TURUN YLIOPISTO

Green landscapes in a city of millions

– Urban ecosystem services in Dar es Salaam, Tanzania

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Rapid urbanization in the becoming megacity of Dar es Salaam threatens the city's green environments in regard of both quality and quantity. Urban green environments provide ecosystem services that support people's everyday needs, and work as buffers for changes brought by climate change. Facing these challenges calls for urban resilience, that aims holistically for a more stable future. Developing and nourishing urban green environments promote resilience in manifold ways.

This study analyzed urban green environments in Dar es Salaam spatially and ecologically at landscape level and studied the provision of five selected ecosystem services as perceived by local experts. The studied ecosystem services were flood protection, food provision, heat stress protection, biodiversity, and social & cultural benefits. The study was based on using a combination of remote sensing and participatory GIS (PGIS) methods. Geospatial data of urban green environments was produced by calculating a normalized difference vegetation index (NDVI) from a Planet high-resolution optical remote sensing image, and the green environments were further analyzed using landscape metrics and holistic image interpretation. Ecosystem service provision was studied by conducting a map-based survey that applied an expert-based ecosystem service assessment matrix methodology. The assessment analyzed the provision of ecosystem services in green landscape character areas.

The results show that river valleys form the only green network in the city leaving many areas disconnected from it. An incomplete green network results in poor ecological connectivity and weakened provision of ecosystem services. Green environments are especially scarce in very densely built settlement areas. The importance of large vegetated green areas for the provision of ecosystem services was clear in the ecosystem service assessment, whereas food provision got prominently low scores, considering its importance for urban resilience. Social and cultural ecosystem services were noted to be provided by different green landscape character areas than other services. The methodological means of this study were seen as good examples of producing purpose-built data for resilience, but refinement of them is needed. Developing urban green environments in Dar es Salaam would strengthen urban ecosystem services and thus reduce the vulnerability of citizens when facing slow and abrupt change.

Key words: urban resilience, remote sensing, PGIS, ecosystem service assessment

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Nopea kaupungistuminen Dar es Salaamissa on kasvattamassa siitä pian megakaupungin, mikä uhkaa kaupungin viheralueita laadullisesti ja määrällisesti. Urbaanit viherympäristöt tarjoavat ekosysteemipalveluita, jotka tukevat ihmisten arjen perustarpeita ja toimivat puskureina ilmastonmuutoksen tuomille muutoksille. Näihin haasteisiin vastaaminen vaatii kaupungeilta resilienssiä, mikä tähtää kokonaisvaltaisesti mahdollisimman vakaaseen tulevaisuuteen. Urbaaneista viherympäristöistä huolehtiminen ja niiden kehittäminen edistävät resilienssiä lukemattomin tavoin.

Tässä tutkimuksessa Dar es Salaamin urbaaneja viherympäristöjä tarkasteltiin spatiaalisesti ja ekologisesti maisematasolla, sekä tutkittiin viiden ekosysteemipalvelun tuotantoa. Tutkitut ekosysteemipalvelut olivat tulvasuojelu, ruoan tuotanto, lämpöstressiltä suojautuminen, biodiversiteetti ja sosiaaliset & kulttuuriset hyödyt. Tutkimus perustui kaukokartoitusmenetelmien ja osallistavan paikkatiedon (PGIS) yhdistelmään. Korkearesoluutioisen optisen Planet satelliittikuvan ja normalisoidun kasvillisuusindeksin (NDVI) avulla tuotettiin paikkatietoaineisto kaupungin viheralueista, joita analysoitiin maisemaindeksien ja holistisen kuvatulkinnan avulla. Ekosysteemipalveluiden tuotantoa tutkittiin karttapohjaisella kyselyllä, jossa sovellettiin asiantuntijatietoon perustuva ekosysteemipalveluiden arviointimatriisia (*ecosystem service assessment matrix*). Ekosysteemipalveluiden arviointi analysoi ekosysteemipalveluiden tuotantoa viheraluepiirteiltään tunnusomaisilla maisema-alueilla.

Tuloksista voidaan havaita, että Dar es Salaamin viherverkosto koostuu ainoastaan jokilaaksoista, ja moni alue on siitä erillään. Puutteellinen viherverkosto johtaa heikkoihin ekologisiin yhteyksiin ja siten heikentyneisiin mahdollisuuksiin ekosysteemipalveluiden tuotannolle. Viheralueita on erityisen vähän hyvin tiheään rakennetuilla asuinalueilla. Suurien kasvillisuuden peittämien alueiden merkitys ekosysteemipalveluiden tuotannolle oli selkeä, kun taas maisema-alueiden ruoan tuotannolliset mahdollisuudet arvioitiin huomattavan heikoksi, kun ajatellaan niiden tärkeyttä urbaanille resilienssille. Sosiaalisten & kulttuuristen hyötyjen tuotanto huomattiin tapahtuvan eri maisema-alueilla kuin ekosysteemipalvelut tyypillisesti. Tutkimuksessa käytetyt menetelmät havaittiin hyviksi aihioiksi resilienssiä edistävien aineistojen tuottamiselle, mutta parannuksia niihin tarvitaan. Dar es Salaamin viherympäristöjen kehittäminen vahvistaisi kaupungin ekosysteemipalveluja ja siten vähentäisi kaupunkilaisten haavoittuvuutta hitaiden sekä äkillisten muutosten edessä.

Avainsanat: urbaani resilienssi, kaukokartoitus, PGIS, ekosysteemipalvelujen arviointi

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1 Introduction

The pressure of urbanization in the Global South is huge and makes it hard to manage the urban growth (Kraas & Mertins 2014; World Urbanization Prospects 2019). The unmanaged population growth in cities has led to well-known problems such as extensive poverty and environmental pollution. The lack of spatial plans or deficiency in their execution leads to informal settlements rising where the space is found. The green environments which, would support people's everyday needs, are left on the losing side in this battle for living space.

The idea of resilient cities has been brought to fore to meet this reality (McPhearson et al. 2011; Kuhlicke et al. 2020). The aims for and the benefits from resilience contribute to climate change mitigation and adaption, but resilience holds more than that. Resilience thinking aims to raise the quality of urban life by creating a well-functioning and easily adaptable city that enables the well-being of its inhabitants, and consequently, gives them ways to cope with external stress factors.

An important way to strengthen resilience in cities is giving the urban nature a chance to thrive (Making Cities Resilient 2017). Well-functioning ecosystems inside cities (1) work as buffers for slow and abrupt changes in the environment, and (2) have a fundamental role in the provision of ecosystem services, that can be directly utilized by people (Termorshuizen & Opdam 2009; McPhearson et al. 2011). In the rapidly urbanizing settings of the Global South, both of these ways of nature to generate well-being for people decline in the same pace with the urban green environments.

The term ecosystem services aim to describe the numerous ways in which humans benefit and depend on nature in both material and immaterial ways (Bolund & Hunhammar 1999; Cilliers et al. 2013). Whereas landscape services is a parallel term that makes their reviewing spatially explicit and bound to a certain time (Termorshuizen & Opdam 2009; Fagerholm et al. 2012). The path how an ecosystem function becomes a service or benefit for people include several steps, and these steps has been conceptualized by Potschin and Haines-Young (2011) as the ecosystem service cascade. The cascade makes the rather abstract concept more tangible and easier to implement in the policy level.

The research of ecosystem services at a landscape scale has been evolving rapidly in the last decades, developing the methodologies used as well (Andrew et al. 2014; Englund et al.

2017). Currently, majority of the research is done via remote sensing methodologies. Even though the effectiveness of them is outstanding, remote sensing does not necessarily identify well the local dynamics and complexities. Combining remote sensing methods with participatory GIS (PGIS) methods enables comprehensive reviewing of the topic (Fagerholm et al. 2012). PGIS methods can better understand and capture local processes, such as ecosystem service demand, therefore, produce more exact spatial data. Creating better spatial accuracy and bringing forth local solutions are steps towards resilience, too.

The emerging megacities of the Global South are often seen as clusters of problems, but the potential for positive change lies in them as well (Grimm et al. 2008). Enhancing the problems through systemic thinking and methods are seen as crucial ways to tackle the complex and dynamic reality (Fischer et al. 2015; Suárez et al. 2020). However, the challenges of the city dwellers cannot be solved without their participation and approval, and therefore engaging locals with the change is ever so important.

This study focuses on the spatial and ecological structure of green environments in Dar es Salaam, Tanzania, and the green environment’s ability to provide ecosystem services. To address these objectives, three research questions were set:

1. What are the spatial and ecological characteristics of urban green environments in Dar es Salaam?
2. How well do the landscape character areas of the urban green environments provide ecosystem services?
3. How can the produced green environment data help to foster urban resilience?

Since there is a little data and previous studies of the city’s green environments, the first research question focused on making a landscape level overview the green environments. This was done using a high-resolution optical remote sensing image and NDVI together with landscape metrics. The second research question aimed to attach the produced proxy data to the local settings. This was done through collecting local experts’ knowledge of the ecosystem services via an online PGIS survey, and an ecosystem service assessment matrix (Burkhard et al. 2012b) was compiled from the answers. Thirdly, the ways on how to use the produced environmental data for urban resilience are discussed using the UNISDR Ten Essentials for making cities resilient framework (Making cities resilient 2017).

Studying the urban landscape and its ecosystem services can help to promote the manifold benefits of urban nature, reveal side effects of urbanization, encourage sustainable and resilient planning, and hazard management. Using open-source data, PGIS methods and freeware enable repetition, refinement, and scalability of the study.

2 Theory

2.1 Rapid urbanization and decline of urban green environments in the Global South

2.1.1 Growth of megacities

Urbanization in the Global South is happening at rates which have never been witnessed before (Kraas & Mertins 2014; World Urbanization Prospects 2019). The process is much more rapid, complex, and dynamic than what has been experienced in the Global North. Urbanization refers to the phenomena where people move from rural areas to cities, in the hope of better life and income (Yamashita 2017). The biggest wave of urbanization in low-income countries of the Global South is happening between now and 2050, and the management of it is essential for achieving global sustainability (World Urbanization Prospects 2019).

Africa is currently the fastest urbanizing continent, but its population is yet mostly rural (World Urbanization Prospects 2019). The urban population in Africa is projected to more than triple between 2010-2050, from 395 million to 1.339 billion urban dwellers (Güneralp et al. 2017,1). Most of the urbanization in Africa is happening in small and medium-sized cities, but there is a high rate of urban primacy, meaning that every country has one city that is several times bigger, by population, economic activity, and many other measures, than the second largest city (Yamashita 2017; Güneralp et al. 2017). The development of these primary cities, a legacy from the colonial times, has enforced the current trend of urbanization where bigger and bigger cities are forming worldwide.

Currently, there are 33 megacities of over 10 million inhabitants in the world, which are strongly concentrated in the Global South (World Urbanization Prospects 2019, xix). Megacities hold enormous population and rapid development dynamics (Kraas & Mertins 2014). The bigger the city the more it allows to develop simultaneously in different parts of the city but also among different social groups in the city and that creates the vast complexity and dynamism in the urban development. Megacities have become of global importance because since they hold an enormous amount of people, they have an enormous impact on the surrounding world, too. There are clear challenges in the development of these large cities. However, if their urbanization is managed well enough there is also a huge hidden potential that can lead to positive development paths globally (Grimm et al. 2008).

The reality of many rapidly urbanizing cities, however, meets the definition of over-urbanization (Kraas & Mertins 2014; Yamashita 2017). This means that the city's neither governmental nor infrastructural structures and development cannot keep pace with the rising number of citizens and their needs, and this results in a high rate of informal markets and structures. Fundamentally, over-urbanization results from the situation where employment creation in the city is less than the population growth (Yamashita 2017,48), and it has a wide range of social and environmental consequences, such as extensive poverty, water and air pollution. These are problems widely in the cities of the Global South and they have roots in inadequate governance and persistent political instability (Güneralp et al. 2017).

The big cities of the Global South have been urbanizing without adequate planning for many decades now (Hill et al. 2014; Kraas & Mertins 2014). And most of the city area have developed under this time and under the informal circumstances. Informality is accepted as the way things are in many cities in the low-income countries. It means unregulated or illegal processes and markets that have emerged when formal processes and markets do not exist, or they reach only a few. Informal processes raise the level uncertainty in everyday life and make the overall governability of the city weak. However, they are many times the dominant processes and thus are hard to replace (Kraas & Mertins 2014).

2.1.2 Unregulated urban spatial development

The spatial characteristics of an informally developed city differs from a one which development has been guided by urban spatial planning (Kraas & Mertins 2014; Hill et al. 2014). Fundamentally, the urban landscape become more heterogenous by its land use and more densely built if no, or poor, planning takes place. Since there are no formal housing markets, people build houses where one happens to get a plot from the informal markets. Sometimes the settlement patterns are influenced by local customs such as building around the local church. This type of development forms unique urban settlements, patterns and landscapes, which often lack infrastructure and open areas, since there is no authority managing the whole.

In unregulated urban development the density of housing is mainly dependent on the neighborhoods inhabitant's income (Kraas & Mertins 2014; Hill et al. 2014; Todd et al. 2019). The low-income settlements have houses built directly next to each other without room for even basic infrastructure such as water pipes or roads passable by cars. This kind of urban pattern forms bottlenecks for the provision of everyday basics such as drinking water or emergency precautions and makes the settlement hard to access for the inhabitants themselves. The providers of infrastructure are usually in the hands of private companies, so the service provision is dependent on the company's interest.

The dense settlements are not dense only for the people, but also for the green environments. The urban green is pushed to a minimum and especially in low-income settlements single trees are all that is left. The correlation between urbanization and the amount of green space in the city has so far in the history been very straight forward ─ when urbanization increases, green space decreases (Mng´ong´o 2004; Chen & Jim 2008; Güneralp et al. 2017). This is many times not seen as a problem since the monetary gain from green environments is not straight forward and is still usually neglected. However, many urban settlers would benefit from diverse green environments in fundamental ways.

The urban land area only in Africa is going to increase by nearly 600 percent between 2000-2030, so the scale of the phenomena is growing significantly (Güneralp et al. 2017,3). 600 percent may not be a lot when referred to the total land area of Africa, but many of the urban agglomerations locate in places which are vital for the local ecosystems, such as river deltas, which are important and rich habitats for both plant and animal species (Grimm et al. 2008; Zipperer 2008). Ecosystems are tightly interconnected systems and when you disturb one part of it, the effects can be seen elsewhere, too. Species need a certain habitat, and they cannot move to any place which happen to be left unpopulated. Therefore, even though the urbanized land areas are, and will be, covering a relatively small percentage of the land, they are still a real threat to many species, habitats, and ecosystems.

The decline of green environments in an urban area occur in two ways, in quantity and quality (Grimm et al. 2008; Niemelä et al. 2010; Richards et al. 2017). Quantity means the amount of green areas in the landscape, and quality means that the green environments are less suitable as habitats for species than they have been, and therefore, the remaining green environments have a poor biodiversity. Also, the human preference affects especially the plant species diversity in urban landscapes and many highly managed green areas, such as parks, are less likely to maintain critical ecosystem services than more natural areas. Urban areas can also create biodiversity since they are a distinct habitat that can have a big variety in the environmental conditions and form very specific sub-habitats where species can evolve (Krellenberg 2007; Grimm et al. 2008).

A high quantity of green environments is a precondition for the urban landscape to have a high biodiversity (Krellenberg 2007). Without sufficient quantity of green areas, it is not possible to have them effectively connected to one other to create a network that enable dynamic ecological processes. This fragmentation of green areas due to the decline in their quantity, therefore, leads to decline in their quality.

Better connectivity - and so a better quality - of urban green areas requires both structural and functional connectivity (Wu 2008). Structural connectivity meaning that the connections must be well connected spatially and functional connectivity meaning that the connections need to work well for different ecological processes, for instance for pollination and movement of different sized species. Also, the scale of examination is an important factor when talking about ecological processes. For the management of functional green spaces for both humans and nature it is important to look at the green connections at different scales and pay attention to the patterns they form. The connectedness needs to work at all scales ─ from connections inside a green area, to connections of the whole urban green network to major green areas outside the city.

There are a handful of challenges in the management of urban green areas, which affect their decline and make it harder to restore them (Herslund et al. 2018). The green environments in a city are rarely managed as a whole and there are physical and abstract boundaries in the management because of administrative units or many different landowners. These boundaries do not exist in nature and a holistic way of management would contribute to urban sustainability. Holistic management includes both managing the area without unnecessary administrative boundaries and including all kinds of green environments as part of the green network. Many times, the definition of green areas is too vague, and large areas result in being excluded from green area management. This issue is evident especially in the Global South, where majority of the green areas might be privately owned (Cilliers et al. 2013; Herslund et al. 2018).

2.1.3 Ecosystem services of urban green environments

Urban areas are conventionally thought as separate from nature (Bolund & Hunhammar 1999; Grimm et al. 2008; Niemelä et al. 2010). This polarized view sees cities as centers of consumption and the surrounding, and far away, hinterlands as a provider for the urban life. This discourse allows the decline of green environments in urban areas, since their benefits are not truly recognized and thus their protection is not prioritized. However, natural ecosystems sustain all life on earth and are vital for human well-being everywhere, also in the urban surroundings. The importance of nature can be conceptualized through ecosystem services, which are nature goods and services that provide benefits to people (Niemelä et al. 2010; Burkhard et al. 2012a).

In the rapidly urbanizing context of the Global South, people are dependent on ecosystem services in their daily lives (Cilliers et al. 2013; Mlozi et al. 2014; Constanza 2016). Many of these services are linked to basic human needs and well-being. Small-scale agriculture and food gathered straight from nature are the basis of survival to people with low income globally and the urban people are no exception. Also, it is not only the low-income people that the ecosystems services are for, but they are important for all people around the globe and despite of income level (Bolund & Hunhammar 1999; Burkhard et al. 2012a). Many issues in urban areas are locally created and the only sustainable way to deal with these issues is locally, too. Without ecosystem services people are exposed to e.g., extreme weather events or locally generated pollution problems that will affect them whether they are rich or poor. The only way to deal with these problems are through local solutions.

Ecosystem services are classified to four types of services, provisioning, regulating, cultural and supporting services that maintain the other four types of services (MA 2003). Provisioning services refer to goods that can be consumed as such, e.g. food and timber. Regulating services are ecological functions and processes that regulate the nature around us, such as air purification, heat leveling and nutrient cycling. People use the regulating services secondary for e.g. cultivation or by breathing clean air. Cultural services refer to those that affect humans' psycho-physical and social well-being such as the presence of natural elements in their surroundings.

These examples of ecosystem services highlight that ecosystem functions only become services when they are used by people. Potschin and Haines-Young (2011) have conceptualized this as the ecosystem service cascade (figure 1), which is a pragmatic way of linking nature and what it provides for people. The service cascade is built on the idea that there are several steps in between nature's biophysical structures and process, through which they become something that has value for people. The model also presses that the use of ecosystem services creates pressure to the biophysical structures and process and that there are several steps on which policy action can be aimed at to sustain the natural capital. The cascade not only makes the ecosystem service concept tangible to other stakeholders than those in the scientific community, but also describes the scientific discussion around the topic and the key elements that it consists of.

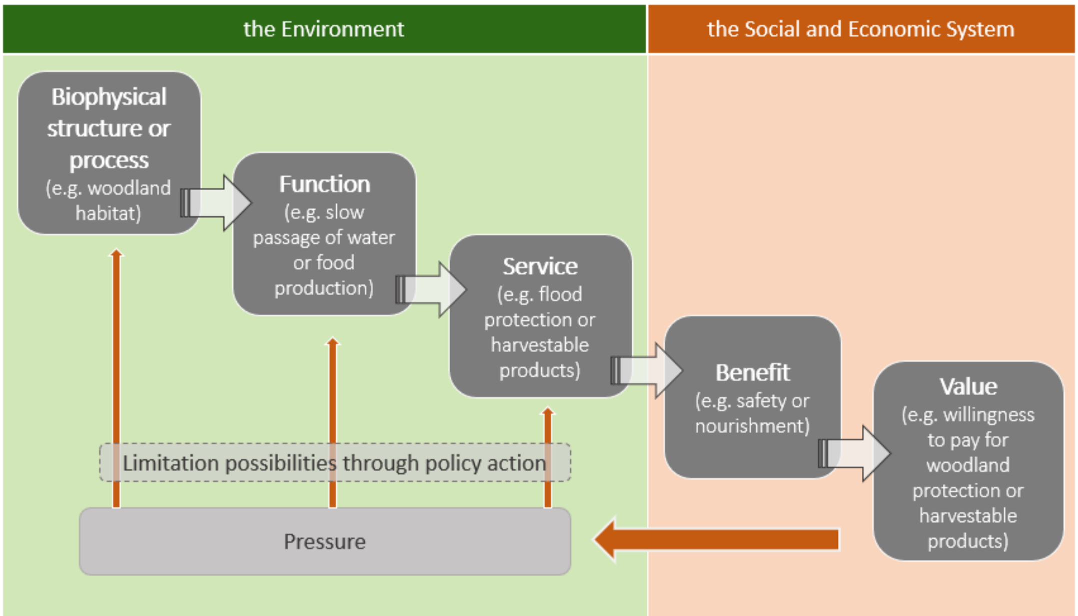


Figure 1. The ecosystem services cascade that models the steps how nature's biophysical structures and processes are linked to human needs and well-being and how the usage of the ecosystem services causes pressure back to nature's processes. There is no one correct way of putting together the cascade, but it can be constructed in many ways. For a final service, benefit, or value there are multiple structures and processes that support them. (Potschin & Haines-Young 2011, modified).

Ecosystem services in urban areas create healthy and resilient living environments (Richards et al. 2017; Kuhlicke et al. 2020). Even though there is a strong scientific consensus on this matter, green environments are not effectively implemented in planning (Burkhard et al. 2012a). In the Global South context there is a general lack of urban planning activities and even when the planning is done, it might be guided strongly by other, often private sector, interests and forces (Kraas & Mertins 2014). Also, ecosystem services is not necessarily an easily understood term and its understanding requires a good acknowledge of how the local ecosystems work (Niemelä et al. 2010). The term might also provoke attitudes for exploiting nature as other services are exploited rather than giving nature the opportunity to thrive.

However, the use of the term ecosystem services is getting more popular and it is broadly seen as a useful concept to promote the benefits of nature to people and to frame important questions that need to be asked to achieve sustainability (Burkhard et al. 2012a; Potschin & Haines-Young 2011). The ecosystem service framework combined with the service cascade model creates possibilities for policy action to embrace the question one step at a time and restrain the use of ecological systems. Also, the framework permits monetary evaluation of ecosystem services that is at times seen necessary to spotlight their value (Potschin & Haines-Young 2011; Cilliers et al. 2013).

