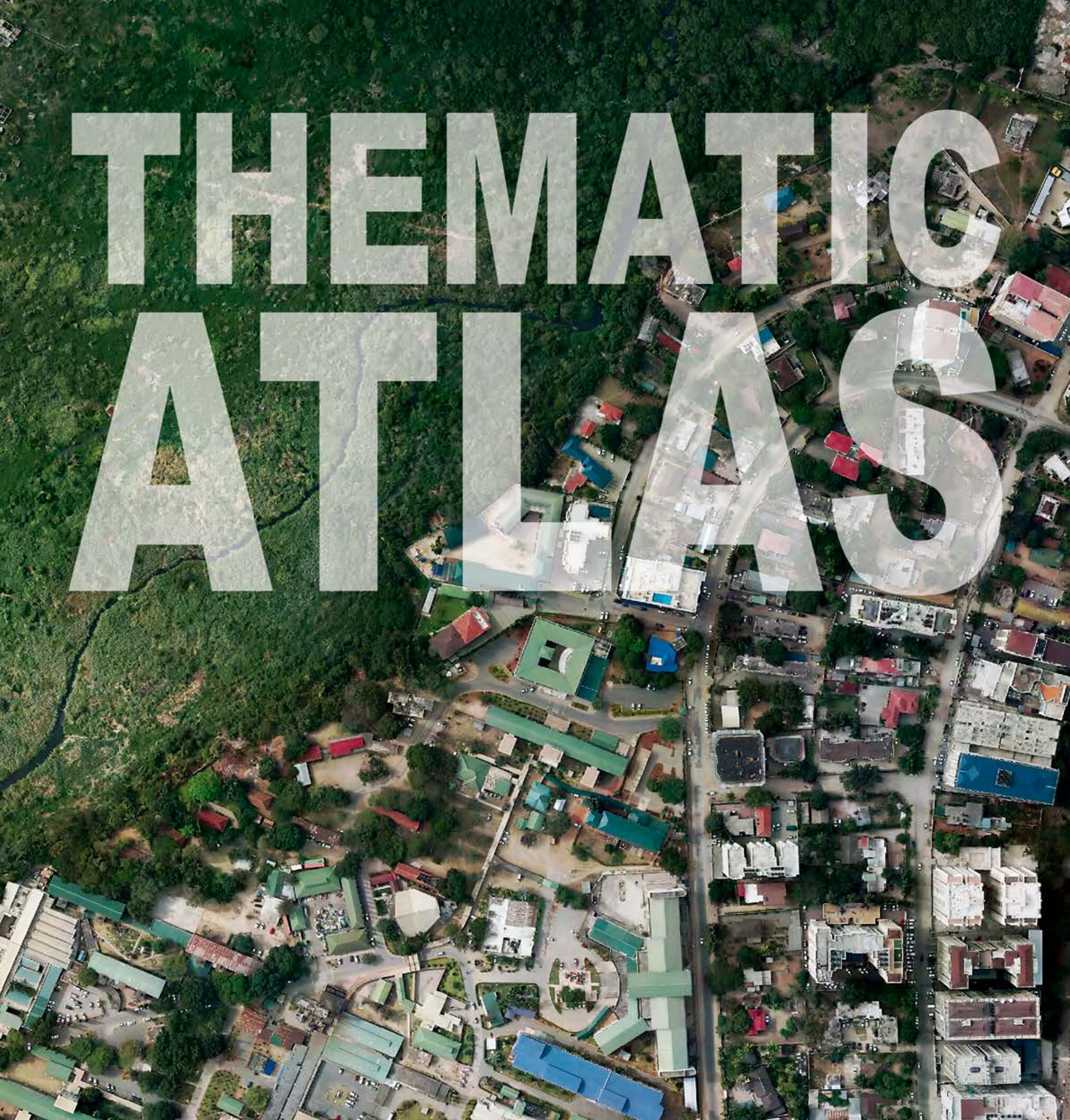


THEMATIC ATLAS

A Thematic Atlas of Nature's Benefits to Dar es Salaam

Critical reasons for greening the city and for keeping urban and peri-urban ecosystems intact

INTERACT-Bio
Integrated action on biodiversity

HELMHOLTZ
CENTRE FOR ENVIRONMENTAL RESEARCH – UFZ

ICLEI Local Governments for Sustainability

CBC Cities Biodiversity Center

Published by

Helmholtz Centre for Environmental Research – UFZ
04318 Leipzig, Germany

ICLEI Local Governments for Sustainability – Africa Secretariat
7441 Cape Town, South Africa

Suggested citation:

Karutz R., Berghöfer A., Moore L.R., and van Wyk, E. (2019). A Thematic Atlas of Nature's Benefits to Dar es Salaam. Leipzig and Cape Town: Helmholtz Centre for Environmental Research and ICLEI Africa Secretariat. 78 pages.

Disclaimer:

These maps do not constitute any official position with regard to any territorial issues, or ongoing disputes. Where possible, official map and data have been used. However, the resulting thematic maps do not represent public decisions on private or public space. The maps are intended as guidance and stimulus for public debate on the future spatial development of Dar es Salaam.

Aerial pictures on cover page, back page and chapter headings:

Ministry of Lands, Housing and Human Settlements Developments (MLHHSD), 2016. Orthophoto of Dar es Salaam.

The Dar es Salaam City Council expressed the need for, and initiated the development of, this Thematic Atlas as a tool to support the strategic prioritisation around greening for improved wellbeing of Dar es Salaam's citizens. The Thematic Atlas is acknowledged and supported by the following national Ministries of Tanzania: The President's Office: Regional Administration and Local Government, The Ministry of Lands, Housing and Human Settlements Development and the Vice President's Office: Environment Division.

