NDVI values comes from UGS that are well protected and gaining crown cover yearly (Figure 4-8). The city has ten of these recreation parks mostly located in Masongola and Mtiya wards but not currently used as parks as they are not maintained for that purpose, except for a portion of Likangala park which has some park amenities like children's swings and climbing frames. Their informality and neglected state means natural gain in tree growth and increased greenness of the area they are in, like the proposed Ndola park which is gaining some good canopy cover (Figure 4-8 a) and Likangala park (Figure 4-8 b), both from Likangala ward. On the other hand, despite that Masongola had the greatest loss in tree vegetation, both formal and informal UGS present like the botanical garden (Figure 4-8 c) continue to buffer for the loss as the trees continue growing and increasing their greenness.

a) Aerial view and camera position (white dot) for the ground image of Ndola park as of November 2019. (Source: Author's fieldwork, 2019).

a) Aerial view and camera position (white dot) for the ground image of Likangala park as of November 2019. (Source: Author's fieldwork, 2019).

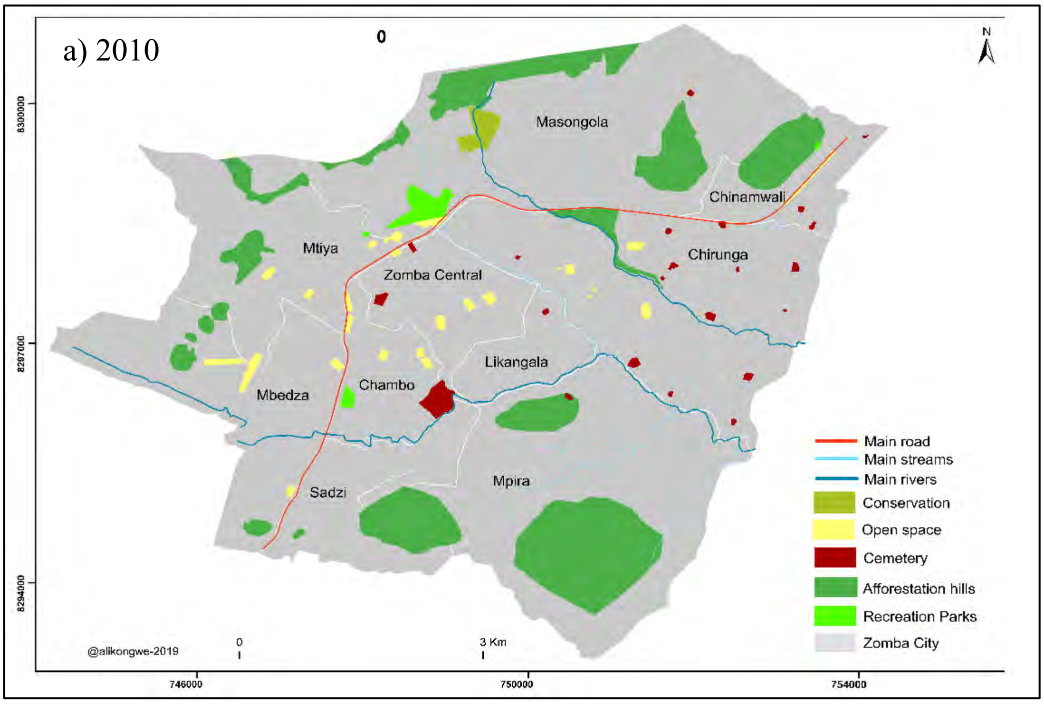
b) Aerial view and camera position (white dot) for the ground image of Botanical gardens as of November 2019. (Source: Author's fieldwork, 2019).

Figure 4-8: Sample of UGS quality from selected recreation parks and a conservation area

4.3.3 Quantity and distribution of formal and informal UGS

The city has more formal UGS compared to the ones indicated on the 2010 land use map. Under the formal UGS, the city has recreation parks, a botanic garden, cemeteries and other open spaces as extracted from the 2010 land use map for the city (Figure 4-9). The parks are fully under the city council, one private recreation garden and the conservation garden which is public but run under statutory arrangement. The designated formal UGS within the city are not fully managed by the city authorities. These include the botanic gardens and the golf course. Open spaces, mainly the playgrounds in schools, are also considered formal in this case, with a majority having trees around them or in some areas. For the informal UGS, the city has urban forests, other intact conservation areas, river belts, street trees, afforestation hills and other private UGS. Some of the private UGS were consolidated and shared by two or more house yards.

An inquiry into all the UGS within the city as of 2018 showed some changes as compared to 2010 land use map. Other UGS which the city authorities knew but were not mapped in the 2010 land use map were also followed up and mapped as outlined in the updated 2018 UGS map for the city (Figure 4-9).



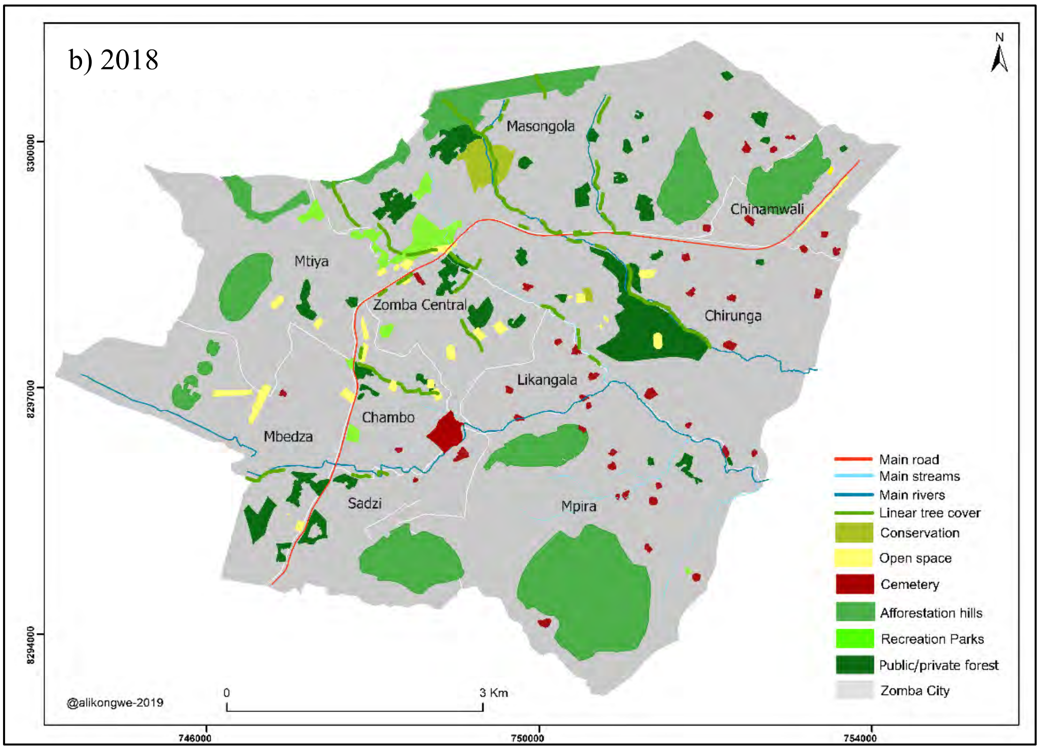


Figure 4-9: Greenspace distribution map for Zomba city in 2010 and 2018.

As of the end of 2018, all UGS, both formal (2.9 %) and informal (16.6 %), contributed 19.5 % to the total urban area, of which the afforestation hills alone contributed 11.8 % while parks and cemeteries only 1.4 % and 0.8 %, respectively (Figure 4-10). However, the hills alone contribute half (60.5 %) of the total UGS area available in the city with the least contributed by the conservation areas at 3.0 % (Figure 4-10).

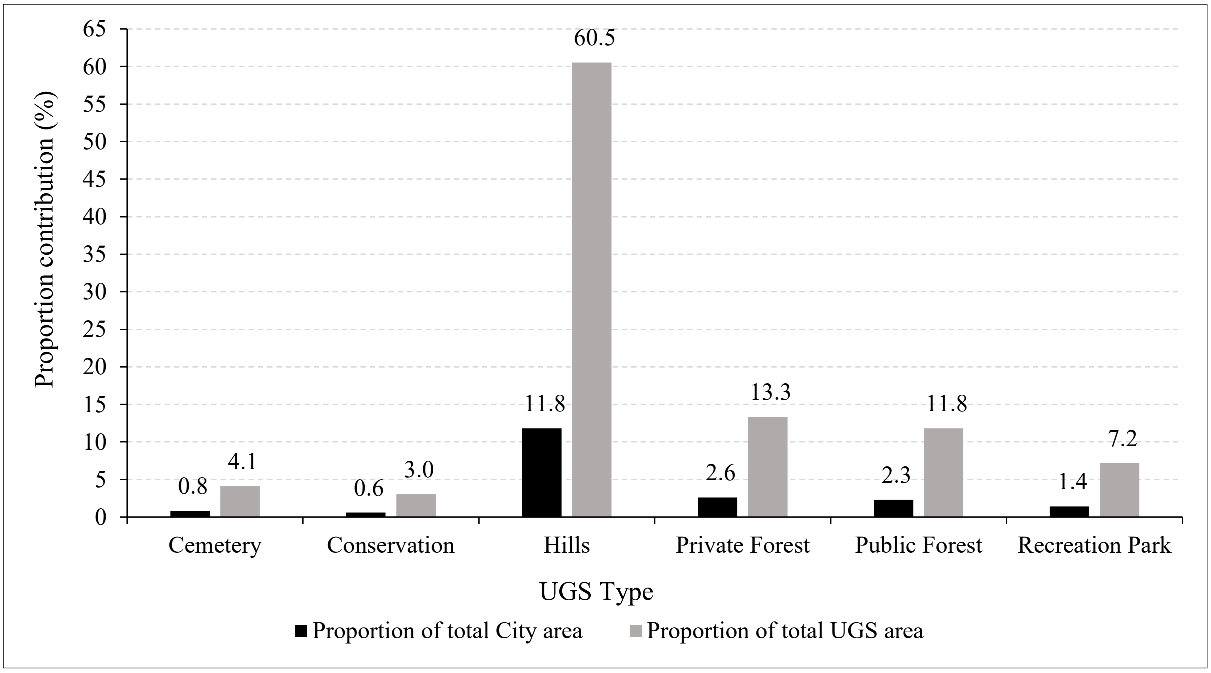


Figure 4-10: Proportional contribution UGS to the total city area and total UGS area in 2018

Both formal and informal UGS cover 817.2 ha, comprising of 122.0 ha formal UGS and 695.2 ha informal UGS, mostly contributed by Masongola, Mpira and Chirunga wards (Figure 4-11). Much of the informal UGS are mainly coming from the afforestation hills as well as public and private institutions like the University of Malawi and the Catholic Church. Further to this, there are other small pockets of UGS scattered on private property. In terms of linear UGS cover, mainly from the rivers and roads, much of it was also from Masongola, Mpira and Mbedza wards (Figure 4-12).

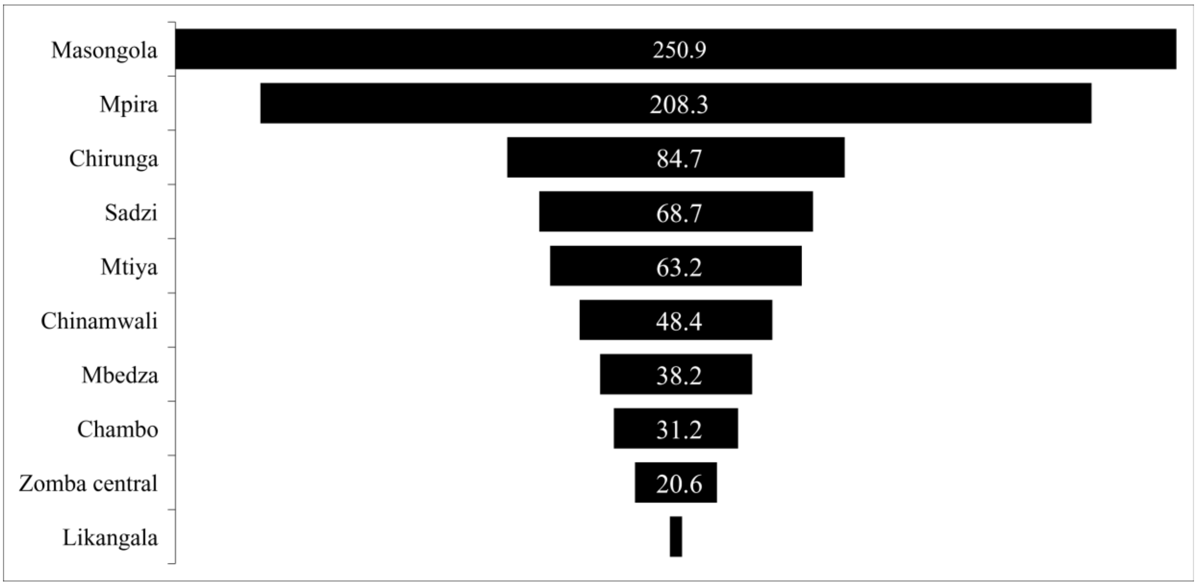


Figure 4-11: Total area (ha) of formal and informal UGS per ward.

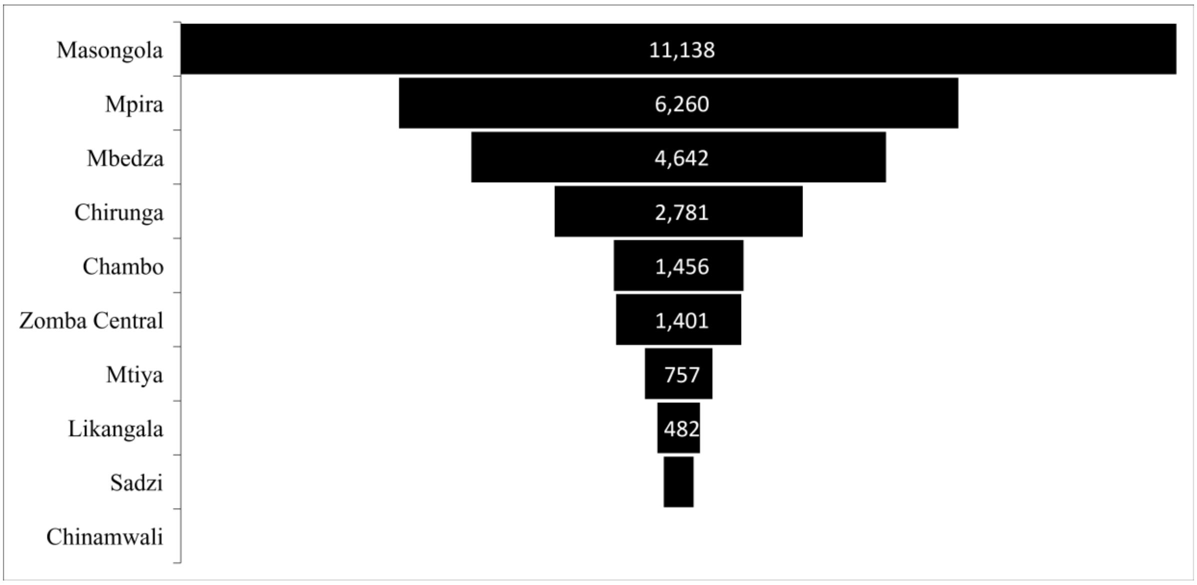


Figure 4-12: Total distance (m) of formal and informal linear UGS per ward.

Estimates of the per capita greenspace area for each ward based on the 2018 population census figures is presented in Table 4-2. Masongola ward boasts a per capita urban greenspace of 97.7 m^2/person whereas Chinamwali, Likangala and Sadzi wards have less than 3 m^2/person of formal UGS. Consolidating both formal and informal UGS gives a per capita greenspace area of 77.8 m^2/person, with the formal per capita greenspace area of 11.6 m^2/person, just slightly above the WHO recommended minimum of 9 m^2/person. The total area of formal and informal UGS covers 19.5 % to the total area of the city, with Masongola ward alone contributing 6 % followed by Mpira at 5 % with the rest contributing less than 2.1 % each (Table 4-2).

Table 4-2: Per capita greenspace available for each ward based on 2018 figures

Ward	Area of Ward (ha)	Population	Formal (ha)	Formal (m^2/person)	Informal (ha)	Informal (m^2/person)	No. of UGS/ Ward	All UGS (%)
Chambo	170.0	5,584	16.6	29.7	14.7	26.3	13	0.7
Chinamwali	186.5	15,207	3.0	2.0	45.4	29.8	5	1.2
Chirunga	690.1	12,277	11.6	9.4	73.1	59.5	21	2.0
Likangala	118.3	15,682	3.2	2.0	-	-	6	0.1
Masongola	874.8	5,494	53.7	97.7	197.2	358.9	31	6.0
Mbedza	451.3	7,783	9.5	12.2	28.7	36.9	12	0.9
Mpira	803.2	16,932	6.3	3.7	202.0	119.3	15	5.0
Mtiya	401.4	5,778	10.5	18.2	52.7	91.1	11	1.5
Sadzi	280.7	14,219	1.6	1.1	67.1	47.2	11	1.6
Zomba Central	200.1	6,057	6.0	9.9	14.5	24.0	11	0.5
Totals/ Average	**4,176.7**	**105,013**	**122.0**	**11.6**	**695.2**	**66.2**	**136**	**19.5**

Efforts need to be put in place to increase the per capita UGS area in the wards that have below the WHO recommended rate of 9 m^2/person, namely Chinamwali, Likangala, Mpira and Sadzi. The increase in population from 1998 to 2018 has resulted in a 37 % decrease in per capita green space from 18.5 m^2/person to the current 11.6 m^2, a trend that will continue if development is not clearly planned. Most of the parks are found in the low housing density areas where the colonialists first settled. This is represented by 44.0 % of the parks being found in Masongola ward, followed by Chambo ward at 13.6 %. The rest of the eight wards have no designated formal public parks, the only available UGS are the hills, cemeteries, and forests, both public and private. For distribution of formal and informal UGS within the city, a Lorenz curve showed some inequality in their distribution (Figure 4-13). A Gini coefficient of 0.72 was registered for the formal and informal UGS area distribution with the city. This shows that about 70 % of the UGS area is coming from about 10 % of the total number of formal and informal UGS, in other words, 90 % of the formal and informal UGS are making up 30 % of the total UGS area, an indication of concentration of UGS in one area or dominance of a few UGS within the city.

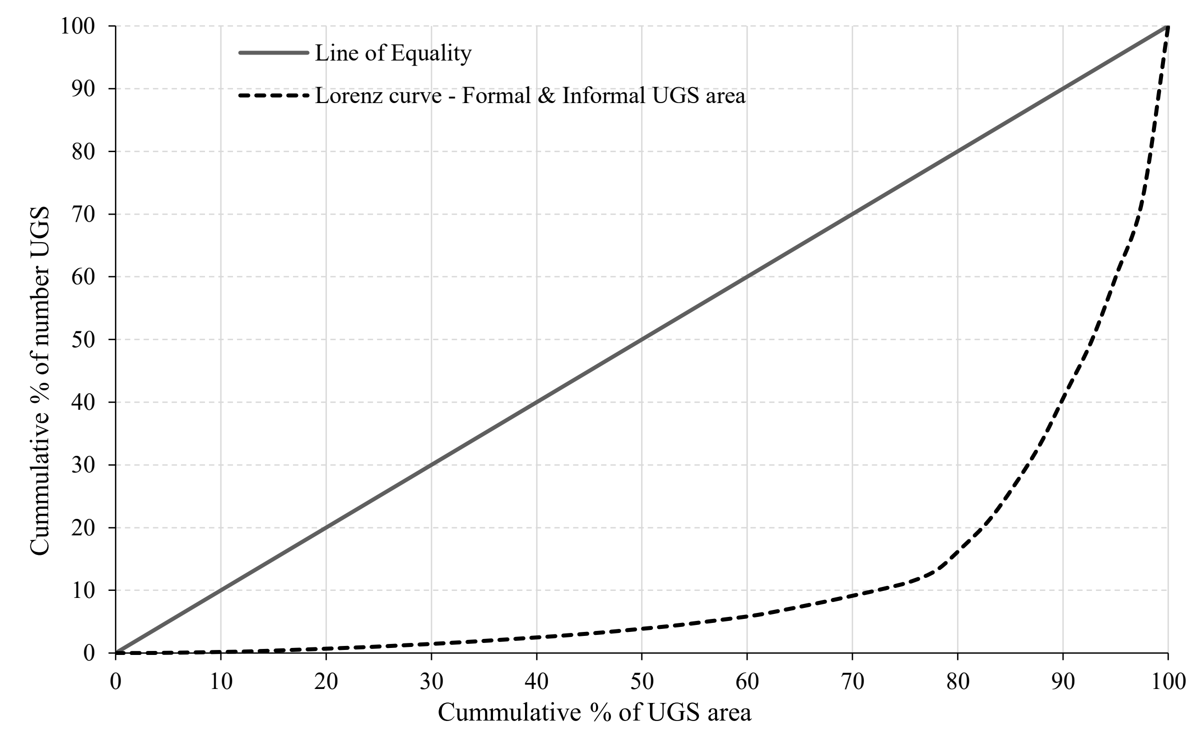


Figure 4-13: Lorenz curves for the distribution of formal and informal UGS in 2018.

4.4 Discussion

4.4.1 Spatial and temporal status of UGS cover in the city

Despite the many benefits that UGS and trees provide, instead of reserving these in urban environments, the opposite is often true. Loss of UGS and trees in urban settings is a global concern, especially in developing countries (Richards & Belcher, 2020). Zomba city is no exception as evidenced by the 14 % drop in canopy cover over the last two decades. The steady population growth in the city from around 24,000 people in 1977 to the current 105,000 people in 2018 (from 615 to 2,500 inhabitants per km^2), at an annual population growth rate of 2.5 % (National Statistics Office, 2019a), underlay the loss in UGS and tree canopy cover. The demographic pressure has a direct impact on land use changes, coupled with continued reliance on trees for different ecosystem services, resulting in a further increase in demand for fuelwood for energy, clearing trees for living space and related construction materials as noted by UN-Habitat (2011).

The 14 % drop in UGS cover for the city is not as severe as Dakar, Senegal, where only formal greenspace within the city dropped by 34 % in a space of twenty years between 1988 and 2008 (White et al., 2017). The kind of demographic pressure observed in Zomba was more pronounced in Addis Ababa, Adama and Hawasa cities in Ethiopia, with cases of urban sprawl and low land use efficiency during the period 1987 to 2017 (Terfa et al., 2019). du Toit et al. (2018) also reported of intense pressure on UGS for different human activities based on studies from several African countries. This has left many urban areas with very low proportions of greenspace. For instance, Kumasi city in Ghana, once a Garden city of West Africa, had only 10.7 % under UGS (Amoako & Korboe, 2011), while Lagos in Nigeria had less than 3 % (Mensah, 2014), with a very insignificant proportion of formal UGS to the total area in cities such as Luanda (Angola), Cairo and Alexandria (Egypt), Accra (Ghana), Monrovia (Liberia) and Mogadishu (Somalia) (Mensah, 2014). Addis Ababa city lost its 'forest city' status due to rapid and unplanned expansion and commercial development. The city's population pressure is exerting negative impacts on UGS and the city is heating up because of the urban heat island effect (Abebe & Megento, 2016). Mafikeng, South Africa, also lost seven out of nine original public UGS to residential, school, and commercial land uses by 2016 (the two remaining UGS totalling to 4 ha), a near exponential decline in quantity of the public UGS during the analysis period (1992 and 2016) (Munyati & Drummond, 2020).

Such changes are not restricted to Africa. For example, recent conversion of green field sites into rural and urban development have caused substantial pressure on the extent of the natural capital in southern, eastern, and south-western Australia and continue to pose major problems for environmental managers (Ghofrani et al., 2020). In a study of 245 major cities across the globe by The Nature Conservancy (2016), it was clear that trees and UGS provide significant ecosystem services. These urban ecosystem services will be greatly needed following projected increase of 2.5 ºC in summer temperatures by 2050 that will lead to a projected 50 % increase in human mortality caused by $PM_{2.5}$ (particulate matter) in urban areas, from 3.2 million people to 6.2 million deaths per year (The Nature Conservancy, 2016). The Nature Conservancy study further found a decline in forest cover between 2000 and 2010 in 26 % of the cities, compared to 16 % of the cities registering an increase in forest cover. Elsewhere, depletion of UGS and trees indicate that out of the 25 European cities that were assessed on land-use change, between 7.3 % and 41 % of the land reserved for UGS was lost to different land-use types (European Environment Agency (EEA), 2002). A similar trend was also reported in a study from 274 metropolitan areas in the USA where 1.4 million hectares of UGS were lost to different land developments (McDonald et al., 2010). The drop in UGS cover in Zomba corresponds to the highest $PM_{2.5}$ pressure in the north of the city around the major road, (Chinamwali and parts of Chirunga wards) which diminishes in a south-easterly direction (Mpira and parts of Chirunga wards), with a widespread heat pressure (Fletcher et al., 2021). With continued increase in world population, Mörtberg et al. (2017) emphasised the need to reduce the rate of physical urban extension to protect the ecosystem services that are critical for sustaining human life.

Faced with declines in UGS and trees, some city authorities and other stakeholders have initiated targets to counter the drop. For instance, Kualar Lumpur, Malaysia, set a target of 30 % tree canopy cover almost double the current 17 % cover, with strategic plans to increase this tree cover which includes roof top planting and protection of recreational forests and trees in public parks and housing areas (Kanniah, 2017). According to Plant et al. (2017), Melbourne, Australia, aims to increase tree canopy cover in public streets and parks from 22 % in 2014 to 40 % by 2040 as one way of reducing urban heat island impacts on human health, while London intends to increase it to 30 % by 2050 as a way of buffering the city from floods and hot weather (Salbitano et al., 2016). Hashimoto et al. (2005) proposed that ecologically, a 10 % tree canopy cover throughout an urban area is necessary for creating an ecologically sustainable city. However, targets vary across different climatic and ecosystem conditions, with optimal canopy cover targets depending on the ecological, economic, and social services provided by the trees, their cost and community desire (Kanniah, 2017). Suffice to say, Siriwardena (2016) in USA confirmed that property values are maximised at about 38 % tree cover at county-level and 30 % at property level, while American Forests recommended a tree coverage of between 40 and 60 % in forested states in the USA to keep the temperatures low, provide extremely effective onsite stormwater management and keep the air clean (Leahy, 2017).

4.4.2 Spatial and temporal changes in quality of UGS

Temporal changes in quality of UGS as estimated by NDVI are influenced by other factors like rainfall, land surface temperature, land use cover change, population, digital elevation model and nightlight, in that order of importance (Yang et al., 2019). The NDVI value of 0.78 from the study corresponds to Atasoy (2018) who agreed that NDVI values of 0.6 to 0.8 represent tropical forest land with vegetation coverage while 0.2 to 0.3 represents shrubs and grass land while - 0.1 to 0.1 represent degraded land. Changes in deforestation and afforestation in Malawi are positively associated with development, population pressure and demographic factors (Bone et al., 2017; Gondwe et al., 2021). The four cities of Malawi showed the greatest loss in forest cover and at the same time the greatest gain between 1972 and 2009, with a net loss of 5 % (Bone et al., 2017). However, in the study city, the increase in NDVI is attributed to the overall increase in both area under tree vegetation and increased growth of the UGS resulting to more tree canopy cover. The overall net gain of 104 ha observed in tree vegetation in all the wards, mainly Mpira, Chirunga and Sadzi is attributed to the gains from Nkholonje hill, Chirunga forest and Sadzi hill. These voluminous UGS within the city transformed mainly from bare or non-vegetation followed by non-tree vegetation classes to tree vegetation from around 2010 for Chirunga forest (Chiotha, 2010), from 2013 for Sadzi hill (Likongwe et al., 2021), and Nkholonje hill from 2014 (Mwantani, 2021). The increase in tree vegetation is speaking to the increase in NDVI following restoration efforts that involved both natural regeneration and tree planting initiatives, championed by either the institutions or the community members in the area (Chiotha, 2010; Likongwe et al., 2021; Mwantani, 2021).

4.4.3 Quantity and spatial distribution of formal and informal UGS

From the results on quantity, the 19.5 % tree canopy cover of the city's land and 11.6 m^2 per capita, greenspace cover in Zomba is at the boarder line, as compared to the minimum by the World Health Organisation, though slightly higher than other cities. Similar classifications in other SSA cities revealed that greenspace covered 5.1 % of Dar es Salaam, Tanzania. Of this, bushland took up 51.5 % and the rest was taken up by riverine, marsh/swamp, mangrove, and mixed forest, whereas formal UGS only accounted for 0.7 % (CLUVA, 2013). Douala, Cameroon, boasted 17.7 % greenspace cover, but very low formal UGS at 0.2 %. Ouagadougou, Burkina Faso, had 16.8 % vegetation cover and 1.4 % of the city space left for formal UGS where parks contributed 88.7 % to this share. Addis Ababa, Ethiopia, had 11.8 % vegetation cover with formal UGS covering 1.9 % of the city with the Botanical gardens contributing 72.7 % and parks only 6.9 % (CLUVA, 2013). Elsewhere, Kuala Lumpur, Malaysia, tree canopy cover stood at 17 % compared to its neighbouring Singapore where aerial images showed a vegetation cover of 40 % in 2011 (Kanniah, 2017).

In Brazil, the city of Curitiba's growing population in the 1970s reduced per capita greenspace to 1 m^2/person, afterwards it was increased to 51.5 m^2/person through a clear priority and local authorities' consistent efforts (Carmona et al., 2003). In selected cities in China, Wang (2009) reported an increase in per capita greenspace from 3.5 m^2 in 1986 to 6.5 m^2 by 2000 and still increasing through targeted increase in tree planting.

However, comparing per capita greenspace area of Zomba city with other regional averages and selected cities across the continent confirms the shortage of formal UGS within many urban environments, more so in SSA (Figure 4-14). The low contribution of formal UGS in Zomba is not different from other cities from several other developing countries like Monrovia (Liberia), Luanda (Angola), Alexandra and Cairo (Egypt), Kumasi and Accra (Ghana) and Mogadishu (Somalia) where such public parks and gardens cover an insignificant proportion of the city (Mensah, 2014). Per capita greenspace figures for smaller cities the size of Zomba in SSA are not available, an indication that indeed most city authorities do not know much about their UGI.