2.1.4 Towards resilient cities

The concept of resilient cities been brought to fore to meet the reality of rapid urbanization, the decline of urban green and the uncertainties brought up by the climate change, among other contemporary challenges (McPhearson et al. 2011; Kuhlicke et al. 2020). Resilience has multiple definitions, but most of which have the same core (Meerow et al. 2016). Summarizing the definitions of Ahern (2011,341) and McPhearson et al. (2015,153) resilience means the capacity to dynamically cope with abrupt or slowly occurring challenges or uncertainties. Having this capacity, it is possible to continue being functional regardless of the challenges and find a way forward, perhaps to a new direction.

Before the latter half of the 20th century the concept of resilience was used among scientist mainly to describe the capability of nature, but also other matters, to bounce back after a shock or change (Meerow et al. 2016; Kuhlicke et al. 2020). This was challenged by Holling (1973), who widened the concept by spotlighting that nature actually has multiple states of stability. During the last 20 years the concept has become more holistic including both ecological and social resilience (Kuhlicke et al. 2020). This started first from the research of social and ecological systems, through which the resilience of social systems was also brought to fore. This formed the concept to be more future-oriented, too, changing the meaning more towards bouncing forward.

Until the last ten years or so, the concept of resilience was mainly used in the academic world, but now it has been brought up and to use in the policy level as well (Meerow et al. 2016; Mykhnenko 2016; Kuhlicke et al. 2020). The global challenges of environmental change, threats of national and international security, international migration, global economic turbulences, to name a few, has been seen to rise feelings of exposure and vulnerability that has increased the willingness and need for resilience thinking. Coming to the 2020's the resilient cities are now in the center of the work of big stakeholders, such as the UN (see e.g., Urban Resilience Hub s.a.), the World Bank (see e.g. Tanzania Urban Resilience Program 2022), and the Global Facility for Disaster Reduction and Recovery (see e.g., City Resilience Program 2020).

Resilience is easily understood as a rather abstract concept but implementing it in the policy level makes it tangible for stakeholders. In the policy level resilience culminates to implementing steps through which it can be pursued and achieved. The United Nations Office for Disaster Risk Reduction (UNISDR) has clarified resilience into the Ten Essentials, which were updated 2017 (Making Cities Resilient 2017) (figure 2). The meaning of these essentials is to point out concrete steps of how to work towards resilience.

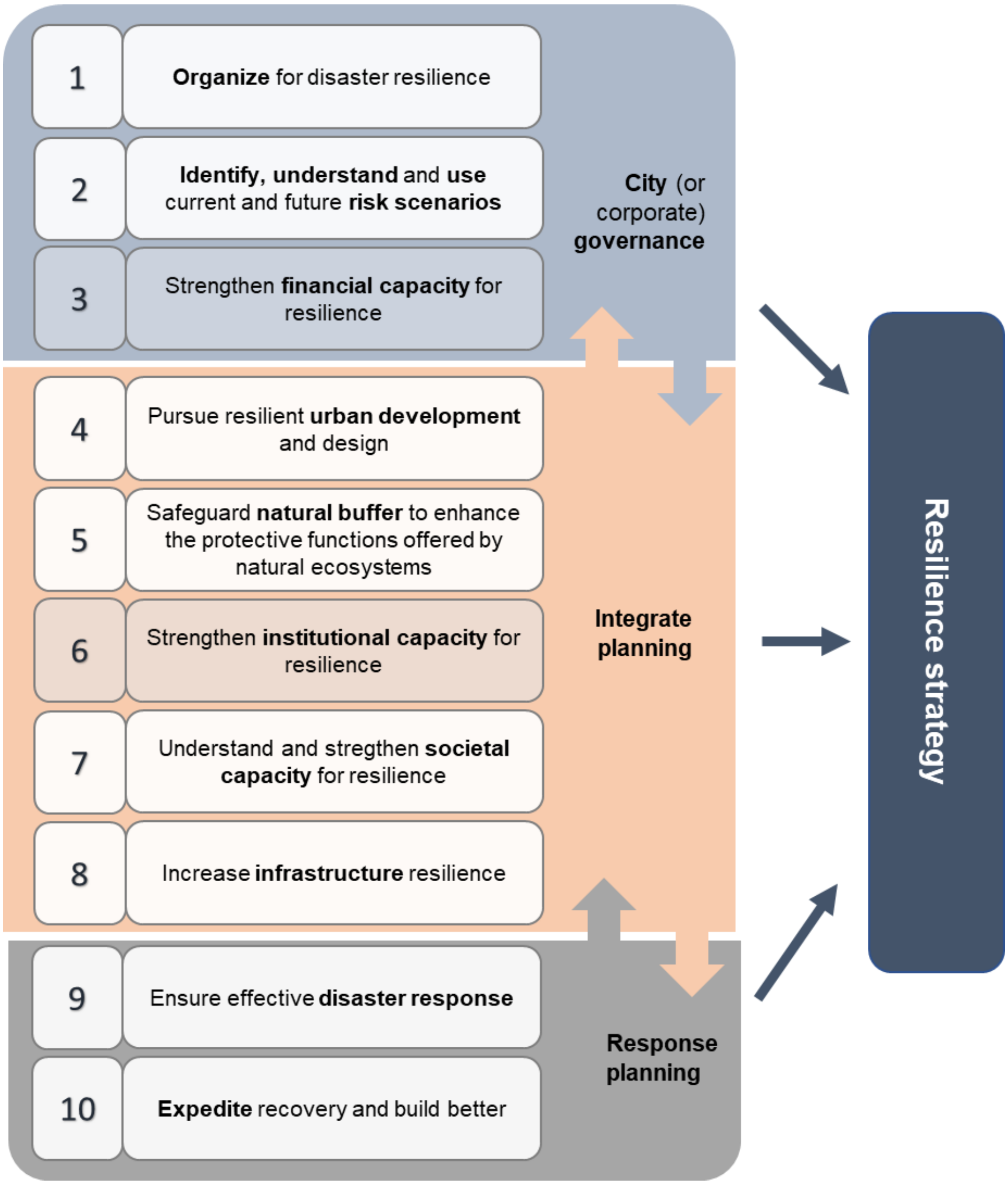


Figure 2. The Ten Essentials of the UNISDR Making Cities Resilient handbook (2017, modified) which focuses on advocacy activities to achieve urban resilience. All but two of the Ten Essentials directly relate to urban green environments. This underlines how vital urban green environments are for urban resilience. The two Essentials which are not related to the topic are 3 and 6 (pale white). The Essential 1 is seen related since it enables working on all the rest of the Essentials.

Many of the Ten Essentials are related to green environments and ecosystem services. This points out how holistically enhancing urban green development can contribute to achieving resilience (Making Cities Resilient 2017). Improving urban ecosystem services can give people actual ways and abilities to cope with external stress factors. This starts from filling people's basic needs, such as access to nutrition. Ecosystem services do not, however, provide people with only direct help, but also makes living more resilient in many indirect ways.

The key idea of resilience is to promote the well-being of both humans and nature in the changing world, and this can come in the same package, by enhancing the urban nature (McPhearson et al. 2015; Making Cities Resilient 2017). Even though resilience is currently an ambiguously defined concept it is noteworthy that there is a strong consensus in the scientific literature that resilience is a positive concept through which it is also possible to change the direction of negative development paths and to enhance the positive accumulation in the rapidly developing megacities (Kraas & Mertins 2014; Meerow et al. 2016).

2.2 Urban landscapes

2.2.1 Landscapes as social-ecological systems

As urbanization continues, the life in cities shapes its' landscapes at a fast pace. Urban areas, in which people live at high densities and where built structures cover much of the land surface, are where a landscape is the most notably created and actively used by people (Pickett et al. 2011, 333; Dobson 2018). A landscape, defined in landscape ecological terms, is a very heterogeneous area, that consist of different sized and shaped smaller areas, patches (Turner et al. 2001, 3). The patches are homogeneous inside them, but they have borders when compared to their surroundings. An urban landscape in the Global South, is typically even more heterogeneous than the in the Global North, due to the different cultures, history and capacities of spatial planning (Kraas & Mertins 2014).

The basic idea of landscape ecology is that the spatial patterns affect the ecological processes in a landscape and vice versa (Turner et al. 2001). However, the patterns of human influenced landscapes do not come just from ecology, but the cultural, historical, and political aspects have a crucial role in shaping them (Arts et. al. 2017). All landscapes have formed as a result of many historical happenings which have affected the land use type in a temporal perspective. These happenings have been both natural and human affected. Understanding the historical perspective of landscapes is crucial for interpreting the present patterns because the present state of a landscape is always a sum of everything that has happened in the past. In other words, knowing the past helps to understand the present.

Since landscapes are so strongly influenced by humans, the term ecosystem services become vague in the mouth of landscape ecologists. To better match the perspective, that is strongly connected to its' spatiotemporal frame, the term landscape services, has been proposed and discussed instead (Termorshuizen & Opdam 2009; Fagerholm et al. 2012). Landscape services is a complementary concept with ecosystem services and makes their reviewing spatially explicit and bound to a certain time. The term ecosystem refers only to the biotic and abiotic natural world and its' interconnections, but a landscape is a more interdisciplinary and holistic concept and refers to a human-ecological system. A landscape consists of both natural and human affected patterns and is a result of strongly contextual occurrences, which is why the landscape is attached to a spatiotemporal frame (Arts et al. 2017).

The landscape service concept also recognizes the value that humans put to the landscape, without the human influence many ecosystem services are only natural functions and processes which do not automatically turn into benefit for people (Termorshuizen & Opdam 2009; Haines-Young & Potschin 2010; Fagerholm et al. 2012). Landscape services are of greatest use when connecting the ecosystem and landscape services to the benefits that people get from them. Ecosystem functions turn into ecosystem and landscape services when they are valued by humans.

As the urban landscape is heterogeneous and consists of patches, that can be identified as settlements, industrial land, agriculture, wasteland or a maintained or natural green environment, to name some examples, the landscape is a sum of the processes of both humans and nature (Turner et al. 2001). However, in the urban surroundings, the influence of human actions is many times dominant and affects natural processes, in one way or other. For these reasons the urban landscape fits well the definition of a social-ecological system since these both systems have their part in the whole.

The social-ecological systems (SES) approach has been created to better highlight the interconnectedness of the social and the ecological system (Berkes & Folke 1998; Herrero-Jáuregui et al. 2018). The social system refers to what is conventionally seen as the human system, that in urban settings can consist of e.g., knowledge, the physical structures of a city, and the interaction between people. The ecological system, in the other hand, refers to what is conventionally seen as the natural system, consisting of the biotic and abiotic parts of the natural world. In urban settings, separating these two become hard and rather unpractical since the two systems are existing hand in hand.

Another reason for the emerge of the SES approach has been the need for more interdisciplinary knowledge production in the era of climate change and other global challenges, such as rapid urbanization (Ostrom 2009; Fischer et al. 2015; Herrero-Jáuregui et al. 2018). Social and ecological phenomena have traditionally been studied separately among different disciplines and with different theories and methods, without establishing too many transdisciplinary linkages. This way the created knowledge stays isolated and creating a holistic understanding of the system is not possible. The SES perspective seeks to bring the two sides together to

1) foster comprehensive understanding of systems and to
2) enable interdisciplinary knowledge creation.

The SES approach has been discussed and conceptualized by e.g. Berkes & Folke (1998), Ostrom (2009) and Suárez et al. (2016). Who all have their own focus and perspective on the matter. Recently SES has been mostly used to study themes such as resilience, ecosystem services, sustainability, governance, and adaptive management (Herrero-Jáuregui et al. 2018). Thus, the SES approach is used in various ways and with various methods and there is no one good way of implementing it. SES is also used to show the context and perspective to the study, without further defining or discussing it. What seems to be the consensus, however, is that a SES always consists of several subsystems and that the system is never stagnant, rather it constantly evolves in nonlinear ways (McPhearson et al. 2015; Meerow et al. 2016).

The SES approach in cities has even been argued to be critical to secure the resilient provision of ecosystem services, and thus also, is critical for the human well-being (McPhearson et al. 2015; Making Cities Resilient 2017). This links to the ability of SES, as a systemic approach, to see the urban system holistically and realize the linkages that resilient ecosystems provide for the whole system. Ecosystems in and outside the city reduce risks from hazards, buffer impacts of climate change, and at the same time help to fulfill the basic needs of everyday life regarding nutrition and a healthy living environment, among other.

The SES approach has been mostly used in research of the Global South and most of this has been done in affiliation with the institutions of the Global North (Herrero-Jáuregui et al. 2018). This research setting must always be realized and its' effects on the results should be minimized by e.g., incorporating local knowledge in the research process. Also, possible solutions or conclusions must be thought carefully and subjectively to the local context, and no conclusions should be generalized and implemented in other context of the Global South without further consideration of the local SES.

Systems science perspectives, as landscape ecology and the SES approach, both meet the contemporary need for interdisciplinary knowledge creation (Fischer et al. 2015). Systems thinking has become a core methodology and a way of thinking that helps to enhance and tackle complex issues and enable transdisciplinary work.

2.2.2 Methodologies for mapping ecosystem services at a landscape level

Research methodologies for mapping ecosystem services at a landscape level are diverse, and accordingly, they produce a good range of different types of data (Andrew et al. 2015; Potschin & Haines-Young 2016; Englund et al. 2017). Diverse and many times complementary methods help to form a holistic understanding of the topic. On the other hand, the different types of data produced become easily inconsistent as whole and are incomparable to each other, and this does not promote the use and implementation of ecosystem service based thinking at the policy level.

Regardless of the multitude of methods, the service cascade model (figure 1) has been well adopted in research to demonstrate the study perspective (Potschin & Haines-Young 2016; Maes et al. 2016). The data and results concluded with disperse methodologies are hard to grasp on, if you are not an expert on the field, and referring to the cascade model can make it easier to comprehend which step of the cascade is discussed. This way the study results can also be easily communicated forward.

Currently, the most popular way to map ecosystem services are proxy methods that are mainly based on remote sensing data and techniques (Andrew et al. 2014; Liquete et al. 2016; Englund et al. 2017). Remote sensing provides easily accessible, temporally, and spatially consistent and comprehensive datasets, that make analyzing efficient and easy compared to field studies. Satellites can monitor elements in the landscape and this data can be associated with one or several steps of the ecosystem service cascade via proxies or indicators. Later socio-economic data can be compiled with remote sensing data to address the benefits that ecosystem services create to people.

Even though remote sensing methods are widely used for their efficiency, there are several downsides or risks in their use (Englund et al. 2017). The spatial resolution of remote sensing data varies a lot and there is a considerable risk of generalization error, both in the research process and in the later use of the results. Especially the scale, in which the data is suitable to be used, must be well thought and communicated, so that the results will not be generalized to a scale that they are not suitable for. Proxy methods are also prone to undermine the processes, dynamics, and complexities of a landscape and therefore, are at their best when the results are well validated through ground truthing, and maybe even combined with other types of data. However, remote sensing based proxy methods are outstanding for identifying broad-scale trends and for rapid assessments.

Another way to map ecosystem services are through participatory GIS (PGIS) methods (Brown & Fagerholm 2015; Englund et al. 2017). These approaches emphasize participation of local stakeholders and understanding of the context and thus, are in some ways even contrary to the proxy methods. The PGIS methods focus on analyzing bundles of services provided by a particular landscape, that being the typical scale. This enables holistic reviewing, and also examination of trade-offs and synergies between services. The PGIS methods lean on the idea of crowd wisdom, where complex problems can be tackled with collective intelligence (Brown & Fagerholm 2015). The involvement of stakeholders in the research process can also raise motivation and level of knowledge needed for the implementation of the results in practice.

There are various ways to collect PGIS data for ecosystem service assessments and one way is to collect it through expert participation (Andrew et al. 2015). Expert opinions can provide valuable knowledge about local values and needs, that create the demand for ecosystem services. This form of data collection can be useful especially when there is a lack of adequate data or other resources and it has been used in assessments done in the Global South (see e.g., Fagerholm et al. 2012; Sieber et al. 2021). The collection of expert opinions can be conducted in several ways, such as through matrix approaches and social landscape value mapping.

Matrix approaches, that aim to summarize expert opinions to an easy-to-understand tables, have been widely adopted especially after Burkhard et al. (2012b) proposed a well described methodology for an expert-based ecosystem service supply matrix. The matrix links spatial landscape units to ecological information. Local experts of the topic give a score from 1 to 5 to each cell of the matrix and the outcome is calculated from averages of all answers. This approach involves the common challenges of participatory mapping methods, but suggestions have been made to improve the quality of the assessment (Jacobs et al. 2015). The suggestions include asking experts the confidence of the answers given and providing a clear description of the method used and whose opinions it includes. Recently, the matrices have included a confidence index for better quality control (see e.g., Sieber et al. 2021).

Social landscape value mapping is another way to involve locals in the assessment process (Raymond et al. 2009; Fagerholm et al. 2012). This approach highlights the need to map community values to achieve holistic reviewing of ecosystem services, when usually economic and biophysical values are given more importance. In this method not only expert opinions are collected, but more broadly local stakeholders, who optimally represent all groups of the society.

The social landscape value mapping can be performed in a workshop, through a map-based survey, or other platform found suitable in the study's settings (see e.g., Raymond et al. 2009; Fagerholm et al. 2012; García-Díez et al. 2020). Aerial images have been found to be a powerful tool which can be utilized in the mapping itself and depending on the context, either a digital survey platform or even printed aerial images can be used (Fagerholm et al. 2012; García-Díez et al. 2020). It is good to have in mind that not always a digital platform is the most suitable for the target group, even though that have become the norm in the recent decades. However, methods leaning to face-to-face interaction are many times not possible to conduct for the lack of resources.

Since the PGIS methods to map ecosystem services are based on involvement of local stakeholders, there are several things to consider in their use (Brown & Fagerholm 2015; Andrew et al. 2015). The informants can have a very different perception of the handled terms, topics and the drivers behind them, due to different backgrounds and values. To collect quality data, it needs to be assured that the informants have sufficient knowledge and understanding of the topic, so that the facilitators and informants are on the same page.

Sometimes data collected with PGIS methods are only seen as directive and that quality data is collected with methods of more exact accuracy (Andrew et al. 2015). However, McCall (2006) and Fagerholm et al. (2012) argue, that even though the nature of participatory data is not exact, and it many times includes ambiguity, this is nature of landscape services in the real world as well. Collecting as exact data as possible might not even be functional in the complexity of local contexts. But even more importantly, in the occasion of PGIS data, the methods need to be described in a way that not only explains the process, but also allows its' repetition (Brown & Fagerholm 2015).

As ecosystem services exist globally at all scales, they are studied at all scales from global to local, too (Kienast & Helfenstein 2016). The landscape level, presenting a medium-scale area of the earth's surface, is considered important since it captures the processes related to the ecosystem services better than a very local perspective. Many ecosystem service assessments are based on widely available spatial datasets, such as land-cover data, that also affects the scale of the study (Andrew et al. 2015). Using secondary data, that is not created for the study's purpose, has also been found to lead to simplified assumptions of ecosystem services.

To avoid simplifications, Andrew et al. (2015) have concluded that quantitative spatial data would better represent the ecosystem's properties and help on creating more accurate and reliable results. One way of producing better fitting quantitative spatial data is through landscape ecological methodologies, such as holistic image interpretation, landscape character mapping and landscape metrics (Antorp & Eetvelde 2000; Käyhkö et al. 2018).

Holistic image interpretation is a way of understanding the complexities of a landscape (Antorp & Eetvelde 2000). It leans to the idea of holism in landscape ecology, where a landscape is considered a complex whole that is more than the sum of its composing parts (Antorp & Eetvelde 2000,43-44). This indicates the fundamental idea of landscape ecology, where the patterns and processes of a landscape constantly shape each other's. The human perception is able of characterizing and distinguishing the spatial patterns that lie in the landscape, and landscape characters that are important from the point of view that he is looking from. Image interpretation is a highly objective method that depends from the interpreter's background views and perceptions as well as the aims of the study.

Holistic image interpretation can lead to classification of the landscape through landscape character mapping. Landscape character mapping aim at communicating spatial features of a landscape in a simplified form, so that they become easily interpretable for stakeholders (Käyhkö et al. 2018). Interpreting a landscape is strongly contextual since it depends on the interpreter's values and knowledge. What forms a meaningful feature to map or how it is named are strongly contextual choices affected by the social and cultural circumstances of the interpreter.

Regardless of landscape character mapping's contextuality, it has been found to be a useful tool to deal with the contemporary global challenges and building resilient cities and societies (Fairclough et al. 2018). Landscape character mapping can help to address many challenges from climate change mitigation and adaption to the decline of green environments. The methodology also suits well the need of ecosystem service assessments since landscape and patch characteristics has been found to influence the quality and amount of various ecosystem services (Andrew et al. 2015). In fact, landscape structure can be more explanatory of the spatiality of ecosystem services than the widely used land-cover and land-use (LULC) data.

The spatial approaches to ecosystem service assessments enhance variables that are seen as important in the search for resilient futures (Potschin & Haines-Young 2016). Proxy methods enable wide-scale examination of the spatiality and trends of ecosystem service supply. Yet, proxy methods are well capable to map the supply of services, but the demand for them is always produced locally by the people. More local methods are able to assess the multifunctionality of landscapes, as they combine transdisciplinary methods and systemic ways of thinking. Enhancing the local context through participation gives a chance to create meaningful solution-oriented research that can be embraced by locals already during the process and be well implemented afterwards.

3 Study area: Dar es Salaam

Dar es Salaam is Tanzania's largest city with estimated population of 7 million inhabitants (Dar es Salaam Population 2021). It is expected to be a megacity by 2030, making it one of the fastest growing cities in Africa and the biggest urban area in East Africa (Hill et al. 2014; Guma 2016). Dar es Salaam's location at the coast of the Indian Ocean with a large port in the city center and the status as the old capital of the country have ensured a long-lasting urban growth. The city has been urbanizing significantly since 1970's, and currently, natural population increase in the city has overruled rural to urban migration as main driver of population growth, since birth rates of the inhabitants have remained big.