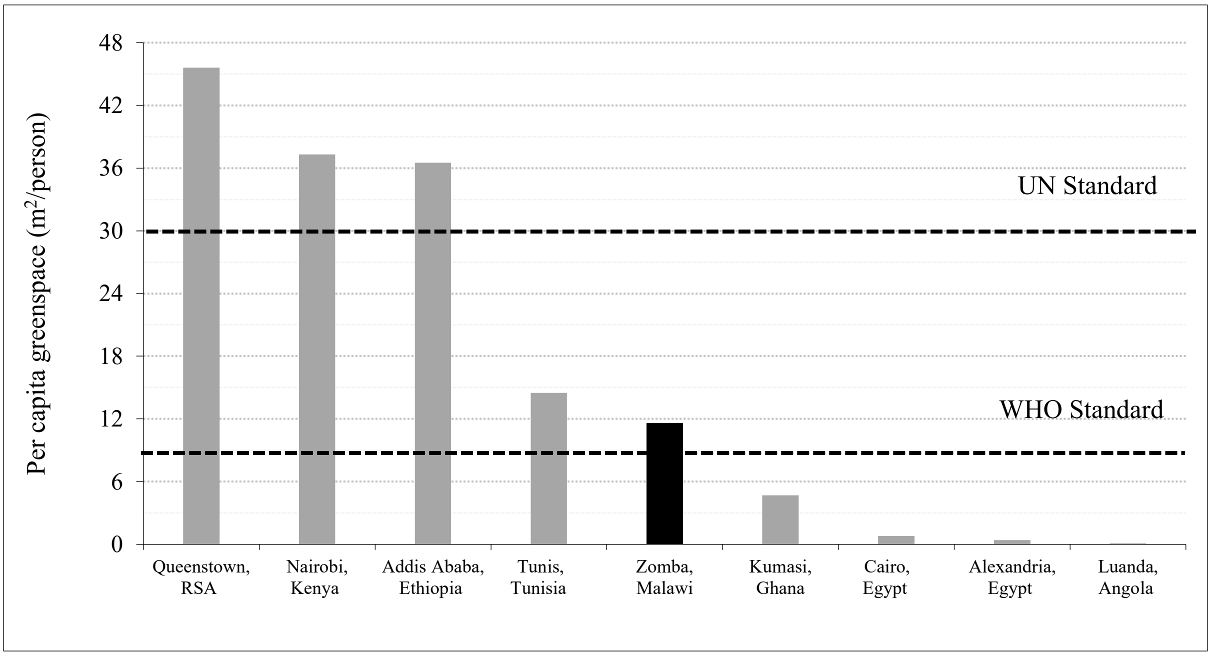


Figure 4-14: A synopsis of per capita greenspace in selected cities across Africa

Zomba has several formal greenspaces that are not fully functional as they are not well managed. The informal greenspaces however take up much of the vegetated area within the city, contributing significantly to per capita urban greenspace. Such informal greenspaces are important within urban settings as they constitute the majority of UGS available to urban dwellers, mostly in developing cities. For example, Manyani et al. (2021) found that in two small towns in Eastern Cape, 63 % of residents patronised public UGS, and 40 % also visited informal UGS. However, these informal UGS were less preferred (0.8 %) as compared to formal UGS (73.1 %), with negative attitudes towards informal UGS as they were mostly littered, associated with anti-social behaviours and were associated with fear as expressed by some respondents. In Funda commune, Luanda metropole, Pedrosa et al. (2021) noted the importance of informal UGS as they offered children an alternative to formal UGS through acting as parks and serving as sources of fruits, recreation and leisure activities and a means to connect classroom lessons with nature. Similarly, informal UGS including domestic gardens, vacant spaces, riparian zones, parks, institutional grounds, cemeteries, farms and dumping sites were used for foraging in Potchefstroom and Thabazimbi, South Africa (Garekae & Shackleton, 2020). Generally, informal UGS are largely overlooked in management, urban planning and policy despite providing many social and ecological benefits to its urban citizens (Garekae & Shackleton, 2020; Mata et al., 2019; Riley et al., 2018).

Despite informal UGS perhaps providing more disservices compared to formal UGS, they need to be acknowledged within city masterplans as they provide an opportunity to increase access to UGS and associated ES. Their absence in the 2010 land use plan for the city of Zomba was an indication that they are not regarded as an important element within the cityscape. However, during the course of the study, the city was interested in the 2018 UGS map, an indication that they are now being recognised. Malawi Vision 2063 recognises the importance of UGS such as parks, sports fields, and vegetation, as a key element in integrated urban planning in view of the creation of world class urban centres and related creation of secondary cities (Government of Malawi, 2020). Richards et al. (2017) adds that developing cities should aim to protect a substantial quantity of semi-natural greenspace from an early stage of development, as these habitats cannot easily be re-created in the future, and are likely to provide higher levels of some critical ecosystem services than heavily managed parks and gardens.

4.5 Conclusion

The chapter has presented the status of green infrastructure in Zomba City in terms of quantity, quality and distribution of formal and informal greenspaces. It has shown that Zomba has very few formal UGS, which are decreasing as the population increases. UGS comprise 19.5 % of the total city area (formal – 2.9 % and informal – 16.6 %). A total of nine greenspace types were identified. As plans are under way to extend the city boundaries, there is need to pro-actively designate room for formal UGS to enhance provision of ecosystem services from UGS for social interactions, air purification, lowering extreme temperatures, noise reduction, aesthetic beauty, health, and well-being, amongst others, to the city residents. With the afforestation hills comprising much of the land, having them fully afforested with a good forest cover can enhance a sustained supply of provisioning, regulating, and supporting ecosystem services and hence improving the liveability of the city. This extends to the linear UGS, especially along the major streams, rivers and roads running through the city, which are not fully networked with trees.

Quantity alone is inadequate if the quality is low. The same applies to high quality and low quantity greenspace. At 11.6 m^2/person, the per capita formal UGS area is slightly above the World Health Organisation recommendation. The low per capita greenspace cover is a Global South problem and young cities like Zomba need to act swiftly in the wake of such a revelation. This is a call to action as the greenspace area declined from 23 % in 1998 to 9 % in 2018, in the process reducing the resilience of the urban ecosystem and the multiple ES that residents could benefit from. However, along the way, a noticeable increase in NDVI from 2013 to 2021 points to increase in tree vegetation cover, mainly from restoration efforts from the two hills and other institutional UGS, post 2010. This increase in quality has illustrated the impacts of the restoration efforts, a diversion from business-as-usual attitude which would mean continuous loss of UGS and related quality within the city. With a greater contribution of the informal UGS to per capita UGS for the city, these are low hanging fruits that the city can take up. The city authorities and relevant key stakeholders need to include them in the masterplan and work around them to reduce the general negative attitudes towards them through planning for safe, inclusive and resilient UGS for the citizenry of Zomba city.

5. PREFERENCES FOR AND PERCEPTIONS OF URBAN GREENSPACES IN ZOMBA, MALAWI

‘When we create big parks and the big museum in the middle of a city, only certain kids use it, but if we build smaller and more locally, all neighbourhoods benefit’ – City Lab, 2018

5.1 Introduction

Public urban parks are one of the core components of urban green infrastructure (UGI) that promote urban environmental sustainability, climate resilience and liveability as cities and nations strive to achieve Target 11.7 of the Sustainable Development Goals. This target ambitiously indicates that ‘By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities’ (United Nations, 2015). These green and public spaces can also be referred to as urban parks, a word that has multiple meanings. This study understands public urban parks (hereafter referred to as UP) as formally designated and managed patches of land in cities accessible to the public that incorporate nature, including some vegetation (Taylor et al., 2020), where the term ‘nature’ is used to incorporate biodiversity and refer to non-human features and processes, including vegetation, water, air, animals, landscapes and geological processes (Hartig et al., 2014). According to the UN Habitat standards, UP need to be conveniently located at a walking distance of no more than five minutes from one’s residence, which is equated to 400 m (UN-Habitat, 2018).

Urban parks are inclusive spaces and have the potential to provide a range of key ecosystem services (ES) that are valuable to the well-being of city dwellers and may also be considered as nature-based solutions to tackle multiple environmental problems in cities, such as flooding, noise arbitration or food insecurity (Mexia et al., 2018). There are many reports on the positive relationships between urban greenery, UP inclusive, and many facets of human well-being. For example, UP provide recreational services, are spaces for physical activity (Schetke et al., 2016; Shan, 2014), facilitate social interaction and even encourage social cohesion amongst people from a variety of backgrounds, and contribute to the social well-being and the health of a community (Paul & Nagendra, 2017; Zhang & Li, 2017). UP offer a refuge from city life and provide contact with nature, allowing people to get away, relax and socialise (Dinda & Ghosh, 2021). They also play a vital role as part of a city’s infrastructure and resilience, providing air and water purification, erosion prevention through reduced runoff, carbon sequestration, wildlife habitat, micro-climate regulation, and amelioration of the urban heat island effect (Brill et al., 2017; Finlayson et al., 2005). Plieninger et al. (2015) noted that UP provide cultural ES which have an impact on governance of cities, and influences how communities engage with nature.

However, UP can also be sources of ecosystem disservices (EDS), i.e., ‘ecosystem generated functions, processes and attributes that result in actual or perceived negative impacts on human well-being’ (Shackleton et al., 2016). EDS may also result from natural phenomena like floods, wild fires, winds or side-effects from manipulation of the ecosystem (Lyytimäki & Sipilä, 2009; Roman et al., 2021). Both ES and EDS place human needs, values and attitudes at the centre of biodiversity management (Lyytimäki & Sipilä, 2009). For instance, Tian et al. (2020) concluded that urban residents from central China perceived high levels of ES and low levels of EDS as provided by UP and other UGS types. This perception is also shared by Palliwoda et al. (2020), where EDS were dropped from the results as they were mentioned by only two respondents in a study on how green components of UGI influence the use of ES in Leipzig, Germany. Roman et al. (2021) stress the need for an integrated approach to social-ecological sustainability that addresses the complexities of competing and compounding interactions among ES, EDS, management costs, and differing perceptions among and within stakeholder groups.

The services UP provide to people in social-ecological systems are the same in the Global North and the Global South (Rigolon et al., 2018). However, the perceptions of and preferences for UP could be based on different ES, EDS, and willingness to pay. Many people in the Global North have in the last few decades left cities for suburbs and the countryside to live in healthier and greener areas (Browning et al., 2021). This behaviour had been rekindled with the advent of the COVID-19 pandemic, where many urbanites in the Global North were seeking life in low-density areas with scenic beauty and outdoor recreation opportunities (Whitaker, 2021). In a study on ES provided by four different categories of UP in Beijing, nine ES were perceived by park users from all 50 UP studied (Wang et al., 2021). The perceived ES and related benefits included environmental improvement, biodiversity, history and culture, social interaction, aesthetic appreciation, education, religion, physical and mental recovery and recreational activities; with recreation being the most perceived service, while education was the least (Wang et al., 2021). Amongst the perceived qualities of UP, park proximity was a dominant factor for the elderly (above 60 years of age) from Hong Kong as it facilitated longer visitation times to the UP, which is associated with better physical and mental well-being (Lau et al., 2021). Fontán-Vela et al. (2021) found in Madrid, Spain, that a higher proportion of park users from high social-economic status performed physical activities in UP than those from middle and lower social-economic status. Factors like park maintenance, work constraints, insecurity and crime, differential perceptions by age, and availability of organised activities in the UP influenced UP use and perceptions.

With cities in SSA growing at a faster rate than the rest of the world (OECD & Club, 2020), there is a threat of significant loss of natural habitats and biodiversity reduction and deterioration of UGS (Barau, 2015). These problems may lead to psychological and physical stress that will be caused by lack of, or reduced contact with nature in urban environments (Cox & Gaston, 2018). This growth is not just in megacities, but is also seen in the rapid increases in small towns and cities (Kalantari et al., 2018). Africa's urban population is projected to double to 1.2 billion by 2050, with the majority of this increase occurring in informal settlements and slums and in the small towns and cities (Kalantari et al., 2018). Despite the threats to UGS and associated ES in SSA, the value placed on them by urban populations vary in line with local context, culture, social-economic status of the people and the extent of active use of the greenspaces (Guenat et al., 2021; Shackleton et al., 2015).

With limited spaces as a result of informality and urban growth, increasing the provision of UP can be a difficult task for urban planners and decision makers. Peschardt et al. (2012) highlighted that it could be practical to include smaller UGS that would be integrated into people's daily lives. The small UGS that could also offer recreational benefits could be pocket parks of less than 5,000 m^2 (the size of a football pitch) or other forms, such as street trees, flower beds or green roofs (Danford et al., 2018; Mesimäki et al., 2019). In a systematic review, pocket parks were identified to provide access to nature for individuals living in urban areas, and had a higher potential in promoting mental well-being, social benefits and physical health than bigger parks (Kerishnan & Maruthaveeran, 2021). The WHO (2017) is still encouraging local governments to increase the provision of UP irrespective of form or size.

The global trend in reduction of UGS has not spared Malawi. With the dawn of a multiparty system of government in 1994, there has been progressive urban growth and urbanisation that has seen a reduction in UGS, for instance a drop in vegetation cover of 7.3

% in Blantyre between 1994 and 2018 (Mawenda et al., 2020). Change in the political dispensation resulted in encroachment on UP land earmarked for recreational activities, while some deteriorated due to lack of financing (UrbanAfrica.net, 2015). The cities have witnessed massive environmental degradation, pollution, deforestation and uncontrolled development, threatening biodiversity in the process (IIED et al., 2015; Phiri et al., 2019). In a drive to reverse the degradation of UP and responding to the UN call on increasing access to UGS, urban authorities in Malawi are responding positively. For instance, Lilongwe, the capital, is in the process of creating a 13-ha recreational park (called Eden Park) along the Lilongwe River at the exact point that government used to pump water and draw earth for the construction and landscaping of Capital Hill, the seat of government (UrbanAfrica.net, 2015). Blantyre City Council in the south has embarked on rehabilitation of recreational parks and so far, four are being rehabilitated and others are already being used by the residents, with other earmarked parks awaiting public private partnerships (Blantyre City Council, 2020). Mzuzu City Council in the north is also in the process of developing a leisure park to supplement the few private parks available and further plans to turn open spaces within the city into 'small parks' (Chirwa, 2017). Zomba city plans to turn an old graveyard in Ndola to an UP and resuscitate one of the old parks closer to the general hospital with support from stakeholders (Khakona, 2017). The government of Malawi plans to partner with the private sector to operate recreational centres to support its efforts in urban biodiversity conservation, enhancement, use and management of the available blue-greenspaces within the cities (UrbanAfrica.net, 2015). However, as previously mentioned, use and values of UP differs across countries and communities, therefore it is imperative that these plans in Malawi need local voices and needs. Therefore, they need insights into local preferences and concerns, which requires talking and listening to local communities (Shackleton & Njwaxu, 2021)

However, there is a dearth of research on perceptions of and preferences for UP and other UGS from small and medium sized cities in SSA, more so in Least Developed Countries (LDC) like Malawi, with Zomba as a case study. Taylor et al. (2020) stress the need to understand why urban citizens visit parks and how they feel when in the parks. The significance of this study is therefore fourfold. The study (i) examined associations between social-demographic characteristics of park users and the UP visited; (ii) which helped explain any preferences for visiting time and time taken to visit an UP; (iii) revealed perceptions of key ES and EDS experienced by the park users and in home yards, and (iv) user perceptions regarding park management. An understanding of these perceptions of and preferences for

UP and other UGS in the local context will inform the government's efforts to provide functional UP as well as sharing the experiences and perspectives from a small city in a LDC.

5.2 Methods

5.2.1 Study site

Refer to Chapter 1 for a description of the study area. However, the targeted UGS serving the purpose of UP are outlined in Figure 5-1.

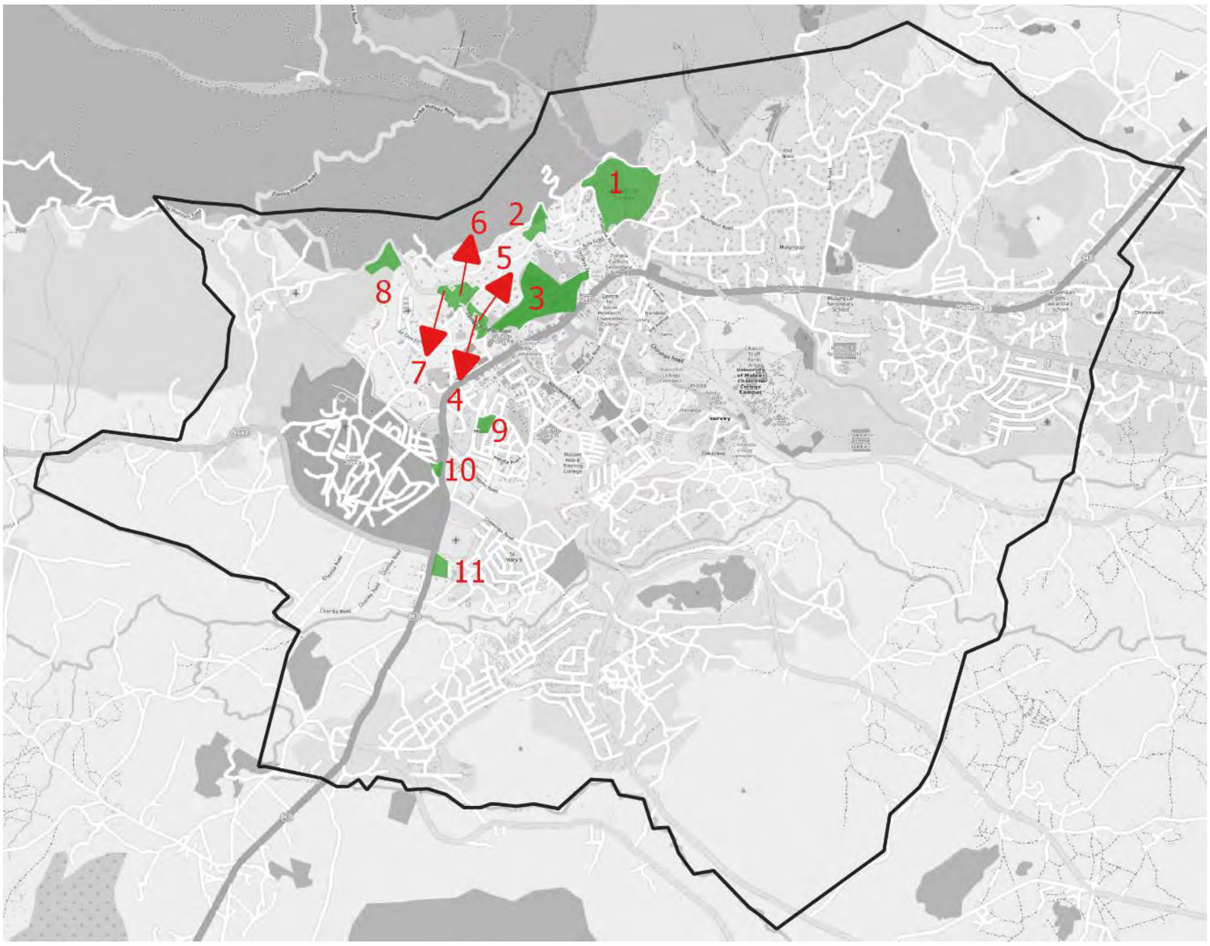


Figure 5-1: Location of formal, public urban parks within Zomba, showing the botanical garden (1) and Gymkhana golf course (3) whose users were interviewed for the preferences and perceptions survey.

5.2.2 Data collection

An integrated approach using park intercept surveys and qualitative surveys was used to collect primary data from park users (Neckel et al., 2020). Data was collected in October and November 2020 through a field survey done with adults (18 years old and above) in a face-to-face interview, i.e., on-site survey, in the UP they patronised. Since the population patronising the UP was not known, sample size was estimated using Equation 5-1 below:

$$n = \frac{z^2 \times \hat{p}(1-\hat{p})}{\varepsilon^2} \qquad \text{Equation 5-1}$$

where: n is the sample size of 208 people which is based on z score which is 1.44 for 85 % confidence, the margin of error (ε) of 5 %, and the proportion of the unlimited population ($\hat{p}$), based on 50 %, allowing for a chance to the citizenry to either visit or not visit the park (Nnodim et al., 2022). This sample was reached at based on 143 direct UP survey and 71 from the household surveys that claimed to have visited an UP (detailed below), as one way of maximising on the available limited resources, totalling to 214 respondents, with an extra 6 from the calculated sample size.

Another survey done with residents within their homesteads, provided input to this in that only those respondents that claimed they visited a park or UGS were considered in the park user analysis. For the household questionnaire, those that indicated that they visit parks and mentioned where they visit, follow-up questions concerning UP were asked. Out of 272 households surveyed, only 71 (26 %) claimed to have visited a park or other UGS in the last 12 months. Those that were found within the parks and those households that indicated to have visited a park are summarised in Table 5-1, comprising the sample for the study. In both surveys, verbal consent was requested from either the park user or household member for their involvement in providing their preferences for and perceptions of the different aspects related to status of UP. Once the verbal consent was granted, the face-to-face interaction ensued based on the interview questions administered through a mobile device that had pre-loaded the questionnaire for the interviews using the Kobo Toolbox (Nampa et al., 2020).

The park questionnaire included the respondents' demographic information, preferred UP visit frequencies, where they reside, motives for visiting the parks, perception of ES and EDS noted, opinions and attitudes on UP preferences. For willingness to pay or work, respondents were requested to answer this question: ‘If you were to be involved in improving and managing this park, how much money would you comfortably contribute to the authorities managing this park every month?’ and ‘If you were to be involved in improving and managing this park, how many hours per week would you offer to help in working in this park?’ Participants in UP were chosen based on convenience sampling, i.e., anyone present in the UP as a visitor and not a worker was chosen for an interview (Bernard, 2013). For those that were in groups, two to five members, depending on the size of the group, were called to respond to the questionnaire. Questionnaires took about 20 to 30 minutes in an effort to minimise intrusion on the park user's time in the UP.

Table 5-1: Number of survey participants in each park visited and general neighbourhood visited

Urban Park	In the park	Claimed to visit the park	Total
Botanical garden	68	22	90
Gymkhana golf course	75	14	89
Other greenspaces	0	35	35
Total	**143**	**71**	**214**

For perceived ES from the UGS, data from the household survey was used. A simple random selection of at least 26 household members, preferably household heads, per ward, from a population of about 20,000 households within the ten city wards (National Statistics Office, 2019a) were selected to participate in this survey. As in the UP interview, verbal consent was requested from each respondent for their involvement in providing information on their perceptions of the ecosystem services they enjoy from the UGS within the city and their private yard. Once the verbal consent was granted, the face-to-face interaction ensued like in the UP interviews. The structured questionnaire had both closed and open-ended questions to allow survey participants provide responses in their own words, provide more options and opinions thereby giving the data more diversity, authenticity and unexpected feedback which is absent if the questionnaire has only closed questions (Agustianingsih & Mahmudi, 2019).

The questionnaire included the respondents' demographic information, where they reside, type of UGS within their yard, ecosystem services and top three natural resource items frequently used within their homesteads. A total of 272 households were surveyed and after data cleaning, 267 household responses were considered for analysis. This was based on a simple random selection of at least 26 households from each of the ten wards. A ward is also taken as a standardised enumeration area during the population and housing census survey by National Statistics Office (National Statistics Office, 2019a). The questionnaires for both UP users and households were both translated to the local language, Chichewa, for ease of communication. Each household interview took about 45 minutes on average. Approval for both the project and the research questionnaires was done at two levels. First was the approval from the Rhodes University Ethical Standards Committee under Rhodes University with reference No. ES18_32 (Appendix 8-3). Second approval was from the National Committee on Research in the Social Sciences and Humanities under the National Commission of Science and Technology (NCST) protocol No. P.01/20/446 (Appendix 8-4). Lastly was clearance to carry out the research within Zomba and approval was granted by the city council under reference No. ZCC/DM/ADMIN/118, also attached (Appendix 8-5).

5.2.3 Data analysis

Based on the four research objectives, the data collected was subjected to four types of analysis. Both qualitative and quantitative data were transferred to Microsoft Excel 2013 for cleaning. Simple descriptive data analysis, presented in the form of proportions, tables and graphs were used to calculate frequencies of responses on the social-economic status of the park visitors. Pearson Chi-Square tests were run to test for significant differences in responses between social-economic and demographic groups. Social-economic groups in this study are the three housing categories, i.e., low, medium and high housing densities, while demographic groups included gender, age class, education, occupation and tribe.

Second, was an analysis of time preferences for park visits where descriptive statistics in the form of frequencies were done to appreciate the most frequently visited days of the week, months of the year and general visit frequencies like once a week, once a month or as they wish. Network analysis was used in QGIS 3.8 software (2018) to estimate the approximate time taken by park users from their wards to the visited UP. QGIS 3.8 software is an open-source software that effectively provides numerous spatial analyses and this includes Network analysis. In this context, two data sets were deployed: (i) digitised roads of Zomba extracted from Open Street map, and (ii) UP location and location of the respondent were captured with KoBo Collect app during the data collection phase. These two datasets were imported into QGIS 3.8 where a Network analysis was carried out by navigating to processing tool box, network analysis then shortest path (point – point). The computed values were visualised in the attribute table where they were in the form of speed (km/hr). The speed was then converted to minutes by using a raster calculator where the speed was multiplied by 60 minutes.

Analysis of perceptions of key ES enjoyed within the parks and any EDS was via content analysis in NVivo, using codes and nodes. Nodes are the containers or generated themes for coding and are usually made for each topic or concept to be stored (Bazeley & Richards, 2000). Nodes were created based on the participants' responses and two themes were identified under key ES. The two themes were regulating services and cultural ES. The regulating services theme covered noise abatement and carbon sequestration. Cultural ES had two nodes, (i) social benefits (recreation, aesthetic beauty), and (ii) psychological and health benefits (getting fresh air, relaxation, mental peace, physical exercise, playing, connecting to nature).

For the perceived ecosystem services from the household survey, data was pooled in Microsoft Excel. Responses from the survey participants on what benefits they obtain or value from the trees and UGS around them were ranked as first, second and third choices. These responses were then categorised into the relevant ES and summarised as frequencies. Other related variables like where they reside, type of UGS within their yards, top three natural resource items frequently used within their homesteads were also summarised as frequencies to augment the perceived ES mentioned.

Perceptions of park management were expressed firstly in the form of getting views from the UP users on the specific benefits they get from the UP, if the UP is well managed, what they would love to have within the UP and their willingness to pay (WTP) or willingness to work (WTW) as support towards managing the UP. WTP probed on how much money a park user would willingly pay while WTW was on time (hours per week) a park user was willing to work in the UP. Both WTP and WTW were solely on the understanding that it was meant to support in managing the UP. Several other pointers on how best the UP can be managed to the benefit of the people visiting were also analysed. A non-parametric Chi-square test was used to analyse any significant differences in gender, age, education, housing density, education, occupation and tribes. All statistical tests were run in R Studio v1.3.1056 (2009-2020) while NVivo was used for all content analysis from related qualitative data.

5.3 Results

5.3.1 Profile of the park users

Respondents have been living in the city for an average of 11±10 years, with over 42 % having lived in the city for at least five years. The gender ratio of park users was fairly even at 51 % males and 49 % females (Table 5-2). There was no significant relationship between gender and the UP visited despite having more males (58 %) than females (42 %) visiting the golf course. However, there was a significant relationship between gender and park usage, with more females and less males found at home despite an equal gender representation in UP users. The youth, between the ages 18 and 39, were the most common age group in UP (82 %). There was a significant relationship between age group and park visited ($X^2 = 22.03$; $p < 0.001$) with adults preferring to visit the other greenspaces rather than the botanical garden and golf course.

Almost half (45 %) of the park users were from the high housing density areas. There was no significant relationship ($X^2 = 8.64$; $p < 0.072$) between the park visited and the housing density class the respondent was coming from. Suffice to say, the botanical garden was dominated by visitors from Masongola ward where it is situated (32 %), the golf course was also dominated by residents from the neighbouring wards, i.e., Mtiya and Likangala at 19 % and 18 %, respectively. For the other greenspaces, visitors were mostly from Sadzi (23 %), Chambo (17 %) and Chirunga (17 %). There was a significant relationship between park use and housing density ($X^2 = 9.33$; $p < 0.009$), with a high proportion of high housing density residents using parks relative to non-users of UP. The proportion of non-park users from the medium housing density area was higher than those that were found at the park.

Most (56 %) of the park users had secondary education (Table 5-2). There was a significant association between park visited and level of education ($X^2 = 30.83$; $p < 0.001$), with high representation of those with tertiary and secondary education. The significant association was also evident between park users and non-park users ($X^2 = 17.96$; $p < 0.001$), with a very low proportion of non-park users (17 %) that had a tertiary level education compared to park users with tertiary education (34 %). A majority of the park users were not employed (54 %). There was a significant relationship between occupation status and park use ($X^2 = 35.14$; $p < 0.001$), with more of the unemployed being found at the golf course. Checked between park users and non-park users, there was a significant relationship ($X^2 =$

20.40; $p < 0.001$) with occupation status. The business class were most likely non-users as compared to the employed who were found in higher proportion in the UP as compared to non-users. The unemployed were equally found in the UP (54 %) and amongst non-users (55 %). Across the parks, the most encountered group were of the Lomwe tribe (26 %), with the least represented tribe being the Tumbuka (10 %). The same observation was also made with non-users, with Lomwe tribe (28 %) and the Tumbuka (8 %). There was no significant relationship between tribe and park usage ($X^2 = 11.60$; $p < 0.307$) as well as no significant relationship between the tribes from park users and non-park users ($X^2 = 4.72$; $p < 0.447$).

Table 5-2: Social-demographic characteristics of urban park visitors and non-park users

Attribute		Park Visited (%)			Chi-square value (X^2)	P value	Park Use (%)		Chi-square value (X^2)	P value
		Botanical garden (*n* = 90)	**Golf course (*n* = 89)**	**Others (*n* = 35)**			**Park Users (*n* = 214)**	**Non-Park Users (*n* = 201)**		
Gender (%)	Female	54.4	41.6	57.1	6.00	0.049	49.5	65.7	13.39	0.001
	Male	45.6	58.4	42.9			50.5	34.3		
Age (%)	Youth	85.6	86.5	60.0	22.03	0.001	81.8	72.1	9.41	0.008
	Adult	13.3	12.4	40.0			17.3	24.9		
	Elderly	1.1	1.1	0			0.9	3.0		
Housing density (%)	Low	27.6	16.7	8.6	8.64	0.072	19.9	10.9	9.33	0.009
	Medium	35.6	35.7	31.4			35.0	55.7		
	High	36.8	47.6	60.0			45.1	33.3		
Education (%)	Primary	7.8	6.7	25.7	30.83	0.001	10.3	17.4	17.96	0.001
	Secondary	43.3	65.2	65.7			56.1	65.2		
	Tertiary	48.9	28.1	8.6			33.6	16.9		
Occupation (%)	Business	16.7	18.0	34.3	35.14	0.001	20.1	34.3	20.40	0.001
	Employed	38.9	14.6	22.9			26.2	10.9		
	Not employed	44.4	67.4	42.9			53.7	54.7		
Tribe (%)	Chewa	18.9	11.2	8.6	11.60	0.307	14.0	14.4	4.72	0.447
	Lomwe	22.2	31.5	20.0			25.7	28.4		
	Ngoni	16.7	22.5	17.1			19.2	12.9		
	Others	13.3	13.5	28.6			15.9	18.9		
	Tumbuka	15.6	7.9	2.9			10.3	8.0		
	Yao	13.3	13.5	22.9			15.0	17.4		

5.3.2 Time preferences and time taken for park visitations

Half of the respondents (53 %) preferred to visit UP as the need arose without any pattern. Only 6 % claimed to visit the UP daily (Figure 5-2a). The top three days of the week, in order of importance, that park users prefer to visit UP were Saturday, Sunday and Tuesday (Figure 5-2b.). Further insight reveal that these chosen days followed that the respondents were free from other duties like work and school (71 %), followed by time spared for studies and other academic work like group discussions (14 %), with the least reason being recreation and relaxation (8 %). Others cited spiritual reasons where they normally go to pray in the parks, while others just love the natural green environment with good shelter from trees, fresh air, and fresh water (in some cases). Park visitors preferred spending time in UP during August, September and October, peaking in patronage in that order; whilst February was the least visited month of the year at 1.6 % (Figure 5-2c.). Park visitors preferred these months as they are hot months and the trees provided the much-needed shade, fresh air, and good views.

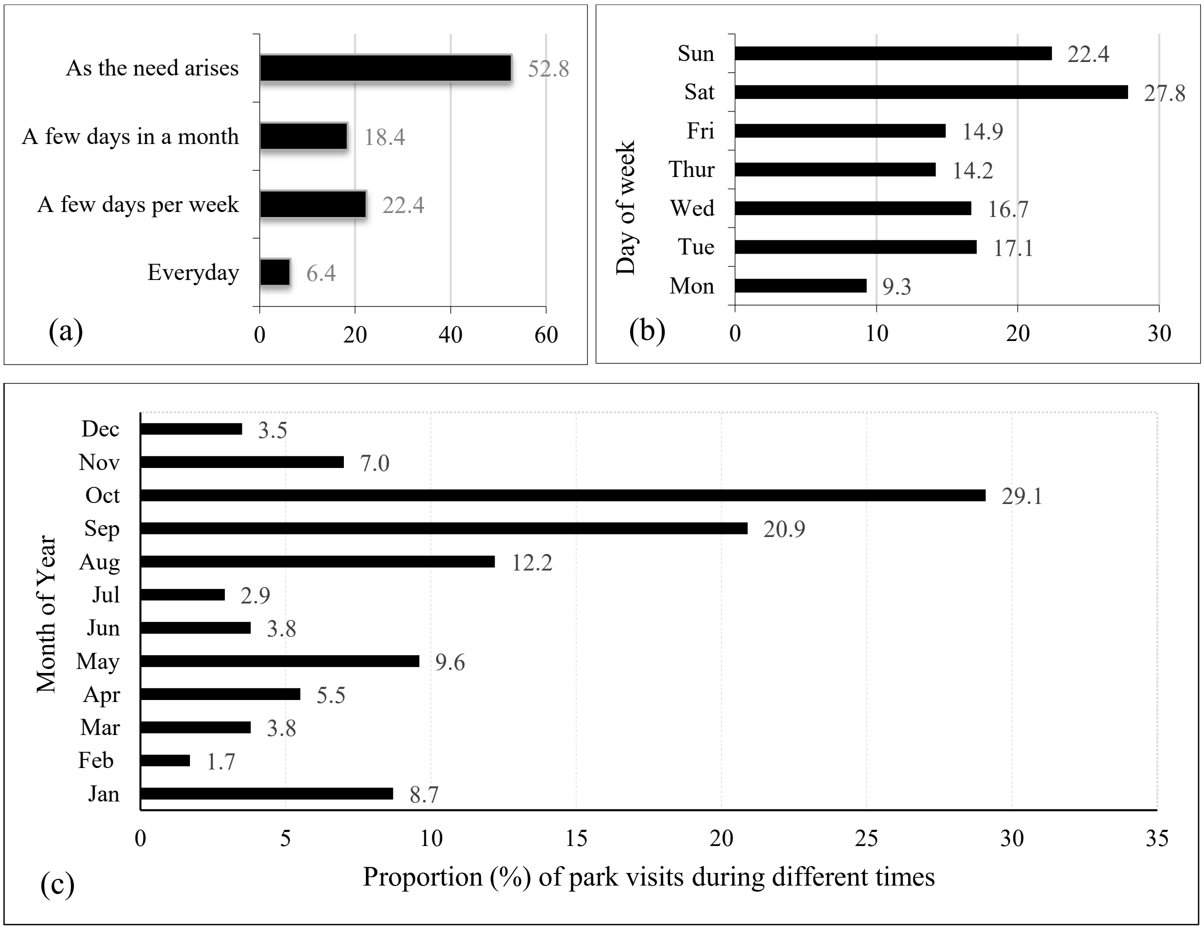


Figure 5-2: (a) Preferred frequency of park user's visits (b) days of the week and (c) months of the year.

It is worth noting that walking time taken to visit a park was highest for those visiting the golf course, at an average of 41±16 minutes. However, the time taken to visit other greenspaces (12±9 minutes) was significantly less to that taken to visit either the botanical garden (t = 5.27, $p < 0.001$) or the golf course (t = 3.29, $p < 0.001$), with no significant difference between those two. Overall, only 6 % of the park visitors spent five minutes or less to get to a park or green space, 9 % between six minutes and 10 minutes and the rest (85 %) took more than 10 minutes (Figure 5-3).

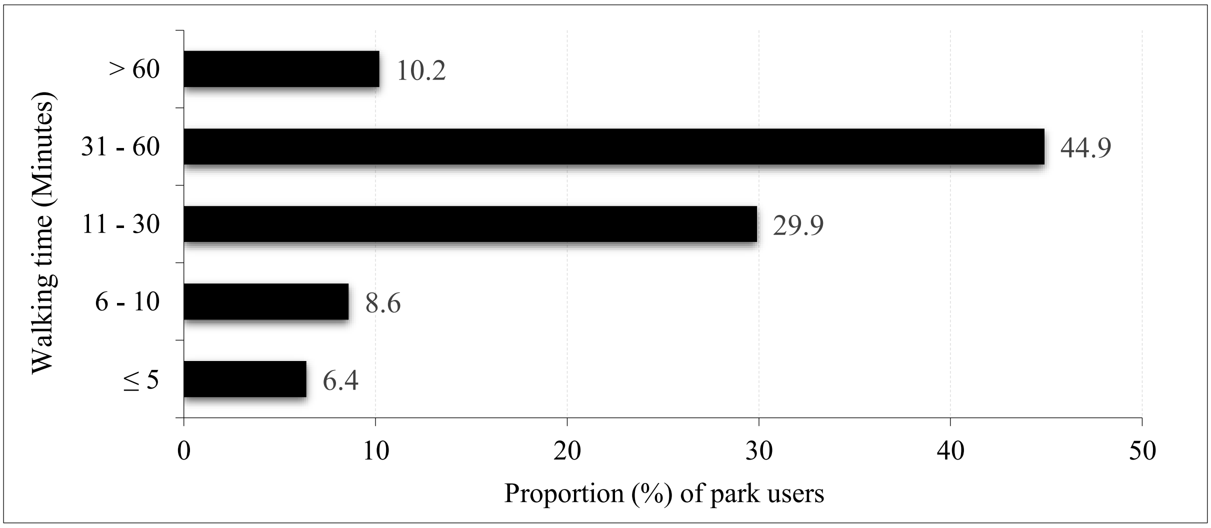


Figure 5-3: Distribution of time taken by park users to walk to their preferred park

5.3.3 Perceived ES and EDS in urban parks

All park users affirmed the need for UP in Zomba. Motives behind visits to the parks were categorised into either environmental or social-cultural benefits. No economic benefit was outlined by any park visitor. The environmental benefits were mostly regulating services like noise abatement, fresh air, carbon sequestration, shade or shelter and lowering air temperature, while the social-cultural benefits included aesthetic beauty, spiritual and religious benefits, recreational activities, cultural and social activities, and physical and mental health. The most mentioned benefit by the park users were under environmental benefits (76 %), which were connected to social-cultural benefits (26 %), while only 8 % of those that indicated purely social-cultural benefits did so without reference to environmental benefits.

These benefits were enjoyed equally across the parks with no significant differences between the park visited. However, more of the benefits were mentioned by users of the golf course (59 %). One of the major reasons for being at the golf course was because of its free entry, as alluded to by 76 % of the visitors. From Figure 5-4, the most perceived ES that motivated park users to visit an UP was the quietness that facilitated academic studies, spiritual and mental health; fresh air from the trees and to connect with nature, which included an appreciation of the running water especially within the botanical garden, the natural views and to watch small wildlife like monkeys and birds. Other ES mentioned by a few people with less than 1 % contribution each were space for physical exercise and carbon sequestration. On EDS from UP, 85 % of the park users indicated that there are no threats in patronising an UP. However, at both UP, some users expressed fear of snakes and cases of attacks from insects and monkeys (10 %) and anti-social behaviour manifested through threats of robbery (5 %).

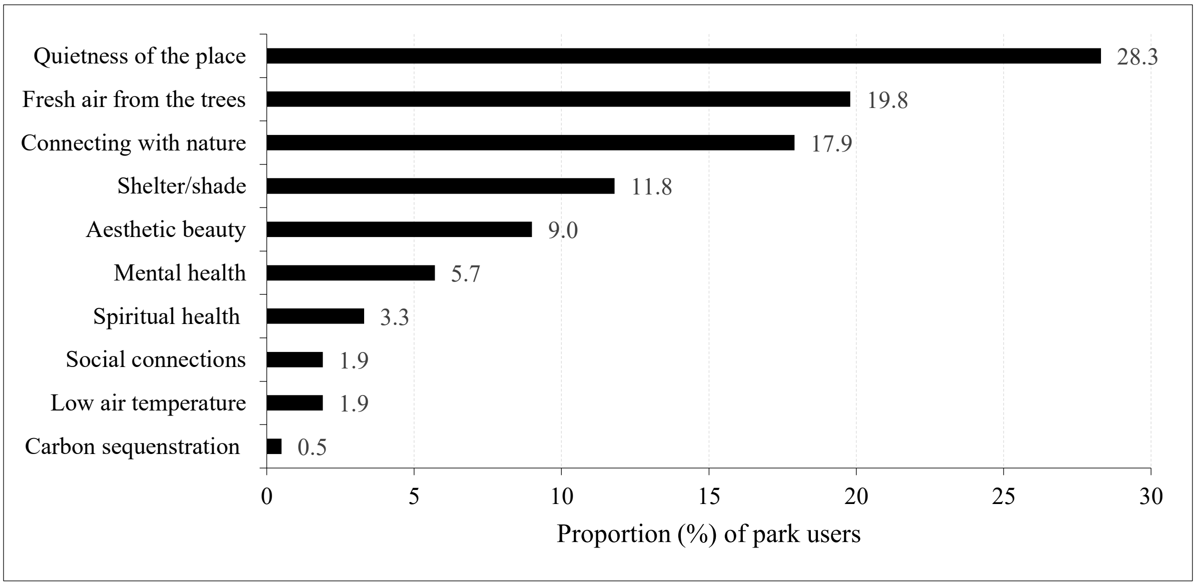


Figure 5-4: Distribution of responses on perceived ES outlined by park users.

5.3.4 Perceived ES from household respondents

The available elements of UGS within the households were dominated by trees (86 % of the households), followed by home gardens (22 %) and vegetable gardens (19 %). About 11 % of the respondents had no UGI within their households (Figure 5-5). Perceived ES were dominated by those from the regulatory category (89 %), the least being from cultural ES category at 3 % (Figure 5-6). Regulatory ES mentioned by the respondents were from trees and UGS, including: fresh air, shade or shelter, minimisation of flooding episodes, support in rain formation, improving soil fertility, support in moisture retention, wind break to prevent damage to infrastructure from strong winds and regulation of the micro-climate. The composition of elements within the provisioning ES was dominated by energy (63 %) from charcoal and firewood followed by food (34 %) mainly fruits and the least was medicine (2 %) and flowers (1 %). Cultural ES mentioned covered aspects of aesthetic beauty of the place and the city in general.

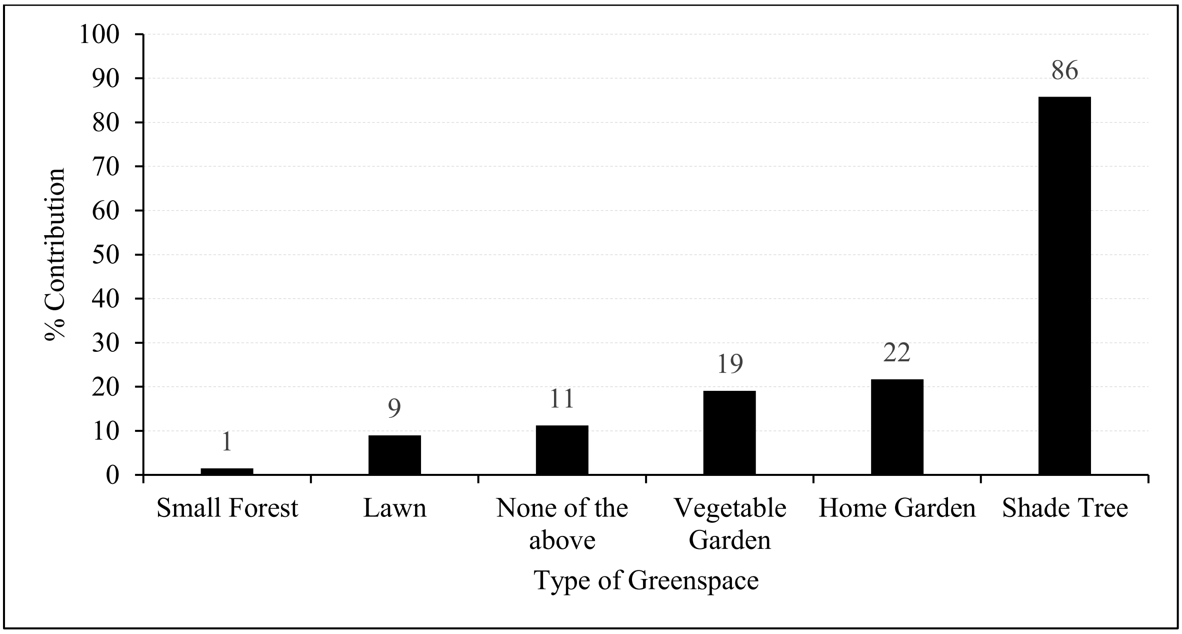


Figure 5-5: Elements of UGS found within the sampled households

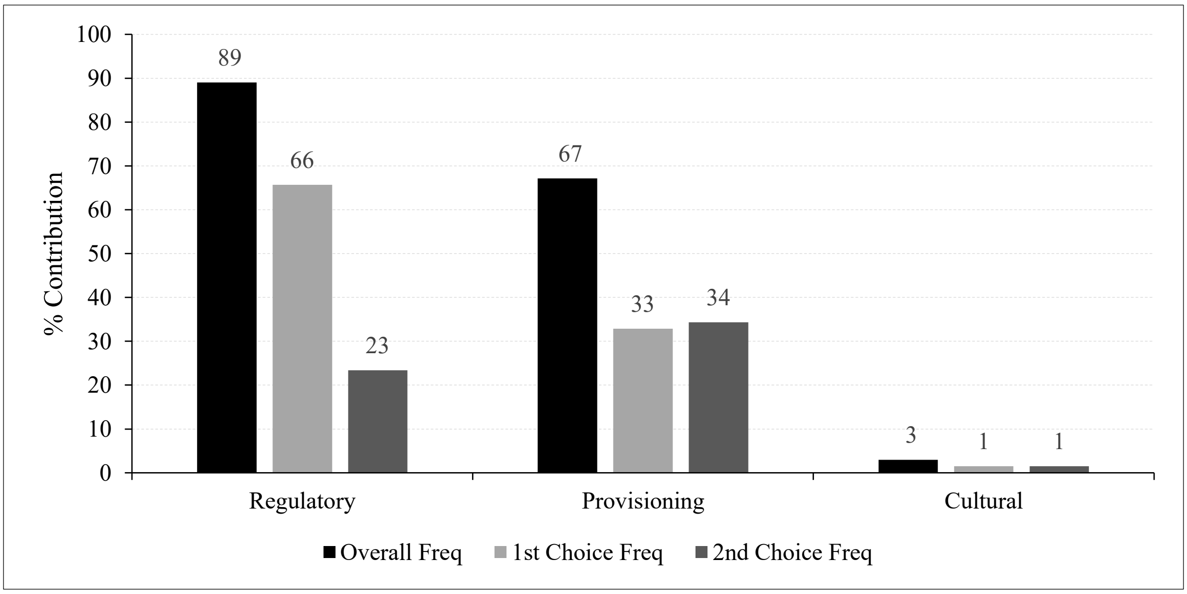


Figure 5-6: Perceived ecosystem services from the sampled respondents

The respondents were dominated by females (63 %) from both rented (71 %) and owned homes (29 %). The age brackets of 18 – 29 and 30 – 39 were most common (71 %) followed by 40 to 49 (19 %). Most of the respondents had a secondary level of education (63 %) followed by primary (19 %) and tertiary level (17 %). Over half of the respondents were not employed (51 %) while 33 % were in business, the remaining 15 % were either in full-time or part-time employment. There was a good representation from the main tribes available within Zomba, dominated by the Lomwe (28 %) followed by Yao (17 %), Chewa and Ngoni at 13 % each, Tumbuka (8 %) and the rest (21 %) were the other tribes of Mang'anja, Sena, Nyanja, and Tonga.

5.3.5 Management of UP

Almost three-quarters (72 %) of the respondents found in UP indicated that the UP were not well managed. Several suggestions to improve the UP were provided by the park users (Figure 5-7), with the most mentioned being environmental management and cleanliness, followed by enhancement of the park beauty through planting more flowers, lawns and trees, and provision of picnic tables or benches, gazebos with electrical power for charging phones or laptops and provision of points for drinking water. Other suggestions with each scoring less than 2 % included introduction of areas for children play, sports, entertainment and provision of a car park close to picnic places. About 4 % of the respondents were satisfied with the way the UP were and did not suggest any improvements.

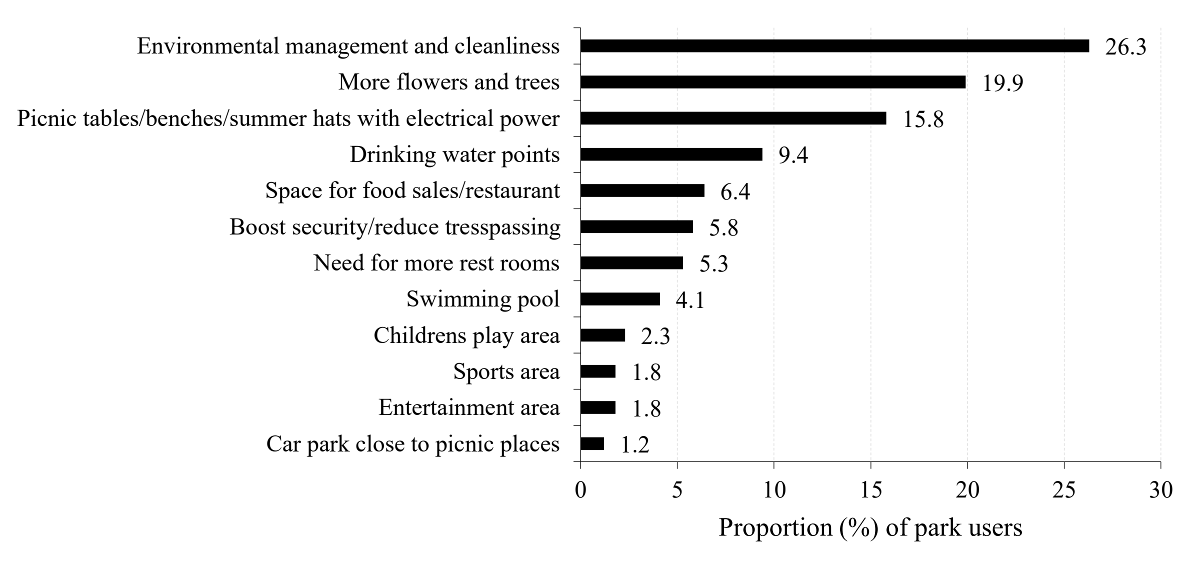


Figure 5-7: Park user ideas related to improvements that can be done to the UPs

Having suggested the improvements to UP, respondents were further asked to indicate willingness to pay or willingness to work in the UP as one way of contributing to their management (Figure 5-8). A majority of the park users (61 %) indicated that they would spend an average amount of K 638.58 (approximately $ 0.85 per month or $ 10.20 per year) to support managing the park. About 11 % of the park users were not willing to pay anything for the management of the park, and only 3 % indicated they would pay an average of K 8,428.57 ($ 11.28 per month equivalent). There were no significant differences between males and females across the different UGS in terms of WTP ($X^2 = 2.85$, $p < 0.271$). There were however significant associations between WTP by members visiting the UP in terms of differences in age class ($X^2 = 92.99$, $p < 0.009$), education ($X^2 = 23.58$, $p < 0.0001$) and occupation ($X^2 = 15.47$, $p < 0.003$). There were some park users (3 %) that were willing to pay more than the rest, and these were mostly found at the botanical garden (86 %), were male (86 %), youthful (86 %), employed (57 %), with tertiary level education (71 %) and had spent an average of 10 years living in the city of Zomba.

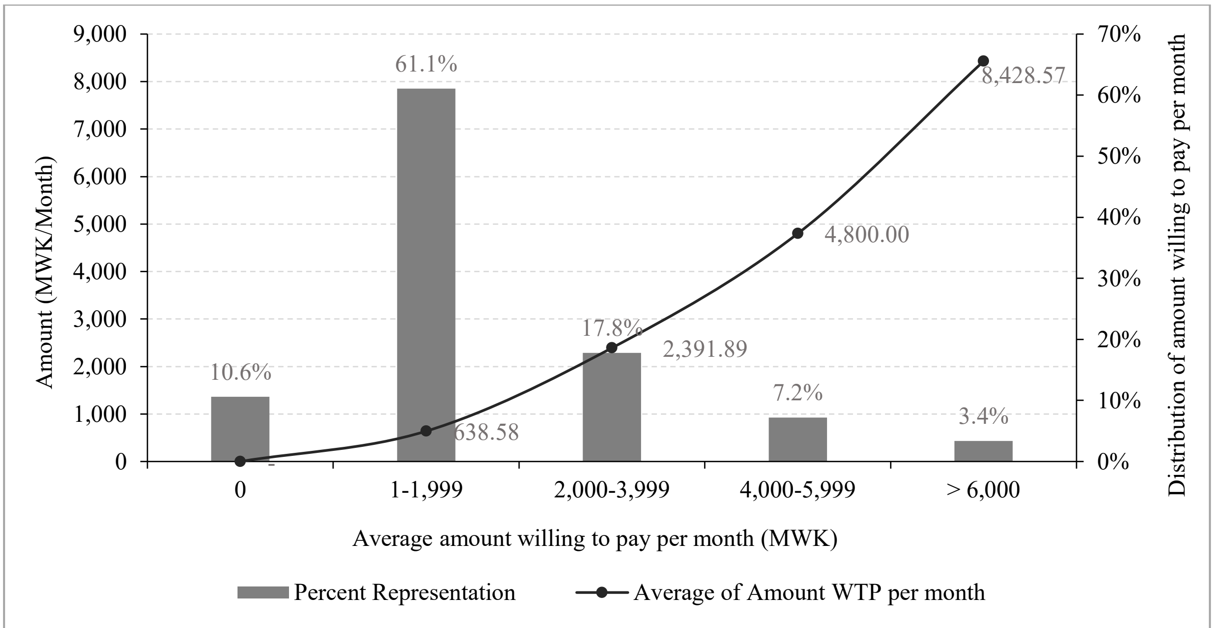


Figure 5-8: Average amount park users were willing to pay (in MWK per month) and distribution across the amounts (1 US$ = MWK 747.15, average for November 2020)

Willingness to work (WTW) in the form of hours they can offer to work in the respective parks showed no significant differences between the three park types and gender ($X^2 = 2.85$, $p < 0.271$). However, WTW in the different parks showed significant differences in terms of age class ($X^2 = 11.99$, $p < 0.009$), education ($X^2 = 23.58$, $p < 0.001$) and occupation ($X^2 = 15.47$, $p < 0.003$). Park users indicated they can work in the parks at an overall average of 3 hr ± 90 min per week (an average of 12 hours per month) to support management of the UP. Low housing density residents offered the least time to work in the golf course (1 hr 54 min ± 0.42 min per week), whereas other park users from outside the city were willing to give more hours per week (4 hr 42 min ± 96 min) to work in the botanical gardens (Table 5-3), an indication of the value they give to the park despite that it is not practical to come to work in the park commuting from outside the city. These park users were coming from the outskirts of the city like Songani, Thondwe, Ndege and outside Zomba district like Liwonde, Nkhatabay and a majority (64 %) from Blantyre, the neighbouring commercial city.

Table 5-3: Mean time (hours per week) that park users were willing to work to help manage the park they patronised

UP	**Housing Density**				**Mean/UP**
	Low	**Medium**	**High**	**Outsiders**	
Botanical garden	3:06±1:12	2:48±1:36	3:06±1:30	4:42±1:36	**3:06±1:30**
Golf course	1:54±0:42	2:48±1:48	3:18±1:48	2:12±1:48	**2:48±1:42**
Other greenspaces	3:18±1:30	3:18±1:36	3:06±1:12	0:00	**3:12±1:18**
Mean/Class	**2:42±1:12**	**2:54±1:36**	**3:12±1:36**	**3:06±1:30**	**3:00±1:30**

Additional to the introduction of parks into every ward, they also made some management suggestions which are outlined in Figure 5-9. Most mentioned was the need to improve the management of the parks, improve park security, planting more trees in the UP, provision of park amenities, a stop to illegal selling of trees and land and enforcing penalties on offenders. Other suggestions made by less than 3 % of the respondents included a call on reducing charcoal use by reducing electricity costs, calls to have a fair park entry fee, to manage UP well so they can generate income for the city, maintaining free entry to UP, and civic education programmes on the importance of trees. Despite all park users agreeing to the need for UP within the city and its wards, only 8 % of the park users had either an UP or an UGS in the area they lived, while another 8 % of the respondents indicated that there is space which can be allocated for the creation of UP.

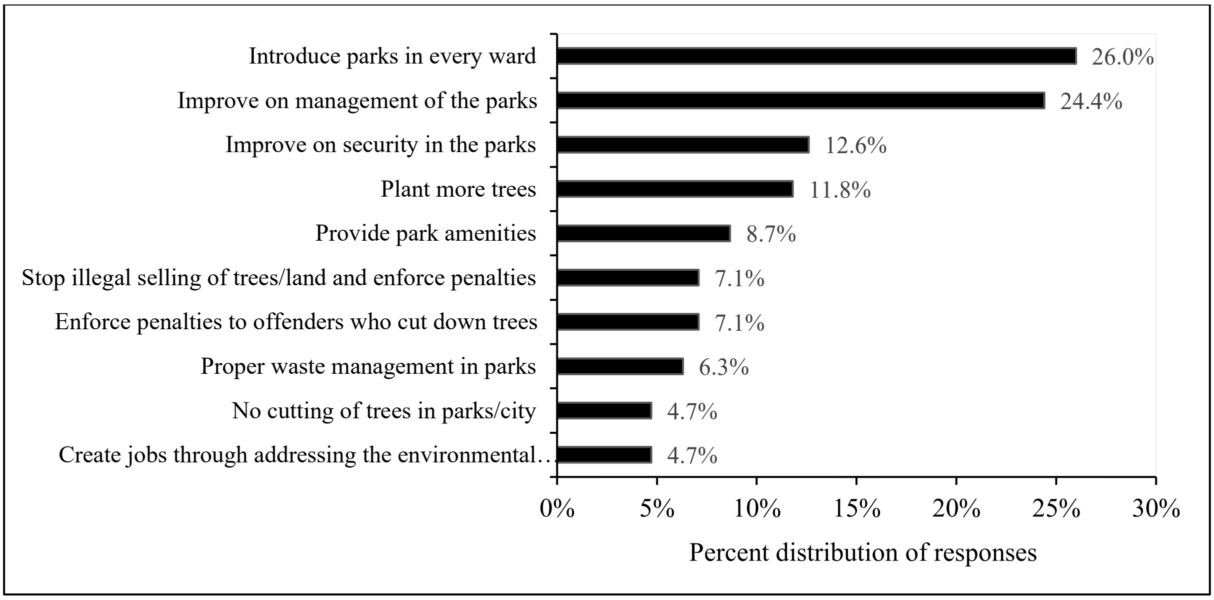


Figure 5-9: Messages from park users to the city council and other UP managers on management related actions on urban parks.

The worry from the park users that city authorities need to stop illegal selling of land and trees within the city boundaries are expressed through these sentiments:

> 'The council should ensure that they are not selling land that could serve as good greenspaces in a corrupt manner' – *Female, youth, 18 years living in the city, Gymkhana golf course.*
>
> 'They should stop handcuffing innocent people that pick ordinary logs on the ground rather, they should be handcuffing criminals that cut down trees illegally' – *Male, elderly, 38 years living in the city, Gymkhana golf course*.
>
> 'They should stop illegal selling of trees i.e., Bluegum, and Mibawa (Mahogany). I recall in the past this place had so many trees but they have cut them all in the name of 'this place is for the government' despite this place being in the hands of golf club' – *Male, elderly, 38 years living in the city, Gymkhana golf course*.

Similar sentiments were expressed in the call for better security as shared by some female park users:

> 'Remove shrubs, and employ enough security guards to minimize rape cases' – *Female, youth, 21 years living in the city, Gymkhana golf course*.
>
> 'There is no major environmental threat, however my friend was raped in the evening, it happened around 6 pm' – *Female, youth, 17 years living in Zomba, Gymkhana golf course.*

‘It’s quite and also the security is good compared to other gardens’ – *Female, youth, 4 years living in Zomba, botanical garden.*

5.4 Discussion

Most park users were youths (18 – 39 years), disproportionately higher (82 %) than in the general city population (around 39 %) according to National Statistics Office (2019). The dominance of youth is similar to other studies, like in neighbourhood parks in Addis Ababa, Ethiopia, (Yeshitela, 2020), urban parks in Kolkata, India (Dinda & Ghosh, 2021) and two towns in Eastern Cape, South Africa (Manyani et al., 2021). Most park users were well-educated, more so than non-users. The park user’s education levels are similar to those from studies done by Dinda & Ghosh, (2021) in Kolkata, India, Tibesigwa et al. (2020) in Dar es Salaam, Tanzania, and Yeshitela (2020) in Addis Ababa, Ethipia. Occupation, which determines income levels, was also found to significantly influence park visitation, with more patronage from the employed class than others. Despite these significant factors, almost every category of participants visited UP irrespective of their gender, age groups and tribe. However, residents from high housing density areas, well-educated and working class use the UP more than others, an indication of the need to service high housing density areas with UP. On top of age, education status and occupation significantly contributing to park use, Paul & Nagendra (2017) and Azagew & Worku (2020) also found gender to be a factor; with males being more common users than females.

5.4.1 Time preferences for park visitations

Park visitation patterns within Zomba are not that different from other studies, with most patronage at weekends or during holidays when working people are free. Similarly, Dinda & Ghosh (2021) found that 40 % of the respondents visited parks during the weekends. High patronage in the UP over weekends and holidays was also noted in several parks in Tehran, Iran (Bahriny & Bell, 2020). This trend was also noted by Manning & Anderson (2012) who argue that a calm and peaceful park environment, with fewer social conflicts even during peak times over the weekends or holidays, motivates city dwellers to visit parks.

The two UP studied are centrally located within and close to the central business area of Zomba. The fact that more than 85 % of the park users spend more than 10 min to get to a park signifies the value they put to UP services. Shanahan et al. (2015) concluded that those who have a strong connection with nature are more likely to travel to visit more vegetated UP with greater tree cover. This explains why about 85 % of the park users in Zomba were willing to travel long distances to get to an UP, in this case the botanical garden and golf course as are both natural with a combination of abundant greenery and high plant richness. Despite the love for nature and recreational services, there are stack differences in access to an UP as citizens from high and medium housing density areas where UP are non-existent have to travel the longest. Venter et al. (2020) reported through a national remote-sensing survey that on average, white households in South Africa lived within 700 m of a public park while generally poorer black households live 1.7 km away from parks. Azagew & Worku (2020) considered accessibility to UGS in Addis Ababa, Ethiopia, and found that over 90 % of the urban residents had no access to UP within the minimum walking distance threshold. Rigolon et al. (2018) also noted some inequalities in UGS proximity, quantity and quality amongst the different social-economic status groups in Global South cities, suggesting an increase in quantity and quality of UGS would translate to public health benefits.