The urban structure of Dar es Salaam has clear marks from previously occurred planning (Todd et al. 2019). The city development was more or less guided by masterplans from 1949 to 1992, when the Sustainable Urban development Program (SUDP) was introduced for better planning. Many of the master plans were insufficient from the beginning and were never through toughly implemented. Establishment of the SUDP strategies included introduction of environmental management, too, and at that time, eight priority environmental issues were identified: solid waste management, informal settlements, conflicts, urban renewal, traffic congestion, air, surface and groundwater pollution. The history of failed master plans reached to the implementation of SUDP strategies, and their implementation remained poor.

During the 21st century, removal of informality and regularization of unplanned settlements have been key topics of urban development and, most recently, this has been done through private partnerships (Todd et al. 2019). The 21st century planning has been done through project-based development plans in the cross pressure of accelerating urbanization and external donors funded projects, which have not necessarily been aligned with existing development plans. The lack of coordination between (privatized) sectors providing basic level social services and the lack of involvement of local leaders in land ownership questions are some of the remaining challenges of urban planning. Today, the city is still lacking a legal plan of urban spatial development.

Even though these efforts have had their footprint in the urban structure of Dar es Salaam, the vast majority of the city area has developed under informal circumstances. In the beginning of 2010's 75 % of settlements were informal (Guma 2016, 37-38), and this trend has presumably been rising. Informality has been the norm for decades and there are path dependencies that favor its continuation. The provision of basic services has mainly been privatized and the provision basic infrastructure such as water pipes are in the hands of the law of demand and supply (Hill et al. 2014).

The unplanned urban spatial development can be noticed in the patterns of the city's landscape (figure 3). As typical for a rapidly developing city in the Global South, the landscape is formed by very heterogeneous patterns, dense housing, industrial clusters and only a little open space. In Dar es Salaam, an industrial cluster splits the city along a railway line built in the colonial era. Also, the four highways leading out of the city affect the urban pattern.

The rapidly self-developing small-scale urban land-use patterns in Dar es Salaam are guided by larger-scale natural boundaries such as rivers, creeks, and the Indian ocean coastline. The major rivers flowing through the city are the regularly flooding Msimbazi river, that crosses important roads and creates a big river valley near the city's Central Business District, other two major rivers, the Kizinga river and Mzinga river flow into the bay splitting the city. The Central Business District is located on the west bank of the bay and near the ocean coastline.

Dar es Salaam belongs to the tropical savanna climate (Aw) of the Köppen-Geiger climate classification (Beck et al. 2018) and to the biome of tropical and subtropical moist broadleaf forest (Olson et al. 2001). The rain season occurs twice a year in March-May and in November-December, and the winter rains are fewer compared to summer rains (Climate Dar es Salaam 2019). Vegetation is partly phenological due to the dry seasons in between rains. Dar es Salaam, as the whole east coast of Africa from Cape Horn to the Horn of Africa, belong to a biodiversity hotspot area in global terms (Karutz et al. 2019; Noon et al. 2022). The East African Coastal Forests provide habitat for many endemic species and host e.g., mangrove forests that are not only vital as habitats but as a significant carbon storage, too.

A major contemporary challenge in Dar es Salaam is the flooding of rivers in the rainy season, especially the Msimbazi river floods may cut major roads even twice a year (Karutz et al. 2019). The dominance of built-up environment in the urban area and natural surfaces hardened by dry season lead to the overflow of water channels when the rains come. The problem is exaggerated by a malfunctioning drainage system in the city as well as land degradation in the catchment areas of the rivers.

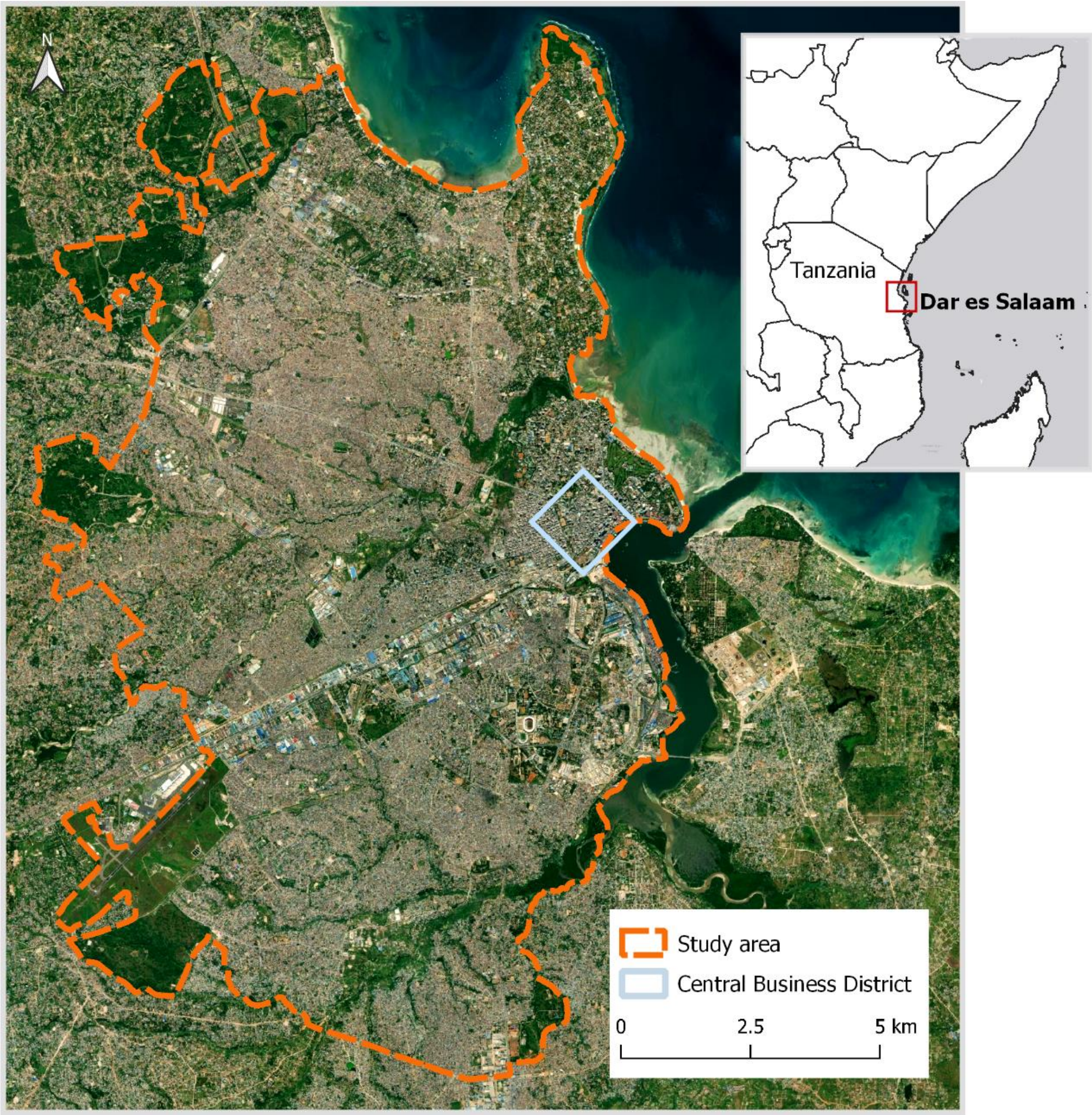


Figure 3. The study area includes the most densely built part of the city and the large green areas connected to it.

The study area represented in figure 3 includes the most densely built urban area of Dar es Salaam. The area is generally referred to in this study as the dense urban area. The decline of green environments inside this area relate mostly to densification processes of the city structure (Karutz et al. 2019). The study area locates in the municipalities of Kinondoni, Ubongo, Ilala and Temeke of the Dar es Salaam region. The most peripheral wards of these municipalities were dropped off since their settlement structure was looser than in the dense urban area. The administrative wards bordering the study area from north to south were Kawe, Makongo, Ubongo, Makuburi, Kimanga, Liwiti, Vingunguti, Kipawa, Kitunda, Kiburugwa, Mbagala, Mbagala Kuu and Kijichi (these wards are inside the study area), the border of the study area does not necessarily go along with the ward borders but along the landscape patterns inside these wards. The population density in the study area ranged from 2 827 (Kivukoni) to 47 246 (Tandale) persons per km^2 (Population and housing census… 2013).

4 Data and methods

4.1 Research methodology

The methodological workflow of the study was a three-step process (figure 4). The workflow started by going through existing and open-source datasets in Climate Risk Database (2022) and the study approach was further defined by the existing data and travel restrictions brought by COVID-19. In the Step 1 an NDVI was calculated from a Planet satellite image to extract information about green environments in Dar es Salaam. The formed data was sampled, and landscape metrics were calculated for the samples to analyze the green environments in landscape ecological terms. The Step 2 included a visual interpretation of the city's landscape, based on which, a landscape level classification of the green environments was made.

The classification was used as a base for Step 3, where a participatory GIS survey was designed to collect local expert knowledge about the green environments and their ecosystem services. This step provided valuable in situ data to accompany the analyzes made based on proxy data in the step 1. The survey data was used to analyze urban ecosystem services using an ecosystem service assessment matrix methodology (Burkhard et al. 2012b).

It is defined in the figure 4 which results were used to answer research questions one and two. For the part of question three, both the urban green environments data as well as the ecosystem service provision matrix were discussed as examples on how resilience can be enhanced through environmental data. The UNISDR Ten Essentials (figure 2) framework was used to structure the discussion.

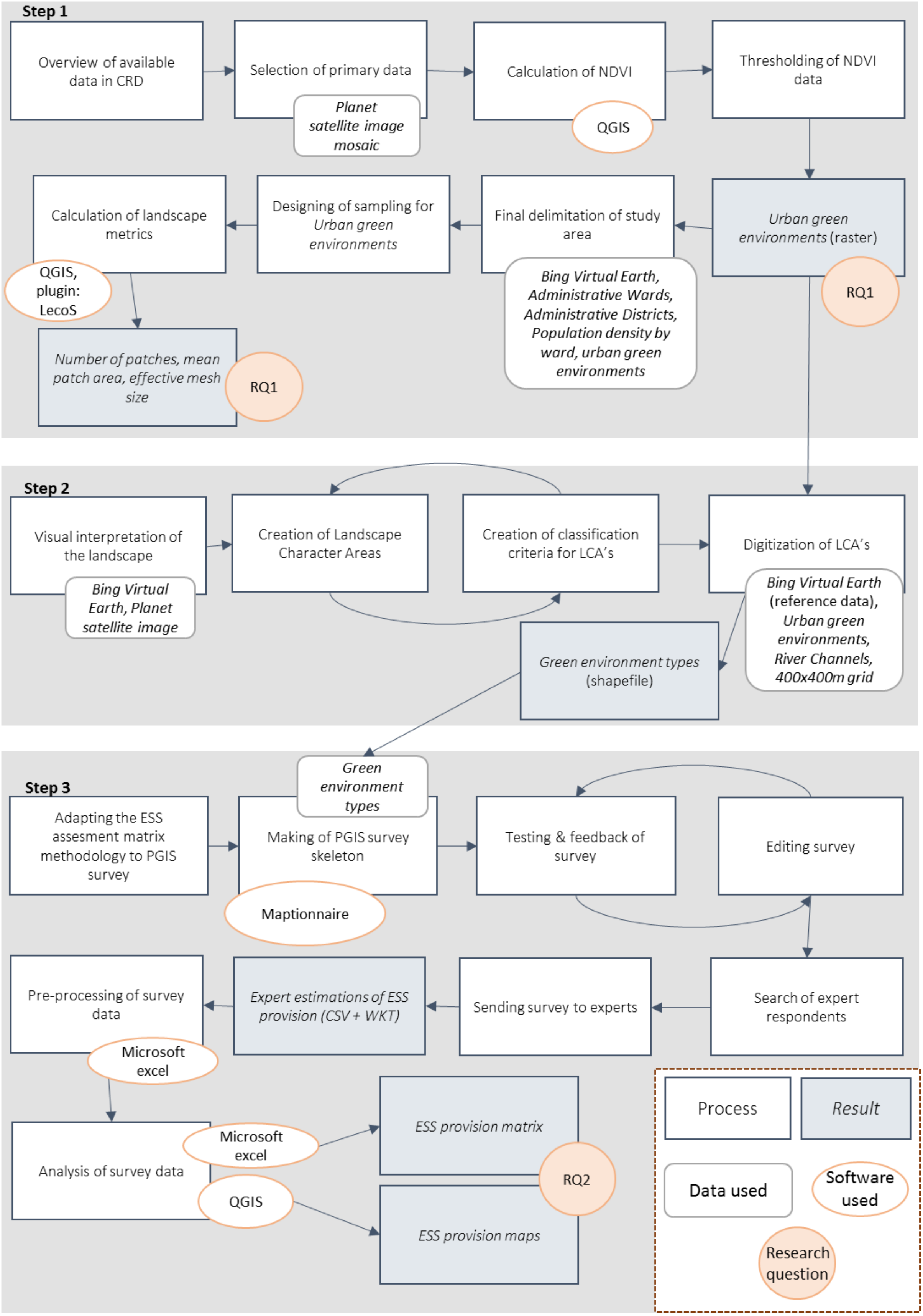


Figure 4. A flowchart of the research methodology. Abbreviations: ESS = ecosystem services, LCA = landscape character area. The RQ articles indicate which data was used to answer which research question.

4.2 Spatial datasets

Data used in this study was open-source geospatial data and data gathered with a participatory GIS survey during the study. All used geospatial data are specified in table 1. This data was mainly accessed through Climate Risk Database (2022) (later CRD), a digital geospatial data repository managed by the Tanzania Resilience Academy (2022).

Table 1. Geospatial datasets used in the study.

DATA	EXTENT	PUBLISHED	PRODUCER	DATA TYPE	ACCESS	ADDITIONAL INFO
Planet satellite image mosaic (1st quarter)	Dar es Salaam, larger metropolitan area	2018	Planet	raster (3,7 m)	CRD	Spectral Bands Blue: 455 – 515 nm Green: 500 – 590 nm Red: 590 – 670 nm NIR: 780 – 860 nm
Bing Virtual Earth (satellite imagery)	Global	2019	Bing Maps	raster	XYZ tiles/ QGIS	Web map. Images captured during 2017-2019.
Administrative wards	Dar es Salaam	2012, updated 2018	Tanzania National Bureau of Statistics/ Ramani Huria team	vector	CRD	Boundaries of sub-municipal administrative areas.
Administrative districts	Dar es Salaam	2016	Tanzania National Bureau of Statistics	vector	CRD	Boundaries of municipalities in Dar es Salaam metropolitan area.
River channels	Central Dar es Salaam	2018	JBA Consulting	vector	CRD	Line data of streams running in Dar es Salaam.
Population density by ward	Dar es Salaam	not published	Ohto Nygren	vector	private	Original open-source datasets from TSED and CensusInfo Tanzania (2012) & CRD.

4.3 Analyzing urban green environments

4.3.1 NDVI vegetation index

Extracting geospatial data of urban green environments was a prerequisite for the rest of the study, as illustrated in figure 4 in step 1. Since any comprehensive dataset was not readily available, the data was extracted from a Planet high-resolution satellite image using NDVI. The Planet satellite image mosaic (table 1) was downloaded from Climate Risk Database (2022), and the 4-band cloud-free mosaic has been acquired with a PlanetScope camera instrument on a Dove CubeSat satellite (PlanetScope instruments 2022). The image mosaic consists of images taken during the first quarter of the year 2018. Image mosaics from the third and fourth quarter of the year were also available in Climate Risk Database (2022), but the first quarter image was selected because it is after the November-December rain season, so it was seen the best for analyzing green vegetation (Climate Dar es Salaam 2019).

Seasonality of green vegetation, image cloudiness and the rapidly developing and changing urban landscape are matters that generally affect the accuracy of NDVI calculations (Horning et al. 2010, 101). For the seasonality of green vegetation, a second quarter image could have been even more optimal for NDVI calculation, but it was not available. A Digital Globe satellite imagery with 0,3 m spatial resolution was available in CRD, but it was not used for its cloudiness and lesser spatial extent. The Planet satellite image selected was the newest high-resolution image available, but to be noted is that Dar es Salaam is a highly dynamic and rapidly developing urban area and a satellite image from year 2018 presumably lacks newly occurred dynamics of the landscape.

The Normalized Difference Vegetation Index (*NDVI*) is a broadly used vegetation index that enables the analysis of relative biomass in the area of interest (Horning et al. 2010). The index's ability to detect vegetation is based on that assimilating vegetation reflects well infrared and near-infrared wavelengths but absorb well the red wavelength of visible light. The outcome is played as a raster surface where the cell values range from 1 to -1, and the highest value represents the greenest area and negative values fall to non-green areas such as bare land or other abiotic land covers. NDVI calculates only relative greenness values based on the reflectance values of a satellite image, and so does not take a stand on the type of green vegetation. Thus, the outcome includes all types of vegetation from grasses and bushes to trees and forests and no conclusion of their quality is made.

The image processing was done in QGIS 3.16, as well as all other spatial data analyzing in the study. After downloading the Planet satellite image tiles were merged and clipped to the extent of Dar es Salaam administrative boundaries. The NDVI was calculated using the Raster Calculator, following the NDVI formula (NIR – RED) / (NIR + RED) (Horning et al. 2010,110), with the Planet satellite image bands NDVI = (band 4 – band 1) / (band 4 + band 1), respectively.

The continuous NDVI layer was then thresholded, where a limiting value is found that separates green environments from non-green environments, and this enables transformation of continuous data into binary data (Lang et al. 2018). A threshold of 0,32 was used to create a binary layer called the urban green environments with Raster Calculator. After this smaller than 6 pixels clusters were removed with Sieve function to avoid unnecessary complexity of the layer.

4.3.2 Landscape metrics

The spatial and ecological characteristics of the urban green environments data was analyzed through sampling and landscape metrics. Landscape metrics are indices that enable quantification of different aspects of a landscape (Kupfer 2012). With quantitative data it is possible to get standardized and comparable information about many times abstract landscape functions and their spatiality. Using a sampling-based approach enabled comparison of standardized areas, and this method has also been discussed to be able to improve the accuracy of landscape metrics (Ramezani et al. 2013). This being important since the discussion about the accuracy of landscape metrics remains vivid (see e.g., Li & Wu 2004; Spanowicz & Jaeger 2019). With careless use of landscape metrics, deriving misleading information with them is easy.

In this study, stratified random sampling was selected as the sampling method. In stratified random sampling the sampled unit is divided into subunits called strata (Wang et al. 2012, 4-5). The units are non-overlapping and together comprise the whole. In this study the urban green environments data was coarsely divided into two strata, one which included predominantly green areas and the other including predominantly built-up areas. This sampling method was selected because the urban landscape of Dar es Salaam is highly heterogeneous and this way different types of areas got presented in the samples. No more than two strata units was made because the separation of the highly heterogeneous built-up areas would have been very complicated and inefficient. The two strata were named *built-up* and *green*.

The size of the sampling plot was designed so that it captures the variability of the green structure. Keeping this in mind, a sample plot size of 600x600 m was selected. This size of the plot was able to capture both the scattered green structure of the built-up strata as well as the possible fractures in the more continuous green structure of the green strata. Eight sample plots were randomly placed to both strata, in total this meant 16 sample plots. The plots were created in QGIS 3.16 using Random points in Layer Bounds and Buffer tools. After which the urban green environments data was clipped by the sample plots using Clip Raster by Mask Layer.

The landscape metrics selected to be used in this study were number of patches (NP), mean patch area (MPA) and effective mesh size (meff). The first (NP) calculate the amount of patches of a particular habitat type, the second (MPA) calculate the average area of the patches of a particular habitat type (McGarigal et al. 1995), and the third (meff) was used to measure connectivity of the green environments (Spanowicz & Jaeger 2019). Since ecological connectivity is divided to functional and structural connectivity, there are also different metrics for these two. Measuring functional connectivity would need data about species behavior, and so, effective mesh size was used to measure structural connectivity, only.

Effective mesh size is a landscape metric that considers both within-patch and between-patch connectivity (Spanowicz & Jaeger 2019). Some connectivity metrics measure only between-patch connectivity, and this has led to misleading results. The effective mesh size is based on calculating the probability that two randomly chosen points within a landscape are connected, and the result of the metric represents the average amount of habitat accessible to an individual dropped randomly in the landscape (Spanowicz & Jaeger 2019, 2266-2267). Spanowicz & Jaeger (2019,2267-2268) have presented and opened up the equation for calculating the metric, too.

Finally, the landscape metrics were calculated for the sample plots using LecoS (Jung 2016), a landscape ecology statistics plugin in QGIS 3.16 that enables the calculation of landscape metrics inside the software. The landscape metrics available in LecoS are based on the metrics in the widely used Fragstats software (McGarigal et al. 1995).

4.4 Characterizing green environments with holistic image interpretation

A holistic image interpretation of Dar es Salaam was made from satellite images to form a comprehensive understanding of the landscape and its green characteristics, as illustrated in figure 4 in step 2. The dense part of the city was classified to four landscape character areas, that classify the landscape based on its green characteristics. The classes came to prominence after a visual interpretation of Planet and Bing Virtual Earth satellite images of the area. A classification criterion was made after which the classes were digitized with QGIS 3.16. The classification was done to form a generalized overview of the different kinds of urban green environments in Dar es Salaam, and their patterns and linkages to each other. The classification was to be later used as a basis for the participatory GIS survey.

The area classified was decided based on the level of urbanization and the patterns of the landscape and this also served as the final delimitation of the study area. Areas with predominantly green vegetation and/or rural settlements, based on Bing Virtual Earth and the urban green environments data, were excluded from the study, since this study focuses on the fragmented green environments in the central, dense part of the city. In the excluded areas there also was a lot of small-scale agriculture fields, which being seasonally green, made the accuracy of NDVI weaker. The data used to help the visual interpretation of the landscape was Bing Virtual Earth, Urban green environments, River Channels and a 400 x 400 m grid created with QGIS. Also, the population density by ward data was used to ensure that no ward with high population density (>15 000 people per sq. km) was left out of study area (see table 1 for information about used datasets).

The green landscape character areas mapped were: coastal green environments, riverine green environments, continuous green environments and urban environments with remnant greenery, and they were digitized based on the criteria shown in figure 5.