5.4.2 Perceived ES and EDS from the UP

Park users provided a range of reasons for visiting UP, covering the environmental and social benefits. More respondents cited the environmental benefits, like getting fresh air, connecting with nature and getting some shelter or shade (Figure 5-4). This agrees with Taylor et al. (2020) who underscored the need to maintain UP and biodiversity throughout the urban matrix to provide the necessary ecosystem functioning to support human well-being. The overwhelming response on the need for UP within the city echoes observations made by several authors who indicated that the demand for cultural ES is ever increasing due to high population density, congestion and pollution in urban ecosystems (Guo et al., 2010; Ingold & Zimmermann, 2011; Pickett & Grove, 2009). Visits to UP with preference driven by environmental benefits agrees with Fletcher et al. (2021) who used demand mapping to assess the benefits of green and blue space in cities from four continents (Leicester, Medellin, Kigali, Zomba and Dhaka). It was estimated that UGS, either formal or informal, functional or non-functional, provided mean cooling effects of between 0.60 ºC to 0.65 ºC when averaged across the entire urban footprint in Zomba, Kigali and Dhaka, more than that of Leicester (0.44 ºC) as it is from a temperate region, with the largest cooling effect observed in Medellin (0.98 ºC). Practically, in a study by Ngulani & Shackleton (2020), there was a marked difference of 3.6 ºC between UGS area and built-up, with a cooling effect that extended up to 1.7 km from the centre of an UGS. Additional to the environmental benefits, a few respondents cited social benefits from the UP, such as space for academic studies, mental and spiritual health. Shackleton et al. (2018) reported a positive relationship between woody plant species abundance or richness and self-reported psychological or mental well-being of high school learners and church goers in small and medium-sized towns in South Africa.

Threats from insect and snake bites and monkeys are a good example of EDS observed in this study. Crime and rape threats in and around an UP is mistakenly attributed to an EDS but in actual fact, it is a social disservice (Shackleton et al., 2016). However, if the fear for crime or rape is generated due to dense trees, then it is an EDS as the definition includes actual or perceived negative impacts on human well-being. Some EDS are a result of failure to manage the UP. For instance, failure to manage parks, gardens, brownfields, wetlands and wastelands allows the vegetation within them to grow freely to any size and render them not fit for public use, often considered to be unpleasant and ugly, despite that they may host high biodiversity (Shackleton et al., 2016).

5.4.3 Perceived ES from the household respondents

The dominance of trees within the domestic yards in this study (86 %) echoes findings by Gwedla & Shackleton (2019) from 10 urban areas across multiple-social economic contexts in South Africa where 87 % of the urban residents had positive perceptions of urban trees. There are very many documented benefits of urban trees and more insights on the distribution of trees in Zomba are presented in Chapter 3. Despite the very many benefits of trees and the mantra that ‘trees are good’, Roman et al. (2021) flag the need to also consider EDS from urban trees as there are some unavoidable negative impacts from them. A blind eye towards the EDS associated with urban trees may lower support for tree planting programs and thereby not meeting the intended sustainability goals.

The urban residents of Zomba clearly indicated the regulating ES from the UGS and the trees within their premises followed by provisioning services and lastly cultural ecosystem services. This trend is similar to results from Tian et al. (2020) from the cities of Wuhan, Changsha and Nanchang in China, where respondents perceived that UGS provided an overall score of 4 out of 5 on regulatory urban ES which included climate regulation, air quality regulation and erosion prevention, on top of cultural and amenity services which were not fully mentioned by the residents in this study. Respondents’ appreciation of the role of trees and UGS biased towards the regulatory and provisioning services further agrees to findings by Shackleton et al. (2015) in South Africa, mostly from low-income RDP and township suburbs. This appreciation was previously qualified by (Cilliers et al., 2013) where they observed that more affluent communities focus more on regulating services while the poorer communities have a higher demand for provisioning services.

Provisioning ES of trees and UGS within urban settlements have also been reported in other studies. For instance, Shackleton et al. 2018) in a study across nine small and medium urban settlements in South Africa found that an average of 64 % of the dwellers used at least one wild resource, either for sale to relatively high-income households or home use, with around one-fifth of cash and non-cash income being from the wild resources. Zomba being a developing city, the high scores in both regulating and provisioning services attests to the findings that direct reliance on local ES for provision of human needs gets reduced with urbanisation (Ferreira et al., 2019). This assertion was echoed by Richards et al. (2020) where there was a clear shift in use of regulating and provisioning ES by the pre-1960 respondents to cultural ES by the 1989-1999 respondents in Singapore. However, Schlesinger et al. (2015) show no such decline while Shackleton and De Vos (2022) show that on average, 67 % of the Global South urban dwellers use provisioning ES.

Home and vegetable gardens were reported in 63 % of the households. Some households practice rain fed crop production within their yards (22 %) and engage in vegetable production after the rains (19 %) in small patches of land that they can easily manage. This presence was less than the 72 % of households that had vegetable gardens in Lubumbashi, Democratic Republic of Congo (Balasha et al., 2019). Benefits shared by owners of gardens in Lubumbashi included contribution to food security through access to a variety of vegetables, strengthening relationships between families and neighbours through sharing vegetables, conservation of agricultural traditions and a place for children to learn agriculture. Zomba, like other small and medium cities in the Global South, has considerable home and vegetable gardens within the households. This calls for an in-depth study to appreciate their contribution and how they can be supported considering that the city is urbanising at a rapid rate.

5.4.4 Management of urban parks

Focus on environmental management of UP in Zomba was currently centred on managing the trees, shrubs, lawns and general cleanliness of the UP. This was followed with enhancing the beauty of the UP with planting of more vegetation, especially trees and flowers. Botkin & Beveridge (1997) argued that 'vegetation is essential to achieving the quality of life that creates a great city and that makes it possible for people to live a reasonable life within an urban environment.' Much as it is appreciated that the two major UP in this study have their core functions, it is worth noting that residents felt denied of the proper recreational services with amenities that befit UP like availability of recreational facilities which were not available in both UP. There were no benches to sit on, swings or barbeque stands, with free access to the UP unlike the botanical garden which demands for a park entry fee. Similar concerns were also reported by Manyani et al. (2021) who found that most respondents preferred formal UP over informal UGS as they had a variety of recreational facilities such as benches, swings, play grounds and barbeque stands, yet many UP from two towns in Eastern Cape, South Africa had limited recreational facilities and lacked management, deterring many residents against visiting them.

The management and cleanliness related findings in this study agree with several authors who related these to the quality aspects of UP. For instance, Madureira et al. (2018), in a comparative study on preferences for urban green space characteristics in three cities of Portugal, concluded that investing in cleanliness and maintenance within public greenspaces and improving plant species richness was one of the most highly valued green space attributes across the cities. Furthermore, rating of the top 10 attributes of preferred greenspaces, from top to bottom included, maintenance and cleanliness, richness of plant species, existence of water bodies, sufficient benches, tranquillity, existence of playground, richness of animal species, opportunities for sporting activities, good facilities and existence of car parks (Madureira et al., 2018). Nine of these are common with what Zomba park users felt need attention. These vital quality aspects of UGS that can influence individual preferences for UP use are also alluded to by others, like Conedera et al. (2015) on the variety and care of plants and provision of facilities for people with disabilities (Karanikola et al., 2016). While Suppakittpaisarn et al. (2019) found not only tree density but dense understory and bioretention vegetation important quality aspects from across five Midwestern cities and seven U.S cities from three geographical regions and lastly high greenery quantity (Mousavi Samimi & Shahhosseini, 2021).

Generally, poor management of UP is a common problem in SSA cities. For instance, in Kisumu, Kenya, Rabare et al. (2009) reported poor urban park visitation due to poor park maintenance and lack of adequate facilities. In Nairobi, Kenya, Makworo & Mireri (2011) noted degradation of UGS as a result of weak management, alongside other issues like rapid urbanisation, poor planning and illegal alienation. In Abidjan, Cote d'Ivoire, the situation is similar, with Djibril et al. (2012) noting that there is poor management and poor use of UGS for scientific, recreational or aesthetic purposes. Liljestrom & Persson (2014) indicated that encroachment or invasion from both planned and uncontrolled settlements, resulting from poor management of greenspaces in Dar es Salaam, Tanzania, led to a decrease of the available greenspaces at an alarming rate. Additional to poor management, high entrance fees and distance to UP were reported as some of the factors that limit park visitations in Ibadan, Nigeria (Simon, 2015). This is similar to the current situation in Zomba where entrance to the botanical garden is at a fee (K300.00 or $0.40 per day) which most of the park users in the golf course complained of. Additionally, Arku et al. (2016) added political interference, development pressure and complexity as inhibitors in the provision of public UP from views of residents and visitors in Accra, Ghana. In Bamenda, Cameroon, Kimengsi & Fogwe (2017) reported on challenges the city is facing in managing greenspaces. Tibesigwa et al. (2020) reported the same UP management problems in Dar es Salaam, as was the case reported by Manyani et al. (2021) on attitudes and perceptions on public UGS patronage, where poor cleanliness and management was a major deterrent to visiting the UP in two towns in South Africa.

It is known that investment in UGI contributes positively to ecological resilience in cities, more so in the face of climate change (Lo et al., 2017). However, management of natural infrastructure elements like UP requires a sustainable solution given that many city authorities in developing countries face a tight budget which limits their ability to develop or maintain UP (du Toit et al., 2018). As a solution to the management related problems in UP, park users' willingness to pay (WTP) or to work (WTW) was explored. In this study, 11 % of the respondents were unwilling to pay for improving the UP, characterising either protesting to pay or they are indifferent respondents who do not know if they wish to pay or work or not (Ntuli et al., 2018). Despite this, 89 % were willing to pay some amount to improve UP in Zomba, echoing the 87 % that were also WTP in order to get into a park in Kolkata, India (Dinda & Ghosh, 2021). A majority were WTP a mean of US$3.42 per month, higher than results on WTP for nature parks, multi-use parks and neighbourhood parks in Dar es Salaam, that ranged between US$0.10 - US$0.75 per person per month (Tibesigwa et al., 2020), US$0.69 - US$0.73 in Yaoundé, Cameroon (Tameko et al., 2011), US$1.88 per person per month for using and preserving UGS in Kumasi, Ghana, (Dumenu, 2013) and down to US$0.20 per person per month, using a choice experiment, for establishing a nature trail along the Sundays River estuary in Eastern Cape, South Africa (Lee et al., 2016), but higher WTP, ranging from US$3 – US$12 in different suburbs in two towns in South Africa (Shackleton & Blair, 2013). The higher average amount park users were WTP in Zomba could be that these were the actual park users as compared to the other studies which were on ordinary resident's claims and to an extent due to inflation over time. This is a good starting point as an alternative to financing upgrades and maintenance efforts on UP whose poor conditions are partly blamed on lack of funding. The WTW for the park users with an overall range of 3 to 4.5 hours per week can support the call by the park users for UP in all the wards within the city. The amount of time a park user was WTW was high from those in the high-density housing area as compared to the rest, though not different statistically. Respondents were willing to work in the UP towards improving and managing it. This corroborates Shackleton et al. (2018) who also found that about half of the respondents in small and medium-sized towns in South Africa were WTP some amount towards maintenance or establishment of a park in their neighbourhood. The proportion WTP was increasing with wealth of the suburb while WTW was higher in the low-income neighbourhoods as compared to the affluent houses whose time input was lower. A similar observation was also made in the towns of Fort Beaufort and Port Alfred, South Africa, where more affluent towns and suburbs were willing to pay more than the poorer ones, while the poorer ones were willing to provide more time than the affluent ones (Shackleton & Blair, 2013).

As most UP users were not satisfied with the management of the parks, a clear message to the city authorities was to improve on management of the UP. Rigolon et al. (2018), in a systematic review on access to UGS in the Global South, cited authors who noted the need for improved UGS maintenance that would increase UP use, its perceived aesthetics and health benefits. The outlined suggestions to city planners and managers by the different social-economic groups patronising the UP serves as a call to consider building small, accessible parks or pocket parks, transforming unused vacant land rather than building large parks (Rigolon et al., 2018). Dipeolu et al. (2021) suggested need for adequate attention to the provision of high-quality and well-equipped UP that maximise both environmental and health benefits.

The demand for more trees within the UP as a management issue echoes what Gwedla & Shackleton (2019) found, i.e., 87 % of the urban residents in South Africa had positive perceptions of trees and that over 70 % of the residents underscored the importance of urban trees for quality of life. On top of these, security was another area of concern as studies show that women are more concerned and affected than men (Bahriny & Bell, 2020). Dinda & Ghosh (2021) found that park safety, security, sanitation facilities and noise level had the greatest weights in seven parameters of a park suitability index. Manyani et al. (2021) reported respondents' preferences for parks that were fenced with a security guard in control, which are present in the botanical gardens where factors of supervision, maintenance, activity and access control are visible. These factors are considered in Crime Prevention Through Environmental Design (CPTED), an approach that uses planning and design to deal with issues of insecurity by establishing principles for all indoor and outdoor built environments to prevent anti-social behaviour and instil a sense of safe environment (Cisneros, 1996). Despite these real perceptions by the respondents, many studies show an inverse relationship between neighbourhood UGS and the incidence of crime (Bogar & Beyer, 2016). However, the level of maintenance has a bearing on this.

5.5 Conclusion

This study has provided a voice of the urban park users' preferences and perceptions that will help Zomba planners and managers in UP development and management. Zomba as a city has several designated park areas and other UGS but none of these are fully functional as a park, limiting residents to only two UGS, i.e., the botanical garden and golf course. With increasing population and pressure on land, the non-functional greenspaces are at a risk of being turned to other land uses as 'neoclassical theory predicts that if the land earmarked for green infrastructure does not yield better returns to investment or has low value, then the next best alternative will take over' (Tibesigwa et al., 2020). Through the interactions with the park users and residents, this study yielded four important findings.

Firstly, is that the social-demographic profile shows that much of the patronage to the parks is from the educated youth, a majority of them from high housing density areas who have no UP within their wards. Secondly, inequality was relatively low in accessing the UP as nearly every park user (85 %) took more than 10 minutes to walk to an UP or UGS. Thirdly, the UP users mostly enjoyed environmental benefits and less of the social and no economic benefits. On the other hand, residents perceived more of the regulating ES followed by provisioning ES with a trace of cultural ES from the trees and UGS around them. Lastly, most respondents felt UP management was poor, calling for action on the unmanaged parks already mapped in the city plus several other patches of UGS that can be turned into pocket parks, to be made available in each and every ward.

6. URBAN COMMUNITY POWER: ENHANCING URBAN FOREST DIVERSITY AND REVERSING ECOSYSTEM DISSERVICES IN ZOMBA, MALAWI

'The right to the city is far more than the individual liberty to access urban resources: it is a right to change ourselves by changing the city.' – David Harvey, 2008

6.1 Introduction

In pursuit of sustainable and resilient cities, urban greenspaces (UGS) are increasingly recognised worldwide as a necessary component of UGI (Gairola & Noresah, 2010; Titz & Chiotha, 2019; WHO, 2017). Research confirms that UGS, which include open spaces, whether formal or informal, private or public but mostly covered by vegetation, offer a spectrum of benefits and values, also known as ecosystem services (ES), to the ecological, social and economic systems in urban landscapes (Haines-Young & Potschin, 2018). UGS are known to provide cultural benefits including among others: spiritual and religious significance, symbolic values, educational values, recreational values, and property value improvement (Jim & Chen, 2006; O'Brien et al., 2017). They are also recognised in regulating local weather (Farhadi et al., 2019), reducing water run-off (Yao et al., 2015), improving air quality (Nowak et al., 2006, 2013), and conserving biodiversity. Central to these ES are trees and forests which bring an important vegetation component (Gong et al., 2013; Hernández & Villaseñor, 2018).

The diversity of benefits that UGS offer to urban landscapes and residents ought to justify for their conservation, management and expansion. Surprisingly, statistics indicate that UGS are declining at an alarming rate across the globe (Mensah, 2014). In Africa, the situation is even worse. This is attributed to factors such as: weak policies (Murtala & Manaf, 2019), inadequate resources, urbanisation pressure (Gwedla & Shackleton, 2017), lack of priority to UGS in development agendas (Mensah, 2014), and inadequate involvement of urban communities (Mensah, 2014; Mensah et al., 2017). In the majority of African countries, management of UGS is usually under the responsibility of city authorities with little or no community involvement (Azadi et al., 2011; Shackleton & Njwaxu, 2021). While management by the city has some advantages, such as fast implementation of activities in UGS, it is associated with a lot of disadvantages. There is a broad consensus that poor involvement of urban communities in management of UGS has led communities to think that managing UGS is solely the duty of city authorities. This line of thinking may result in misuse of UGS due to a lack of involvement and voice (Shackleton & Njwaxu, 2021).

There has been a growing advocacy for community involvement in urban planning and management of UGS (Mensah et al., 2017; Johnston & Shimada, 2004; Mahjabeen et al., 2009; Mattijssen et al., 2018; Mattijssen et al., 2017; Shackleton & Njwaxu, 2021). Community involvement entails actively engaging urban communities at all levels of decision making on matters concerning urban development. According to Vargas-Hernández et al. (2017), community involvement and engagement in UGS creates a sense of ownership which may promote caring, resourcing, innovations, and subsequently long-term sustainability. Meanwhile, most empirical evidence on the value of community involvement in management of UGS is from European and American countries (Mattijssen et al., 2018; Wamsler et al., 2020), and very few from African countries (Mensah et al., 2017; Chimaimba et al., 2020). SSA countries are critically understudied.

It is against this background that the study aimed at assessing the effect of urban community management efforts of UGS by comparing two UGS in Zomba, Malawi. The study compared Sadzi hill and Chiperoni hill, UGS that have different management systems. Specifically, the study compared the differences by comparing tree species composition, diversity indices, vegetation cover, ES and EDS.

6.2 Materials and methods

6.2.1 Study site

Refer to Chapter 1. However, the study focused on the two hills of Chiperoni and Sadzi, from Mpira and Sadzi wards, respectively (Figure 6-1). Zomba is endowed with six afforestation hills which contribute 11.8 % to the total urban area. The hills under study are in close proximity to each other where the social-economic status of the surrounding communities is mixed, that of medium and high-density housing as well as informal settlements.

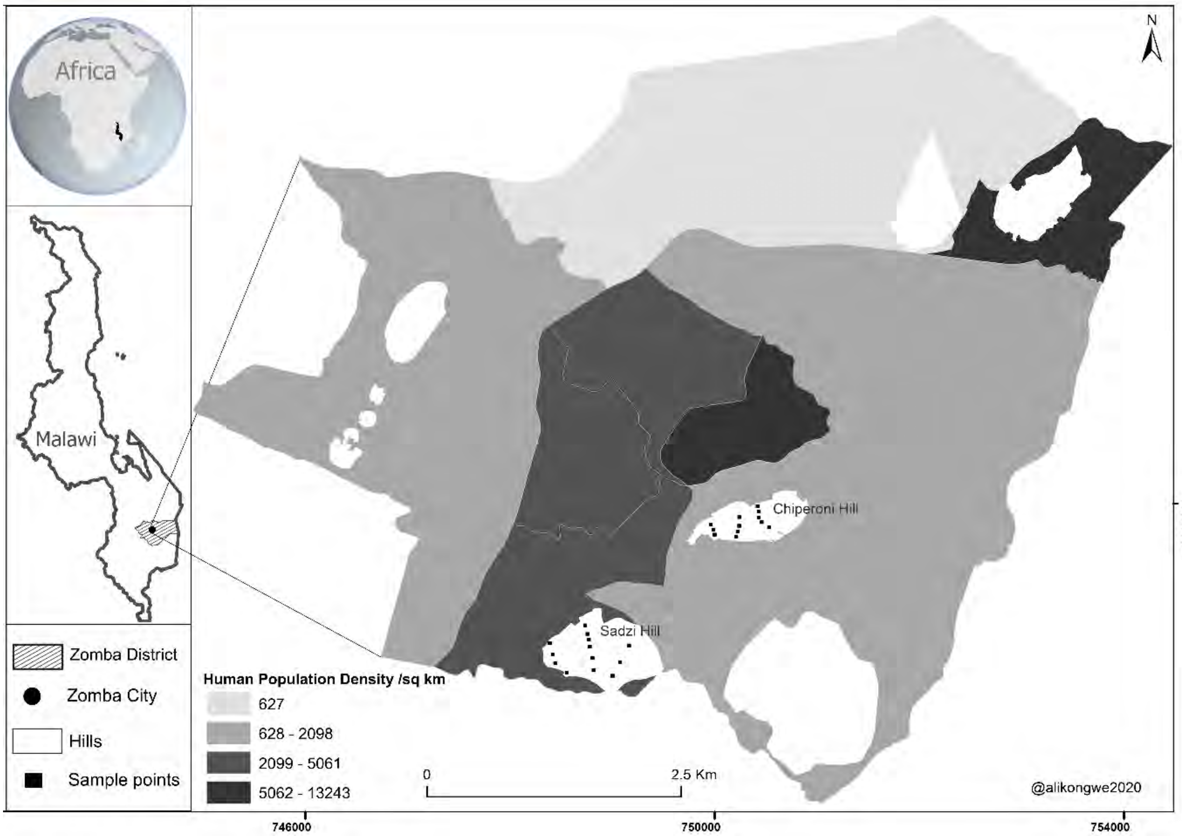


Figure 6-1: Location of the study hills within Zomba city, Malawi.

Sadzi hill was once protected under the wood energy World Bank project. The World Bank's 13 year multi-million-dollar wood energy project, were implemented in the 1980s and 1990s across the country to address the fuelwood gap. Smallholder farmers were given *Eucalyptus saligna* to plant because it could be supplied in large quantities and grew quickly to provide the much-needed fuelwood energy (Walker, 2004). In Zomba, Sadzi hill was targeted under this project. However, at the end of the project in 1996, the hill experienced serious environmental degradation due to high demand for forest products, and encroachment for farming and settlement. Before the restoration drive, over 350 farming plots were active within the 110 ha Sadzi hill area. The degradation resulted in EDS such as soil erosion, and mud and rock slides from the hill top to the residential properties below (Chimaimba et al., 2020). These EDS were more pronounced during the rainy season. This prompted the Sadzi community leaders to elect a 15 member Sadzi Concerned Citizen committee that was mandated to manage the hill's recovery. As of 2014, the committee were mandated to implement a management plan through tree planting and natural regeneration, plus protection from wildfires.

The first tree seedlings planted were provided by Leadership for Environment and Development (LEAD) and the Forestry Research Institute of Malawi (FRIM) through the

Lake Chilwa Basin Climate Change Adaptation Programme (LCBCCAP), the city council through Malawi Social Action Fund (MASAF III) project, Christian Aid and the Sadzi Concerned Citizens committee. The committee has never received any financial support for its endeavours to restore the degraded hill, but benefited from technical advice from the district forest office and the city of Zomba. The community deployed guards who were paid from the MK 2,000 (an equivalent of US$2.72 at K735.29 to a US$1 – 2019 average) monthly contributions made by each committee member. Currently, the committee and the city council authorities are working on formalising the by-laws for the management of the hill as well as the committee to sit on the environmental committee of the city council. All these arrangements were absent at Chiperoni hill (32 ha) which still remains a common pool resource with minimal community and local government involvement in managing it.

6.2.2 Data collection

To compare the differences in tree species composition and diversity at the two sites, 25 plots (20 × 20 m), 50 m apart, were randomly selected from three transects in each hill, 12 from Chiperoni and 13 from Sadzi hill between March and May 2018. In each plot, a full inventory of trees taller than 1.5 m and of Diameter at Breast Height (DBH = 1.3 m from the ground) of ≥ 5 cm was made. Trees in each plot were identified to species level with the help of tree experts from the National Herbarium and Botanical Gardens (NHBG) and Forestry Research Institute of Malawi (FRIM). The name of each identified tree species was documented as either ‘indigenous’ or ‘exotic’ based on their origin alongside its DBH and height measurements (Appendix 8-1). DBH was measured in centimetres (cm) for each stem using a diameter tape. Height for each stem was estimated using hypsometer, and the GPS coordinates were taken for each plot with the help of a Garmin 62sc.

Google Earth Pro Satellite imagery for both hills were captured at a resolution of between 15 to 30 m. This was done in May 2013 before the community management interventions and around the same time, May 2020 for Sadzi and May 2021 for Chiperoni hill, mindful that all tree cover is available as shedding of leaves sets in from August each year. The land cover on the hills (represented as either bare land or vegetation) was classified between the two time periods mainly to appreciate any vegetation cover differences between the two hills.

Additionally, 11 key informant interviews were conducted with participants drawn from various stakeholders (Table 6-1). These informants were purposively chosen based on their knowledge, expertise and long-term experience in environmental advocacy and the position they held in the community, government departments and conservation agencies. The 11 interviews are within the recommended 9 – 17 interviews that will lead to saturation of responses, from interviews that are targeting a homogenous population and narrowly defined objectives (Hennink & Kaiser, 2022). The interviews were conducted by the researcher together with a research assistant telephonically as we were battling with the third wave of the COVID-19 pandemic with level 3 control measures (UNICEF Malawi, 2021). In each call, the researcher introduced himself and the research assistant, established rapport through an introduction of the subject, the clearance given by the city council to do the research (Appendix 8-5), seeking informed consent (Appendix 8-6) and then engaging the respondent through the interview guided by semi-structured questions from the interview guide (Appendix 8-7). Each call was recorded and the research assistant supported in taking notes for follow up questions where necessary before the call ended. On average, the duration of the interviews ranged between 20 – 30 minutes. The key informant interviews, which took place in June 2021, sought to contextualise any differences acquired from the three species composition and diversity plus satellite imagery by understanding the impacts of the community interventions on tree management and any related ES or EDS accrued. Key guiding questions included: What are the ES obtained from the hills over time? Is there any change in the delivery of ES? How are different stakeholders, including communities, involved in the decision-making process?

Table 6-1: Details of the key informants interviewed and justification for selection in the study.

Key Informant	Number	Why Selected
Parks and recreation department	1	The department oversees all greenspaces in the city including the hills
Non-Governmental Organisation (NGO)	1	NGO had extensive work experience with the two hills
City council	2	These represented the administrative and political leaders of the city
Forest department	1	The department provides technical expertise on trees within the city
Conservation committee leaders	2	Leaders of the committees responsible for managing the hills
Community leaders	2	The greenspaces (hills) are within their jurisdiction
Community members	2	To have a community perspective

6.2.3 Data analysis

Tree species data was entered in Microsoft Excel 2013 where descriptive statistics and preliminary summaries were executed, like classifying the DBH into the four size classes of: (1) 5 – 10 cm, (2) 11 – 20 cm, (3) 21 – 30 cm and (4) > 30 cm, and data arrangements made prior to export to R for further analysis. Student's T-test was used to test for significant differences in the growth variables of individual trees from the two hills. All other analyses were computed in the R environment under RStudio (version 1.2.1335; R Core Team 2019). The 'vegan' community ecology package (Oksanen et al., 2019) functions of specpool and diversity, were used to analyse extrapolated values for species richness and Shannon-Weiner diversity index, respectively. The computation models for the growth parameters and biodiversity indices undertaken are summarised in Table 6-2. Species accumulation curves showed that the sampling efforts were exhaustive enough for each hill.

Table 6-2: Growth parameters and biodiversity indices computed in the study.

Diversity Index	Equation	What for
Chao1	$S_{est} = S_{obs} + \frac{a^2}{2b}$	Estimating potential species richness in each hill
Shannon-Weiner	$H' = -\sum_{i=1}^{s} P_i \text{In}(P_i)$	Tree species abundance and richness – diversity
Shannon's Maximum Diversity	$H_{max} = \text{In}(S)$	Maximum species diversity
Shannon's Equitability	$H_E = \frac{H'}{H_{max}} = \frac{-\sum_{i=1}^{s} P_i \text{In}(P_i)}{\text{In}(S)}$	Species evenness
Bray-Curtis Dissimilarity	$BC_{ij} = 1 - \frac{2C_{ij}}{S_i + S_j}$	Species composition dissimilarity between the hills
Importance Value Index	IVI = RF + RD + RD_o	Aggregate species importance at each hill

RF = Relative Frequency; RD = Relative Density and RDo = Relative Dominance

For vegetation cover classification, the extracted satellite images were imported into QGIS 3.8 where they were classified using Semi-Automatic Classification Plugin. The obtained classified results were used for analysing and predicting the extent of land cover under bare land and vegetation. Thereafter, the classified areas were computed and converted to percentages for explicit results, and ground truthed with visits to some randomly selected coordinates on the hills.

Interview data acquired from the KII was consolidated as notes and audio files that were transcribed. Common themes were then identified from the data through what emerged from the interviews, respondents, specific quotes that supported the analysis and overall summary that captured the respondents' thoughts, beliefs and recommendations.

6.3 Results

6.3.1 Tree species composition and structure

In total, 445 individual trees were recorded from the 25 plots at both hills. The composition at both hills was dominated by indigenous species, with more at Chiperoni hill (97 %) than Sadzi hill (90 %). Sadzi hill had a mean of 27.8 ± 12.7 trees per plot, with a maximum of 57 trees in one plot as compared to Chiperoni whose values were lower (9.7 ± 8.0). There were more tree families at Sadzi than Chiperoni (Table 6-3). There was a significant difference in tree abundance between the two hills ($t = 4.17$, $p < 0.0005$), with Sadzi having an estimated 695 trees/ha and Chiperoni at 244 trees/ha (Table 6-3). All plots in Sadzi hill had trees, except one plot which was fully covered with bamboo (*Oxtenanthera abyssinica* – Local bamboo). For Chiperoni, out of the 12 plots, three plots had a different composition. The first plot had only one tree (*Pterocarpus angolensis)*, the second plot had no trees and was covered with grass (*Hypatheria dissolute)*, and the third plot was bare, an abandoned garden.

Table 6-3: Summary of tree species composition from the two hills

Parameter	Chiperoni hill	Sadzi hill
Number of plots sampled	12	13
Number of trees sampled	112[a]	333[b]
Mean number of trees/plot	9.8 ± 8.0[a]	27.8 ± 12.7[b]
Maximum number of trees/plot	29[a]	57[b]
Estimated number of trees/ha	244[a]	695[b]
Indigenous trees	95 %	82 %
Indigenous species	97 %	90 %
Mean DBH (cm)	6.3 ± 2.2[a]	6.5 ± 1.7[a]
Maximum DBH (cm)	22.0[a]	19.6[a]
Mean height (m)	4.3 ± 1.0[a]	4.7 ± 1.2[a]
Maximum height (m)	7.1	9.5
Number of tree species	32[a]	42[b]
Number of genera	25[a]	34[b]
Number of families	13[a]	16[a]

* Means sharing the same superscript letter between the sites are not significantly different ($p > 0.05$).

Fifty-one tree species were recorded across both hills, belonging to 40 genera and 17 families. The most common family was Fabaceae, with 20 tree species, seconded by Anacardiaceae, Combretaceae and Phyllanthaceae families, each with four species. Four families had doubleton species each, while nine families were represented by singletons. For the genera, the most common was *Brachystegia* with five species followed by *Dalbergia* with three species. There were five genera, *Eucalyptus*, *Strychnos*, *Combretum*, *Albizia* and *Searsin,* each with doubleton species, while the rest of the 33 genera had singleton species. Sadzi hill hosted 42 of the 51 tree species and 34 genera which were not significantly greater than those of Chiperoni ($X^2 = 0.052$, $p < 0.827$), while the number of families between the hills were not significantly different (Table 6-3). The top six species in terms of abundance from both hills were *Dalbergia boehmii* (n=49), *Diplorhynchus condylocarpon* (n=39), *Eucalyptus saligna* (n=29), *Pterocarpus angolensis* (n=25), *Bauhinia petersiana* (n=24) and *Anonna senegalensis* (n=21). More details are outlined in Appendix 8-8. The overall mean DBH was 6.4 ± 1.8 cm and overall mean height of 4.6 ± 1.2 m. Chiperoni hill recorded a lower mean DBH of 6.3 ± 2.2 cm (Sadzi hill – 6.5 ± 1.7 cm) and a lower mean tree height of 4.3 ± 1.0 m (Sadzi hill – 4.7 ± 1.2 m) (Figure 6-2). The boxplots are however excluding two tree individuals of *Uapaca kirkiana* that were the only big trees at a DBH of 44.5 cm and 44.6 cm from Chiperoni and Sadzi hill, respectively.

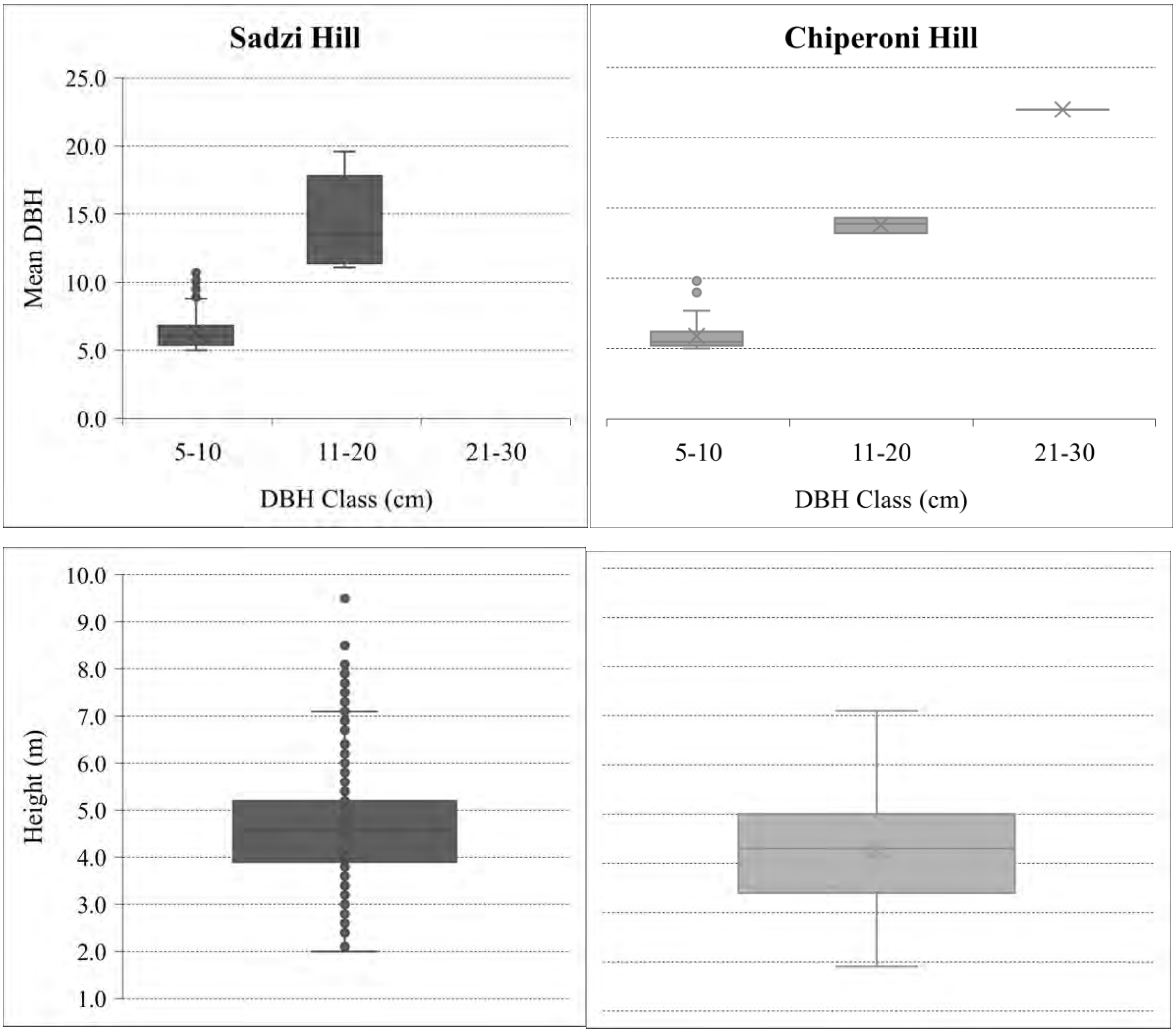


Figure 6-2: DBH (cm) and height (m) of individual trees from the two hills.

The tree stratum at both hills is in the regeneration phase as they were dominated by a small DBH class of 05 – 10 cm, represented by 95.7 % of all individuals recorded. Comparatively, Sadzi hill had slightly more exotic tree species (13.7 %) than Chiperoni (3 %). However, for each hill, there were more indigenous species in the first DBH class of 05-10 cm (Figure 6-3). The first two classes accounted for 99.3 % of the trees in both hills.

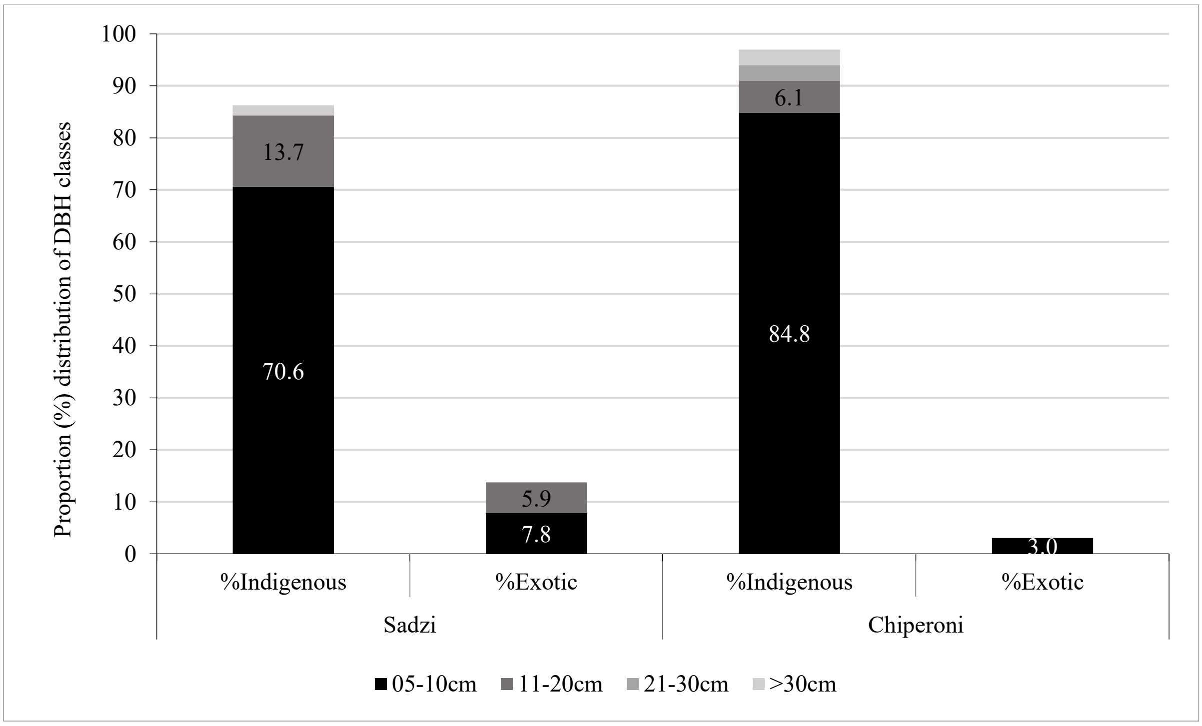


Figure 6-3: Tree species contribution in different DBH classes from Chiperoni and Sadzi Hills

6.3.2 Biodiversity indices and importance value index

The estimated tree species from the hills using Chao1 revealed that Chiperoni has more tree species (380) than Sadzi. The Shannon-Weiner diversity index, maximum diversity and Shannon's equitability indices between the hills were not statistically different from each other, but all were higher from Sadzi hill. However, the Shannon equitability index of 0.89 for Chiperoni hill was higher than that of Sadzi hill (Table 6-4). There is a 75.7 % dissimilarity in the tree species between the two hills, in other words, only 24.3 % of the tree species found in both hills are similar.

Table 6-4: Summary of growth parameters and biodiversity statistics from the two hills

Statistic	**Chiperoni hill**	**Sadzi hill**
Chao1 (S_{est})	380	292
Shannon-Weiner diversity index (H')	3.03	3.20
Maximum diversity index (H_{max})	3.50	3.80
Shannon's Equitability index (E_H)	0.89	0.86
Bray-Curtis Dissimilarity (BC_{ij}) (%)	75.7	

The species Importance Value Index (IVI) for both hills were very low, with *Diplorhynchus condylocarpon* registering 8.0 % followed by *Dalbergia boehmii* (7.6 %) and *Eucalyptus saligna* (5.4 %). More than half of the IVI (54.2 %) was from the top ten tree species, out of the 51 from both hills. The top ten species added up to 71.6 % (IVI – 214.7) from Chiperoni hill, while the same from Sadzi hill totalled 67.7 % (IVI – 203.1), and not significantly different between the two hills ($t = 1.83$, $p < 0.428$). The relative dominance (Table 6-5) was higher than the relative frequency and relative density. Most of the low IVI species were from Sadzi hill where species with IVI values of less than two totalled to 14 with these lowest five species being *Dalbergia nyasae, Allophyllus africanus, Stereospermum kunthianum, Dombeya rotundifolia* and *Steganotaenia araliacea*. No tree species in Chiperoni hill had an IVI value of less than two. The dominant species was *Dalbergia boehmii* from Sadzi hill with an IVI of 50.3 followed by *Diplorhynchus condylocarpon* with an IVI of 36.7 from Chiperoni hill.

Table 6-5: Summary of growth characteristics for the top ten important value index of tree species from Chiperoni hill, in family order

Species	Family	Chiperoni hill				Sadzi hill			
		RF	RD	RD_o	IVI	RF	RD	RD_o	IVI
Anonna senegalensis	Annonaceae					7.8	5.1	3.7	16.6
Diplorhynchus condylocarpon	Apocynaceae	13.7	9.8	13.5	36.7	4.9	8.4	13.6	27
Cussonia arborea	Araliaceae	7.8	5.4	4.6	17.8	4.9	3.3	3.0	11.2
Parinari curatellifolia	Chrysobalanaceae					3.9	3.6	2.0	9.6
Pteleopsis myritifolia	Combretaceae	2.0	6.3	4.3	12.5				
Bauhinia petersiana	Fabaceae					4.9	5.7	4.5	15.1
Brachystegia bussei	Fabaceae					3.9	5.4	4.1	13.4
Dalbergia boehmii	Fabaceae					2.9	14.1	33.3	50.3
Julbernardia globiflora	Fabaceae	11.8	9.8	11.1	32.7				
Pterocarpus angolensis	Fabaceae	9.8	7.1	6.6	23.6	4.9	5.1	4.0	14.0
*Gmelina arborea**	Lamiaceae					2.9	6.0	8.4	17.4
Strychnos innocua	Loganiacea	2.0	6.3	18	26.1				
Strychnos spinosa	Loganiacea	3.9	4.5	2.1	10.5				
*Eucalyptus camaldulensis**	Myrtaceae	3.9	4.5	2.7	11.1				
*Eucalyptus saligna**	Myrtaceae					7.8	8.7	12.0	28.5
Margaritaria discoidea	Phyllanthaceae	2.0	12.5	19.8	34.3				
Uapaca kirkiana	Phyllanthaceae	2.0	0.9	6.6	9.4				
	Totals	**58.9**	**67.1**	**89.3**	**214.7**	**48.8**	**65.4**	**88.6**	**203.1**

Exotic species are marked with an asterisk (*), RF = Relative Frequency, RD = Relative Density, RDo = Relative Dominance, IVI = Important Value Index

For the family importance value index, from both hills, the maximum IVI was recorded by the Fabaceae family. This was co-dominated by Phyllanthaceae (12.44 %) and Apocynaceae (10.61 %). The top ten families comprised of 90.9 %, with almost equal representation from the relative frequency, relative density and relative dominance (Table 6-6).

Table 6-6: Summary of family importance value index values in both hills

Family	**RF**	**RD**	**RD_o**	**FIVI**
Fabaceae	20.0	45.1	31.9	96.3
Phyllanthaceae	7.6	7.2	22.5	37.3
Apocynaceae	12.4	10.1	9.3	31.8
Myrtaceae	9.5	7.7	5.7	22.9
Araliaceae	8.6	3.8	4.8	17.2
Lamiaceae	3.8	6.3	6.8	16.9
Annonaceae	8.6	4.3	2.7	15.6
Combretaceae	6.7	4.1	2.5	13.2
Anacardiaceae	5.7	2.7	2.5	10.9
Loganiaceae	2.9	2.7	5.1	10.7
Totals	**85.8**	**94.0**	**93.8**	**272.9**

RF – Relative Frequency; RD – Relative Density; RD_o – Relative Dominance and FIVI – Family Importance Value Index

6.3.3 Spatial and temporal vegetation cover changes

Results from the land use classification of the two hills in terms of vegetation cover and bare land proportions in 2013 and 2020 show that Sadzi hill doubled in vegetation cover, while Chiperoni hill lost 10 % of its vegetation cover within the same period (Figure 6-4).

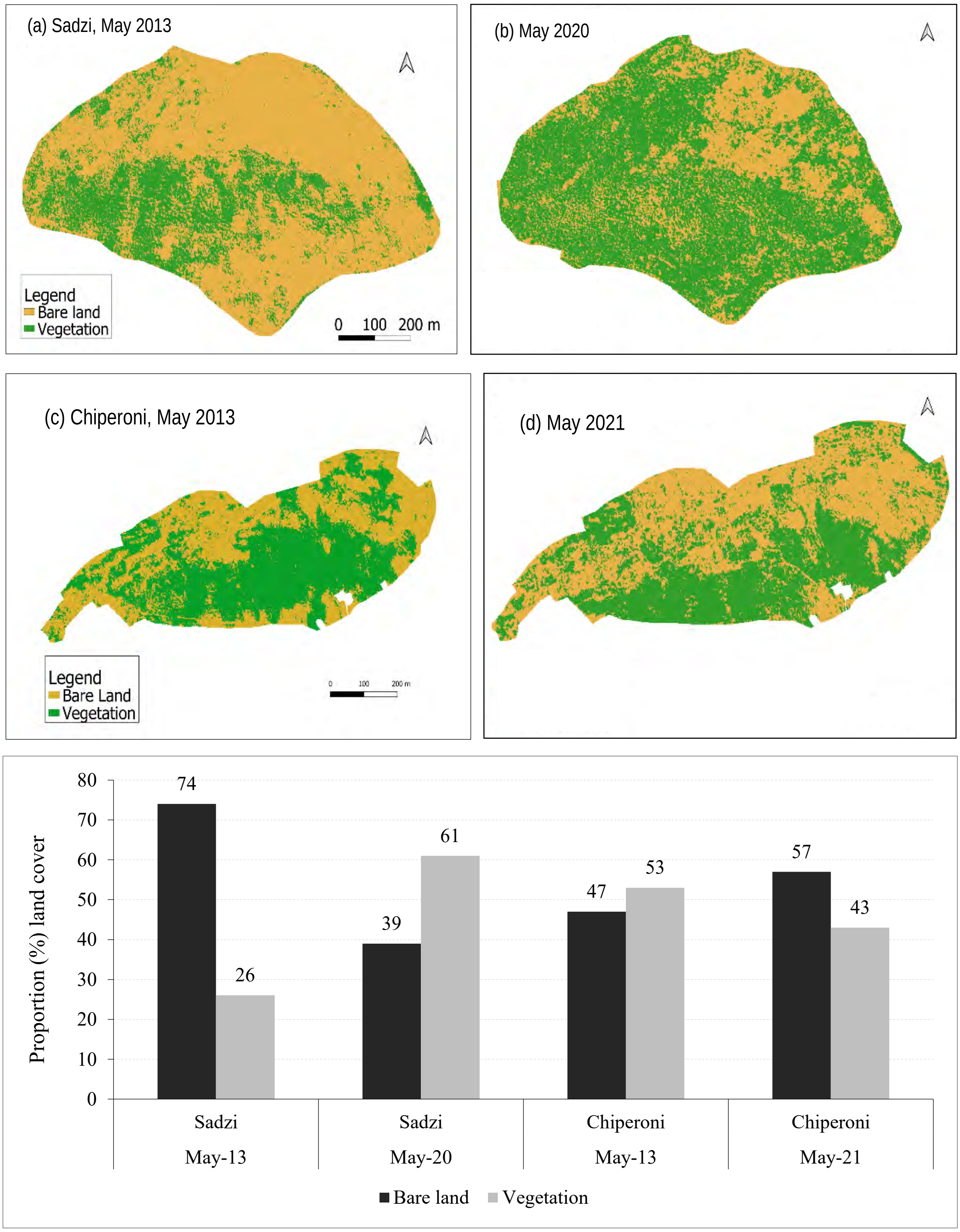


Figure 6-4: Status of land cover from Sadzi and Chiperoni Hills in 2013 and 2020/21 respectively (a, b, c and d) and the proportional loses and gains in bare land and vegetation.

Google satellite images (Figure 6-5) for both hills confirm the changes. While Sadzi is gaining vegetation cover, this scenario was absent in Chiperoni hill where some are claiming ownership of the hill and selling some parcels of land to people who are developing it for houses. An observation on structures built within the Chiperoni hill revealed an increase, with only two houses showing within the hill boundaries in 2013 and 20 houses by 2021, with some spaces cleared in readiness for house construction or gardening. The only untouched green space within the hill is the graveyard, north-east corner, whose tree cover has been maintained throughout the study period.

(a) Sadzi hill image in May 2013

(b) Sadzi hill image in June 2020

(c) Chiperoni hill image in May 2013

(d) Chiperoni hill image in May 2021

Figure 6-5: Google satellite images showing the vegetative gains in Sadzi and encroachment in Chiperoni Hills.

6.3.4 Impact of community management on vegetation cover changes

Key informant interviews revealed that the tree cover gain in Sadzi hill has resulted in numerous ES that the community around is noting and appreciating, unlike communities around Chiperoni hill (Table 6-7). First, mudslides have ceased as the hill has good vegetation cover, from both ground cover growth and trees, which is controlling runoff down the hill. For over three years, there have been no cases of water running into people’s homes around the hill as was the case when the hill was bare.

Table 6-7: Current ecosystem services from Sadzi and Chiperoni hills

Hill	Sadzi	Chiperoni
Provisioning	Wild fruits	Wild fruits
	Medicinal plants	Medicinal plants
	Construction materials	Fuel wood
		Building materials
		Crop cultivation for food
Regulating	Soil erosion prevention	Carbon storage
	Wind break	Pollination
	Temperature regulation	
	Regulation of water flow and runoff	
	Water purification	
	Carbon storage	
	Pollination	
Cultural	Aesthetic beauty	Physical exercise
	Spiritual connection	
	Physical exercise	
	Tourism possibilities	
Supporting	Home to more flora and fauna	Home to flora and fauna
	Maintenance of functional diversity	

Some comments from key informants on the ES and EDS trends are quoted below:

> 'I am very happy with the restoration from the hill as three years now, I have had no problems with muddy waters running from the hill through my house, rainy seasons were a nightmare but that is now history' – *Sadzi community member.*

Biodiversity recovery in terms of fauna on the hill includes baboons, rabbits, guinea pigs, a variety of snakes (including pythons), pollinators, flocks of guinea fowl, quails and numerous other bird species, when none could be seen five years ago. Sentiments of enthusiasm were shared across the respondents and more from the community management group as they aspire to continue with the restoration in all spheres as quoted below.

> ‘Our vision is to continuously restore the hill and allow all other wild animals that are meant to stay in this hill to stay as they were created to be in this area but we chased them off due to our actions’ – *Chairperson from Sadzi Hill Community Management Group.*

More trees are maturing, and they can be used for construction and the same are providing support as wind breaks, calling for a proper management plan as expressed by the forestry officer responsible for the area. The hill is now used as a space for worshiping where five synagogues or ministries meet at their designated times. Further to that, weddings have been officiated within the hill area. The regeneration has brought along the aesthetic beauty and fresh air.

> ‘With the group dully elected, a constitution and by-laws were crafted to aid in managing the hill and now efforts are towards production of a management plan where the hill will be categorised in line with the core function they are providing like tourism and hiking routes, conservation area, bee keeping area, provisioning area for harvesting poles, and other things as agreed by all relevant stakeholders’ – *Forest Extension Officer, Zomba Forestry Department.*

With this recovery, bee keeping initiatives with bee hive support from Zomba Action Project were under way in Sadzi hill as one way of protecting the regenerating urban forest which is now an example and a pride for the city, as shared by the city council Mayor. This covers all the four types of ES of provisioning, regulating, cultural and supporting, a serious gain away from the EDS that prompted them to reverse the status quo.

> ‘Sadzi hill is a shining example in Zomba city and augers well with our vision for ‘A green and clean city’, with plans for a hiking trail, a recreation centre, tourism hotspot, and environmental education centre’ – *Mayor, Zomba City Council.*

Efforts by communities to achieve the attained restoration was first driven by the passion of a group of people who were fed up with the EDS. This was followed by community appreciation of the drive and passion for restoration that the few individuals showed, which was subsequently supported by all relevant stakeholders within the city. This called for formalisation of the group through formal elections for their recognition at all levels. This invigorated the elected group to knock on doors for help which came in form of materials (tree seedlings, tree nursery equipment) and technical expertise. The support was never monetary and the group had their own nursery that supported tree planting in bare areas where regeneration was not possible. Guards were employed to patrol the hill with support from the community management group. For instance, in 2019, a wild fire was put out within a short time with support from the community management group and the residents around Sadzi hill. All in all, community passion for conservation, law enforcement efforts, engagement of key stakeholders at all levels (community members, local chiefs, city council, forestry department, NGOs) from 2014 have contributed to the success of Sadzi hill. In contrast, Chiperoni hill continues to experience vegetation loss and encroachment as key informant interviews revealed that the management committee is weak and lack of community involvement in some decision-making regarding management of the hill. The EDS that the hills were producing before and after restoration are now different (Table 6-8).

Table 6-8: Ecosystem disservices before and after restoration efforts

Site	Ecosystem disservices
Before Restoration	
Sadzi hill	Soil erosion from water and wind, mud and rock slides,
Chiperoni hill	Soil erosion, reduced biodiversity due to fires
After Seven Years	
Sadzi hill	None reported currently
Chiperoni hill	Increased soil erosion, increased biodiversity loss due to unsustainable harvesting of biomass and fires

6.4 Discussion

6.4.1 Tree species composition and diversity

The two afforestation hills are harbouring a considerable number of indigenous tree species perhaps because of high natural regeneration that was observed during the field work and the analysed size classes. The dominance of the Fabaceae family (20 species) outshines that found in the urban forest of Ibadan metropolis and Minna, Nigeria (Agbelade et al., 2016). The Fabaceae family also composed of more tree species and in this study, it commanded 55 % of the tree species in Chiperoni hill and 45 % in Sadzi hill. This confirms what Gentry (1988), Kacholi et al. (2015), and Valencia et al. (1994) reported that the Fabaceae family dominates the lowland tropical forests, dominating by up to 50 % of the species richness especially in the coastal forests of Tanzania (Burgess & Clarke, 2000).

Of the seven tree species planted by the community members interested in managing Sadzi hill, only *Senna siamea* was amongst the sampled species. Four of the eleven protected tree species in Malawi (Msekandiana & Mlangeni, 2002) were available in the hills, three species in both hills (*Afzelia quanzensis*, *Pterocarpus angolensis,* and *Terminalia sericea*) and the fourth one only found in Sadzi hill (*Bridelia micrantha*). The species richness, diversity and evenness were not significantly different between the hills, although all were higher at Sadzi than Chiperoni. Observed tree species richness was lower for Chiperoni but the Chao 1 estimator revealed over three times the observed species richness. However, with the reduced tree density in Chiperoni hill, the chances of getting that higher number of species remains questionable. Furthermore, without having proper management in place, the few remaining singleton and doubleton species could be lost with time. On the other hand, Sadzi hill could have more trees than the estimated number despite registering a higher tree density (almost three times that of Chiperoni hill). This is so as there were more recruits whose DBH values were smaller than the 5 cm minimum, hence not enumerated in this study. The 24.3 % similarity in the tree species between the hills is an indication that the combined diversity between the hills would enrich the tree biodiversity levels within the city.

The Shannon-Weiner diversity indices from the two hills were higher (Sadzi = 3.20; Chiperoni = 3.03) than values from Seminary hill, India at 1.41 (Dhyani et al., 2021) and from the built-up area of Sokoto, Nigeria at 1.84 (Dangulla et al., 2020) with low equitability or evenness values of 0.49 and 0.56, respectively, against 0.86 and 0.89 from the two hills. The high diversity scores, especially in Sadzi, is a result of assisted natural regeneration and deliberate human actions of promoting tree species for their economic, aesthetic, environmental and other values (Dangulla et al., 2020). The high diversity scores observed in Sadzi corroborates to the 'intermediate disturbance hypothesis' which indicates that higher species richness tends to occur in areas of low to moderate levels of human disturbance (McKinney, 2008).

Ecological and conservation importance of species in a given ecosystem is commonly assessed by using the IVI, which also provides an overview of the forest structure (Gopal et al., 2015; Sarkar & Devi, 2014). The top ten tree species from both hills had IVI values (Sadzi = 203.1; Chiperoni = 214.7) that were not significantly different from each other. Tree species with low IVI value need to be prioritised for species conservation as compared to the ones with high values (Kacholi, 2013). Combined from both hills, *Diplorhynchus* *condylocarpon* had the highest IVI value (63.6), a dominant species as found by Kacholi (2019) in a study on Nongeni Forest Reserve in Morogoro, Tanzania. In this study, the top ten families accounted for 90.9 %, while results from Dangulla et al. (2020), the five most dominant families accounted for 88.4 % in a study on urban tree composition, diversity and structural characteristics from two cities in North-western Nigeria. Only the Fabaceae family was present in both study sites, also dominant in Lubumbashi city, the Democratic Republic of Congo (Sikuzani et al., 2019). Other countries where the Fabaceae family dominated include South Africa, Zimbabwe and Angola where it is typically used for medicinal purposes (Novotna et al., 2020; van Wyk, 2020).

6.4.2 Vegetation cover changes and impact of community management efforts on restoration

The vegetation cover analysis for Chiperoni in the period between 2013 and 2021 indicates a 10 % drop in vegetation cover most likely as a result of an increase in human pressure. The Google satellite images show an increase in the number of houses being built on the hill over the period of study. According to Mensah (2014), depletion of urban forests in Africa is caused by an increase in urbanisation, poor enforcement of development controls, conflicting land ownership and lack of priority given to UGS. The encroachment in a way is an invitation to EDS as continued reduction in vegetation cover due to deforestation for construction of houses and farming will likely give way to mud slides, soil erosion and biodiversity loss (The Malawi National Biodiversity Strategy and Action Plan II: 2015-2025) (Government of Malawi, 2015). Hobbie & Grimm (2020) point out that loss of plant and animal species are threatened by habitat loss as a result of urban expansion, human population growth, forestry exploitation, fires and unsustainable harvesting of plants for medicinal purposes.

Human population growth and its exerted pressure on the two hills rendered Sadzi almost bare, however, coordinated efforts in managing the hill reversed the trend as plant and animal species are being restored. The vegetation cover trend for Sadzi hill between 2013 and 2020 shows more than a two-fold increase. This is attributed largely to the strong local community conservation group at Sadzi hill whose management efforts have contributed positively to the gain in tree cover on the hill despite several drawbacks. This concurs with the findings by Mensah (2014) who identified community involvement in management of UGS as one of the factors affecting successful UGS management in Africa. There are many factors that can trigger active involvement of communities in urban forest management. The current study reveals that EDS, such as landslides and soil erosion, activated the communities to begin conservation initiatives of the UGS. The gain in vegetation cover at Sadzi hill is important in these times of climate change as initiatives in UGI or NbS are being encouraged. For instance, climate change related hazards, like high temperatures that exacerbate urban heat island effects, higher night time temperatures, and heat wave problems, can be dealt with via increased tree canopy cover, availability of parks and open spaces and green roofs in urban environments (Hobbie & Grimm, 2020).

The restoration taking place at Sadzi hill provides a good starting point for the creation of UGS where the greenery of the hill can be easily converted to parks for ease of access by the communities around it. Better still, nature walks can be made where city residents can enjoy a walk within the mountain greenery. The WHO recommends at least 9 m^2 of UGS per person, with an ideal of 50 m^2 within a 10 min walk to a nearby park (WHO, 2017). It is common knowledge that parks and other greenspaces should provide multi-functional and multi-scale ES to residents (Benedict & McMahon, 2006; Finlayson et al., 2005; Hansen & Pauleit, 2014) and Sadzi hill is offering that. The ES the hill is providing span provisioning, regulating, cultural and supporting. Provisioning services in the form of food is from the fruit trees (*Annona senegalensis, Parinari curatellifolia, Strychnos spinosa, Parinari curatellifolia, Uapaca kirkiana*), regulating the environment (soil, temperature, water, and air) and playing a cultural role (natural medicine, aesthetic beauty, spiritual connection, physical exercises) and finally the supporting function, providing home to flora and fauna. On food provision from the tree species sampled, both hills had *Anonna senegalensis, Parinari curatellifolia, Strychnos spinosa* and *Uapaca kirkiana*, as wild fruit tree species which the communities around the hill enjoy when in season. Wild fruits add to the dietary diversity of urban residents as reported by Garekae & Shackleton (2020) in two towns in South Africa.

Sadzi hill has moved from delivering several EDS to very few. Contrary to this, Chiperoni hill is on a path to increased EDS as provisioning ES are exploited at the expense of regulating, cultural and supporting ES. The Millennium Ecosystem Assessment advocates for the maintenance of sufficient levels of biodiversity as a primary supporting service hence the need for ecosystem level management frameworks for securing ES for human well-being (Finlayson et al., 2005). However, there are good examples of the link between diminished biomass and biodiversity with increased EDS, like the increased probability and magnitude of flooding of adjacent lands, homes and infrastructure due to loss of riparian vegetation (Shackleton et al., 2016). EDS are rarely discussed in UGS management and biodiversity conservation (Azmy et al., 2016; Lyytimäki, 2015; Lyytimäki & Sipilä, 2009). Despite that there are no recorded EDS from Sadzi hill since the current restoration level, there are risks of snake bites. Some characteristics of UGS perceived negative for human well-being include allergens from trees and flowers, damage to infrastructure by plants and animals, increase in unwanted species such as pests and nuisance animals, fear and stress from dark green areas (Azmy et al., 2016; Shackleton et al., 2016). Azmy et al. (2016) concluded that abundance and species composition of hornets, critical pests in Japan, were both strongly associated with the level of urban greenness where increase in the greenness of urban areas meant an increase in hornet abundance and altered species composition.