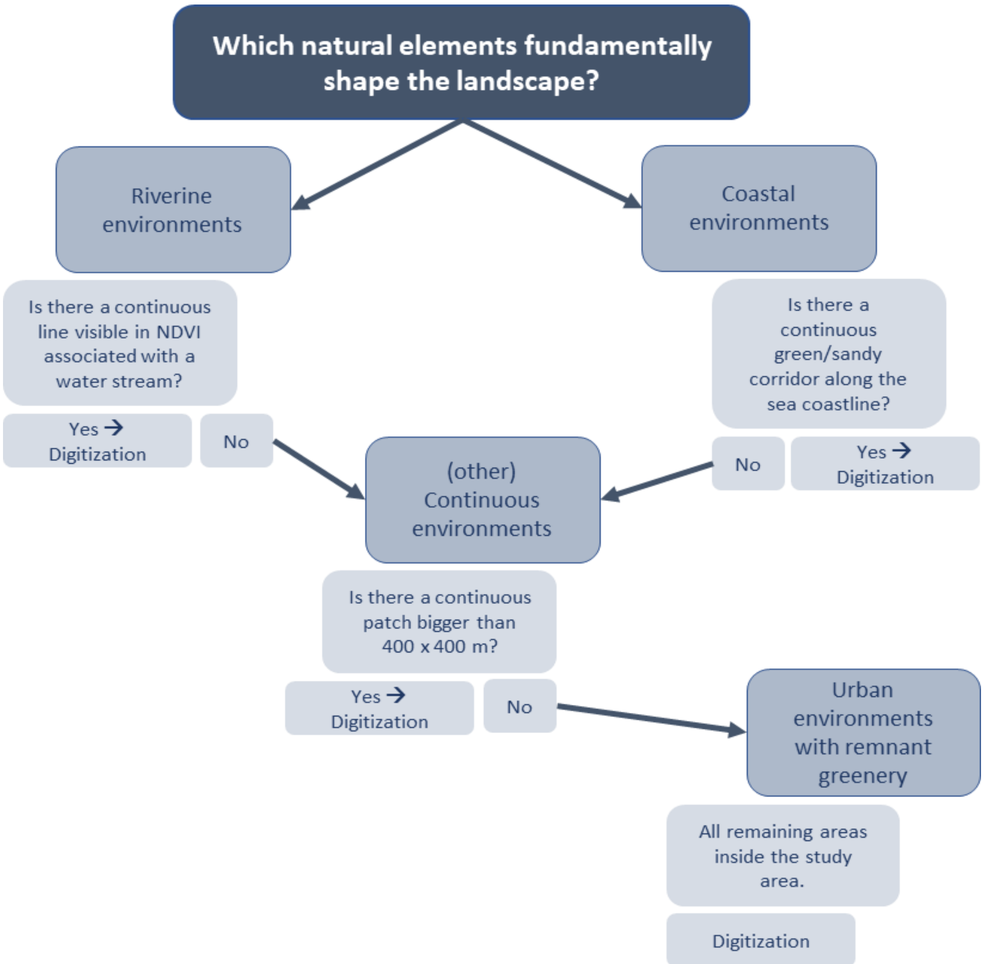


Figure 5. A decision tree used for classification of green environment types in the study area. As a result, the four classes covered the whole study area without overlapping each other.

Since the aim was to make a coarse overview of the green landscape patterns, the scale used during digitization was 1:8 000 as its finest. Smaller than 400 x 400 m landscape patterns inside a class were not mapped, however, corridors narrower than 400 x 400 m were mapped if their shape made them a remarkable pattern in the landscape and the overall size of the patch was bigger than 400 x 400 m. So, it was not the size of the object that made the final decision of which class it belongs to, rather it was weather the object was a dominant element in the landscape, reviewed at the scale selected.

The digitization of the classes started with the *coastal* and *riverine green environments*, since the two fundamentally shape the landscape. The coastal location and the three major rivers, Msimbazi, Kizinga, and Mzinga, running through the city and forming two river deltas are the major factors naturally shaping the city's landscape. For these reasons the two classes were selected as the basis for the classification. Weather a single river channel was decided to be dominant in the landscape or not, was decided based on if it forms a continuous pattern in the NDVI image. Also, the Dar es Salaam River Channels data layer was used to determine whether there is a river or not.

The *coastal green environments* were digitized using the same principle; weather there was a continuous corridor of green or sandy environment or not. Since sand is not well visible in the NDVI image, the Bing Virtual Earth imagery was used too. The Bing Virtual Earth imagery was also used to interpret whether the coastline was in natural/semi-natural form or if it was built environment, in which case it was put to the class of *urban environments with remnant greenery*.

All continuous green areas bigger than 400 x 400 m were classified as *continuous green environments*, and these areas might have included also patches of bare land. Most of continuous green areas located in the outskirts of study area and were prioritized to belong to the study area even though their inclusion made its border incoherently shaped. The decision was made due to the importance of continuous green areas to urban ecology. The remaining areas inside the study area were defined as *urban environments with remnant greenery* and the green environments in this class consist of smaller than 400 x 400 m patches.

The area classified is shown in figure 6 and closer look examples, as well as definitions of each class, can be found in table 2.

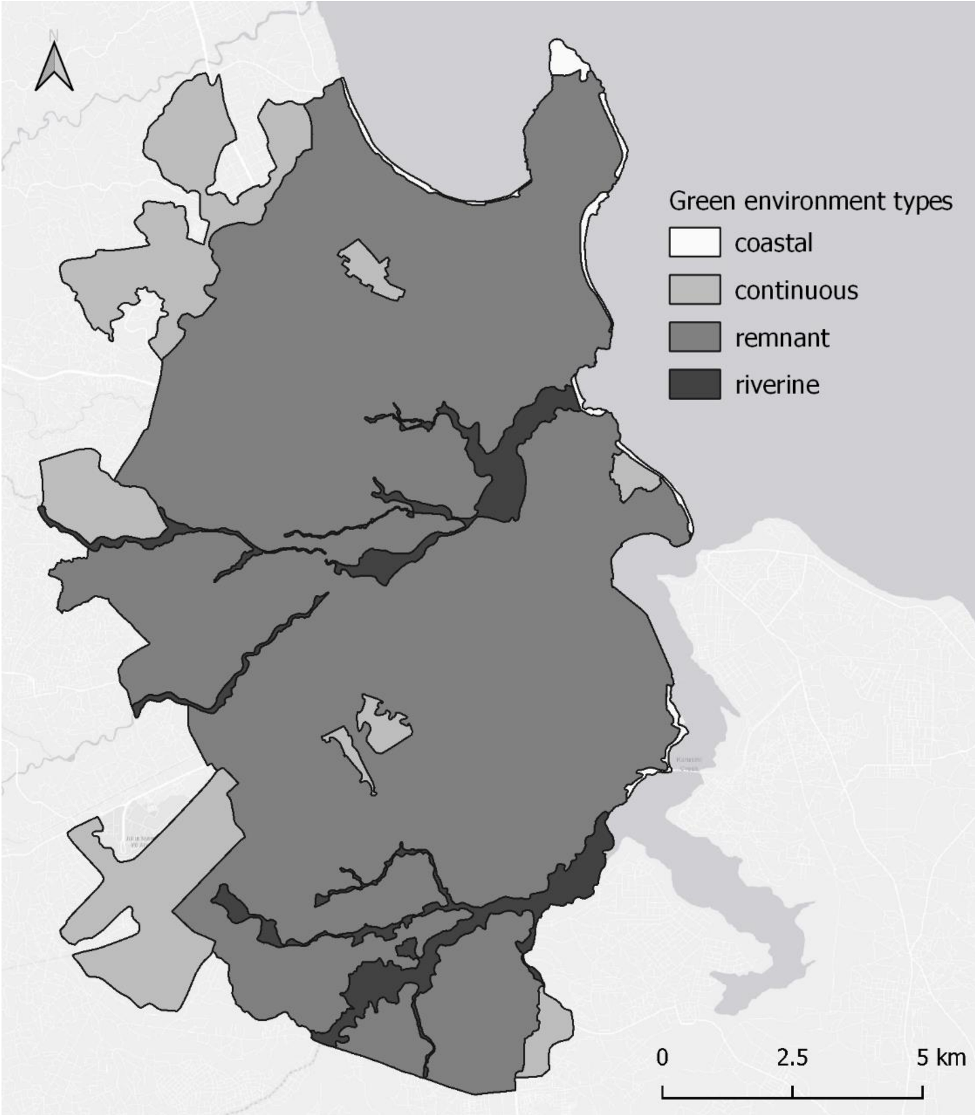
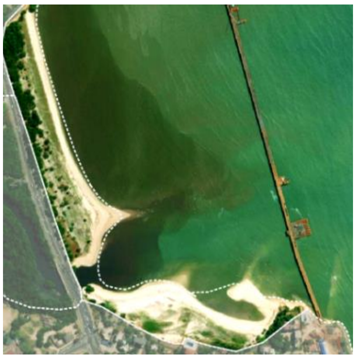


Figure 6. The dense urban area of Dar es Salaam classified to four classes based on their green landscape characteristics. Abbreviations: Coastal = coastal green environments, continuous = continuous green environments, remnant = urban environments with remnant greenery.

Table 2. Examples from each class of the green environment types classification.

GREEN ENVIRONMENT TYPE	**DESCRIPTION**	**EXAMPLE**	
RIVERINE GREEN ENVIRONMENTS	Vegetation corridors along riversides. Typically, mangrove, other tree and bush species and agricultural land.		
COASTAL GREEN ENVIRONMENTS	Vegetation corridors along the ocean coastline. Typically, mangrove and other coastal vegetation, including sandy areas.		
CONTINUOUS GREEN ENVIRONMENTS	A patch dominantly covered with green vegetation. Other land covers do not disrupt the connectivity of green. Typically includes urban forests or grasslands.		
URBAN ENVIRONMENTS WITH REMNANT GREENERY	Built urban environment which' green environments are not well connected to each other. May include yards, parks or solitary trees.		

4.5 Assessing ecosystem service provision

An online PGIS survey was conducted to gather local expert knowledge about the provision of ecosystem services and their spatiality in Dar es Salaam, as illustrated in figure 4 in step 3. The survey was conducted through an online survey tool Maptionnaire (2022) that includes options for asking map-based questions and thus to retrieve spatial data. Maptionnaire has been used for mapping and assessing ecosystem service before (see e.g., Fagerholm et al. 2021; Gottwald et al. 2022). Local data was retrieved with online methods only since the study was conducted during the COVID-19 pandemic and thus in-situ methods for collecting data were out of the question.

The aim of the survey was to collect information to compile an ecosystem service assessment matrix and to collect spatial information about especially important places for the local ecosystem services. Since all methods performed before were based on satellite data acquired remotely, the compilation of ecosystem service provision matrix based on in situ data, was an important step in connecting the analysis to the local setting.

The survey methodology was applied form Burkhard et. al. (2012 b) that presented the ecosystem service assessment matrix as an easy-to-apply solution to the need for quantification of ecosystem services. The matrix links spatial landscape units to ecological information and is filled by local experts (Burkhard et al. 2012 a). Each cell in the matrix is filled with score from 1-5 and the average of all experts then tells the score of each ecosystem service in each landscape unit (Burkhard et al. 2012 a). This information can then be visualized and easily communicated with maps, since each score is readily correspondent to a spatial landscape unit. To raise the reliability of the matrix Burkhard’s research group have proposed a confidence score to be used, where the respondent has a chance to indicate their level of confidence regarding each slot in the matrix (Jacobs et al. 2015).

In this study, the used landscape units were the green environment types; landscape character areas digitized as part of the holistic image interpretation. In respect to the ecosystem services, not all ecosystem services in Dar es Salaam were studied, but those that are among the key ecosystem services visible in people’s everyday life in the local settings. The selected five ecosystem services were seen important based on knowledge in Tanzania Resilience Academy (2022), literature (Mlozi et al. 2014; Karutz et al. 2019) and asking feedback from fellow thesis maker and her supervisor from Sokoine University of Agriculture, Tanzania. The landscape units and the ecosystem services used for the matrix are shown in table 3.

Table 3. The used variables to construct the ecosystem service assessment matrix.

LANDSCAPE UNITS: the green environment types	**ECOSYSTEM SERVICES**
Coastal green environments	Flood protection
Riverine green environments	Food provision
Continuous green environments	Heat stress protection
Remnant green environments	Biodiversity
	Social and cultural benefits

The interactive survey can be found as screenshots in the appendix 2. The survey included background questions, introduction and two survey questions. First survey question was "What is the role of the each mapped green environment type in the provision of ecosystem services?" And the respondent ticked an answer from negative to great for each green environment type. The second survey question was "Map 1-5 green places that in your opinion are the most important for **the ecosystem service in question**" The answers were given separately for each ecosystem service in both questions. After mapping a place, the respondent was asked an open question "Why is this place important?".

The first survey question provided answers for the ecosystem service provision matrix. Since it was not possible in Maptionnaire to give numerical scores as in the original matrix methodology (Burkhard et. al. 2012 b) and a verbal scale was used instead. The scale was five-stepped: negative, poor, moderate, good, great. A negative option was included to give the possibility to show negative effects that an urban or degraded natural environment can have on ecosystem services. The scale for the confidence score remained the same, from 1 to 3. For the limitations in Maptionnaire the questions handled one ecosystem service at a time and the matrix was compiled later from the responses. The second survey question aimed at collecting more precise spatial knowledge to form a comprehensive overall picture of the ecosystem service provision.

The survey link was sent to Tanzania Urban Resilience Program (TURP) (2022) and Tanzania Resilience Academy (2022) partners in Tanzania, that assumingly know the context of Dar es Salaam and were familiar with the importance of urban green environments. The link was sent by email to experts from local universities, the government, and NGO's. The link was also shared within a private WhatsApp group of local and international geospatial experts.

The survey responses were downloaded from Maptionnaire online platform in Excel spreadsheet format. The Pre-processing of the survey data included reviewing the quality of the data and analyzing respondents' sociodemographic variables. Since the survey was sent to a different continent and context than where it was created, with no extra guidance for answering it, a special focus was put in the quality of the results. It was not automatically clear, whether the respondents had understood what was meant with the questions and whether they had the needed background knowledge for answering.

Quality of the survey data was assessed by going through the background variables asked as well as revising the responses to the actual questions to see if the respondents had misunderstood the question or responded indifferently. The survey was intended to be answered by experts who are familiar with the green environments of Dar es Salaam. To assure this, the respondents were expected to have at least some experience working on the field. To assure that the respondents were familiar with the context of Dar es Salaam, the survey link was in the first place sent only to contacts that know the local context. However, this was not reassured in the survey itself.

In total eight responses were excluded from further analysis. The excluded respondents said themselves that they had no relevant areas of expertise, they declared zero years of working experience with the topic of urban green environments, and it could be seen from open questions that they hadn't understood the meaning of the questions well. Also, some respondents were excluded because they had answered with same score through the first survey question and left no answers to the second, map-based, survey questions. This was considered indifferent answering. After this quality control the answers of 27 respondents were included in the analysis.

Eventually, no answers to the map-based second survey question (appendix 2, figures 10-13) were analyzed in the study. It was notable from the answers left to the open pop-up question "Why is this place important?" after placing a mark on the map, that the respondents' reasoning for the mapped places were hugely varied and it was clear that most of the answers did not present important places for the provision of the ecosystem services nor demand for them.

5 Results

5.1 Spatial and ecological characteristics of urban green environments

The NDVI based urban green environments data is visualized in figure 7. It can be seen that the urban green environments in Dar es Salaam are scattered and their spatiality is guided by the heterogeneity of the urban structure as well as the by the major natural elements forming the city: the Indian ocean coast, and Msimbazi and Kizinga river valleys. The two big river valleys divide into smaller rivers, and these riversides make up the most prominent green corridors inside the dense urban area. Some of the riversides reach bigger patches of continuous green on the outskirts of the dense urban area and thus form an important part of the green network in the city.

All larger patches of continuous green vegetation lie in the outskirts of the dense urban area. By continuous green patches is referred to areas where the green cover is only slightly disturbed by urban land uses, so that the connectivity between green areas inside the patch remains evident. There are also some moderate scale continuous patches inside the dense urban part of the city, closer to the city center than the bigger continuous patches, but the majority of these are still fragmented, and their function for structural and functional connectivity is not evident.

The amount of green cover is generally higher near the ocean coastline than in inland parts of the city. The settlement patterns in the coastal areas are looser with bigger yards, leaving more space to green vegetation. Areas with the least green vegetation locate in the in the middle of the dense urban area. These are mainly very densely built settlements or industrial areas, which form anything from small patches in often margin places, to large patterns shaping the city structure. The green vegetation in these places is often very scattered, formulating dotted patterns.

Landscape metrics were calculated to two strata, built-up (samples B1-8) and green (samples G1-8), which fundamentally differed from each other, as do the results. The results for each landscape metric - number of patches (NP), mean patch area (MPA) and effective mesh size (Meff) – as well as outlook of the data of each sample plot can be found in appendix 1. The results are presented in the unit that is typical for the metric in question.

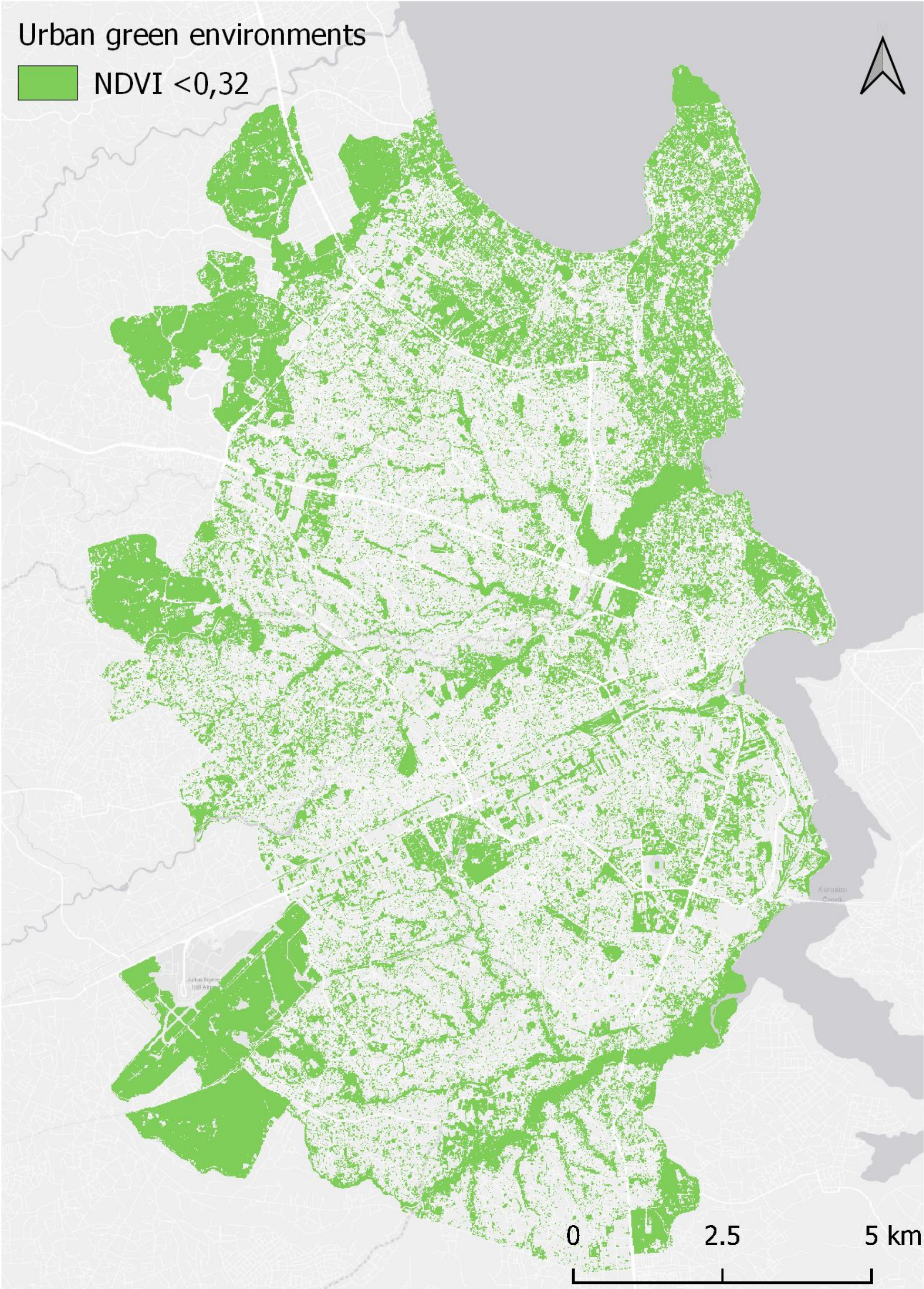


Figure7. The urban green environments data gives an overview of green environments in the densely built part of Dar es Salaam.

As commonly understood in ecology, fragmentation of green environments leads to weaker connectivity of the areas, which restrict the movement of species and so increase their isolation (Krellenberg 2007; Wu 2008). This hypothesis was also supported by the results of landscape metrics of both strata, since increase in NP led to a decreasing overall trend in Meff values. Meff values are also affected by the shape of the patches, since the metric includes both within- and between-patch connectivity, so it creates variation when looking at individual samples.

The results of the of landscape metrics per strata are presented in figures 8 and 9, which rather than focusing on the exact values, illustrates their ratios to one other. The figures are presented so that MPA grows linearly, which theoretically would lead to increase in Meff. However, the increase in Meff would require that the patch areas are not only growing in area but also connected to each other and if they are not, and lie rather scattered in the landscape, Meff value remains lower.

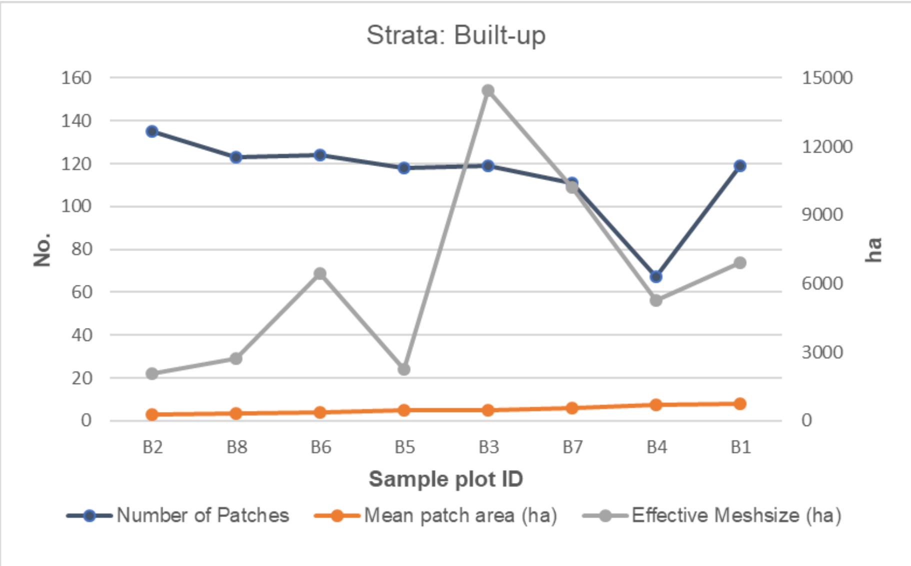


Figure 8. Landscape metrics for built-up strata plotted relatively to each other. Landscape metrics run on the Y axis, NP on the left, and MPA and meff on the right. Sample plots run in the X axis. MPA is growing from left to right.