It is expected that if the regenerating stems are undisturbed, in coming years, afforestation hills like Sadzi can contribute more to the overall carbon stock of Zomba. And with the many small stems below DBH of 5 cm, there is a high potential in increasing the number of tree species present in the hill. The success of Sadzi hill's regeneration is already a contribution Zomba is making to SDG Nos: 3 (good health and well-being), 11 (sustainable cities and communities), 13 (climate action), 15 (life on land) and 17 (partnerships for the goals). In fact, of the 10 targets for SDG 11, three relate to nature-based solutions: increase access to UGS, reduce loss of lives and livelihoods from disasters, and increase city planning to create safe, inclusive, resilient and sustainable cities (United Nations, 2015). The first World Forum on Urban Forests held in Dec 2018, Mantova, Italy, called for action on urban forests and UGS to make cities greener, healthier, and happier for all. They also issued a challenge to all cities of the globe to adhere to the 'Tree Cities of the World Programme.' With more partnerships and support to communities like those of Sadzi, bare hills in urban environments can be a different story, reversing EDS to ES.

It is pleasing to note that the city council has Environmental Management By-laws (2017) that support community participation in natural resource management. One of the clauses in the by-law's states that 'The City of Zomba shall facilitate the formation of area committees within the city in order to promote tree planting, protection and management of trees and forest vegetation with an aim of encouraging community participation.' As much as this is appreciated, the conservation group in Sadzi expressed concern over the conduct of some authorities who still want to take charge of the hill for economic benefits and not conservation. Fines to those caught cutting trees within the hill are not punitive enough. This may result to negative outcomes on the hill where community participation is high. Shackleton & Njwaxu (2021) noted that meaningful community engagement increases the likelihood of more positive outcomes in urban greening projects, however the roles of the municipality should not be ignored. As alluded to by Shackleton & Njwaxu (2021), 'community consultation and participation alone are not sufficient to immunise a created greenspace or park from damage as it requires true community involvement, stewardship and willingness to act to prevent damage from free reign agents.' However, Sadzi hill community lacks true community involvement as the community feels that they were denied access to other economic activities on the hill, like gardening, moulding bricks, tree cutting for fuel wood, charcoal and timber. These economic activities were attributed to the EDS experienced that triggered the restoration efforts driven by a few individuals that showed stewardship and willingness. Despite these efforts by the community group, local municipalities in South Africa were not managing their urban trees and UGS in a planned or systematic manner due to constraining factors such as insufficient funds, insufficient personnel, lack of equipment and lack of political support (Chishaleshale et al., 2015), common in most developing countries in African cities (Mensah 2014).

6.5 Conclusion

With the success story from Sadzi hill, the importance of community involvement in natural resource management and resulting contribution towards biodiversity conservation, availability of UGS and related ES is a win-win situation for the community and the city in general. The higher estimated potential species richness for Chiperoni hill, if supported with community management, could compete with Sadzi hill in biodiversity conservation, provision of UGS and a myriad of other ES. Hills within city environments can provide the ES that are needed by residents if not encroached for agricultural or dwelling purposes. The study has provided the baseline tree composition available in both hills, however, a similar study needs to be done after five years to monitor further changes, if any, in tree species richness, diversity and evenness between the hills and any changes in community management efforts and power dynamics. This will also help to understand the state of biodiversity reserves and ES these UGS are providing to the local communities and the city. Further study can also include the fauna in both hills. To sustain the restoration efforts achieved, there is a need to consider incorporating both ES and EDS that may come up in the management plans for the hill. As efforts are put in place to continuously realise more ES, notable EDS need to be reduced as well as deliberate efforts to build adaptive capacity of the communities to either minimise or respond to EDS. Environmental education and science communication is therefore key in reducing the fear and vulnerabilities that come along with increased urban greenness which may bring along wildlife-human conflicts that are viewed as EDS.

7. URBAN GREEN INFRASTRUCTURE AS A KEY TO URBAN RESILIENCE IN ZOMBA: SYNTHESIS AND RECOMMENDATIONS

'The value of biodiversity is that it makes our ecosystems more resilient, which is a prerequisite for stable societies; its wanton destruction is akin to setting fire to our lifeboat' – Johan Rockstrom, 2015

7.1 Introduction

Malawi is one of the five countries in Africa with an urban population of less than 20 %, alongside Burundi, Rwanda, South Sudan and Niger. However, the average annual urban growth rate is above 4 % alongside 19 other SSA countries (World Bank, 2019). In the study town, Zomba, the urban population is increasing and will continue to do so as the current extent of urbanisation in the four major cities of Malawi is low (12 %), with the town centres and municipalities commanding only 4 %, making an urban population total of 16 % for Malawi (National Statistics Office, 2019a). Zomba grew at an annual rate of 2.5 % between 2008 and 2018 (National Statistics Office, 2019a), while the urban population from SSA grew by an annual rate of 3.9 %, more than ten times higher than that of Europe (0.3 %) between 2015 and 2020 (United Nations, 2019b). This urban growth rate in SSA, by comparison, is double that of urban South or Southeast Asia and four times that of South America (United Nations, 2019). Most of the urban growth in the next two to three decades will be in the Global South (Africa and Asia) where more than 60 % of the urban population live in small and medium-sized cities and towns with a population of less than one million inhabitants (OECD & Club, 2020; United Nations, 2019b). However, this urban growth, through population increases and urbanisation, is one of the major drivers of habitat and biodiversity loss, fragmentation, degradation, erosion of ES and extinction of species, normally resulting to compromised ES delivery, rendering urban dwellers and systems less resilient to hazards and shocks (Elmqvist et al., 2016; Seto et al., 2011).

Although Zomba is experiencing rapid growth and urban sprawl and lacks functional urban planning, it is in its early stage of urbanisation and well-positioned to plan ahead (World Bank, 2016a). This provides an opportunity indeed to plan for inclusion of UGI in the urban resilience strategy. Urban sprawl is understood as the uncoordinated and uncontrolled expansion of a city or a metropolitan area (Johnson, 2001). The effects of urban sprawl are evident in Zomba and mirror what is already observed in most SSA countries (Nagendra et al., 2018). As the population is increasing mostly through more informal urban growth, the available UGS will be threatened, as has already been observed in the study. Networked UGS through UGI promotes the availability of the four types of ES – provisioning, regulating, cultural and supporting at various levels. However, land use changes have altered their function. For instance, Finlayson et al. (2005), through the Millennium Ecosystem Assessment report, noted that over the last half century, a total of 15 out of 24 ES (62.5 %) have deteriorated or were used unsustainably, making protection and sustainable use of ecosystems a key component of any global sustainable development agenda (Haase et al., 2014; Maes et al., 2019). Similarly, Ferreira et al. (2019) reported a loss of 18 out of 19 ES that were analysed and a 73 % loss in estimated ES value due to land use and land cover changes as a result of urbanisation in an area of the Brazilian agreste, a tropical ecotone between the Atlantic Fest and Caatinga biomes.

The concept of UGI broadens the discourse on UGS in urban social-ecological systems as they provide multi-functional and multi-scale ES that can support the development of urban resilience (McPhearson et al., 2015; Pamukcu-Albers et al., 2021). These UGS, as well as blue spaces like rivers and lakes, can either be natural or constructed, available at varying scales from a household, community, city, region and beyond, as well as in varying sizes like pocket parks through to urban forests. On top of providing recreational services, UGS play other important roles like maintaining biodiversity, environmental quality, cultural identity, city structure, and provision of biological solutions to technical problems (Handayani & Mardikaningsih, 2022; Sandstrom, 2002; Trihamdani et al., 2015). The realisation of these benefits started changing the perception of UGS and shaped the definition of UGI, a concept that has been applied within urban settings mainly to guarantee that benefits from natural capital are available within the city matrix which is mostly dominated by built areas (Pamukcu-Albers et al., 2021). For these benefits to be fully available, key in UGI is the interconnectedness of the trees and UGS which are meant to provide the multi-functional and multi-scale ES to urban communities for their well-being.

This study aimed at understanding the status and potential of UGI in building urban resilience of Zomba. This chapter therefore provides an integrated synthesis of the key findings from the status of UGI which can potentially support or undermine efforts towards building urban resilience. Urban planners and decision makers are increasingly using the concept of resilience to develop cities that can survive and thrive in the face of shocks and stressors (Meerow & Newell, 2019; Sharifi, 2019). Using the framework for analysing the resilience of the urban form, five key questions are asked based on the '5W's of urban resilience' which shape how resilience is operationalised and mapped over space and time (Meerow et al., 2016; Meerow & Newell, 2019). The 5W's of resilience are resilience for whom?, resilience of what to what?, resilience for when?, resilience for where? and resilience for what purpose or why resilience? (Meerow et al., 2016). These five key questions were reflected on through this study to establish the reference niche. Then connections were drawn between the study findings and the resilience concepts. Where necessary, the 4R's and other multiple characteristics of resilient systems were also considered. The resilience characteristics include robustness, redundancy, resourcefulness, rapidity (the 4R's), modularity, complexity, flexibility, self-organization, adaptability, and efficiency which make resilient cities 'safe to fail' rather than 'fail-safe' in the face of challenges, (Sharifi, 2019; The Rockefeller Foundation, 2016; The Rockefeller Foundation & ARUP International, 2014).

7.2 Summary of key research findings

This study has extended the understanding on the status of UGI and its potential to support urban resilience in Zomba. This is based on achievement of the four research objectives and integration between them.

7.2.1 Objective 1: Understand the composition, structure, diversity and distribution of trees in Zomba

The findings of this study represent the first comprehensive urban tree inventory from different UGS types in Malawi at a citywide scale (Chapter 3) as highlighted in the following outcomes.

Outcome 1: The findings showed that urban tree composition in Zomba is dominated by indigenous species in the different UGS types, at an overall average of 65 %, with fruit trees dominating the tree composition in residential areas at 66 %. UGS with the most indigenous tree species were the hills, cemetery and conservation sites, with the streets, informal and formal residential sites having the least in that order (section 3.3.1). The availability of more fruit trees within the residential area meant they were planned. The presence of more indigenous tree species within the hills, cemetery and conservation sites emanates from their naturalness and protection, with social norms and belief systems for the cemeteries.

Outcome 2: Urban tree stand structure generally revealed a reverse J-shape profile (section 3.3.2). This is an indication that there is a good regeneration capacity and there's a healthy urban forest. However, the hills and the informal residential areas did not reveal a reverse J-shape distribution.

Outcome 3: The urban tree diversity scores were high, with Shannon-Weiner diversity scores of above 3.0 from six out of the nine UGS types (section 3.3.3). Worrisome were the informal residential areas which had the lowest diversity score (2.65) due to limited residential area and preference for more fruit trees.

Outcome 4: Lastly, urban trees were not equally distributed. The areas where the colonial settlers lived had the majority of the trees (85 %), currently with very few people residing in those areas (section 3.3.4). The post-colonial residential areas have very many people with very few trees and UGS, and devoid of both in some areas.

7.2.2 Objective 2: Analyse spatial and temporal state of formal and informal UGS

This objective delivered a clear understanding of the dynamics of formal and informal UGS in space and time, with a clear overview on both quantity, quality and their distribution in Zomba (Chapter 4).

Outcome 1: The spatial and temporal quantity of UGS in Zomba clearly points to the decline in UGS and tree canopy cover from 23 % to 9 % within two decades (section 4.3.1). The decline is mainly from public UGS that are easily targeted in urbanisation leading to pressure on land for either building infrastructure or agriculture for food production.

Outcome 2: The spatial and temporal quality of UGS in Zomba follows the observed drop in quantity of UGS as outlined in Outcome 1 above. The UGS from the colonial period are mostly intact and gaining green canopy cover over the years (section 4.3.2). However, their contribution towards the general quality of UGS in Zomba was not significant at the city scale as well as in their being in a state of being user friendly due to their unkempt nature.

Outcome 3: The mapped quantity and spatial distribution of formal and informal UGS revealed a greater contribution of informal UGS of 85 %. The per capita UGS of 11.6 m^2 per person from the formal UGS only was slightly above the minimum recommended by

WHO (section 4.3.3). However, the spatial distribution of per capita UGS favoured the former colonial areas (highest being 97.7 m^2 per person in Masongola ward) while post-colonial residential areas had per capita UGS below the recommended minimum by WHO, and almost negligible in some wards like 1.1 in m^2 per person in Sadzi and 2.0 m^2 per person in Likangala and Chinamwali wards).

7.2.3 Objective 3: Analyse preferences for and perceptions of UGS

Despite that the dedicated urban parks are poorly maintained, some of the available UGS that are not managed by the city council serve the purpose of urban parks. This study went further to engage the residents in Zomba to assess their preferences for and perceptions of UGS (Chapter 5) as highlighted below.

Outcome 1: Some social-demographic factors like age, education and occupation status significantly influenced patronage to UGS, but not gender, housing density and tribe. However, compared between park users and non-parks users in terms of use of parks, there were significant differences between the two in all demographic parameters (gender, age, education, housing density and occupation status) except tribe (section 5.3.1).

Outcome 2: Use of UGS was not constant throughout the year as there were some highly preferred months (Oct, Sept, and Aug) and days of the week (Sat and Sun). Generally, a majority of the park users (85 %) took more than 10 minutes walking to reach their nearest UGS (section 5.3.2).

Outcome 3: Residents that used the UGS within the city mostly enjoyed the environmental benefits and less of the social and no economic benefits (section 5.3.3). A few EDS were reported and these were mostly a result of poorly managed UGS.

Outcome 4: On the other hand, perceived ES from the residents' yards and UGS around them revealed that residents benefited more of the regulatory ES followed by provisioning ES as 86 % of all sampled households had a tree within their yard that provided either shade or fruits or both (section 5.3.4).

Outcome 5: The users of UGS expressed concern about the management of the UGS as they were not up to the expected standard. However, a majority of the park users were willing to pay or work in the UGS to support in managing them, with age, education and occupation significantly influencing level of engagement (section 5.3.5). Above all, there was an overwhelming expressed need for urban parks in each ward.

7.2.4 Objective 4: Examine the role of urban community, regulatory framework and biodiversity in building urban resilience

This objective was addressed through a case study approach where Sadzi hill was compared to Chiperoni hill. The former is under urban community management interventions while the latter was not under any management interventions (Chapter 6).

Outcome 1: Urban community management efforts as expressed in the tree composition status of the hills revealed that tree abundance and number of tree species were significantly greater in Sadzi hill (695 trees/ha and 42 species) as compared to Chiperoni hill (244 trees/ha and 32 species). This was a result of the management efforts by the community around Sadzi hill (section 6.3.1).

Outcome 2: The same urban community management efforts have resulted in a 35 % gain in tree canopy cover and improvement in biodiversity of Sadzi within seven years, while at Chiperoni hill the same are declining, with a drop in tree canopy cover of 10 % within eight years. This gain in tree cover and biodiversity has translated to more ES experienced at Sadzi hill and a decline in the EDS the residents around the hill were experiencing (sections 6.3.2 and 6.3.3). In comparison, the EDS from Chiperoni hill were on the rise.

Outcome 3: Involvement of all relevant stakeholders and availability of the constitution and by-laws facilitated the recovery of Sadzi hill, with plans to develop a management plan that will carter for various needs from different stakeholders towards having a sustainable supply of ES from the biodiversity building up in the hill (section 6.3.4).

7.3 UGI and resilience in a growing Global South city: The case of Zomba

The key findings from the empirical chapters in this study, plus the conceptual framing in Chapter 1, all relate to urban ecosystems, a key focus in the global sustainable development agenda, and more specifically to the biodiversity from which ES emanate. The United Nations (2015) Agenda 2030, which has 17 SDGs and 169 targets, underscores the importance of sustainably managing the Earth's natural resources that provide an underlying basis for present and future social and economic development. Of the 17 SDGs, it is SDG 11 that is most relevant to this study. Although SDG 11 focuses on sustainable cities and communities through 'making cities and human settlements inclusive, safe, resilient and sustainable', urban ecosystems contribute to almost all SDGs. Maes et al. (2019) identified 102 targets (99 synergies and 51 trade-offs) related to urban ecosystems, that have potential to realise greater welfare and human well-being alongside building social and physical infrastructure. Sustainable management of urban ecosystems can only be achieved if addressed together with other issues like economic growth, equality and good governance (Maes et al., 2019), some of which have been unveiled for Zomba through this study which assessed the biophysical and social aspects as regards UGI.

With respect to the first resilience for whom, the discussion focused on the resilience of the people and ecosystems within Zomba in general. Planning for resilience is inherently a struggle as it entails considering potential trade-offs between stakeholders (Meerow et al., 2016). It also includes non-human species within the urban matrix that are affected by urban expansion or changes in its boundaries (Wagenaar & Wilkinson, 2015), hence considering the resilience of the SES. The question of 'resilience to what' considers the shocks and stressors. These include natural (floods, fires and wildfires), environmental (climate change adaptation and mitigation, extreme weather events, resource scarcity), social (health related issues, and social issues like lack of interaction, crime) and economic. The management actions towards known and unknown sources of disturbances influence the SES resilience to these shocks and stressors (Vargas-Hernández et al., 2017). Resilience for 'when' or 'at what stage' relates to the stages of resilience which are planning or preparation, absorption, recovery and adaptation (Sharifi, 2019). This relates to the different stages of disaster risk management, with the primary goal of building the resilience referring to the temporal scale, either in line with short-term disturbances or long-term stress, or resilience interventions that focus on anticipating future threats or reacting to past disturbances (Sharifi & Yamagata, 2016; Vale, 2014).

'Resilience for where' considers the inextricable links of the city to its region and globally, as operationalising resilience necessitates some limitation of spatial extent, while reflecting on how fostering resilience at one spatial scale affects others (Meerow et al., 2016). Finally, 'why resilience' or 'resilience for what' connects back to the 'who' question while 'highlighting the need to understand the political context, decision making processes, and powerbrokers that define the resilience agenda and to carefully consider underlying motives' (Meerow et al., 2016). This concerns the qualities and characteristics that can be enhanced to improve the SES resilience while thinking through the 5W's in respect to the empirical research results to illuminate how these trade-offs can work if resilience is operationalised in a specific context or generally as in this study. This section will present and discuss the integrated key findings under colonial legacy, biodiversity, social and human well-being, and governance, within the lens of resilience theory from the results of the study. According to Tanner et al. (2015), the lens of resilience 'requires greater attention to human livelihoods if it is to address the limits of adaptation strategies and the development needs of the planet's poorest and most vulnerable people.' A summary of how the status of UGI can potentially support or undermine contributions towards building urban social ecological resilience is also presented. Social resilience is the ability of communities, through use of their formal or informal social capital, to recover from external shocks that have resulted in the loss of ES (Neil Adger, 1999; Vargas-Hernández & Zdunek-Wielgołaska, 2021). On the other hand, ecological resilience is 'the capacity of ecosystems to collectively adjust and adapt to shifting and potentially novel environmental conditions while preserving desired functions, species, and services' (Grantham et al., 2019).

7.3.1 Colonial legacy

With reference to the historical perspective of Zomba (section 1.6.1), the botanical gardens, the gymkhana club, the residency of the colonial master and other administrative structures were concentrated around the same area, now the Masongola ward and other parts of Mtiya ward. These were being developed with planting of indigenous and exotic tree species, leading to the current disparity in urban tree distribution. This poor distribution of trees within the city as discussed in Chapter 3 indeed has a colonial legacy, as 40 % of the urban population, mostly from former colonial residential areas, with a low housing density, have more of the trees (85 %) within proximity as compared to 60 % of the population mainly from the informal residential area that had only 15 % of the trees. This expands to street trees, which were more common in the former colonial areas of Zomba and not the post-colonial residential areas, except for the main road, as also alluded to in Chapter 2. Furthermore, diversity scores of > 3.0 includes the formal residential area where population density is very low. This relates to the propositions of the 'intermediate disturbance hypotheses' which states that higher species diversity tends to occur in areas of low to moderate level of human disturbance (McKinney, 2008). The inequitable distribution of trees and UGS evident in Zomba means that current residents living where the colonialists used to live are enjoying much of the ecosystem services like increased resilience to urban heatwaves as temperatures are reduced within 300 m surrounding an UGS (Anderson et al., 2022). Where climatic and environmental problems are eminent, the UGS extent is limited like in Likangala and Sadzi wards. However, GI interventions like what the communities around Sadzi hill did, have contributed to building their resilience to climatic and environmental hazards like floods and mudslides (Chapter 6).

On top of poor urban tree distribution, Chapter 5 unveils that almost all formal UGS which are also used as parks, are located where the colonialists settled. The unequal pattern in urban tree and UGS distribution in Zomba corroborates with observations from the Global South where people with a higher social-economic status live closer to UGS, having access to higher quantities and high quality of UGS than those from the low social-economic status areas (Rigolon et al., 2018; Shackleton & Gwedla, 2021; Venter et al., 2020). A colonial legacy is behind most of the urban design and planning, taking after the British style which valued urban parks and botanical gardens (Shackleton & Gwedla, 2021). This planning is evident in Masongola ward, where the colonialists first settled, having the highest formal per capita UGS and more UGS, as detailed in Chapter 4, with the botanical garden providing a significant UGS area in Masongola ward, as outlined in Chapter 1. On the other hand, Likangala ward had the least UGS and this is where the quarters or low-class residents were housed, now followed by informal growth in the post-colonial era. Both Likangala and Masongola wards have a river running through but there have never been cases of flooding in Masongola where the greenspace cover is high, as compared to Likangala which has the least UGS (Chapter 4), rendering the latter less resilient and more prone to environmental and climatic hazards. With reference to the 2018 population and housing census, Masongola had only 628 people per km^2 whereas Likangala had 13,256 people per km^2 (National Statistics Office, 2019a). The influence of the colonial legacy on UGS planning is evident in many of the Global South cities from South Africa, Malawi, Ghana, Zimbabwe, Kenya, just to mention a few (Rigolon et al., 2018; Shackleton & Gwedla, 2021). Some of the cities from these countries were planned as garden cities with enormous influence from Ebenezer Howard's vision of the garden city movement (published in 1902). In his vision, cities were connected with nature to enhance resilience, which is now coupled with the growing need for daily contact with nature and UGS for a happy, productive and meaningful life (Cobbinah & Nyame, 2021; Lehmann, 2021).

7.3.2 Biodiversity

Biodiversity within the city is reflected in tree species composition, structure, diversity and distribution as discussed in Chapters 3 and 6 as well as quantity and quality of UGS as discussed in Chapters 4 and 5. The overall sampled tree species richness of 168 species from 47 families is comparable to other SSA cities at varying degrees, higher than Sokoto, Nigeria (Dangulla et al., 2020); Zaria, Nigeria (Dangulla et al., 2021) and Ibadan, Nigeria (Agbelade et al., 2016). However, the species richness from Zomba was less than that of Kumasi, Ghana (Nero et al., 2018) and Lome, Togo (Raoufou et al., 2011). Despite this, note should be taken that species richness is directly proportional to absolute area sampled. A larger area sampled gives more species hence greater richness. The species richness and the higher proportion of indigenous species from this study agrees with assertations that many SSA cities are biodiverse because they still retain significant remnants of native ecosystems and plant assemblages (Lindley et al., 2018). These plant assemblages with a high proportion of indigenous species that are more diverse, have always been considered to have higher resilience, are able to cope with change and have higher capacity for ES supply, with propositions of mimicking them in restoration interventions (de Carvalho et al., 2022; Vargas-Hernández & Zdunek-Wielgołaska, 2021). The ability to cope with change relates to the characteristics of resilience as reflected in adaptability and flexibility, with one weakness realised in the study site that they are not fully networked to benefit from the ES they can provide at a city-wide scale.

One of the 5W's of resilience is knowing when it is needed, in the short- or long-term, anticipated or in reaction to past disturbance (Sharifi & Yamagata, 2016; Vale, 2014). An anticipated resilience that the city needs to build is reflected in Chapter 1, section 1.6.4 which outlined the threat from increasing urban temperatures that need to be mitigated, calling for the benefits of UGS in amelioration of the UHI effect. Despite that this study did not measure the differences in cooling effects of the different UGS in relation to tree diversity, canopy cover and other indices measured, Wang et al. (2021) concluded that urban tree diversity, canopy cover, and canopy width should be prioritised when designing UGS that are intended to mitigate the UHI effect. However, there was no significant relationship between the mean tree height, DBH, and crown height of the UGS and its colling effect, hence no need for prioritising them (Wang et al., 2021). As the city is planning for tree planting initiatives to reduce the temperature, they are at the same time increasing the tree population and the rich biodiversity that comes with it to produce the ES that will provide the resilience against high temperatures.

Despite the dominance of indigenous tree species, a majority of exotic species were noted in the residential areas (dictated by the high proportion of fruit trees) and the streets. With the growing debate amongst ecologists on role of exotic species to ecological resilience and integrity in designing UGS, a review by de Carvalho et al. (2022) concluded that exotic species are associated with several attributes that constrain resilient and climate-adaptive ecosystems. These include disturbances to ecosystem functioning and integrity through altering the nutrient and water cycles, soil pH, and soil biota; increase in biotic homogenisation and biodiversity loss where indigenous species are systematically replaced with exotic species with similar traits; and the invasive behaviour of some which is a threat to biodiversity conservation, all leading to weakening of the landscape identity and resilience. On the other hand, the low proportion of exotic and invasive tree species within the city is a benefit towards resilience. Better still, most of the exotic species are fruit trees which provide provisioning ES to the residents. However, the major advantages of exotic species are their ease in successfully adapting to climate change and their greater capacity to survive in resource scarce and stressful conditions. de Carvalho et al. (2022) further concluded that indigenous species have no disadvantages and provide additional biodiversity and ES benefits while delivering strong ecological protection. Thus, indigenous species in UGS also contribute towards high landscape diversity that host multiple functions like recreation, sport, contemplation and nature enjoyment, important aspects that make indigenous species preferred by most scientists over exotics in UGS design (de Carvalho et al., 2022).

Additional to the high proportion of indigenous tree species, Chapter 4 exposes the higher contribution of informal UGS (85 % of all UGS and 17.4 % of the urban land) as compared to formal UGS that command only 2.1 % of land only. Although informal UGS is not planned or managed, results from other studies outline the role and benefits of informal UGS, including holding an enormous potential for preservation of biodiversity and urban conservation in cities from both the Global North and Global South (Manyani et al., 2021; Rupprecht et al., 2015; Rupprecht & Byrne, 2014). These informal UGS and other vegetative covers provide the naturalised water flows within the city and therefore developing resilience to urban flooding, an element of robustness which is equated to natural systems or ecological resilience (Bruneau et al., 2017; Zuniga-Teran et al., 2020).

Apart from informal UGS, trees in particular are also a major component of urban biodiversity, providing environmental, social and economic ES (Dangulla et al., 2021). The residential space proved to host more tree species, especially the formal residential area, followed by conservation areas and private institutions, spaces that need further thought as regards biodiversity hotspots. High biodiversity reflected in more tree species from the formal residential areas in Zomba aligns to outcomes most often observed by other researchers. Reasons for such are commonly explained as a either a 'Luxury Effect' – wealth or economic power driving the choice of where they can leave (Hope et al., 2003); a 'Legacy Effects' – where past social inequality patterns continue to shape urban landscapes, amplified by colonialism and land segregation (Cilliers et al., 2013) and/or 'Hierarchy of Needs' – where lower social economic status households are motivated to cultivate more of edible and medicinal plants unlike higher social economic status households who cultivate ornamental plants of greater diversity as they are freed from need (Clarke & Jenerette, 2015). Further to the high tree species in the formal residential areas, there is also a high abundance of fruit trees within the formal and informal residential yards, at an overall average of 66 % from the home gardens alone and 36 % including the other UGS types like the hills which registered five fruit tree species (Chapters 3 and 6). The high proportion of fruit trees within the urban households, with the dominance of *Mangifera indica,* mirrors findings from other SSA cities especially from Tanzania (FAO, 2014), Democratic Republic of Congo (Sikuzani et al., 2019), Nigeria (Agbelade et al., 2016; Dangulla et al., 2020), Zimbabwe and throughout Southern Africa (Shackleton & Mograbi, 2020). This demonstrates that planting of trees within household yards was mostly planned and well thought of in terms of the ES that the households prefer, a niche where formality can also be viewed as a space for a great contribution to biodiversity.

The fruit trees provided the fruits, timber and medicine to an extent, that were lacking from formal UGS within other land use types in the city. Planned trees were more within the formal and informal residential settings than in the rest of the city, except for the main street which had planned street trees. Furthermore, despite having more indigenous tree species and a good proportion of fruit trees, the size distribution of the trees indicated good tree regeneration. About 50 % of all the trees sampled fell in the 5 – 15 cm DBH category, with the first two classes of 5 – 15 cm and 15.1 – 30 cm commanding 77 % of all trees sampled. Further to that, seven out of ten of the big trees with a DBH of more than 100 cm were exotic with only three being indigenous. The reverse J-shape for both DBH and height was observed in each greenspace type except for the hills and informal residential sites which were mostly represented by one and two size classes, respectively. A tree population structure that manifests a reverse J-shape signifies a forest where there is good regeneration (Kacholi, 2014; Nero et al., 2018) which contributes to its resilience.

More of the benefits from trees in Zomba are yet to be enjoyed as only 30 % of the trees had a DBH of 30 cm or greater. Most of the benefits from trees are realised from big trees because large tree canopies trap more particles, store more carbon and can trap more pollutants than small ones and these ES were not at their peak across the city but were highest in UGS like parks and streets (Lehmann, 2021; Motallebi & Kangur, 2016; Russo et al., 2016). The hills, which provide a greater contribution to UGS area, would indeed provide most of the benefits if the hills were well covered with a greater majority of large trees that have DBH of over 30 cm. Generally, trees and UGS anchor UGI and provide the muti-functional ES that support in building resilience while contributing to 15 of the 17 SDGs (Croese et al., 2020; Turner-Skoff & Cavender, 2019).

7.3.3 Social and human well-being

Urban resilience emanates from thriving and healthy ecosystems as illustrated through Chapters 3, 4, 5 and 6, with a focus on ES as a product of UGI or NbS as outlined in Chapter 1. The availability of ES in support of social and human well-being within the city emanate from many different sources like trees and UGS available from different urban land use types. For instance, ES in support of social and human well-being came from home gardens, the high proportion of fruit trees from residential areas (Chapter 3) plus several other ES delivered from the restored Sadzi hill (Chapter 6). Chapter 6 further unveils the social capital through the urban community efforts in reversing the EDS from Sadzi hill, coupled with the availability of a supporting legal framework (by-laws). However, the disparities in per capita UGS distribution, resulting in long walking distances just to enjoy cultural ES from available UGS (Chapter 4) and the increasing EDS from Chiperoni hill undermine the social and human well-being status, thereby undermining their social resilience. All in all, gender, housing density and tribe did not influence UGS patronage amongst park users, while age, gender, housing density, education and occupation influenced the decision of whether to visit the park or not. Finally, the high preference for regulatory and provisioning ES by residents and park users (Chapter 5) is another attribute that would possibly contribute towards building resilience as residents’ resort to tree planting to attain their preferred ES.

The demand for UGS regardless of gender, housing density or tribe relates to the SDGs principle of leaving no one behind (United Nations, 2015). Human behaviour is at the core in social resilience as human systems learn and adapt their behaviour to maintain social ecological resilience (Vargas-Hernández & Zdunek-Wielgołaska, 2021) as demonstrated by the Sadzi hill community. With proper direction and planning, behaviours expressed by residents that were WTP and/or WTW can reverse the observed drawbacks as they work towards having UGS that can provide the cultural, regulatory and provisioning services within their wards.