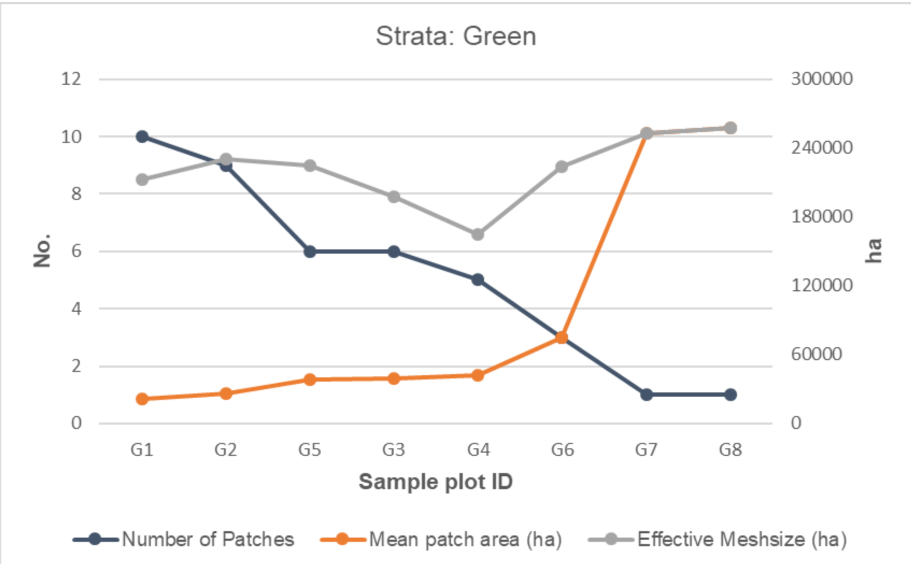


Figure 9. Landscape metrics for green strata plotted relatively to each other. Landscape metrics run on the Y axis, NP on the left, and MPA and meff on the right. Sample plots run in the X axis. MPA is growing from left to right.

For the built-up strata, the urban green environments are scattered across densely built urban landscape in small patches, sometimes connected by green corridors formed by rivers, parks or other urban structures. The patches are typically small and isolated from each other, and this is shown in the landscape metrics calculated. For the built-up strata NP range from 67 to 135, MPA from 287 to 737 ha, and Meff from 2047 to 14449 ha. Means for each metric are 115, 489 ha and 6293 ha, respectively.

Decrease in MPA led to a decreasing trend in Meff values in built-up strata, and green corridors in the landscape form the reason for exceptions from the trend. This can be seen from the sample plots B3 and B7 (appendix 1), where riversides of a small stream form green corridors which have led to the highest Meff values of the strata. These two sample plots can be compared to sample plot B1 which has the largest MPA of the built-up strata, but the patches are scattered and isolated from each other, and the Meff value remains lower than the mean of the strata.

For the green strata, the structure of urban green environments is quite contrary to the built-up strata. The urban green environments are well connected to each other, forming bigger patches. The non-green areas of this strata, however, are typically corridor-like structures that restricts the landscape from having a very good connectivity. For the green strata NP range from 1 to 10, MPA from 21525 to 257380 ha, and Meff from 164755 to 257380 ha. Means for each metric are 5, 94077 ha, and 220652 ha, respectively.

As decrease in MPA led to a decreasing trend in Meff values for built up strata, the same did not apply for green strata. Moreover, decrease in MPA for green strata led to varying Meff results, depending on the structure of the patches. Meff values were relatively high for all samples from green strata. The lowest values were for samples G3 and G4, that both include strong corridor shaped non-green patches.

Figure 10 shows a comparison of four different samples, two from each strata. The samples are similar in terms of NP and MPA to their counterpart from the same strata but differ on the Meff values. Samples G3 and G5 have very similar NP and MPA values and are alike each other visually, but sample G5 has a wider corridor connecting the big black area cutting the long white corridor. This might be the key for higher Meff value. Samples B5 and B3 too, have very similar NPA and MPA values. B3, however, has a significantly higher Meff value due to corridor-like shapes in the landscape. The Meff value of B2 raises even relatively close to the Meff value of G3.

These examples in figure 10 demonstrate how an increase in the amount of green area (MPA) does not necessarily provide good quality, well connected green landscapes. The amount of green patches and their total area can grow, but at the same time the patches might come further and further away from each other, when isolation grows and the real potential for movement of species decreases.

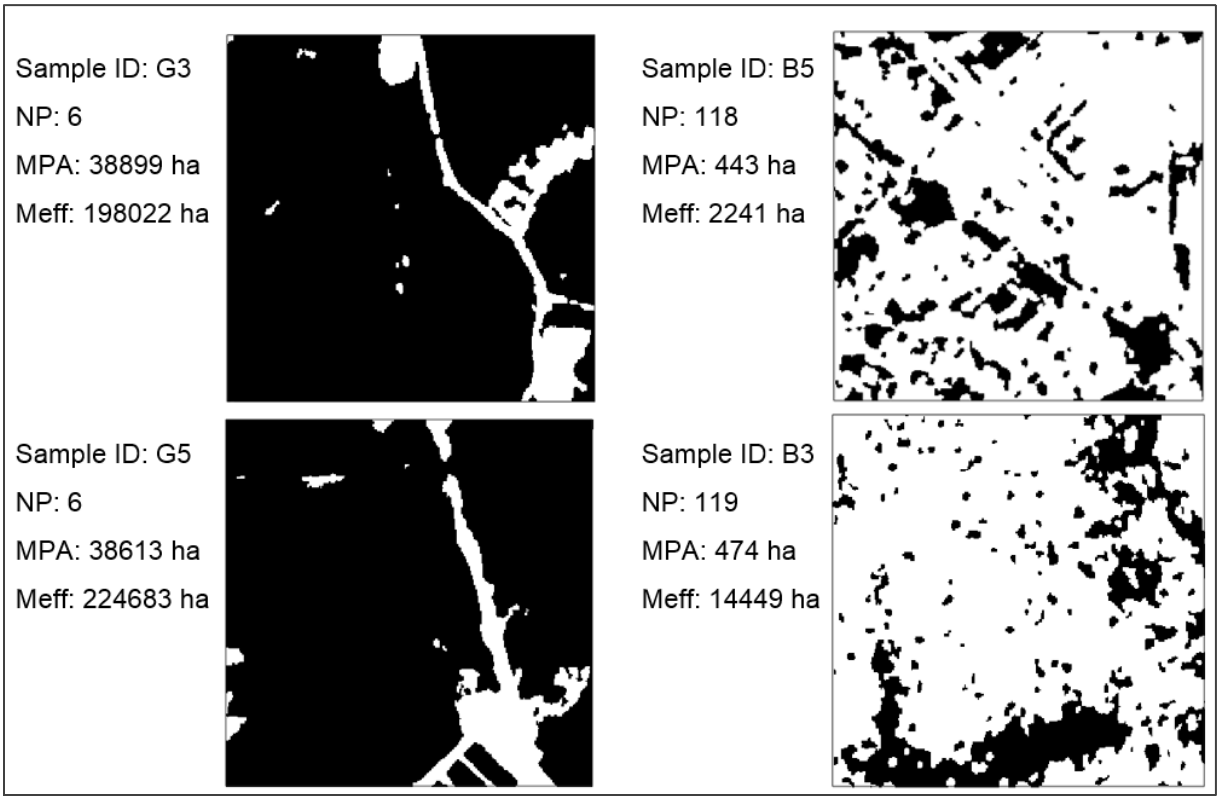


Figure 10. A comparison of four different samples and their landscape metrics. Black areas represent green patches that landscape metrics were calculated for. White areas represent non-green patches.

5.2 Provision of urban ecosystem services

Based on the background questions asked in the beginning of the survey, the respondents formed a heterogeneous group of experts. 70 % of the respondents were men and 30 % women, the age range variated from 28 to 66 years, with a median of only 42 years. Although, six respondents did not mark their age. The professional working experience with the theme of urban green environments variated from 2 to 36 years, with the median of 6 years. Also, one respondent with zero years of working experience with the topic was included, who’s fields of expertise was seen to be relevant, nevertheless, and the answers declared understanding of the questions. The respondents' work background varied between sectors, and there were answers from all relevant sectors (figure 11).

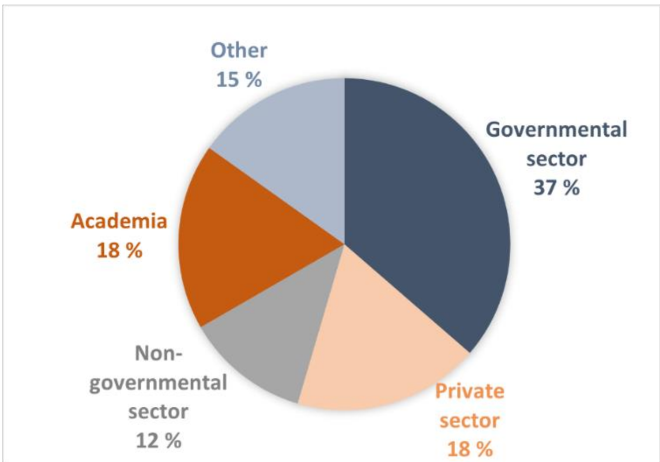


Figure 11. The sector of respondent's working background. Four of the respondents had worked in more than one sector.

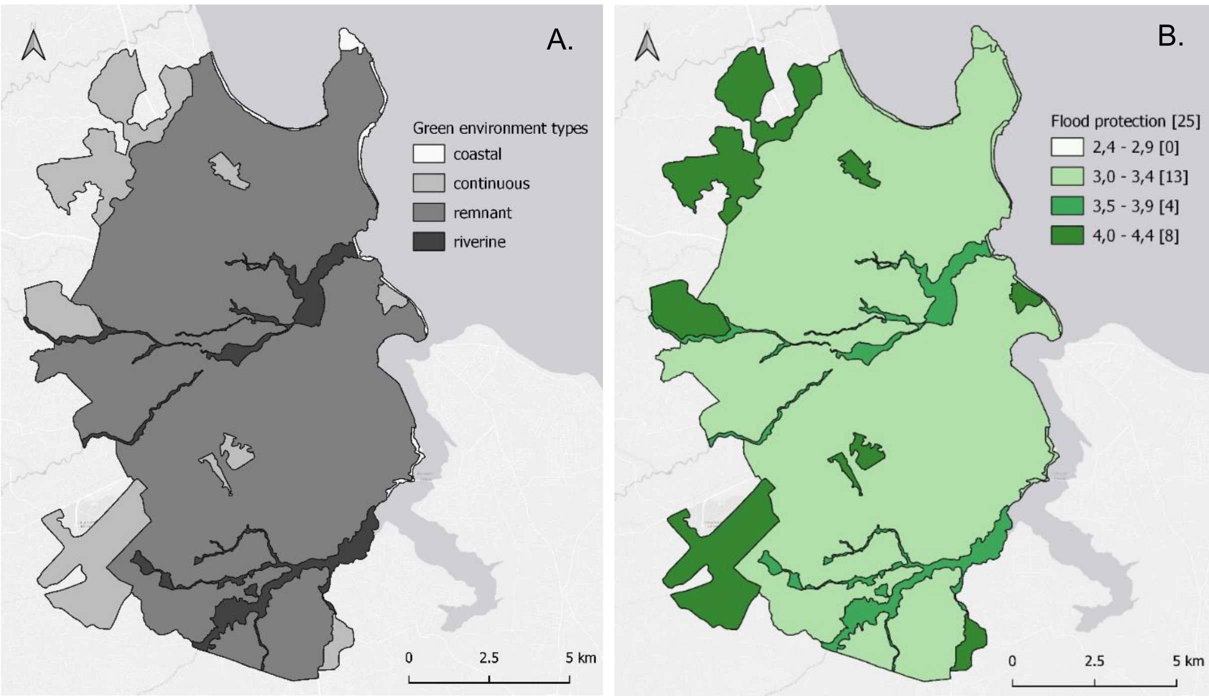
The expert-based ecosystem service provision matrix is shown in table 4 and the ecosystem service provision maps are spatially visualized versions of the matrix (figure 12). The matrix show that the role of dense green environments was considered the most important for the provision of studied ecosystem services. Flood provision, heat stress provision and biodiversity were scored the highest in dense green environments, and also food provision and social and cultural benefits scored the second highest for this landscape character area.

Table 4. The ecosystem service provision matrix illustrates the capacity of each green landscape character area to provide ecosystem services, according to local experts. The scores represent the mean of all experts' answers. The column *average* represents the mean score for each green landscape character area. The confidence score reflects the mean of experts' confidence on their own answers.

	Flood protection	Food provision	Heat stress provision	Biodiversity	Social and cultural benefits	Average
Coastal green environments	3,2	3,1	3,1	3,8	3,9	3,4
Riverine green environments	3,7	3,2	3,1	3,6	3,0	3,3
Dense green environments	4,1	3,1	4,3	3,9	3,7	3,8
Urban environment with remnant greenery	3,1	2,4	3,0	2,6	3,1	2,8
Confidence score (1-3)	2,4	2,2	2,4	2,5	2,4	2,4

Urban green environments with remnant greenery were considered to have the weakest role in the provision of studied ecosystem services. The role of urban green environments with remnant greenery for food provision and biodiversity was seen especially low, and these ecosystem services got the only scores below three. The role of riverine green environments was scored to be the most important for flood protection and biodiversity whereas the role of coastal green environments was scored the highest for biodiversity and social and cultural benefits.

When looking at the scores for each ecosystem service, it stands up that the role of all green environments for food provision was lower than for other services. Also, heat stress protection was significantly better provided by dense green environments than any other types of green environments. On the contrary, biodiversity is significantly less provided by urban environments with remnant greenery than by all other types of green environments. In contrast to these results, that reflect the conventional division where mainly dense green environments are seen as vital for the provision of ecosystem services, the distribution of scores for social and cultural benefits is more varied. Coastal green environments' role for the provision of social and cultural services were seen the highest, followed by dense green environments.



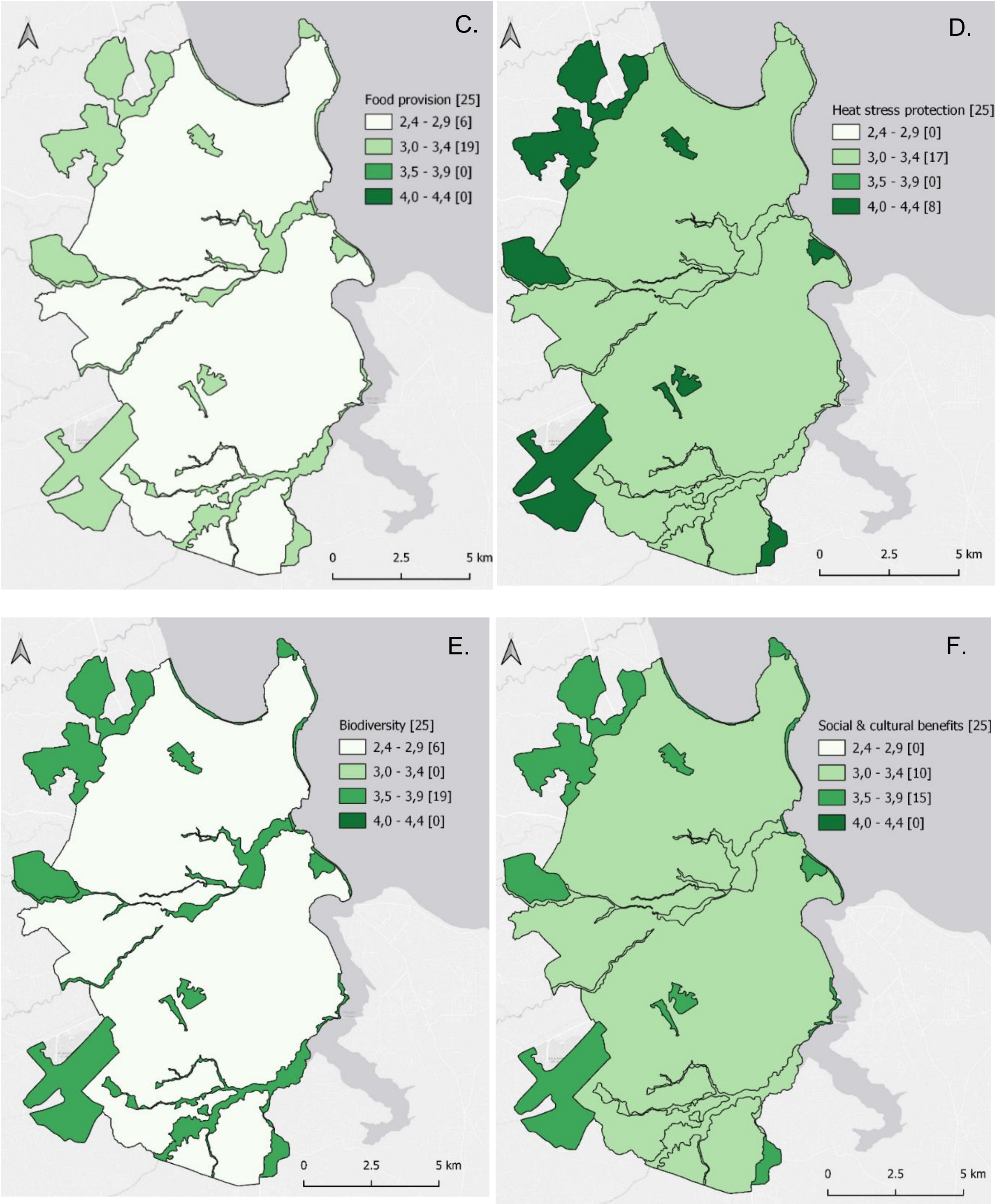


Figure 12 (A-F). (A) the green environment types in Dar es Salaam and (B-F) the ecosystem service provision maps, that display the provision of each studied ecosystem service in the green environment types.

6 Discussion

6.1 Urban green environments from theory to practice

The essence green environments in the dense part of the city of Dar es Salaam is scattered and the only corridors forming a green network are small and big river valleys. All areas with a continuous green vegetation cover lie in the outskirts of the town. The scattered green areas, where vegetation is left only here and there in the otherwise urban fabric, are isolated in terms of ecological connectivity, and so restrict species movement and other ecosystem functions (see e.g., Niemelä et al. 2010). Eventually scattered green environments are not able to provide ecosystem services at the same level that people could benefit them.

Since there are a little guidance for settlement building from the administrative level, reasons for the structure of green environments in Dar es Salaam can be found from the income-level of the settlements (Todd et al. 2019). The amount of green environments in settlement areas increase where more private green space is afforded to be owned. The urban green environments are denser near the ocean coastline, where many high-income settlements areas with bigger private yards locate. There, private gardens can have a significant effect for urban ecosystem services, where public green space is scarce (Cilliers et al. 2013).

The least green environments are found where informal settlements take place, which is wherever space has been found, but mostly in the inland part of the city. The green areas forming the only green network in the city locate in river valleys which are often unsafe places for settlements since river discharge change between seasons (Kuhlicke et al. 2020). Wasteland and small-scale urban farming form some green areas, which many times locate in the river valleys. Also, military areas and golf courses form a significant part of the larger continuous green areas.

The quantitative data derived with landscape metrics enable comparison of green characteristics between studies. Generally, the results of landscape metrics (NP, MPA and meff) calculated in this study are in line with other studies on urban green connectivity (see e.g., Spanowicz & Jaeger 2019). The trends of the landscape metrics reflect the commonly agreed hypothesis of urban ecology, where fragmentation of green environments leads to weaker connectivity of the areas, which restrict the movement of species and so increase their isolation (see e.g., Krellenberg 2007; Wu 2008; Spanowicz & Jaeger 2019). Some samples deviate from the trends, but these are due to variations in the local environment. This conclusion also supports the general trend, where urban development leads to decrease in urban green environments in both quality and quantity (see e.g., Mng´ong´o 2004; Güneralp et al. 2017).

The overall characterization of the urban green environments in Dar es Salaam leans to typical phenomena of the rapidly developing cities in the Global South. The loss of green space, its' fragmentation, dense settlement areas, the vast difference between rich and poor areas, and the raise of private green space as the major open areas in the city (Kraas & Mertins 2014; Grimm et al. 2008). These phenomena characterize many raising cities in the Global South and they challenge the way towards resilience.

Ecosystem services people use and need as part of their daily lives are essential parts of resilience according to the UNISDR Ten Essentials (figure 2). The ecosystem service provision matrix was compiled in this study of ecosystem services that are present in peoples' everyday life. The matrix highlights, that different types of areas inside the city have varying capacities to provide each studied ecosystem service. The selected ecosystem services can also be seen as examples to communicate about the importance of all ecosystem services to urban resilience.

Three major results rose from the ecosystem service provision matrix (table 4). Firstly, continuous green environments were the most important areas for providing ecosystem services. Densely vegetated urban green environments, such as forests, are widely seen as crucial for the provision of urban ecosystem services, since they are good in providing habitats and support well many ecosystem functions (Wu 2008). In Dar es Salaam, however, the areas forming the continuous green environments are mostly private areas: military bases, golf courses and university campuses, mainly, and the accessibility of private area affect the provision of ecosystem services, as discussed in relation to the NDVI based urban green environments data.

Regarding the ecosystem services studied, people can benefit from flood protection, heat stress protection and biodiversity even without an access to the area itself, but food provision and social & cultural benefits are examples of ecosystem services that require the area to be accessible for people. Also, biodiversity of a private urban area is not necessarily as good as it could be, since military areas and golf courses, for example, are fenced preventing the movement of some species and the biodiversity inside the area is more or less simplified and altered depending on the area's use.

Secondly, the ecosystem service provision matrix scores for food provision were significantly lower than for any other service. This is notable for urban resilience since food is a fundamental daily need, and in case of a shock or disturbance the low-income inhabitants are likely to suffer from lack of nutrition. Promoting ways for urban food provision would have significant positive effects on people's lives (Mlozi et al. 2014; Karutz et al. 2019).

Thirdly, the spatial variation of social & cultural benefits from other ecosystem services were remarkable. Social & cultural benefits differ from their nature from other ecosystem services studied (Tibesigwa et al. 2020). Even though their provision is linked to ecological factors such biodiversity, they are, stronger than other services defined by local people, their culture, and habits. The results of social & cultural benefits indicate that even though a green environment would not be significant for other ecosystem services, it can have significance for other reasons, such as aesthetics.

6.2 Observations of the methods

The analysis of the structure of urban green environments was made based on NDVI and the results reflect the estimated area available for ecosystem functions. Thresholding of NDVI was found to be an easy-to-apply and effective method for producing green environment data for a city-scale. Analyzes based on NDVI easily seem like they form a comprehensive data of green environments, but NDVI does not consider any qualitative or societal aspects that affect the ecosystem service cascade (Potschin & Haines-Young 2011), where ecosystem function becomes an ecosystem service for people.

For example, the green observed by NDVI might not reflect the greenness observed by people since the environment might be deteriorated or simply looks different from above than from a pedestrian's perspective (Lang et al. 2018). Nor can assumptions of the accessibility of the green spaces be made based on the data in this study. For example, the areas defined as continuous green environments as their landscape character, might be private and fenced areas and thus, the citizens cannot benefit all ecosystem services that the continuous green environments theoretically could provide.

There were characteristics in the Planet satellite image which could have negatively affected the accuracy of NDVI data. The green vegetation in Dar es Salaam is seasonal, which lays a high importance on the time of the year when the satellite image has been captured. For better accuracy, the NDVI could be calculated to several quarters' images and the results merged, to be sure to cover all phenological vegetation. Using data from several quarters' images would also reduce the impact of cloudiness in NDVI analyzes.

There was very little cloudiness inside the study area in the Planet satellite image mosaic used, however, the image turned quite cloudy outside the dense urban area and conducting the same analyze to a larger area would thus be more difficult with the image used. Also, the image was from year 2018, which is a rather long time ago for a rapidly developing city and there are certainly changes in the landscape that have happened since. The image was, however, the most recent open-source image available with sufficient spatial resolution. The spatial resolution of the satellite image mosaic was 3,7 meters, which is only moderately enough to capture the very heterogenous urban pattern. However, the analyzes were made at landscape level, and the spatial resolution suited well this purpose.

The NDVI captured well the patterns of urban green environments, especially in dominantly green areas and in dominantly urban areas where green vegetation is found only here and there. NDVI worked more poorly for areas with highly heterogenous patterns and with a relatively big percentage of green vegetation, these areas were, however, mostly left out of study area since they located in the outskirts of Dar es Salaam. NDVI captured well the green environments but has also a tendency to give similar scores to close lying shadows and (red) rooftops with similar reflection properties, as Neyns & Carters (2022) have noted too. An accuracy assessment would be necessary to further evaluate the accuracy of NDVI. For repetition and up-scaling of the methodology, the availability and accessibility of high-resolution remote sensing data can become a bottleneck, but the increasing use of drone acquired data can ease the situation (Lahoti et al. 2020).

The notions of limitations of NDVI data apply to the observations made from landscape metrics and especially from the effective mesh size as connectivity metric, too. Landscape metrics should never be reviewed out of their context as numbers only, but rather to strengthen or weaken ready-made hypothesis based on ecological knowledge. The metrics are often based on complicated equations, and it is to be kept in mind that they only indicate exactly what they are made to calculate. The effective mesh size, the landscape metric used to estimate connectivity in this study, is seen to include a comprehensive understanding of connectivity, which is not the case with all connectivity metrics (Spanowicz & Jaeger 2019). Many connectivity metrics focus on between-patch connectivity only, and the results might differ significantly.

The green environment types created through landscape character mapping described well the main structural characteristics of the green environments and their variety. Digitization of the classes was done at the scale of 1:8 000 at its finest and as a result the class boundaries became quite detailed for a landscape level classification. A coarser resolution could have resulted in better data consistency. Some areas, especially coastal and riverine green environments, became partly very narrow corridors and were not well visible in the PGIS survey the classes were used for. However, the classification at a finer scale made it possible for the respondent to zoom in and show how places they found important contribute to urban ecosystem services.

Since Dar es Salaam is a very densely built city, the classification of urban green environments at a landscape level would have become very vague if the narrow corridors were not considered. In the end, the ability of narrow riverine and coastal areas to provide ecosystem services is partly the same as the one of wider corridors of the same kind. The vast majority the city belonged to the class of urban environment with remnant greenery. The spatial patterns of this class were very heterogeneous and their distinction from each other would have required the classification at a much finer scale.

The PGIS survey used to collect local expert opinions about ecosystem service provision in Dar es Salaam is a very subjective methodology in its nature. As in all participatory GIS methods, the respondents cultural and professional background, values, and possible intentions play a big role in the data that is generated (Fagerholm et al. 2012). Especially in international cooperation people from different backgrounds can look at survey questions from very different points of view and therefore, the answers might even reflect something else that what the question was intended to ask in the first place.

Experts responded to the PGIS survey without further follow-up of the process. Presumably all needed information for answering was found in the survey’s introduction page (appendix 2, figure 1). Despite that feedback of the survey was asked several times from people of UTU Tanzania Team researchers with experience on participatory surveys and mapping in Tanzania, it is possible that not all necessary information was not provided for the respondents or that the survey questions were not clear after all. The raw data from the survey was partly very inconsistent and it was noted that all respondents had not understood the questions the way they were meant to understood. This was especially the case with the answers given for the second survey question (appendix 2, figures 10-13). Data from these pages were not eventually used in the study for data inconsistence.

Pre-processing of the data was intended to ensure that only answers which responded the questions were included. Nevertheless, it is possible that answers included in the compilation of ecosystem service provision matrix have been given with a different meaning and focus on mind than what was intended for the study. The matrix compiles experts' perceptions of the situation and they might not have thought all sides of phenomena, for example. Organizing online or in situ workshops to facilitate the answering could lead to better data consistency. By giving and introduction to the study topic and giving the experts a change to ask questions live could have decreased the possibility of misunderstandings and given the facilitator a change to know better the experts, their backgrounds, and premises to answer the survey.

Generally, the scores in the ecosystem service provision matrix were quite high, even though the urban green environments in Dar es Salaam are scattered. The distribution of the answers, from which the ecosystem service provision matrix was compiled, focused on the higher end of the scale. These options in the middle of the scale may have seemed easy to respond, since theoretically the green environments of a rapidly developing soon-to-be a megacity would not get very high scores. However, the confidence score of the answers was also relatively high (table 4). Also, the answers are not directly comparable with the Burkhard et al. (2012 b) methodology, since the scale used in the study was slightly different.

Even though participatory approaches are subjective, and the ecosystem service provision matrix method has its uncertainties, the results were in line with ecosystem service literacy (Wu 2008; Karutz et al. 2019) and the value of participatory and expert-based approaches has their clear advantages, too. Due to COVID-19 pandemic, this study was conducted remotely only, and the remote participation of local experts made it possible to get local data in the first place. There is not much environmental data available of Dar es Salaam to begin with, and local expert-based methods are especially good for collecting data of ecosystem services, since they know the local context where people and resources meet (Fagerholm et al. 2012).

6.3 Green environment data for urban resilience

This study has provided insights to the structure of Dar es Salaam's green environments and the key ecosystem services they provide for local citizens. Functional ecosystems provide all life on earth and cities are no exception of this (McPhearson et al. 2015). Moreover, vulnerability of the city dwellers is in part due to the lack of urban ecosystem services. Nurturing and developing green environments inside a city is an essential part of strengthening ecosystem services and building urban resilience (Making Cities Resilient 2017; Burayidi et al. 2020).

Up-to-date geospatial data is a key to comprehensive and effective management urban green environments. It is also needed to plan for current and future challenges brought by climate change and rapid urbanization. To know the current estate of green environments is a prerequisite for their further management and for the development of a green network in the city. Dar es Salaam is lacking adequate urban environmental data which is needed for the work towards resilience.

The data produced in this study contributes to several of the UNISDR Ten Essentials (Making Cities Resilient 2017). They do not, certainly, answer to the Essentials alone, but they need different data and approaches to accompany to form a comprehensive set of knowledge to answer resilience questions. As the being of resilience is constantly evolving, the data supporting decision-making must be up to date, too. To be up to date, the data must be easily producible. Responding to these matters, the two data produced in this study are an example of how to answer resilience questions.

The production of basic level data, such as the NDVI based urban green environments data, is needed in the society for many, and often sudden, purposes. Basic-level data of urban green environments is needed for resilience in the governance-level as well as the planning-level (figure 2). The NDVI based urban green environments data can help in discovering organizational needs (Essential 1), to understand risks and create risk scenarios (Essential 2).

The expert-based ecosystem service matrix as local ecosystem service data brings up qualities of the urban green environments and therefore, answers to different needs for resilience than basic-level data. Many of the Ten Essentials for urban resilience highlight participatory approaches as well as community engagement and reinforcement. The ecosystem service provision matrix provides information for pursuing resilient urban development and design (Essential 4), to know which areas function the best as natural buffers (Essential 5), and to explore which social and cultural ecosystem services strengthen the community in the local settings (Essential 7). By using participatory approaches in data production processes, it is possible to engage citizens, experts, and other local stakeholders, use their extensive base-placed knowledge and this way ensure that the new policies are supported among the locals, too.

The impact of appropriate data reaches until the planning an effective response to challenges and disasters. Appropriate data enables to understand risks and possible risk scenarios. If this leads to planning and preparedness for risks, it enables more effective disaster response (Essential 9) and expedites recovery from them (Essential 10). On behalf of urban ecosystem services, they contribute to Essentials 9 and 10 by giving people ways to survive during crisis by providing to e.g., food supplies and a strong community.

It is good to keep in mind, that all the Essentials are well intertwined. Resilience is not created by focusing on one of the Essentials at a time, but the Essentials present a bundle of actions needed to create a strategy towards resilience. Therefore, the advantages from different data that help to pursue the Essentials are well intertwined as well and have synergies on many levels.

To reach the advantages of suitable data for resilience, its good implementation is needed as well. Data alone does not make any magic. It needs to lead to action, in improvement of urban ecosystem service provision, in this study's case. Starting the work towards resilience needs to start from the Essential 1, by forming an organizational structure with clarity of coordination and responsibilities, that enable the planning and implementation of actions for the rest of the Essentials.

Further study interests for resilient management of urban green environments include reviewing the quality of the green environments; their present ecological conditions to provide ecosystem services, studying ecosystem service demand to fit the need and supply for ecosystem services together and to examine the local synergies and trade-offs of the UNISDR Ten Essentials to each other's.

Tackling rapid urbanization together with climate change are enormously complicated and intertwined challenges (Rittel & Webber 1973; Suárez et al. 2020). A society will never have enough information to make thoroughly conscious decisions for resilience, but every action towards it counts for a more stable future. Resilience is a constantly evolving concept and the pathway towards it depends on the current situation ─ local implications of climate change as well as the context of the society strongly shape this path. However, the current state of the world gives no reason not to try.

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References

Ahern, J. (2011) From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world. Landscape and Urban Planning 100(4): 341–343. http://dx.doi.org/10.1016/j.landurbplan.2011.02.021

Andrew, M. E., Wulder, M. A., Nelson, T. A. (2014) Potential contributions of remote sensing to ecosystem service assessments. Progress in Physical Geography 38(3): 328–353. https://doi.org/10.1177/0309133314528942

Andrew, M. E., Wulder, M. A., Nelson, T. A., Coops, N. C. (2015) Spatial data, analysis approaches, and information needs for spatial ecosystem service assessments: a review. GIScience & Remote Sensing 52(3): 344-373. https://doi.org/10.1080/15481603.2015.1033809

Antorp, M. & Eetvelde, Van V. (2000) Holistic aspects of suburban landscapes: visual image interpretation and landscape metrics. Landscape and Urban Planning 50: 43-58. https://doi.org/10.1016/S0169-2046(00)00079-7

Arts, B., Buizer, M., Horlings, L., Ingram, V., van Oosten C. & Opdam, P. (2017) Landscape Approaches: A State-of-the-Art Review. Annual Review of Environment and Resources 42: 439–63. https://doi.org/10.1146/annurev-environ-102016-060932

Beck, H. E., Zimmermann, N. E., McVicar, T. R., Vergopolan, N., Berg, A., & Wood, E. F. (2018) Present and future Köppen-Geiger climate classification maps at 1-km resolution. Scientific data 5, 180214. https://doi.org/10.1038/sdata.2018.214

Berkes. F., Folke, C. (1998) Linking Social and Ecological Systems for Resilience and Sustainability. In Berkes. F., Folke, C. (ed.) Linking Social and Ecological Systems: Management practices and social mechanisms for building resilience. Cambridge University Press, Cambridge.

Bolund, P. & Hunhammar, S. (1999) Ecosystem services in urban areas. Ecological Economics 29: 293-301.

Brown, G. & Fagerholm, N. (2015) Empirical PPGIS/PGIS mapping of ecosystem services: A review and evaluation. Ecosystem Services 13: 119-133. https://doi.org/10.1016/j.ecoser.2014.10.007

Burayidi, M. A., Twigg, J., Wamsler, C., Allen, A. (2020) Rethinking Urban Resilience. In Burayidi, M. A., Allen, A., Twigg, J., Wamsler, C. (ed.) The Routledge Handbook of Urban Resilience. Routledge, Oxon.

Burkhard, B., de Groot, R. S., Costanza, R., Seppelt, R., Jorgensen, S. E., & Potschin, M. (2012a) Solutions for sustaining natural capital and ecosystem services. Editorial. Ecological indicators 21:1-6. https://doi.org/10.1016/j.ecolind.2012.03.008

Burkhard, B., Kroll, F., Nedkov, S., Müller, F. (2012b) Mapping ecosystem service supply, demand and budgets. Ecological Indicators 21:17-29. https://doi.org/10.1016/j.ecolind.2011.06.019

Chen, W. Y, & Jim, C. Y. (2008) Assessment and Valuation of the Ecosystem Services Provided by Urban Forests. In Carreiro, M. C., Song, Y.-C., Wu, J. (ed.) Ecology, Planning, and Management of Urban Forests: International Perspectives. Springer, New York.

Cilliers, S., Cilliers, J., Lubbe, R., Siebert S. (2013) Ecosystem services of urban green spaces in African countries – perspectives and challenges. Urban Ecosystems 16:681–702. https://doi.org/10.1007/s11252-012-0254-3

City Resilience Program (2020) Global Facility for Disaster Reduction and Recovery (GFDRR) and the World Bank. World Bank Headquarters, Washington DC. https://www.gfdrr.org/en/crp 3.11.2021

Climate Dar es Salaam (2019). Climate-Data.org <https://en.climate-data.org/africa/tanzania/dar-es-salaam/dar-es-salaam-518/> 3.1.2022

Climate Risk Database (2022) Tanzania Resilience Academy. https://geonode.resilienceacademy.ac.tz/ 2.2.2022

Constanza, R. (2016) Ecosystem services in theory and practice. In Potschin, M., Haines-Young, R., Fish, R., Turner, R. K. (ed.) Routledge Handbook of Ecosystem Services. Routledge, Oxon and New York.

Dar Es Salaam Population (2021) World Population Review <https://worldpopulationreview.com/world-cities/dar-es-salaam-population> 5.1.2022

Dobson, S. (2018) The embodied city and metropolitan landscape. In Fairclough, G. J., Särlöv-Herlin, I., Swanwick, C. (ed.) The Routledge handbook of landscape character assessment. Routledge, Oxon.

Englund, O., Berndes, G. & Cederberg C. (2017) How to analyse ecosystem services in landscapes: A systematic review. Ecological Indicators 73: 4492-504. https://doi.org/10.1016/j.ecolind.2016.10.009

Fagerholm, N., Eilola, S., Arki, V. (2021) Outdoor recreation and nature’s contribution to well-being in a pandemic situation - Case Turku, Finland. Urban Forestry & Urban Greening. 64: 127257. https://doi.org/10.1016/j.ufug.2021.127257

Fagerholm, N., Käyhkö, N., Ndumbaro, F. & Khamis, M. (2012) Community stakeholders' knowledge in landscape assessments – Mapping indicators for landscape services. Ecological Indicators 18: 421–433. https://doi.org/10.1016/j.ecolind.2011.12.004

Fairclough, G. J., Särlöv-Herlin, I., Swanwick, C. (2018) Landscape character approaches in global, disciplinary and policy context. In Fairclough, G. J., Särlöv-Herlin, I., Swanwick, C. (ed.) The Routledge handbook of landscape character assessment. Routledge, Oxon.

Fischer, J., Gardner, T. A., Bennett, E. M., Balvanera, P., Biggs, R., Carpenter, S., Daw, T., Folke, C., Hill, R., Hughes, T. P., Luthe, T., Maass, M., Meacham, M., Norström, A. V., Peterson, G., Queiroz, C., Seppelt, R., Spierenburg, M., Tenhunen, J. (2015) Advancing sustainability through mainstreaming a social–ecological systems perspective. Current Opinion in Environmental Sustainability 14:144–149. https://doi.org/10.1016/j.cosust.2015.06.002

García-Díez, V., García-Llorente, M., González, J. A. (2020) Participatory Mapping of Cultural Ecosystem Services in Madrid: Insights for Landscape Planning. Land 9(8): 244. https://doi.org/10.3390/land9080244

Gottwald, S., Albert, C., Fagerholm, N. (2022) Combining sense of place theory with the ecosystem services concept: empirical insights and reflections from a participatory mapping study. Landscape Ecology 37:633–655. https://doi.org/10.1007/s10980-021-01362-z

Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., Briggs, J. M. (2008) Global change and the ecology of cities. Science 319(5864): 756-60. https://doi.org/10.1126/science.1150195.

Guma, P. K. (2016) The governance and politics of urban space in the postcolonial city: Kampala, Nairobi and Dar es Salaam. Africa review 8(1) 31–43. http://dx.doi.org/10.1080/09744053.2015.1089014

Güneralp, B., Lwasa, S., Masundire, H., Parnell, S. and Seto, K. C. (2017) Urbanization in Africa: challenges and opportunities for conservation. Environmental Research Letters 13: 015002. https://doi.org/10.1088/1748-9326/aa94fe

Haines-Young, R. & Potschin, M. (2010) The links between biodiversity, ecosystem service and human well-being. In Raffaelli, D. G., Frid, C. L. J. (ed.) Ecosystem Ecology: A New Synthesis, 110-139. Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9780511750458.007

Hansjürgens, B. & Heinrichs, D. (2014) Megacities and Climate Change: Early Adapters, Mainstream Adapters and Capacities. In Kraas, F., Aggrawal, S., Coy, M. & Mertins, G. (ed.) Megacities - Our global urban future. Springer, Dordrecht. https://doi.org/10.1007/978-90-481-3417-5

Herrero-Jáuregui, C., Arnaiz-Schmitz, C., Reyes, M. F., Telesnicki, M., Agramonte, I., Easdale, M. H., Schmitz, M. F., Aguiar, M., Gómez-Sal, A., Montes, C. (2018) What do We Talk about When We Talk about Social-Ecological Systems? A Literature Review. Sustainability 10(8):2950. https://doi.org/10.3390/su10082950

Herslund, L., Backhaus, A., Fryd, O., Jørgensen, G., Bergen Jensen, M., Mtwangi Limbumba, T., Liu, L., Mguni, P., Mkupasi, M., Workalemahu, L., Yeshitela, K. (2018) Conditions and opportunities for green infrastructure – Aiming for green, water-resilient cities in Addis Ababa and Dar es Salaam. Landscape and Urban Planning 180: 319-327. https://doi.org/10.1016/j.landurbplan.2016.10.008

Hill, A., Hühner, T., Kreibich, V., Lindner, C. (2014) Dar es Salaam, Megacity of Tomorrow: Informal Urban Expansion and the Provision of Technical Infrastructure. In Kraas, F., Aggrawal, S., Coy, M. & Mertins, G. (ed.) Megacities - Our global urban future. Springer, Dordrecht. https://doi.org/10.1007/978-90-481-3417-5

Holling, C. S. (1973) Resilience and stability of ecological systems. Annual review of ecology and systematics. 4:1-23.

Horning, N., Robinson, J. A., Sterling E. J., Turner, W., Spector, S. (2010) Remote Sensing for Ecology and Conservation: a Handbook of Techniques. Oxford University Press, Oxford.

Jacobs, S., Burkhard, B., Van Daele, T., Staes, J., and Schneiders, A. (2015) The Matrix Reloaded: a review of expert knowledge use for mapping ecosystem services. Ecological Modelling 295:21–30. https://doi.org/10.1016/j.ecolmodel.2014.08.024

Jung. M. (2016) LecoS - A python plugin for automated landscape ecology analysis. Ecological Informatics 31:18-21. http://dx.doi.org/10.1016/j.ecoinf.2015.11.006

Karutz R., Berghöfer A., Moore L.R., and van Wyk, E. (2019). A Thematic Atlas of Nature's Benefits to Dar es Salaam. Helmholtz Centre for Environmental Research and ICLEI Africa Secretariat, Leipzig and Cape Town.

Käyhkö, N., Fagerholm, N., Khamis, M., Hamdan, S. I., Juma, M. (2018) The collaborative, participatory process of landscape character mapping for land and forest planning in Zanzibar, Tanzania. In Fairclough, G. J., Särlöv-Herlin, I., Swanwick, C. (ed.) The Routledge handbook of landscape character assessment. Routledge, Oxon.

Kienast, F., Helfenstein J. (2016) Modelling Ecosystem Services. In Potschin, M., Haines-Young, R., Fish, R., Turner, R. K. (ed.) Routledge Handbook of Ecosystem Services. Routledge, Oxon and New York.

Kraas, F. & Mertins, G. (2014) Megacities and Global Change. In Kraas, F., Aggrawal, S., Coy, M. & Mertins, G. (ed.) Megacities - Our global urban future. Springer, Dordrecht. https://doi.org/10.1007/978-90-481-3417-5

Krellenberg, K. (2007) Urban Environmental Monitoring in Buenos Aires – Determining Green Areas. In Netzband, M., Stefanov, W. L., Redman, C. (ed.) Applied Remote Sensing for Urban Planning, Governance and Sustainability. Springer-Verlag, Berlin.