The city and its residents enjoy ES from the nine different types of UGS (Chapter 4 and 6) and several other UGS elements available in the yards of urban residents (Chapter 5). Some of these UGS types support in stormwater management, exploring on robustness as one of the characteristics of a resilient system. Robustness in this case includes strategies that reduce runoff through increasing stormwater infiltration and storage (Lee et al., 2021). Some of these strategies include rain gardens, urban gardens, trees, parks, rainwater infiltration facilities, detention ponds, permeable pavements, and wetlands. Much of these were not part of the UGS identified in Zomba, but at least urban gardens, trees and parks were available. Urban gardens are multi-functional as they fulfil several regulating and cultural services, contributing to food and nutrition security, and have the potential to increase ecological connectivity (Lindley et al., 2018). Urban gardens cover a large part of the UGI in most cities, like in Zomba, and are therefore a significant contributor to plant diversity and multiple ecosystem services (Kerishnan & Maruthaveeran, 2021). Small private gardens also help mitigate high temperatures as more effective cooling of the surrounding environment is achieved through small gardens that are located in close proximity to one another as compared to having a few large scale UGS in some parts of the city (Lee et al., 2021).

The aspect of having many small UGS located close to each other is lacking in Zomba. This needs to be planned as it is an important element of resilience embedded in redundancy, manifested through a network of small UGS that diminish runoff velocity and stormwater runoff (Lee et al., 2021). Furthermore, the small gardens serving the role of crop and vegetable production are a form of urban agriculture. Urban agriculture is known to have the potential to increase sustainability and resilience of urban communities. This is achieved through increasing local food sovereignty amongst the urban poor, preserving the urban ecosystems, providing room for education, increasing community cohesion and closing the energy and mass loops in a circular economy setup (Balasha et al., 2019; Ferreira et al., 2018; Kanosvamhira & Tevera, 2022). On top of small UGS, trees alone facilitate rainwater infiltration and retention, thereby supporting residents to be robust enough towards building their resilience to erosion and floods. Urban parks, if well distributed within the urban matrix, also act as hubs that can delay and significantly reduce runoff while increasing rainwater storage capacity (Lee et al., 2021).

Urban resilience is also reflected through the hazards that residents living along the river banks are exposed to as outlined in Chapters 2 and 4, calling for an anticipated resilience plan. River belts within the city manifested a decline in UGS cover as most of the trees were cut. The overall river belt tree canopy cover was 42.5 %, but along the Likangala river it was only 6.5 %. The Likangala river mostly passes through the informal residential areas where the river is subjected to various activities like clearing trees for river bank agricultural practices, building houses and dumping of liquid and solid waste (UN-Habitat, 2011b; Zomba District Council, 2017). These human activities contribute to environmental degradation and exposure to hazards when rivers flood during the rainy season (UN-Habitat, 2016). The hazards related to river belts are also a Global South problem since many urban river belts or margins are occupied by marginalised people (Wantzen et al., 2019). Much as these rivers and banks support urban residents with livelihood options like agriculture, sand mining and water for other uses, the depleted UGS cover as outlined in Chapter 4 makes them less resilient and more vulnerable to hazards.

The ES gains around Sadzi hill embrace the current NbS concept. According to Haase (2021), NbS focus on problems and challenges of an environmental or social nature, as was the case with Sadzi hill. Kabisch et al. (2017) understand NbS as living solutions that are cost-effective, simultaneously providing environmental, social and economic benefits as inspired and supported by nature, while helping to increase resilience and adaptation to climate change. And indeed, social, human well-being and biodiversity aspects are clear in Sadzi hill where the flora and fauna are flourishing and the local community no longer experiences flooding or mudslides. The ES function and the design concept of UGI both harnesses NbS for the diverse and specific needs of cities while building their resilience.

Despite that informal UGS are of ecological significance and biodiverse rich, they contribute to social and human well-being of urban residents both positively and negatively depending on the state. Within SSA, informal UGS dominate UGI and offer children an alternative to formal UGS like parks, are a source of food and medicine through foraging, a source of firewood for household energy, provide recreation and leisure activities, a source of water from streams, rivers, wetlands, and hand-dug shallow wells, sites for environmental education, nature and other social, mental and physical benefits (Adegun, 2017; Garekae & Shackleton, 2020; Pedrosa et al., 2021). The downside of informal UGS is their being less preferred due to mostly being unkept with lots of litter, being associated with anti-social behaviours related to theft and physical safety, and attacks by wild animals (Garekae & Shackleton, 2020; Manyani et al., 2021; Pedrosa et al., 2021).

7.3.4 Governance

Urban governance is one of the most important factors affecting urban resilience. It requires a sound policy system that is flexible and adaptive in dealing with disasters and unpredictable events (Huang et al., 2021; Ramyar et al., 2021). According to FAO (2016b), urban governance is key in developing an enabling environment for urban and peri-urban forestry and UGI on top of policies and legal frameworks. The issues of UGS governance are reflected in all four empirical chapters. From Chapter 3, the public UGS were the most accessed where tree densities were lower than those from private UGS. Furthermore, the drop in UGS cover over the last two decades within the city and unequitable distribution of trees and UGS (as outlined in Chapter 4) speaks to issues of governance. Public UGS was frequently targeted for infrastructure development and clearing of land for agriculture. Chapter 5 covers issues of governance through the detailed perceptions of and preferences for UGS where users provided feedback on their dissatisfaction with public UGS due to their being poorly managed, and poorly distributed. In response, the public made offers of support via WTP and WTW.

The ES that were enjoyed within these UGS could be maximised with improvement in their management. The ES being enjoyed by residents around Sadzi hill, as outlined in Chapter 6, are a result of good governance of the UGS. According to the United Nations Economic and Social Commission for Asia and the Pacific (2009), good governance has eight major characteristics. ‘It is participatory, consensus oriented, accountable, transparent, responsive, effective and efficient, equitable and inclusive and follows the rule of law. It assures that corruption is minimized, the views of minorities are taken into account and that the voices of the most vulnerable in society are heard in decision-making. It is also responsive to the present and future needs of society’, attributes available within the urban community that managed to reverse the EDS from Sadzi hill and built their resilience. Urban resilience is viewed as an important outcome of good urban governance (Meyer & Auriacombe, 2019). Furthermore, a NbS approach was illustrated by the Sadzi community as they were integrative and governance-based in their response to the EDS. Their management was not top-down but action-oriented and participatory, involving the principles of co-design, co-creation and co-management (Pauleit et al., 2017).

In this regard, sound governance of UGS in a modern city implies a fundamental transition from the concept of local government to that of local governance in which all stakeholders have the responsibility for policy development, planning and management (FAO, 2016b). Further to this, Afionis et al. (2020) expressed the need for institutional coordination and policy coherence across all levels of government to maximise the societal benefit of UGS and UGI in a study on limits to UGI implementation in the cities of Mzuzu and Lilongwe in Malawi. The decline in UGS as observed through Chapters 4 and 6 are common in urban areas in the Global South compared to the Global North (Richards & Belcher, 2019). The findings from Chapter 4 further reveal that 19.5 % of the city area was under UGS cover, both formal and informal UGS, with the informal UGS contributing 85 %, mostly from the hills. Unfortunately, despite that informal UGS are not well managed, hence warranting their informality, they are not fully integrated into urban planning and land use management in cities from the Global South, including SSA (Adegun, 2017). The decline in UGS weakens the aspect of redundancy in building resilience as the ability to build networks of UGS through hubs and links is diminishing, directly influencing robustness and rapidity of urban resilience (Huang et al., 2021; Lee et al., 2021).

In restoring UGS, some cities have set up ambitious plans and strategies to build UGI to 30 % or more, for instance, Kualar Lumpur, Malaysia (Kanniah, 2017), London, UK (Salbitano et al., 2016) and Melbourne, Australia (Plant et al., 2017). In increasing UGS cover, cities would also be responding to the WHO recommendation of a minimum of 9 m^2, better still the UN minimum standard of 30 m^2 UGS per person. As 85 % of all UGS mapped within Zomba were informal, the city authorities need to consider upgrading some of the informal UGS to formal UGS to increase the formal per capita UGS cover. Further to that would be increasing the overall tree cover within the city from 19.5 % to over 30 % to increase on urban sustainability, resilience and liveability (Kanniah, 2017; Salbitano et al., 2016). To avoid having a separate area or a few big UGS that can provide the 30 % green space cover, there is a new guideline for greener, healthier and more resilient neighbourhood called the ‘3-30-300 rule’ for urban forestry (Konijnendijk, 2022).

In this ‘rule’, Konijnendijk (2022) advocates for the provision of equitable access to trees, UGS and their related benefits by setting thresholds of ‘at least 3 well-established trees in view from every home, school, and place of work; no less than a 30% tree canopy in every neighbourhood; and no more than 300 m to the nearest public green space from every residence.’ Despite the hills in Zomba providing the largest share of the UGS area, this 3-30-300 rule may help build neighbourhood resilience, mostly in the wards with low greenery. UGS strategies or policies support urban resilience while adding social dimensions to UGI planning (Zuniga-Teran et al., 2020). For instance, the Morogoro Municipal Council and Dar es Salaam City Council by-laws of 1998 and 1989, respectively, state that ‘Any person who owns a surveyed plot, which is built up or not, shall plant on such a plot a number of trees, thus high-density shall be one tree at face; medium-density shall be four trees at face and low-density plots shall be six trees at face. Failure to adhere to this shall be guilty against those by-laws and shall be liable to a fine of not less than TSh 5,000 and not exceeding TSh 6,000 or imprisonment of three months or both fine and imprisonment.’ Apart from the lone tree in high-density plots, the medium- and low-density plots have more than three trees that can be planted, already aligning to the part of 3-30-300 rule on the number of trees within house plots.

Although informal UGS are not well managed and maybe a source of other EDS, they also have the potential to improve access to important ES, mostly for the urban poor who have reduced access to formal UGS due to colonial and post-colonial urban planning and development efforts (Cobbinah et al., 2021; Meyer & Auriacombe, 2019). The potential of informal UGS to provide ES would help to address problems associated with a lack of formal UGS while addressing the problems of poor management and declining UGS due to rapid urbanisation (Cobbinah et al., 2015; Cobbinah & Darkwah, 2016).

Several EDS detailed in Chapter 5 were a result of poor management of UGS as alluded to by almost three-quarters of the UGS visitors. The willingness to assist in support of managing the parks was high both in monetary terms as well as time to work towards improving the UGS. What the park users were WTP was a good starting point as it was noted to be higher than amounts offered by residents in Dar es Salaam, Tanzania (Tibesigwa et al., 2020), Yaoundé, Cameroon (Tameko et al., 2011), Kumasi, Ghana (Dumenu, 2013), and

Sunday River estuary, South Africa (Lee et al., 2016). For those that could not afford cash equivalents, they were willing to give in time to work towards maintaining the UGS. A WTP in establishing or maintaining parks within local neighbourhoods was also observed in small and medium sized towns in South Africa (Shackleton et al., 2018), with poorer residents willing to provide more time than money in the towns of Fort Beaufort and Port Alfred (Shackleton & Blair, 2013). The WTP and WTW can be positively used to retrofit existing parks, improve maintenance or establish pocket parks in the underserved wards. The problem of poor management of urban parks cuts across many SSA cities as echoed by findings from Kisumu, Kenya (Rabare et al., 2009), Nairobi, Kenya (Makworo & Mireri, 2011), Abidjani, Cote d'Ivoire (Djibril et al., 2012), Dar es Salaam, Tanzania (Liljestrom & Persson, 2014), Bamenda, Cameroon (Kimengsi & Fogwe, 2017), and Komani and Qonce, South Africa (Manyani et al., 2021), just to mention a few. Resourcefulness is one key characteristic of resilient systems. The WTP and WTW fits perfectly well as available resources to be explored in developing a robust UGI that can deal away with shocks and stressors or to support in the recovery of the system (Vargas-Hernández & Zdunek-Wielgołaska, 2021).

Indeed, the WTP and WTW are resource envelopes which can support resource constrained municipalities to build their UGI (Chishaleshale et al., 2015; Mensah, 2014; Mwathunga & Donaldson, 2018; UrbanAfrica.net, 2015). The WTP and WTW expressed by residents is one of the key ingredients for an inclusive governance needed to build urban resilience through their involvement in creating as well as managing UGS and urban forestry in general (FAO, 2016b). However, constraining it is the state of land management in Zomba which is managed by multiple landlords coupled with a non-functional urban plan. This was realised during the stakeholder workshop at the time the AFRICITY project was being launched. The nature of multiple landlords frustrates some UGI related initiatives, mostly on urban tree planting by individuals and a few projects as they lack a consolidated urban plan which they can feed to. Good urban governance is therefore key in building urban resilience and can be achieved through effective urban management and municipal administration, community participation and stakeholder involvement plus transparency and accountability by the council, just to mention but a few (Meyer & Auriacombe, 2019; United Nations Economic and Social Commission for Asia and the Pacific, 2009). The availability of a functional UGI policy and the good urban governance relates to robustness and rapidity, factors that influence resilience of SES (Huang et al., 2021; Meyer & Auriacombe, 2019).

7.4 Key message: Urban resilience through UGI

A diverse and interconnected network of multi-functional UGS that are distributed throughout the city have the capacity to contribute towards urban resilience by integrating the resilience properties such as redundancy, diversity, connectivity, efficiency, flexibility, multi-functionality, and modularity into urban planning and design (Abdulkareem & Elkadi, 2018; Sharifi, 2019). The Zomba City Resilience Plan (2016-2026) will not work if the processes undermining resilience continue unchecked and if the contributions of UGI are underestimated. Since it was realised that the resilience plan would reduce and mitigate floods by mostly relying on grey infrastructure, the study has made several findings which can support in building urban resilience by engaging UGI. Of utmost importance is governance reflected in a sound policy, related strategies and legal framework that can support urban planning and implementation of UGI related interventions towards urban resilience. The status of UGI within Zomba had several attributes that need to be nurtured to continuously provide the much-needed ES and at the same time, there are several attributes that need to be addressed to prevent erosion of urban resilience in space and time (Figure 7-1).

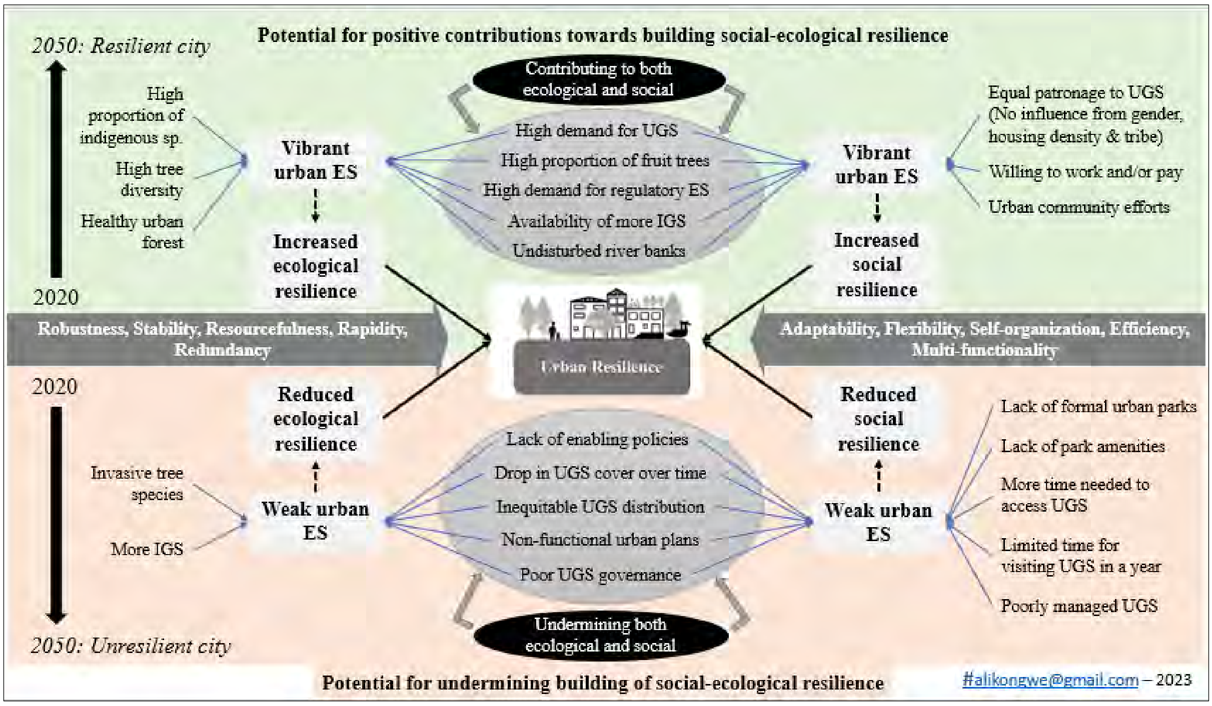


Figure 7-1: Status of UGI within Zomba and their related attributes that can increase either ES or EDS in efforts towards building SES resilience.

The attributes that need to be addressed as they can undermine resilience include, halting the decline of UGS cover within the city, inequitable distribution of UGS, disturbance of vegetation in fragile areas like river banks and steep mountain slopes, poor governance of UGS, non-functional and unsustainable urban planning and design and of utmost need is the presence of policy or strategy that can guide all UGI related interventions. Literature clearly outlines that the networked pattern of UGI is the more resilient and desirable structure, and that governance and urban planning interventions should focus on optimising the core, hubs, and corridors which will eventually produce multi-functional and multi-scale ES from the aspired healthy ecosystem (Benedict & McMahon, 2001; Liu et al., 2020).

On the other hand, several UGI related aspects have the potential to positively contribute towards building urban resilience within the city and other similar urban centres or cities within SSA and the Global South. These include the high proportion of indigenous tree species within most of the UGS, high proportion of fruit trees within residential areas, a healthy urban forest structure, high tree biodiversity scores, high demand for UGS (more especially parks within each ward), the high preference for regulatory ES by both residents and urban park visitors, the WTP and WTW towards managing and improving UGS, no disparities by gender, housing density and tribe in terms of accessing the UGS, and urban community involvement in UGI or NbS interventions. UGI increases urban resilience against environmental, social and economic stresses through reducing UHI effects, increasing thermal comfort, decreasing surface runoff, improving air quality, carbon storage, providing ES like food, aesthetic beauty, social interactions, recreational services, improving human health and well-being and improving property value in areas close to UGS (Canetti et al., 2018; Garden & Ryan, 2016; Kerishnan & Maruthaveeran, 2021; Monteiro et al., 2020; Puchol-Salort et al., 2021; Sikuzani et al., 2019; Turner-Skoff & Cavender, 2019).

7.5 Limitations of the study

The study had some limitations. First, access rights to sample trees from some sacred UGS like cemeteries and private property were not granted, resulting in re-sampling other related UGS. Second, the differences in satellite image quality resulted in using different time periods in analysing quantity and quality of UGS. Much as NDVI is beneficial for environmental studies, its usefulness is compromised by sensor differences emanating from different sources of satellite images (Fan & Liu, 2016). Finally, UGS quality was based on an overhead view from the satellite image analysis. What this study failed to do was to understand the quality of the UGS from the citizenry through questionnaires (Manyani et al., 2021a; Smith et al., 2017). UGS measurements based on eye level and overhead views have shown to reveal different aspects of UGS quality (Aram et al., 2020).

7.6 Suggested future research

Further research following this study can consider looking into differences and related impacts of trees and UGS between formal and informal housing across the three categories of housing density – low, medium and high-density locations, mindful of the fact that there are many informal housing initiatives coming up. Further studies on UGI need to expand on the benefits of tree planting initiatives within the city to understand motives behind them, further analyse the tree species composition, structure and diversity at a deeper level. A deeper engagement with the residents on UGI plans, involving the city managers, landlords, policy makers and other relevant key stakeholders also needs to be done. Results from such biophysical and social research related to UGI could feed into the Malawi Vision 2063 which is calling for green investment, action research and innovation as key in the support and implementation of a national transformative agenda towards a safe, clean, secure and sustainable environment (Government of Malawi, 2020). Therefore, the biophysical and social research results on UGI within the cities and municipalities will inform the type of growth as the country strives to create secondary cities that will have UGS such as parks, sports fields, and vegetation, as a key element in integrated urban planning.

7.7 Conclusion and recommendations

The study aimed to understand the status of UGI within Zomba and its potential to build urban resilience. The realisation of the value of UGI integrated with grey infrastructure is not only important in megacities and developed countries but cuts across all societies. This is more the case especially in resource poor cities as UGI provides efficient alternatives and solutions to environmental, social and economic shocks and stresses. What UGI provides appreciate with time if well planned and managed to provide the multi-functional and multi-scale ES that build urban resilience. The fact that the status of trees and UGS within Zomba is declining and low if compared to international benchmarks, there is room to reverse the situation and work towards building the natural resource base to a sustainable and healthy urban ecosystem that will continuously provide the much-needed ES. The ES that the trees and UGS are providing now will diminish as the trees and UGS decline within the city, especially in areas where management is minimal or the residents have not organised to address the disturbances they are experiencing. The decline in trees and UGS needs to be checked and efforts to reverse the situation engaged.

The findings highlight several limitations that have the potential to undermine urban SES resilience. Firstly, is the lack of a robust network of UGS and trees and the absence of formal UGS to serve the underserved wards, resulting in long walks to find solace in two of the UGS that serve as parks. Second, is the lack of a functional urban plan to provide the direction as far as UGI within the city is planned. Third, is the inequitable distribution of trees and UGS and their related disparities in per capita UGS amongst the wards following the colonial and post-colonial planning legacy. This requires city managers, landlords, planners, environmentalists, policy makers and all relevant stakeholders to consider consolidating the available Environmental Management Guidelines to include UGI, and to come up with a standalone strategy for the city or a component included in urban planning policies that clearly outlines how UGI can be planned and how UGS can be managed. Such a strategy or policy would help provide a holistic vision for all UGS and trees in urban settings, their use and how the future demands and pressures can be met, mindful of the fact that they are on the decline. The results from the study on the state of trees and UGI in space and time is an entry point for input into the strategy or policy towards building urban SES resilience from ES offered by UGI.

8. APPENDICES

Appendix 8-1: Tree inventory data collection form

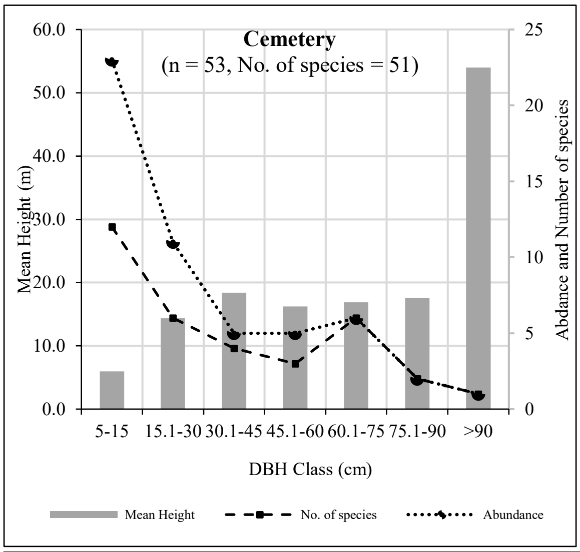
Land use type……………………….. Name of place……………...............................

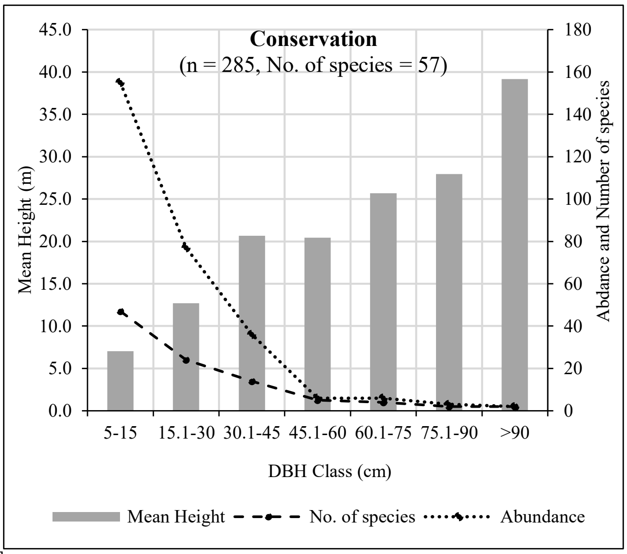
Name of the Ward……………………………….Date……………..……………….

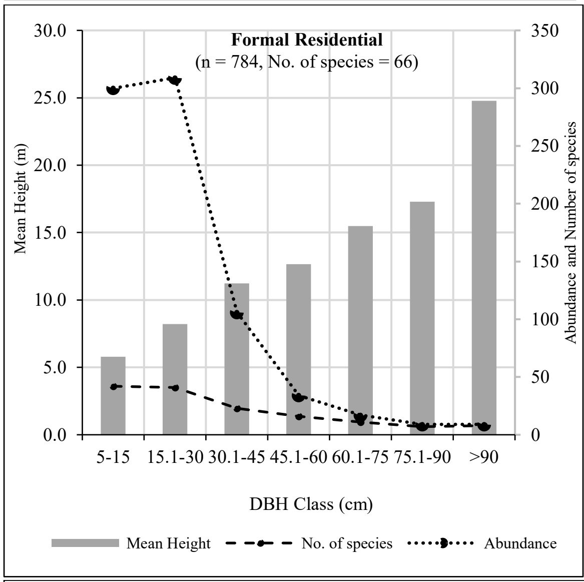
Form No…………..

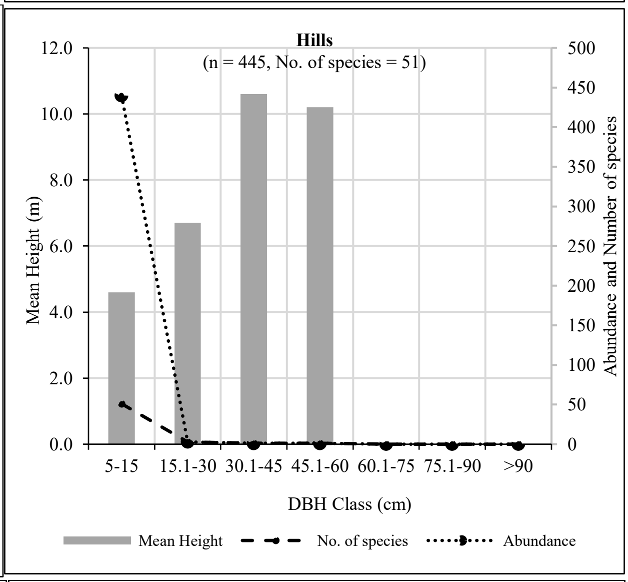
plot no.	PLOT SIZE (M)	GPS Coordinates	Tree No.	TREE SPECIES	Origin (indigenous/exotic)	DBH (CM)	HEIGHT (M)

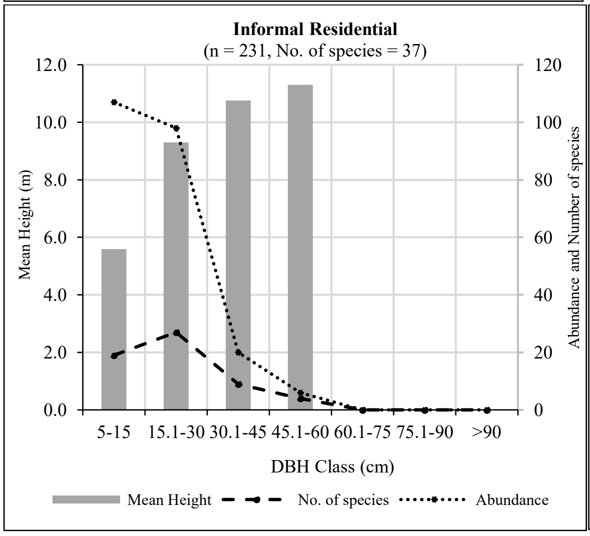
Appendix 8-2: Tree structure dynamics within each UGS type

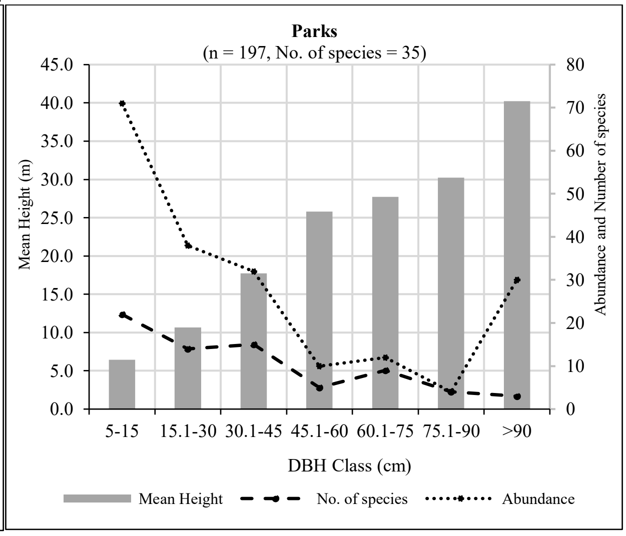


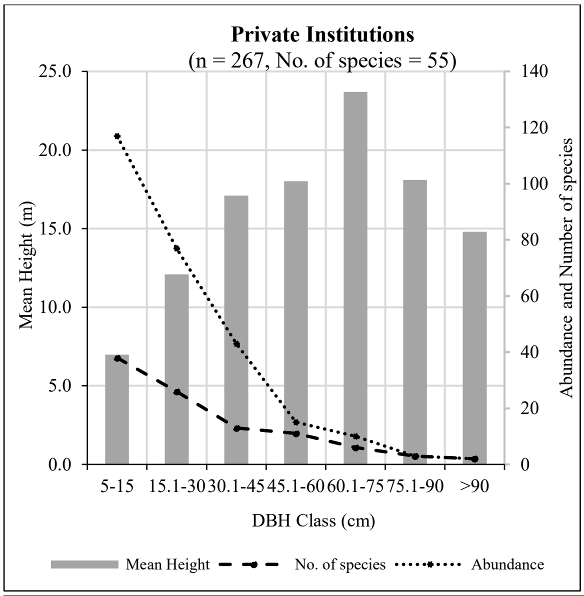


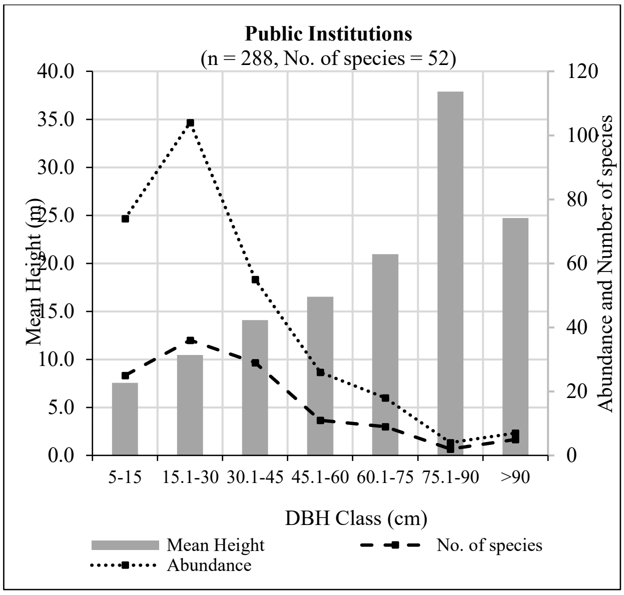


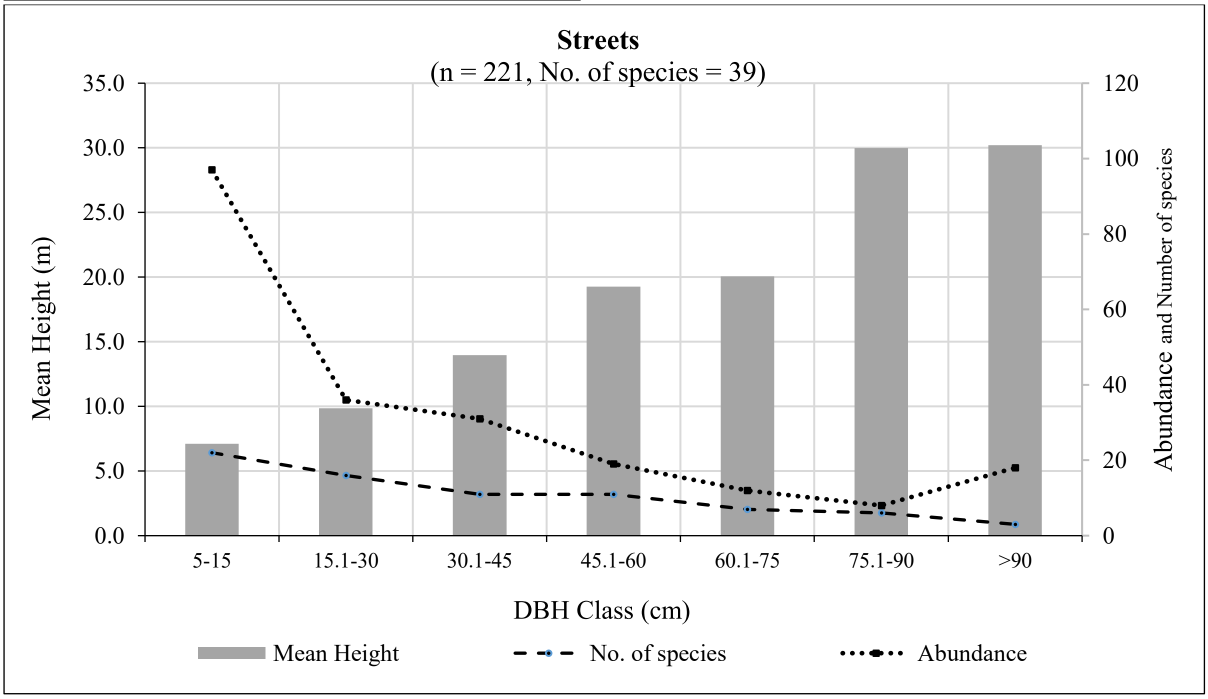







Private Institutions
(n = 267, No. of species = 55)
Mean Height (m)
Abundance and Number of species
5-15
15.1-30
30.1-45
45.1-60
60.1-75
75.1-90
>90
DBH Class (cm)
Mean Height
No. of species
Abundance


Public Institutions
(n = 288, No. of species = 52)
Mean Height (m)
Abundance and Number of species
5-15
15.1-30
30.1-45
45.1-60
60.1-75
75.1-90
>90
DBH Class (cm)
Mean Height
No. of species
Abundance


Streets
(n = 221, No. of species = 39)
Mean Height (m)
Abundance and Number of species
5-15
15.1-30
30.1-45
45.1-60
60.1-75
75.1-90
>90
DBH Class (cm)
Mean Height
No. of species
Abundance

Appendix 8-3: Approval letter from Rhodes University

RHODES UNIVERSITY
Where leaders learn

Rhodes University Ethical Standards Committee
PO Box 94, Grahamstown, 6140, South Africa
t: +27 (0) 46 603 8055
f: +27 (0) 46 603 8822
e: ethics-committee@ru.ac.za

www.ru.ac.za/research/research/ethics

22 July 2019

Dear Prof Charlie Shackleton & Patrick Likongwe

Re: HUMAN SUBJECTS ETHICS APPLICATION
Status and Potenial of Green Infrastructure to Support Urban Resilience in Zomba City, Malawi.
Reference number: ES18_32

This letter confirms that the above research proposal was reviewed by the Rhodes University Ethical Standards Committee (RUESC) – Human Ethics (HE) sub-committee on 28 February 2019.

The committee decision is
Approval

Ethics approval is valid for a year. An annual progress report is required in order to renew approval for the following year.

Please ensure that the ethical standards committee is notified should any substantive change(s) be made, for whatever reason, during the research process. This includes changes in investigators. Please also ensure that a brief report is submitted to the ethics committee on completion of the research. The purpose of this report is to indicate whether the research was conducted successfully, if any aspects could not be completed, or if any problems arose that the ethical standards committee should be aware of. If a thesis or dissertation arising from this research is submitted to the library's electronic theses and dissertations (ETD) repository, please notify the committee of the date of submission and/or any reference or cataloguing number allocated.

Sincerely,

Prof Jo Dames
Chair: Human Ethics committee, RUESC- HE

Note: The ethics committee cannot grant retrospective ethics clearance.

Appendix 8-4: Approval letter from National Commission of Science and Technology

NATIONAL COMMISSION FOR SCIENCE & TECHNOLOGY

Lingadzi House
Robert Mugabe Crescent
P/Bag B303
City Centre
Lilongwe

Tel: +265 1 771 550
+265 1 774 189
+265 1 774 869
Fax: +265 1 772 431
Email: directorgeneral@ncst.mw
Website: http://www.ncst.mw

NATIONAL COMMITTEE ON RESEARCH IN THE SOCIAL SCIENCES AND HUMANITIES

Ref No: NCST/RTT/2/6 **10th March 2020**

Mr Patrick J Likongwe,

LEAD SEA,

Private Bag 7,

Zomba.

Email: plikongwe@leadsea.mw

Dear Mr Likongwe,

RESEARCH ETHICS AND REGULATORY APPROVAL AND PERMIT FOR PROTOCOL NO. P.01/20/446: STATUS AND POTENTIAL OF GREEN INFRASTRUCTURE TO SUPPORT URBAN RESILIENCE IN ZOMBA CITY, MALAWI

Having satisfied all the relevant ethical and regulatory requirements, I am pleased to inform you that the above referred research protocol has officially been approved. You are now permitted to proceed with its implementation. Should there be any amendments to the approved protocol in the course of implementing it, you shall be required to seek approval of such amendments before implementation of the same.

This approval is valid for one year from the date of issuance of this approval. If the study goes beyond one year, an annual approval for continuation shall be required to be sought from the National Committee on Research in the Social Sciences and Humanities (NCRSH) in a format that is available at the Secretariat. Once the study is finalised, you are required to furnish the Committee and the Commission with a final report of the study. The committee reserves the right to carry out compliance

Committee Address:
Secretariat, National Committee on Research in the Social Sciences and Humanities, National Commission for Science and Technology, Lingadzi House, City Centre, P/Bag B303, Capital City, Lilongwe3, Malawi. Telephone Nos: +265 771 550/774 869; E-mail address: ncrsh@ncst.mw

inspection of this approved protocol at any time as may be deemed by it. As such, you are expected to properly maintain all study documents including consent forms.

Wishing you a successful implementation of your study.

Yours Sincerely,

Yalonda .I. Mwanza
NCRSH ADMINISTRATOR
HEALTH, SOCIAL SCIENCES AND HUMANITIES DIVISION

For: CHAIRMAN OF NCRSH

Committee Address:
Secretariat, National Committee on Research in the Social Sciences and Humanities, National Commission for Science and Technology, Lingadzi House, City Centre, P/Bag B303, Capital City, Lilongwe3, Malawi. Telephone Nos: +265 771 550/774 869; E-mail address: ncrsh@ncst.mw

Appendix 8-5: Clearance letter from Zomba City Council

ZOMBA CITY COUNCIL

Your Ref:....................................

P.O. BOX 43
ZOMBA
MALAWI

Our Ref: ZCC/DM/ADMIN/118

Tel.: (265) 01 525039
Fax.: (265) 01 525 362
E-mail:info@zombacitycouncil.org

29th May , 2020

TO WHOM IT MAY CONCERN

RE: PERMISSION TO CONDUCT ACADEMIC RESEARCH IN ZOMBA CITY.

Reference is made to your letter dated 21st May 2020 regarding the above captioned matter.

Permission is hereby granted to the bearer of this letter, **Lead** to conduct academic research on the topic of ***Status and Potential of Green Infrastructure to Support Urban Resilience in the City of Zomba, Malawi.*** The research will involve the residents of Zomba city through questionnaires and group discussions with stakeholders.

Details of the conditions attached include;

a) The permission is starting from 15th June to 15th November 2020
b) The participation must be voluntary
c) Solely for academic purpose

Please assist them accordingly.

The under copied is being informed about this permission

CHIEF EXECUTIVE OFFICER
ZOMBA CITY COUNCIL
03 JUN 2020
P.O. BOX 43
ZOMBA

Davie Mlose
For: CHIEF EXECUTIVE OFFICER

Cc: The Officer In- Charge, Zomba Police Station, Box 43, Zomba

ALL CORRESPONDENCES TO BE ADDRESSED TO THE CHIEF EXECUTIVE

Appendix 8-6: Informed consent form

Form No.
…………

AFRICITY Research Project – Consent Form
To be kept away from the questionnaires.

Consent form for all study interviews.

Status and Potential of Green Infrastructure (GI) to Support Urban Resilience in Zomba City, Malawi.

My name is ……………………………………… and I want to invite you to participate in a research study that is being conducted by the AfriCity[1] Research Project under LEAD SEA. Thank you for taking your time to read this information leaflet before agreeing to take part in this study. This research project is led by Prof. S. Chiotha and our details are included at the end of the consent form.

The purpose of this research is to understand the status of greenspaces and trees over space and time to support urban resilience in the city of Zomba, Malawi. This will be through knowing the quantity, quality, diversity and distribution of urban greenspaces; understanding the role of residents, institutions and institutional frameworks available in planning and managing greenspaces and trees; identifying any ruptures, contestations and inequities in planning, management and governance of urban greenspaces and finally sharing scenarios for the possible futures of GI in support of urban resilience amongst the many ecosystem services (ES) urban GI can provide to city residents.

Your participation will consist of completing a questionnaire. The time required to complete this questionnaire will vary among individuals, but typically it is not more than 30 minutes. We may also use a voice recorder so as to retrieve the chat after the interviews. Where necessary, we may also take pictures mostly of the environment and not that of people as the research focus is on green infrastructure. If the green infrastructure is private, the owner will provide the go ahead for taking pictures. Therefore, in signing this consent, the respondent is also agreeing to the capture of photos. There are no foreseeable risks nor personal benefits to participation in this study.

Your participation is entirely voluntary and you may choose to not participate, and you may withdraw at any time during the study procedures without any penalty to you. You will be anonymously identified to the responses as the signed consent form will be kept away from the questionnaire that you will respond to. We will keep this information confidential by preventing any other individuals' access to the research data and keeping it in a secure location. The researcher and the AfriCity Research Team are the only parties that will be allowed to see the data, maintaining anonymity at all levels. If a report of this study is published, or the results are presented at a professional conference, only group results will be stated, unless you have agreed otherwise. There are expected to be approximately 350 participants in this study (individuals/households – 350 and institutions – 20). Soft copy data will be kept under lock and key and be anonymised, i.e. if someone gets the soft data, they could not link any responses to any persons' identity. As the work is publically funded, properly anonymised data will be stored on the AfriCity research project repository and other public or open access sites for use by the city or other agencies. Hard copies will be systematically destroyed after three years. We may follow up with you to learn additional details about the specific GI practices.
If you have any questions about the study procedures, you may contact the PhD researcher at: Leadership for Environment and Development (LEAD); Private Bag 007; Zomba. Tel: +265 1 525 988/898; email: alikongwe@leadsea.mw or contact

The Administrator, National Committee on Research in the Social Sciences and Humanities, National Commission for Science and Technology, Lingadzi House, City Centre, P/Bag B303, Capital City, Lilongwe3, Malawi. Telephone Nos: +265 771 550/774 869; E-mail address: ncrsh@ncst.mw
If you agree to take part in this research through responding to interviews from the questionnaire, focus group discussions with a voice recorder in use and taking pictures of the environment around you, please sign below.

Participant's Name: ………………………………… Participant's Signature: …………………………………

Date: ……………… Contact Address, Phone or Email: ……………………………………………………

[1] AfriCity stands for Adaptability, Food Security, Risk and the Right to the City in sub-Saharan Africa: Towards Sustainable Livelihoods and Green Infrastructure.

Appendix 8-7: Semi-structured key informant interview guide

KII GUIDE FOR SADZI AND CHIPERONI AFFORESTATION HILLS

Guiding questions

1. Motivation or driver(s) to manage the urban forests.

2. Any benefits to date from the communal urban forests management efforts? (Ecosystem services compared between 2014 and 2020).

2014	*2020*

3. Can you differentiate the benefits between when it was not managed and when managed communally?

4. Any role the government and the surrounding communities (forest department and city council) is playing on this urban forest initiatives?

5. What is the role of the chiefs?

6. Challenges or Barriers and enablers of the urban forest communal management?

7. Any suggested solutions to the challenges?

8. What activities are being done in the communal urban forest management?

Appendix 8-8: List of tree species (DBH ≥ 5 cm) recorded in the study sites and their abundance; species with asterisk (*) are exotic.

Family	Tree Species	Chiperoni	Sadzi	Total Abundance
Anacardiaceae	*Lannea discolour*	2	4	6
	Sersia longipes		3	3
	Sersia natalensis		2	2
	Sclerocarya birrea		1	1
Annonaceae	*Anonna senegalensis*	2	17	19
Apiaceae	*Steganotaenia araliacea*		1	1
Apocynaceae	*Diplorhynchus condylocarpon*	11	28	39
	Holarrhena pubescens		3	3
	Rauvolfia caffra	3		3
Araliaceae	*Cussonia arborea*	6	11	17
Asteraceae	*Vernonia corolata*	1	1	2
Bignoniaceae	*Stereospermum kunthianum*	1	1	2
Chrysobalanaceae	*Parinari curatellifolia*	1	12	13
Combretaceae	*Combretum mole*	2	4	6
	Combretum zeyheri	2		2
	Pteleopsis myritifolia	7		7
	Terminalia sericea	1	2	3
Fabaceae	*Acacia gerrardii*	5		5
	Afzelia quanzensis	1	3	4
	Albizia antunesiana	1	1	2
	Albizia versicolor		6	6
	Bauhinia petersiana	5	19	24
	Bobgunnia madagascariensis		7	7
	Brachystegia boehmii		1	1
	Brachystegia bussei		18	18
	Brachystegia longifolia	1	3	4
	Brachystegia spiciformis		2	2
	Brachystegia utilis	1	6	7
	Dalbergia boehmii	2	47	49
	Dalbergia melanoxylon	2		2
	Dalbergia nitidula	2	4	6
	Dalbergiella nyasae		1	1
	Julbernardia globiflora	11	8	19
	Pericopsis angolensis		8	8
	Piliostigma thonningii		5	5
	Pterocarpus angolensis	8	17	25
	**Senna siamea*		5	5
Lamiaceae	**Gmelina arborea*		20	20
	Vitex doniana		8	8

Loganiaceae	*Strychnos innocua*	7		7
	Strychnos spinosa	5		5
Malvaceae	*Dombeya rotundifolia*		1	1
	Grewia micrantha	1		1
Meliaceae	**Toona ciliata*		7	7
Myrtaceae	**Eucalyptus camaldulensis*	5		5
	**Eucalyptus saligna*		29	29
Phyllanthaceae	*Bridelia micrantha*		2	2
	Margaritaria discoidea	14		14
	Pseudolachnostylis maprouneifolia	1	9	10
	Uapaca kirkiana		4	4
Sapindaceae	*Allophyllus africanus*		1	1

Appendix 8-9: Indigenous and exotic tree species across the seven UGS types sampled in Zomba city (0 = tree species not found)

Tree species name	Family	Origin	Cemetery	Conservation	Hill	Institution	Park	Residential	Streets
Acacia gerrardii	Fabaceae	Indigenous	0	0	5	0	0	0	0
Acacia polyacantha	Fabaceae	Indigenous	0	0	0	1	0	6	0
Acacia xanthophloea	Fabaceae	Indigenous	0	0	0	6	0	0	0
Adansonia digitata	Malvaceae	Exotic	0	0	0	0	0	1	0
Afzelia quanzensis	Fabaceae	Indigenous	0	3	4	0	0	1	1
Albizia adiathfolia	Fabaceae	Indigenous	0	9	0	4	4	1	1
Albizia antunesiana	Fabaceae	Indigenous	0	1	2	1	0	0	0
Albizia lebbeck	Fabaceae	Indigenous	0	0	0	11	0	1	9
Albizia procera	Fabaceae	Exotic	0	0	0	0	0	1	28
Albizia versicolor	Fabaceae	Indigenous	0	1	6	2	0	2	0
Aleurites montana	Euphorbiaceae	Exotic	0	0	0	2	2	1	0
Allophylus africanus	Sapindaceae	Indigenous	0	0	1	0	0	0	0
Anacardium occidentale	Anacardiaceae	Exotic	0	0	0	0	0	3	0
Annona muricata	Annonaceae	Indigenous	0	0	0	0	0	1	0
Annona reticulata	Annonaceae	Exotic	0	0	0	0	0	1	0
Annona squamosa	Annonaceae	Exotic	0	0	0	2	0	4	0
Anonna senegalensis	Annonaceae	Indigenous	0	3	19	4	1	1	0
Anthocleista grandiflora	Gentianaceae	Indiginous	0	1	0	0	17	0	0
Antidesma venosum	Phyllanthaceae	Indigenous	2	7	0	1	1	0	0
Araucaria excelsa	Araucariaceae	Exotic	1	1	0	2	0	0	0
Artocarpus heterophyllus	Moraceae	Exotic	0	0	0	0	0	2	0
Azadirachta indica	Meliaceae	Exotic	0	0	0	0	0	2	0
Azanza garckeana	Malvaceae	Indigenous	0	0	0	1	0	0	0
Bauhinia petersiana	Fabaceae	Indigenous	4	6	24	35	0	5	5
Bauhinia variegata	Fabaceae	Exotic	0	0	0	9	0	30	3

Tree species name	Family	Origin	Cemetery	Conservation	Hill	Institution	Park	Residential	Streets
Bersama abyssinica	Francoaceae	Indigenous	0	0	0	0	1	0	0
Bobgunnia madagascariensis	Fabaceae	Indigenous	0	0	7	0	0	0	0
Brachychiton acerifolius	Malvaceae	Exotic	0	0	0	5	0	0	0
Brachystegia boehmii	Fabaceae	Indigenous	0	0	1	0	0	0	0
Brachystegia bussei	Fabaceae	Indigenous	0	0	18	0	0	0	0
Brachystegia longifolia	Fabaceae	Indigenous	0	2	4	0	0	0	0
Brachystegia manga	Fabaceae	Indigenous	0	0	0	10	0	0	0
Brachystegia spiciformis	Fabaceae	Indigenous	1	0	2	1	0	2	0
Brachystegia utilis	Fabaceae	Indigenous	3	0	7	8	0	5	0
Breonadia salicina	Rubiaceae	Indigenous	0	0	0	2	0	0	0
Bridelia cathartica	Phyllanthaceae	Indigenous	0	0	0	1	0	0	0
Bridelia micrantha	Phyllanthaceae	Indigenous	5	16	2	24	8	36	6
Broussonetia papyrifera	Moraceae	Exotic	0	0	0	0	0	0	3
Burkea africana	Fabaceae	Indigenous	3	0	0	5	0	0	0
Callistemon viminalis	Myrtaceae	Exotic	0	0	0	13	0	6	0
Carica papaya	Caricaceae	Exotic	0	0	0	4	0	68	0
Cascabela thevetia	Apocynaceae	Exotic	0	0	0	5	0	43	7
Casimiroa edulis	Rutaceae	Exotic	0	1	0	2	1	45	2
Celtis gomphophylla	Cannabaceae	Indigenous	0	0	0	0	6	0	0
Citrus lemon	Rutaceae	Exotic	0	0	0	2	0	17	0
Combretum molle	Combretaceae	Indigenous	1	6	6	0	0	2	0
Combretum zeyheri	Combretaceae	Indigenous	0	0	2	10	0	0	0
Commiphora caurulea	Burseraceae	Indigenous	0	0	0	0	0	0	1
Cordia africana	Boraginaceae	Exotic	0	0	0	0	0	2	5
Cupressus lustanica	Cupressaceae	Exotic	0	15	0	0	16	11	9
Cussonia arborea	Araliaceae	Indigenous	1	2	17	4	0	0	0
Dalbergia boehmii	Fabaceae	Indigenous	0	0	49	4	0	0	0

Tree species name	Family	Origin	Cemetery	Conservation	Hill	Institution	Park	Residential	Streets
Dalbergia melanoxylon	Fabaceae	Indigenous	0	0	2	0	0	0	0
Dalbergia nitidula	Fabaceae	Indigenous	0	2	6	14	0	1	0
Dalbergiella nyasae	Fabaceae	Indigenous	0	0	1	1	0	0	0
Delonix regia	Fabaceae	Exotic	0	0	0	26	1	22	2
Diospyros zombensis	Ebenaceae	Indigenous	0	4	0	0	0	2	0
Diplorhynchus condylocarpon	Apocynaceae	Indigenous	4	0	39	11	0	0	0
Dombeya rotundifolia	Malvaceae	Indigenous	0	0	1	1	0	0	0
Dracaena fragrans	Asparagaceae	Indigenous	0	0	0	0	0	3	0
Dracaena steudneri	Asparagaceae	Indigenous	0	0	0	20	0	0	0
Ekebergia benguelensis	Meliaceae	Indigenous	0	0	0	1	2	0	0
Elephantorrhiza goetzei	Fabaceae	Indigenous	0	1	0	0	0	0	0
Eriobotrya japonica	Rosaceae	Exotic	0	0	0	0	0	6	0
Erythrina abyssinica	Fabaceae	Indigenous	1	0	0	1	1	1	0
Erythrophleum suaveolens	Fabaceae	Indigenous	0	7	0	0	0	0	0
Erythroxylum emarginatum	Erythroxylaceae	Indigenous	0	2	0	0	1	0	0
Eucalyptus camaldulensis	Myrtaceae	Exotic	0	0	5	16	0	1	2
Eucalyptus saligna	Myrtaceae	Exotic	0	3	29	5	10	0	3
Eucalyptus tereticornis	Myrtaceae	Exotic	0	0	0	0	0	17	0
Euphorbia ingens	Euphorbiaceae	Indigenous	0	0	0	1	0	2	0
Euphorbia leucocephala	Euphorbiaceae	Exotic	0	0	0	0	0	1	0
Ficus natalensis	Moraceae	Indigenous	0	0	0	6	0	0	0
Ficus Sur	Moraceae	Indigenous	0	1	0	0	0	0	0
Ficus sycomorus	Moraceae	Indigenous	0	0	0	1	3	1	0
Ficus thonningii	Moraceae	Indigenous	0	0	0	1	0	3	0
Ficus trichopoda	Moraceae	Indigenous	0	0	0	0	0	0	0
Ficus umbellata	Moraceae	Exotic	0	0	0	1	0	0	0
Ficus vallis-choudae	Moraceae	Indigenous	0	3	0	0	4	0	1

Tree species name	Family	Origin	Cemetery	Conservation	Hill	Institution	Park	Residential	Streets
Ficus variegata	Moraceae	Exotic	0	0	0	0	0	2	0
Filicium decipiens	Sapindaceae	Indigenous	0	0	0	0	0	1	0
Flacourtia indica	Salicaceae	Indigenous	0	0	0	0	4	4	0
Gmelina arborea	Lamiaceae	Exotic	0	0	20	0	0	0	0
Grevillea robusta	Proteaceae	Indigenous	0	0	0	5	6	0	0
Grewia micrantha	Malvaceae	Indigenous	0	0	1	0	0	0	0
Harungana madagascariensis	Hypericaceae	Indigenous	0	4	0	0	1	0	0
Holarrhena pubescens	Apocynaceae	Indigenous	0	0	3	3	0	0	0
Jacaranda mimosifolia	Bignoniaceae	Exotic	0	0	0	23	2	9	10
Julbernardia globiflora	Fabaceae	Indigenous	0	0	19	1	0	1	2
Khaya anthotheca	Meliaceae	Indigenous	3	13	0	5	34	4	25
Kigelia africana	Bignoniaceae	Indigenous	0	2	0	2	0	0	0
Lannea discolor	Anacardiaceae	Indigenous	0	0	6	2	0	0	0
Leucaena leucocephala	Fabaceae	Exotic	0	0	0	0	0	26	5
Liquidambar styraciflua	Altingiaceae	Exotic	0	0	0	5	0	2	0
Macadamia intergrifolia	Proteaceae	Exotic	0	0	0	0	0	1	0
Macaranga capensis	Euphorbiaceae	Indigenous	0	5	0	0	1	5	0
Mangifera indica	Anacardiaceae	Exotic	2	10	0	43	5	296	33
Margaritaria discoidea	Phyllanthaceae	Indigenous	1	3	14	5	0	0	0
Markhamia obtusifolia	Bignoniaceae	Indigenous	0	3	0	0	0	0	0
Maytenus senegalensis	Celastraceae	Indigenous	0	3	0	0	0	0	0
Melia azedarach	Meliaceae	Exotic	0	5	0	7	0	2	4
Millettia dura	Fabaceae	Exotic	0	1	0	0	0	0	0
Mimusops zeyheri	Sapotaceae	Indigenous	0	0	0	2	0	0	0
Moringa oleifera	Moringaceae	Exotic	0	0	0	0	0	7	0
Morus alba	Moraceae	Exotic	0	0	0	0	1	11	0
Newtonia buchananii	Fabaceae	Indigenous	0	42	0	0	0	0	0

Tree species name	Family	Origin	Cemetery	Conservation	Hill	Institution	Park	Residential	Streets
Ochna schweinfurthiana	Ochnaceae	Indigenous	0	2	0	4	0	0	0
Oncoba spinosa	Salicaceae	Indigenous	0	0	0	0	4	0	0
Oxyanthus speciosus	Rubiaceae	Indigenous	0	1	0	0	0	0	0
Ozoroa reticulata	Anacardiaceae	Indigenous	0	2	0	2	0	0	0
Parinari curatellifolia	Chrysobalanaceae	Indigenous	4	0	13	4	0	1	3
Parinari excelsa	Chrysobalanaceae	Indigenous	0	6	0	0	0	0	0
Parkia filicoidea	Fabaceae	Indigenous	0	1	0	4	1	4	4
Pericopsis angolensis	Fabaceae	Indigenous	3	8	8	0	0	0	0
Persea americana	Lauraceae	Exotic	0	1	0	4	0	94	1
Philenoptera violacea	Fabaceae	Indigenous	0	1	0	0	0	0	0
Piliostigma thonningii	Fabaceae	Indigenous	0	0	5	3	0	1	0
Pinus patula	Pinaceae	Exotic	0	0	0	3	0	1	3
Pittosporum viridiflorum	Pittosporaceae	Indigenous	1	2	0	0	0	0	1
Plumeria rubra	Apocynaceae	Exotic	0	0	0	5	0	29	0
Prunus persica	Rosaceae	Exotic	0	0	0	0	0	14	0
Pseudolachnostylis maprouneifolia	Phyllanthaceae	Indigenous	0	0	10	0	0	0	0
Psidium guajava	Myrtaceae	Exotic	0	0	0	11	8	51	12
Psorospermum febrifugum	Hypericaceae	Indigenous	0	0	0	1	0	0	0
Pteleopsis myritifolia	Combretaceae	Indigenous	1	0	7	0	0	0	0
Pterocarpus angolensis	Fabaceae	Indigenous	0	0	25	5	0	3	0
Rauvolfia caffra	Apocynaceae	Indigenous	0	2	3	0	0	1	0
Rhus longipes	Anacardiaceae	Indigenous	0	0	3	0	0	0	0
Rhus natalensis	Anacardiaceae	Indigenous	0	0	2	0	0	0	0
Ricinocidendron rautanenii	Euphorbiaceae	Exotic	0	0	0	0	0	0	2
Rourea orientalis	Connaraceae	Indigenous	0	1	0	0	0	0	0
Sclerocarya birrea	Anacardiaceae	Indigenous	0	0	1	0	0	0	0

Tree species name	Family	Origin	Cemetery	Conservation	Hill	Institution	Park	Residential	Streets
Senna petersiana	Fabaceae	Indigenous	0	0	0	0	0	1	0
Senna siamea	Fabaceae	Exotic	0	0	5	14	0	20	3
Senna spectabilis	Fabaceae	Exotic	0	0	0	1	5	6	0
Sericanthe domingensis	Rubiaceae	Indigenous	0	2	0	0	0	0	0
Shirakiopsis ellepticus	Euphorbiaceae	Indigenous	0	19	0	3	16	3	3
Spathodea campanulata	Bignoniaceae	Exotic	0	0	0	13	2	3	0
Steganotaenia araliacea	Apiaceae	Indigenous	0	0	1	0	0	1	0
Sterculia quiqueloba	Malvaceae	Indigenous	0	2	0	0	0	0	0
Stereospermum kunthianum	Bignoniaceae	Indigenous	0	0	2	0	0	0	0
Strychnos innocua	Loganiaceae	Indigenous	0	0	7	0	0	0	0
Strychnos spinosa	Loganiaceae	Indigenous	0	0	5	0	0	0	0
Syzygium cordatum	Myrtaceae	Indigenous	0	0	0	0	1	0	1
Syzygium cumini	Myrtaceae	Indigenous	0	0	0	1	0	2	6
Syzygium guineense	Myrtaceae	Indigenous	0	1	0	0	1	0	0
Syzygium manghamii	Myrtaceae	Exotic	0	0	0	0	0	3	0
Tabernamontana elegans	Apocynaceae	Indigenous	0	0	0	1	0	0	0
Tecoma capensis	Bignoniaceae	Indigenous	0	0	0	0	0	0	6
Tecoma stans	Bignoniaceae	Exotic	0	0	0	0	0	8	0
Terminalia catappa	Combretaceae	Indigenous	0	0	0	12	0	1	0
Terminalia ivorensis	Combretaceae	Exotic	0	0	0	21	0	0	0
Terminalia sericea	Combretaceae	Indigenous	1	1	3	4	0	0	0
Thuya orientalis	Cupressaceae	Exotic	0	0	0	12	0	0	0
Toona ciliata	Meliaceae	Exotic	8	5	7	14	22	24	5
Trema orientalis	Cannabaceae	Indigenous	0	0	0	2	0	0	1
Trichilia emetica	Meliaceae	Indigenous	0	7	0	0	4	0	1
Uapaca kirkiana	Phyllanthaceae	Indigenous	0	23	6	8	0	0	2
Uapaca sansibarica	Phyllanthaceae	Indigenous	1	0	0	1	0	0	0

Tree species name	Family	Origin	Cemetery	Conservation	Hill	Institution	Park	Residential	Streets
Vangueria infausta	Rubiaceae	Indigenous	0	0	0	0	0	4	0
Vernonia corolata	Asteraceae	Indigenous	0	0	2	0	0	1	0
Vitex agnus-castus	Lamiaceae	Exotic	0	0	0	0	0	2	0
Vitex doniana	Lamiaceae	Indigenous	1	4	8	8	0	4	0
Vitex payos	Lamiaceae	Indigenous	1	0	0	0	0	0	0
Xylopia parviflora	Annonaceae	Indigenous	0	2	0	0	0	0	0
Zahna golumgoensis	Sapindaceae	Indigenous	0	3	0	0	0	0	0
Ziziphus mauritiana	Rhamnaceae	Exotic	0	0	0	2	0	2	0
Ziziphus mucronata	Rhamnaceae	Indigenous	0	1	0	0	0	0	0
Grand Total		**Total counts**	**53**	**285**	**445**	**553**	**197**	**1015**	**221**

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