Kuhlicke, C., Kabisch, S., Rink, D. (2020) Urban resilience and urban sustainability. In Burayidi, M. A., Allen, A., Twigg, J., Wamsler, C. (ed.) The Routledge Handbook of Urban Resilience. Routledge, Oxon.

Kupfer, J. A. (2012) Landscape ecology and biogeography: Rethinking landscape metrics in a post-FRAGSTATS landscape. Progress in Physical Geography. 36(3): 400–420. https://doi.org/10.1177/0309133312439594

Lahoti, S., Lahoti, A., Saito, O. (2020) Application of Unmanned Aerial Vehicle (UAV) for Urban Green Space Mapping in Urbanizing Indian Cities. In Avtar, R., Watanabe, T. (ed.) Unmanned Aerial Vehicle: Applications in Agriculture and Environment. Springer, Cham. https://doi.org/10.1007/978-3-030-27157-2_13

Lang, S., Blaschke, T., Kothencz, G., Hölbling, D. (2018) Urban green mapping and valuation. In Qihao, W., Quattrochi, D., Gamba, P. E. (ed.) Urban Remote Sensing. CRC Press, Boca Raton.

Li, H. & Wu, J. (2004) Use and misuse of landscape indices. Landscape ecology 19:389-399. https://doi.org/10.1023/B:LAND.0000030441.15628.d6

Liquete, C., Haas, E., Bondo, T., Hirzinger, C., Schnelle, M., Reisinger, D., Lyon, D., Finisdore, J., Ledwith, M. (2016) Mapping of Ecosystems and Ecosystem Services Using Remote Sensing. In Potschin, M., Haines-Young, R., Fish, R., Turner, R. K. (ed.) Routledge Handbook of Ecosystem Services. Routledge, Oxon and New York.

Maes, J., Crossman, N. D., Burkhard, B. (2016) Mapping Ecosystem Services. In Potschin, M., Haines-Young, R., Fish, R., Turner, R. K. (ed.) Routledge Handbook of Ecosystem Services. Routledge, Oxon and New York.

Making Cities Resilient (2017) How to Make Cities More Resilient - A handbook for Local Government Leaders. United Nations Office for Disaster Risk Reduction (UNISDR), Geneva.

Maptionnaire (2022) Maptionnaire Community Engagement Platform. <https://maptionnaire.com/> 21.4.2022

McCall, M. (2006) Precision for whom? Mapping ambiguity and certainty in (Participatory) GIS. Participatory Learning and Action 54: 114–119.

McGarigal, K. Marks, B. J. (1995) FRAGSTATS: spatial pattern analysis program for quantifying landscape structure. General Technical Report PNW-GTR-351. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland.

McPhearson, T., Andersson, E., Elmqvist, T., Frantzeskaki, N. (2015) Resilience of and through urban ecosystem services. Ecosystem Services 12:152-156. http://dx.doi.org/10.1016/j.ecoser.2014.07.012

Meerow, S., Newell, J. P., Stults, M. (2016) Defining urban resilience: A review. Landscape and Urban Planning 147: 38–49. https://doi.org/10.1016/j.landurbplan.2015.11.011meero

Mlozi, M. R. S., Lupala, A., Chenyambuga, S. W., Liwenga, E., Msogoya, T. (2014) Building Urban Resilience. Assessing Urban and Peri-urban Agriculture in Dar es Salaam, Tanzania. Padgham, J., Jabbour, J. (ed.) United Nations Environment Programme (UNEP), Nairobi.

Mng´ong´o, O. S. (2004) A Browning process – The case of Dar es Salaam city. Doctoral Dissertation. Royal Institute of Technology, Department of Infrastructure, Division of Urban Studies. Stockholm.

Mykhnenko, V. (2016). Resilience. A right- winger’s ploy? In Springer, S., Birch, K., MacLeavy, J. (ed.) The Handbook of Neoliberalism. Routledge, London.

Neyns, R., & Canters, F. (2022) Mapping of Urban Vegetation with High-Resolution Remote Sensing: A Review. Remote sensing 14(4):1031. https://doi.org/10.3390/rs14041031

Niemelä, J., Saarela, S.-R., Söderman, T., Kopperoinen, L., Yli-Pelkonen, V., Väre, S. & Kotze, D. J. (2010) Using the ecosystem approach for better planning and conservation of urban green spaces: a Finland case study. Biodiversity Conservation 19:3225–3243. https://doi.org/10.1007/s10531-010-9888-8

Noon, M. L., Goldstein, A., Ledezma, J. C., Roehrdanz, P. R., Cook-Patton, S. C., Spawn-Lee, S. A., Wright, T. M., Gonzalez-Roglich, M., Hole, D. G., Rockström, J., Turner, W. R. (2022) Mapping the irrecoverable carbon in Earth’s ecosystems. Nature Sustainability 5: 37–46. https://doi.org/10.1038/s41893-021-00803-6

Olson, D. M., Dinerstein, E., Wikramanayake, E. D., Burgess, N. D., Powell, George V. N., Underwood, E. C., D'amico, J. A., Itoua, I., Strand, H. E., Morrison, J. C., Loucks, C. J., Allnutt, T. F., Ricketts, T. H., Kura, Y., Lamoreux, J. F., Wettengel, W. W., Hedao, P., Kassem, K. R. (2001) Bioscience 51(11): 933-938. https://doi.org/10.1641/0006-3568(2001)051[0933:TEOTWA]2.0.CO;2

Ostrom, E. (2009) A General Framework for Analyzing Sustainability of Social-Ecological Systems. Science 325(5939):419-422. https://doi.org/10.1126/science.1172133

Pickett, S. T. A., Cadenasso, M. L., Grove, J. M., Boone, C. G., Groffman, P. M., Irwin, E., Warren, P. (2011) Urban ecological systems: Scientific foundations and a decade of progress. Journal of Environmental Management 92(3): 331– 362. https://doi.org/10.1016/j.jenvman.2010.08.022

PlanetScope instruments (2022) Earth Online. European Space Agency. <https://earth.esa.int/eogateway/missions/planetscope> 28.4.2022

Population and housing census 2012 (2013) Population distribution by administrative areas. National Bureau of Statistics, Ministry of Finance, Dar es Salaam.

Potschin, M., B. & Haines-Young, R., H. (2011) Ecosystem services: Exploring a geographical perspective. Progress in Physical Geography 35: 575. https://doi.org/10.1177/0309133311423172

Potschin, M., Haines-Young, R. (2016) Defining and Measuring Ecosystem Services. In Potschin, M., Haines-Young, R., Fish, R., Turner, R. K. (ed.) Routledge Handbook of Ecosystem Services. Routledge, Oxon and New York.

Ramezani, H., Holm, S., Allard, A. & Ståhl, G. (2013) A review of sampling-based approaches for estimating landscape metrics. Norsk Geografisk Tidsskrift 67(2): 61-71. https://doi.org/10.1080/00291951.2013.784800

Raymond, C. M., Bryan, B. A., MacDonald, D. H., Cast, A., Strathearn, S., Grandgirard, A., Kalivas, T. (2009) Mapping community values for natural capital and ecosystem services. Ecological Economics 68: 1301–1315. https://doi.org/10.1016/j.ecolecon.2008.12.006

Richards, D. R., Passy, P., Oh, R. R. Y. (2017) Impacts of population density and wealth on the quantity and structure of urban green space in tropical Southeast Asia. Landscape and Urban Planning 157:553-560. http://dx.doi.org/10.1016/j.landurbplan.2016.09.005

Rittel, H. W. J. & Webber, M. M. (1973) Dilemmas in a general theory of planning. Policy Sciences 4:155-169.

Sieber, I. M., Campagne, C. S., Villien, C., Burkhard, B. (2021) Mapping and assessing ecosystems and their services: a comparative approach to ecosystem service supply in Suriname and French Guiana. Ecosystems and People 17(1):148-164. https://doi.org/10.1080/26395916.2021.1896580

Spanowicz, A. G. & Jaeger, J. A. G. (2019) Measuring landscape connectivity: On the importance of within-patch connectivity. Landscape Ecology 34: 2261–2278. https://doi.org/10.1007/s10980-019-00881-0

Suárez, M., Gómez-Baggethun, E., Onaindia, M. (2020) Assessing socio-ecological resilience in cities. In Burayidi, M. A., Allen, A., Twigg, J., Wamsler, C. (ed.) The Routledge Handbook of Urban Resilience. Routledge, Oxon.

Tanzania Resilience Academy (2022) Tanzania Urban Resilience Program. <https://resilienceacademy.ac.tz/> 27.4.2022

Tanzania Urban Resilience Program (TURP) (2022) The World Bank. <https://www.worldbank.org/en/programs/tanzania-urban-resilience-program> 27.4.2022

Termorshuizen, J. W. & Opdam, P. (2009) Landscape services as a bridge between landscape ecology and sustainable development. Landscape Ecology 24:1037–1052.

Tibesigwa et al. (2020) Valuing recreational ecosystem services in developing cities: The case of urban parks in Dar es Salaam, Tanzania. Cities 106: 102853. https://doi.org/10.1016/j.cities.2020.102853

Todd, G., Msuya, I., Levira, F., Moshi, I. (2019) City Profile: Dar es Salaam, Tanzania. Environment and Urbanization Asia 10(2):193–215. https://doi.org/10.1177/0975425319859175

TSED and CensusInfo Tanzania (2021) http://www.dataforall.org/tanzania/ 14.11.2021

Turner, M. G., Gardner R. H., O´Neill, R. V. (2001) Introduction to Landscape Ecology. In Turner, M. G., Gardner R. H., O´Neill, R. V. (ed.) Landscape Ecology in Theory and Practice. Pattern and Process. Springer, USA.

Urban Resilience Hub (s.a.) City Resilience Global Programme. UN-Habitat, Barcelona. https://urbanresiliencehub.org/ 3.11.2021

Wang, J.-F., Stein, A., Gao, B.-B-, Ge, Y. (2012) A review of spatial sampling. Spatial Statistics, 2:1-14. https://doi.org/10.1016/j.spasta.2012.08.001

World Urbanization Prospects (2019) The 2018 Revision. ST/ESA/SER.A/42. United Nations, Department of Economic and Social Affairs, Population division. United Nations, New York.

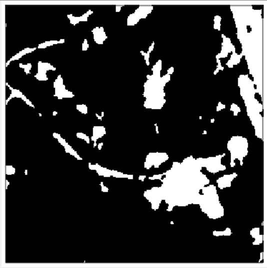
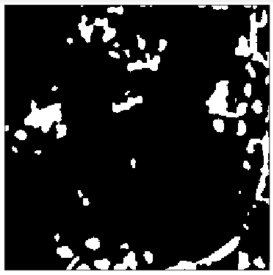
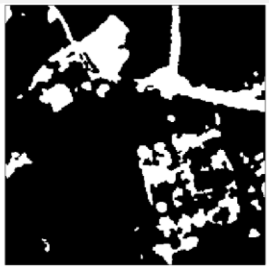
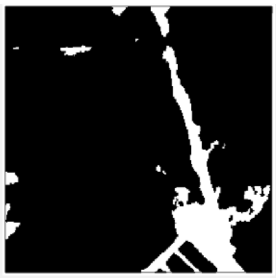
Wu, J. (2008) Toward a Landscape Ecology of Cities: Beyond Buildings, Trees, and Urban Forests. In Carreiro, M. C., Song, Y.-C., Wu, J. (ed.) Ecology, Planning, and Management of Urban Forests – International Perspectives. Springer, New York.

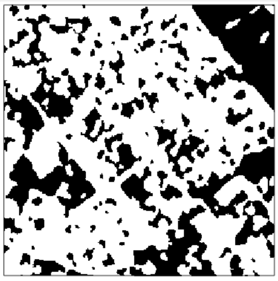
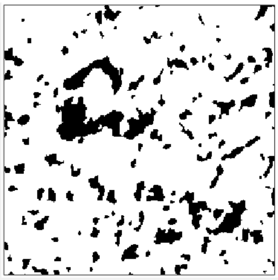
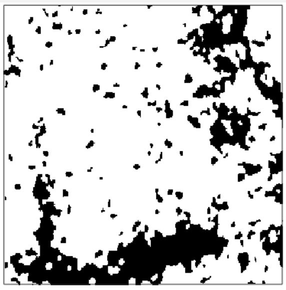
Yamashita, A. (2017) Rapid Urbanization in Developing Asia and Africa. In Murayama, Y., Kamusoko, C., Yamashita, A., Estoque, R. C. (ed.) Urban Development in Asia and Africa: Geospatial Analysis of Metropolises. Springer Nature, Singapore. https://doi.org/10.1007/978-981-10-3241-7

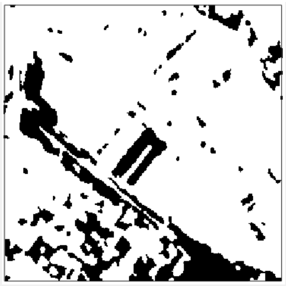
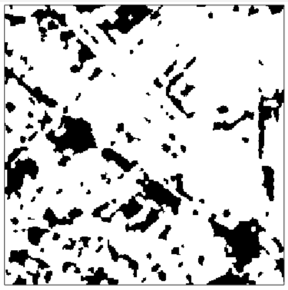
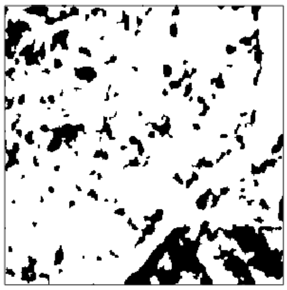
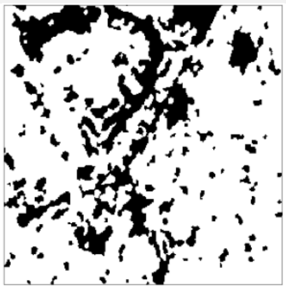
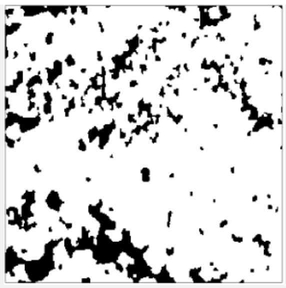
Zipperer, W. C. (2008) Applying Ecosystem Management to Urban Forestry. In Carreiro, M. C., Song, Y.-C., Wu, J. (ed.) Ecology, Planning, and Management of Urban Forests – International Perspectives. Springer, New York.

Appendices

Appendix 1. Landscape metrics

SAMPLE PLOT ID	**STRATA**	**LANDSCAPE METRIC** number of patches	mean patch area (ha)	effective mesh size	**OULOOK OF DATA** black: 1 (green) white: 0 (non-green)
G1	Green	10	21525,2	213034,7	
G2	Green	9	25744,9	230474,5	
G3	Green	6	38899,3	198021,8	
G4	Green	5	42454,4	164755,2	
G5	Green	6	38612,7	224682,7	

G6	Green	3	75033,3	223902,9	
G7	Green	1	252964,0	252964,0	
G8	Green	1	257380,0	257380,0	
MEAN of strata		5	94076,7	220652,0	
B1	Built-up	119	737,4	6927,3	
B2	Built-up	135	286,7	2047,0	
B3	Built-up	119	473,6	14449,3	

B4	Built-up	67	698,4	5290,0	
B5	Built-up	118	443,3	2241,2	
B6	Built-up	124	385,5	6439,9	
B7	Built-up	111	543,3	10231,2	
B8	Built-up	123	344,7	2718,8	
MEAN of strata		115	489,1	6293,1	

Appendix 2. Participatory GIS survey

The online PGIS survey as screenshots from Maptionnaire online platform.

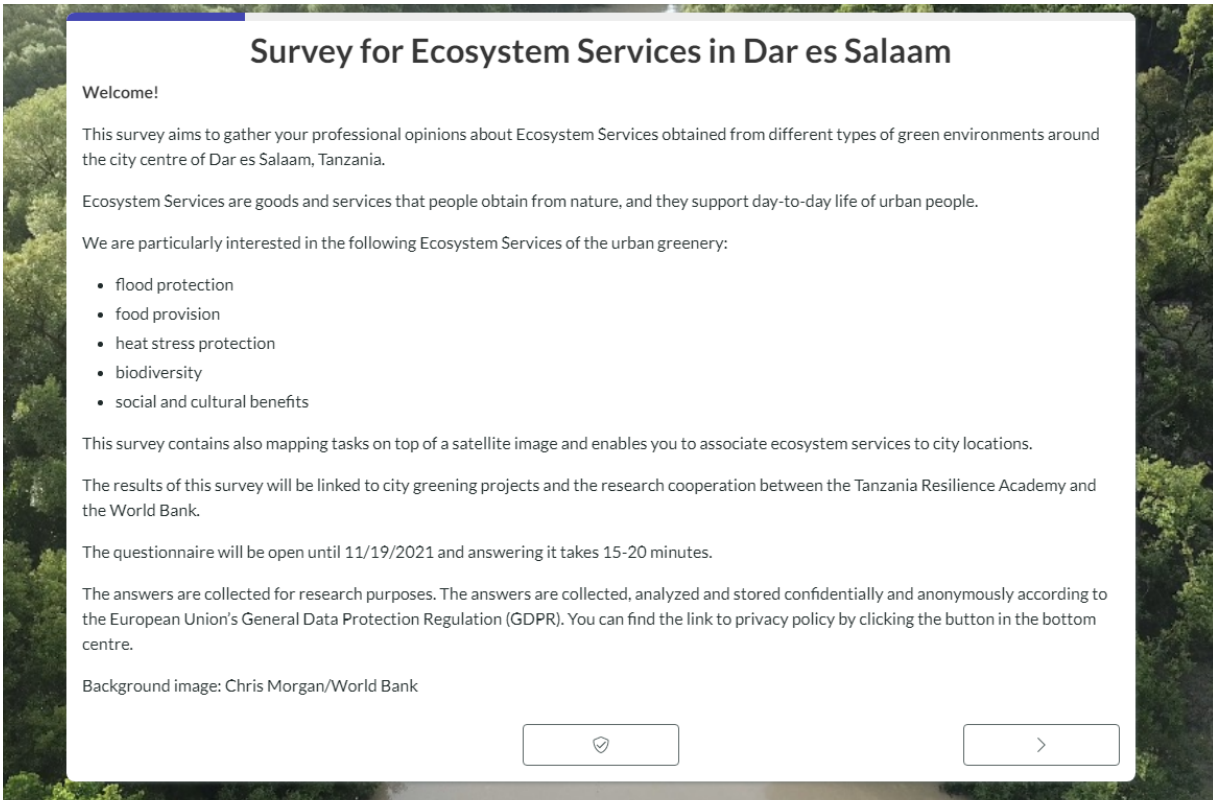


Figure 1. Survey page 1

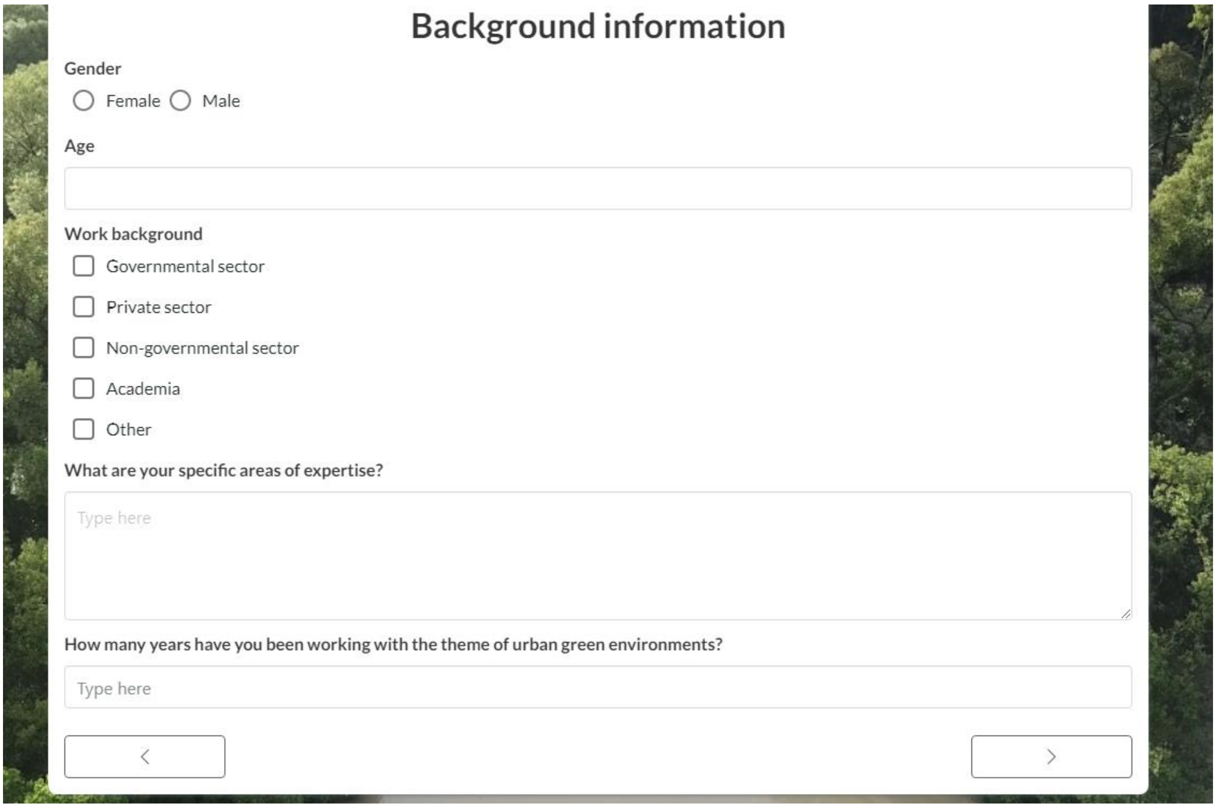


Figure 2. Survey page 2

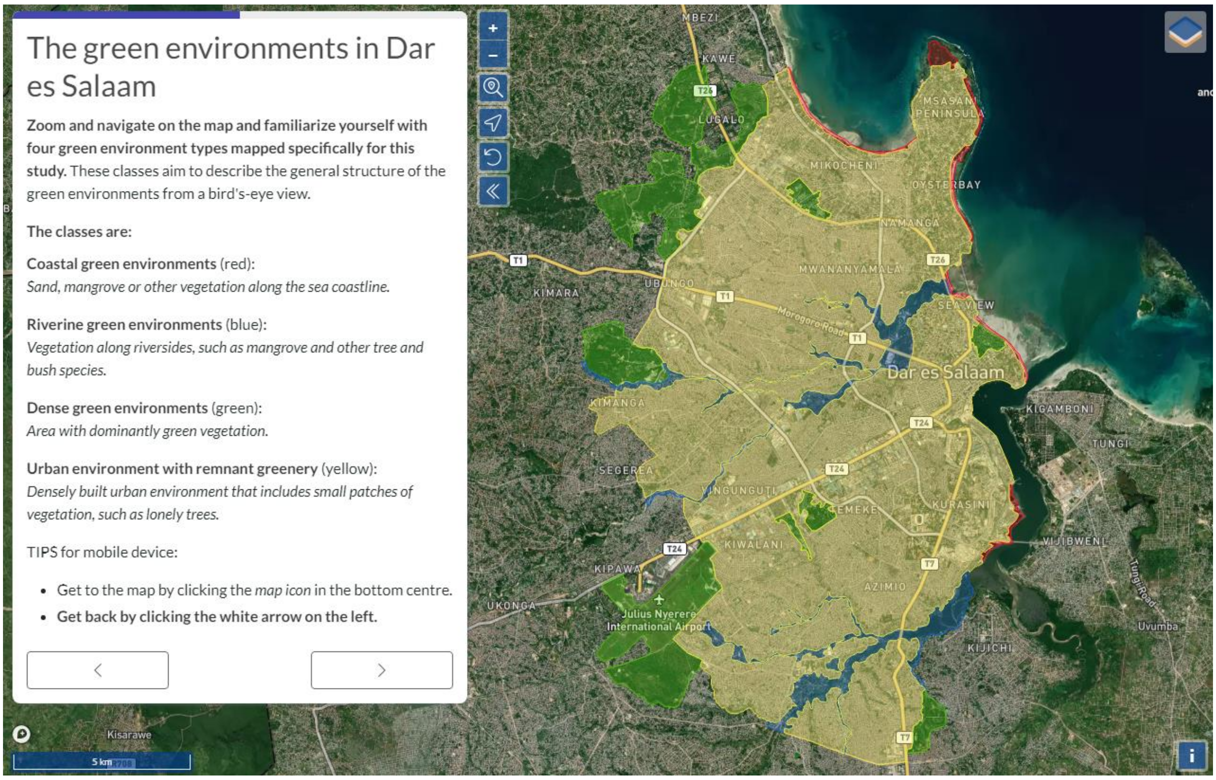


Figure 3. Survey page 3

Figure 4. Survey page 4: The first survey question. (1/6)

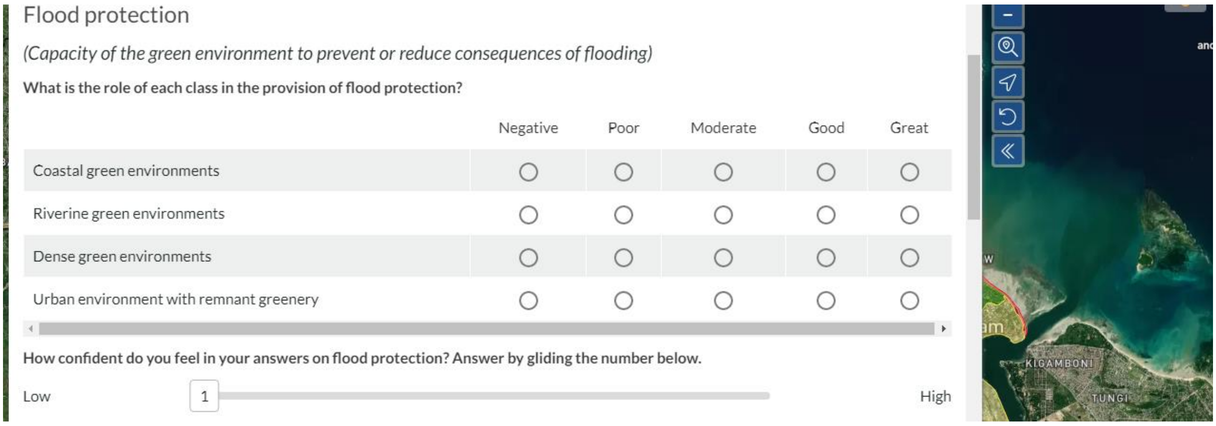
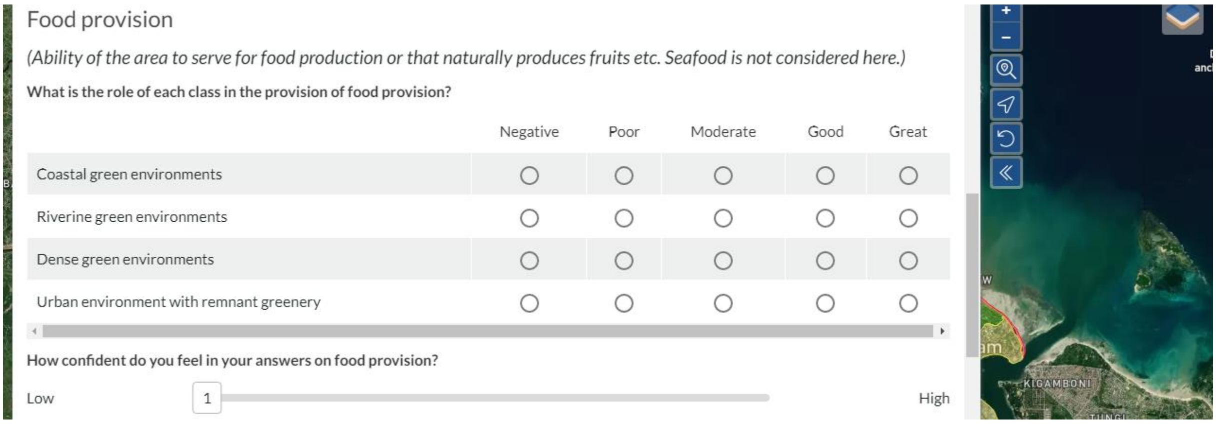


Figure 5. Survey page 4 (2/6)



Food provision

(Ability of the area to serve for food production or that naturally produces fruits etc. Seafood is not considered here.)

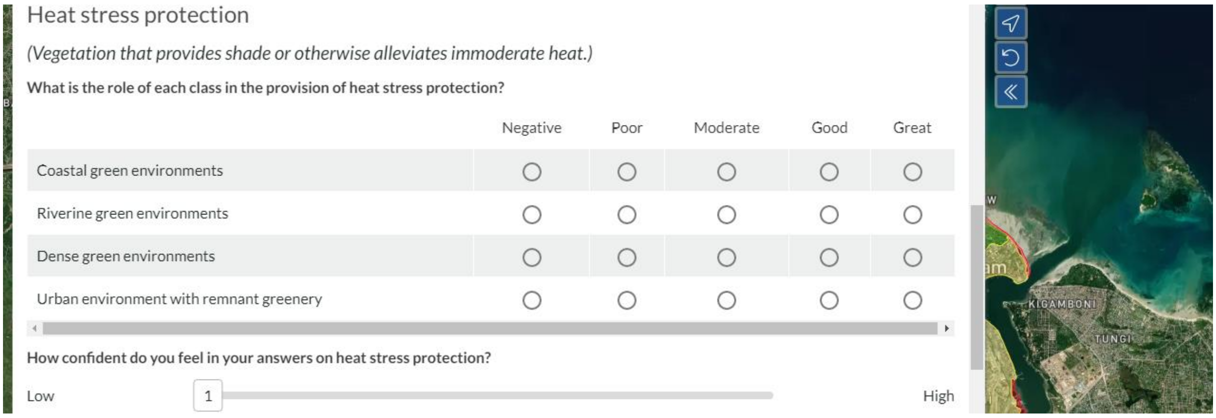
What is the role of each class in the provision of food provision?

	Negative	Poor	Moderate	Good	Great
Coastal green environments	○	○	○	○	○
Riverine green environments	○	○	○	○	○
Dense green environments	○	○	○	○	○
Urban environment with remnant greenery	○	○	○	○	○

How confident do you feel in your answers on food provision?

Low 1 High

Figure 6. Survey page 4 (3/6)



Heat stress protection

(Vegetation that provides shade or otherwise alleviates immoderate heat.)

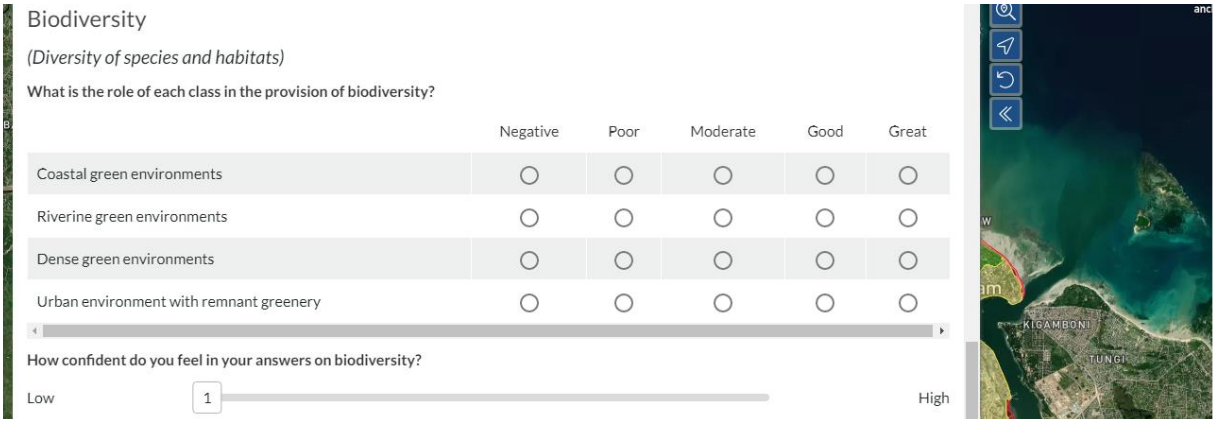
What is the role of each class in the provision of heat stress protection?

	Negative	Poor	Moderate	Good	Great
Coastal green environments	○	○	○	○	○
Riverine green environments	○	○	○	○	○
Dense green environments	○	○	○	○	○
Urban environment with remnant greenery	○	○	○	○	○

How confident do you feel in your answers on heat stress protection?

Low 1 High

Figure 7. Survey page 4 (4/6)



Biodiversity

(Diversity of species and habitats)

What is the role of each class in the provision of biodiversity?

	Negative	Poor	Moderate	Good	Great
Coastal green environments	○	○	○	○	○
Riverine green environments	○	○	○	○	○
Dense green environments	○	○	○	○	○
Urban environment with remnant greenery	○	○	○	○	○

How confident do you feel in your answers on biodiversity?

Low 1 High

Figure 8. Survey page 4 (5/6)

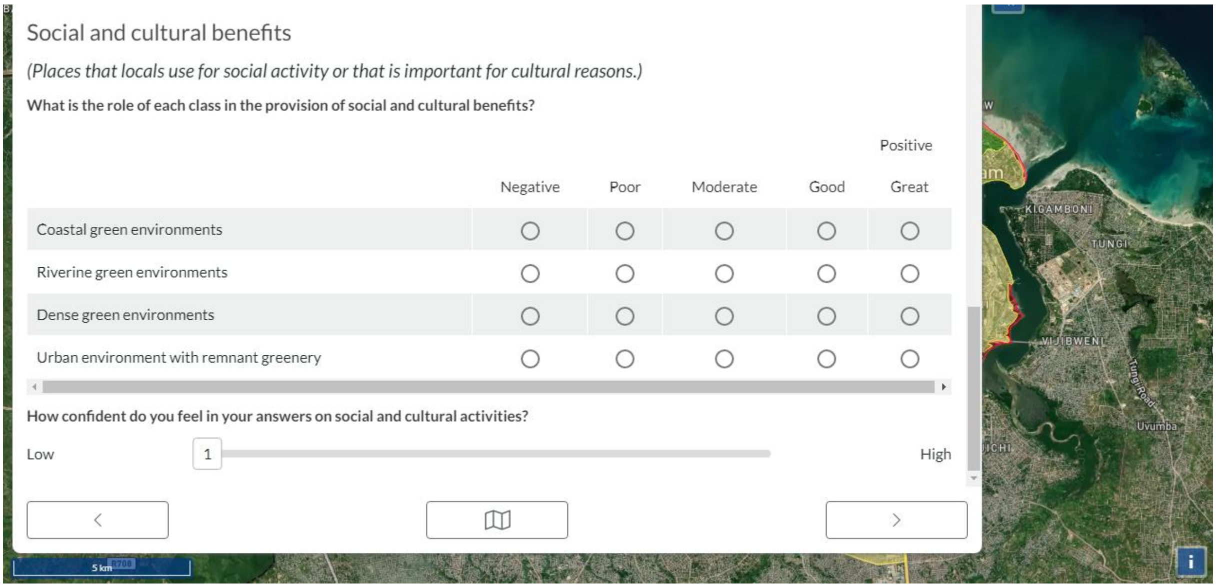


Figure 9. Survey page 4 (6/6)

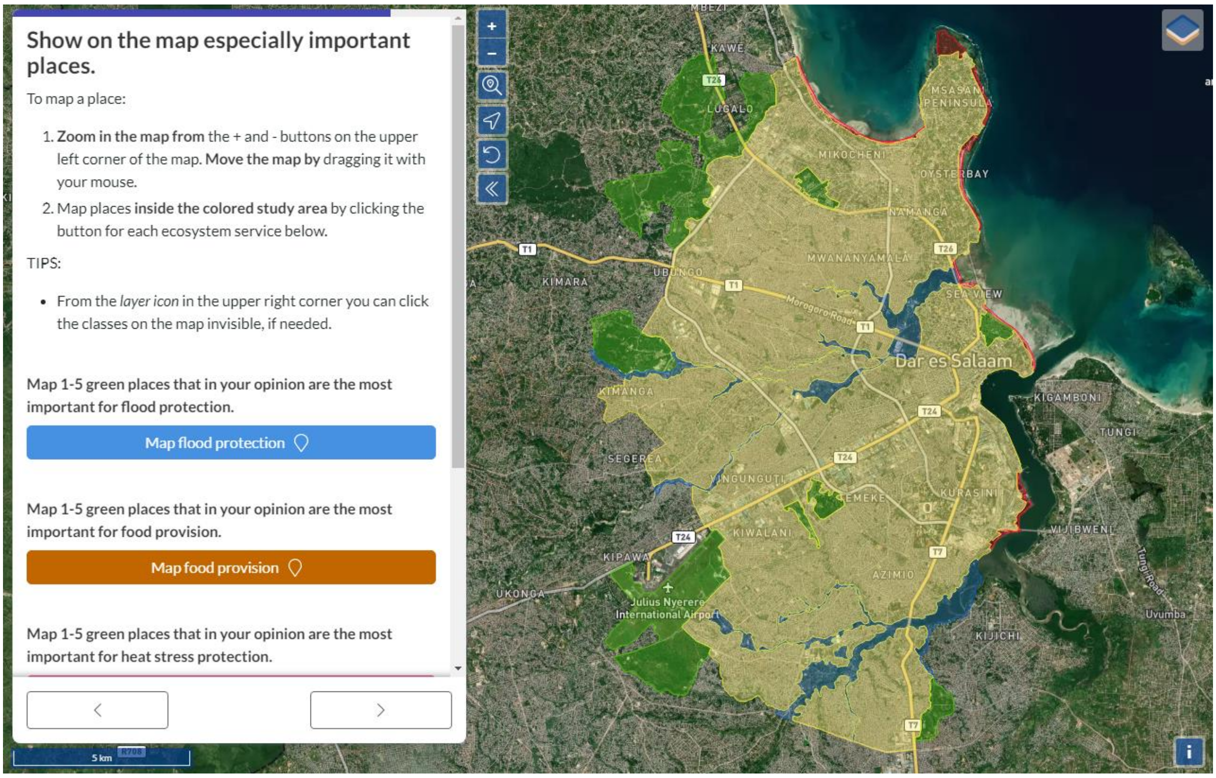


Figure 10. Survey page 5: The second survey question. (1/3)

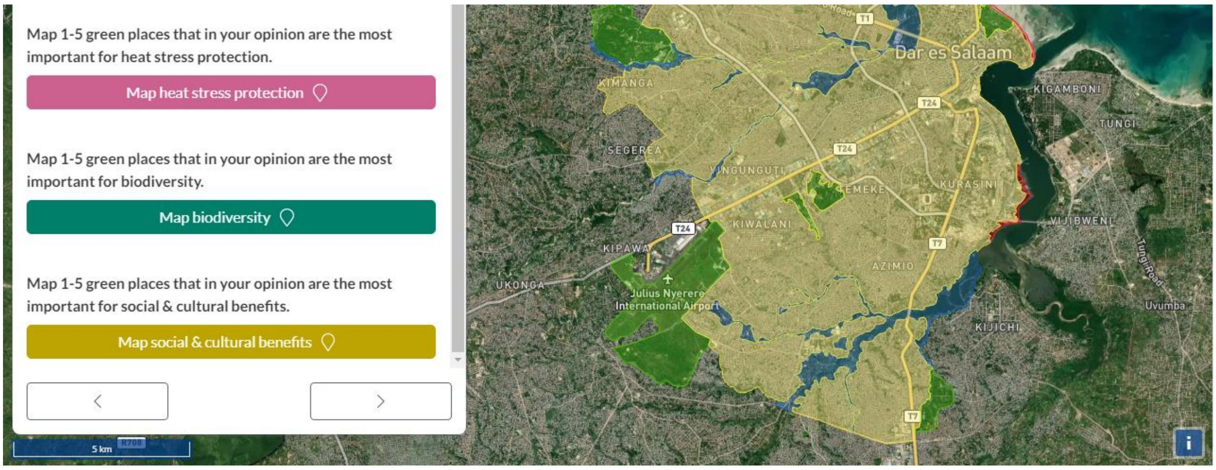


Figure 11. Survey page 5 (2/3)

Figure 12. Survey page 5 (3/3) The user interface when mapping places. The texts in Finnish are a bug in Maptionnaire and they were seen in English by the respondents. The marker text says "Place the marker here by clicking the map".

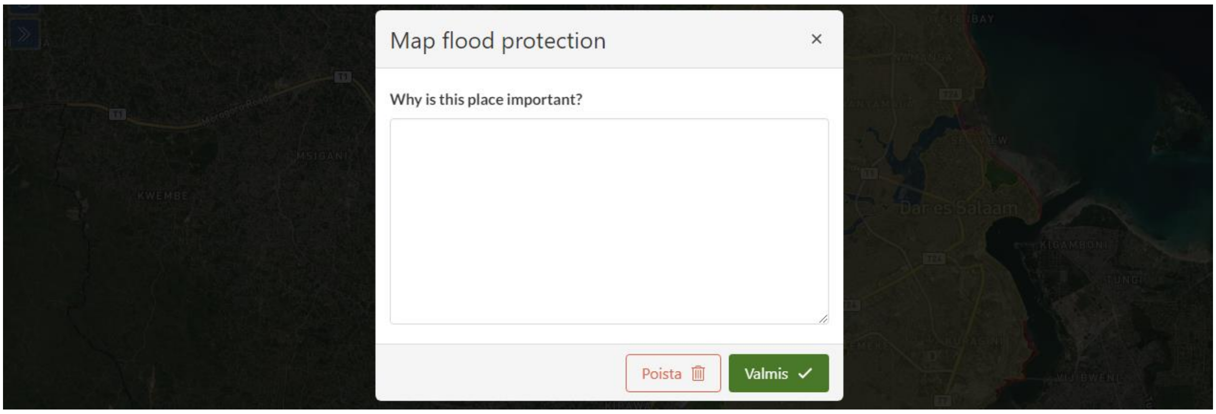


Figure 13. Survey page 6. A pop-up window after mapping a place on page 5.

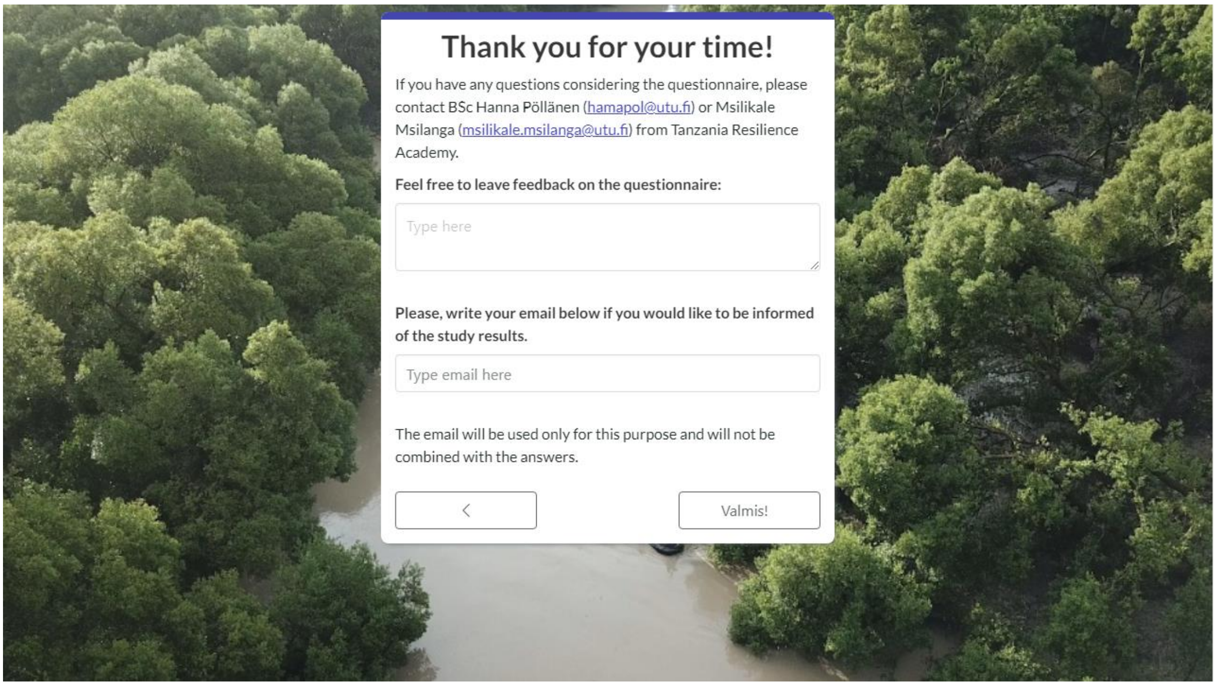


Figure 14. Survey page 7.