Various institutions supported the development of this Atlas in the form of funding, data, contextual insight and advice:

Supported by: Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

based on a decision of the German Bundestag

UNA RIVERS FOR LIFE

Ministry of Lands, Housing and Human Settlements Developments

BORDA AFRICA

Stockholm Resilience Centre — Sustainability Science for Biosphere Stewardship

Stockholm University

SwedBio — A programme at Stockholm Resilience Centre

Raphael Karutz, Augustin Berghöfer, Luke Moore and Ernita van Wyk

A Thematic Atlas of Nature's Benefits to Dar es Salaam

Critical reasons for greening the city and for keeping urban and peri-urban ecosystems intact

Dar es Salaam, Tanzania
2019

Executive Summary

Dar es Salaam (DSM) is one of the fast growing metropoles in the world. The population, located across five municipalities – Kinondoni, Ilala, Ubungo, Temeke and Kigamboni – is estimated to grow by about 1000 inhabitants per day. The metropolitan region currently has approximately 6 million residents and this number is expected to rise to over 10 million by 2030. How can all citizens of Dar es Salaam live in a safe environment, enjoy a good quality of life and make a sustainable living?

Healthy and functioning urban ecosystems are part of the solution to the challenges of rapid urban growth. Cities are man-made, but all built infrastructure has a natural base and is embedded in a landscape. Each landscape has natural processes such as water, carbon and nutrient cycles. People are part of this landscape, as they live in it, transform it, and depend on it.

DSM's natural places, public greenspaces and adjacent rural areas meet fundamental human needs, such as safe drinking water, temperature regulation, or protection from floods. However, DSM is losing greenspace at a fast pace. In fact, many cities around the world witness the loss of healthy ecosystems and nature. From other places we know: The earlier greenspace losses can be stopped and reversed, the better the chances for safe and good living conditions in a growing city.

The Atlas has been developed in the context of two projects: INTERACT-Bio and UNA Rivers – both led by ICLEI – Local Governments for Sustainability. The Helmholtz Centre for Environmental Research – UFZ, Germany, was responsible for its scientific coordination. Many others have contributed: With their knowledge, data, and judgment, the maps in this Atlas have become rich in insights. Without resources for conducting original field research, we opted for eliciting and consolidating existing knowledge and data and interpreted it through an 'ecosystem services perspective'. This perspective emphasises the many links between nature and human well-being.

This Atlas shows how and where DSM depends on nature. The maps provide an overview of what is at stake if DSM continues in a 'business as usual' trajectory. Each chapter describes one area where action is needed, explains why, and makes suggestions about what can be done.

Selected key findings and policy recommendations:

1. **Protecting and enhancing urban greenspaces provides huge benefits** in face of the problems related to DSM's growth. For example, it improves community health, reduces the city's vulnerability to climate change, and it likely saves future costs for water supply, for sustainable livelihoods, and for a truly enjoyable city. Authorities should therefore further prioritize the maintenance and conservation of greenspace.

2. **There are many options** for promoting healthy ecosystems and maintaining high-quality greenspace **that apply to different scales, actors, and policy areas**. For example: The inner city could be revitalised with small-scale solutions, including small parks, vertical gardens, green pavements and green roofs. Private sector associations need to become active partners in maintaining greenspace and in implementing pollution controls. In peri-urban areas, enhanced participatory planning processes are needed to secure critical near-natural habitats against conversion.

3. Maintaining DSM's ecosystems is a cross-cutting task. Many **government sectors, companies, and organisations stand to gain from collaboratively engaging in this task**. For example: Mangrove protection and sustainable beach development is a prerequisite for local fisheries income, but it is equally important for coastal protection in view of climate change, and for the emerging tourism industry in DSM.

4. **Urban farming** sustains thousands of livelihoods and allows DSM to have a high degree of food independence. Urban farmland also regulates air temperature, and water infiltration in case of heavy rainfall. Yet, the loss rate of agricultural land is high due to urban densification. Thus, growing competition over land threatens agriculture as a relatively secure source of income in DSM. **Authorities should engage in advancing relevant by-laws and their implementation**. Zoning land for agriculture and enhancing land tenure security are key issues, as well as technical extension services and the strengthening of local agricultural value chains.

5. **Peri-urban ecosystems supply safe drinking water to rapidly growing DSM**. Various challenges exist: The shallow water aquifer below DSM is threatened by over-extraction and pollution. In addition, the Ruvu River and other rivers of the Eastern Arc Mountains (which collectively provide freshwater to ca. six million Tanzanians in the wider region) are threatened by rapid deforestation rates in the catchment. This will affect water availability in the near future: By 2030, water shortages are expected if no additional sources are secured. Appropriate legislation for watershed protection has been adopted, nonetheless, **DSM authorities are encouraged to engage pro-actively as partners in implementing these laws**, and to boost practical watershed conservation efforts.

6. In DSM, road traffic is a major contributor to urban air pollution – with severe health impacts. **Street trees and greenspaces have the capacity to fixate toxic substances from polluted air**. Yet, DSM is estimated to lose about 10% of its trees annually. It is recommended that tree planting efforts are intensified. Furthermore, partnerships with public institutions (e.g. schools), neighbourhood associations and with the private sector should be promoted to **improve care-taking of recently planted trees**.

7. **Greenspace provides recreation benefits and supports communal quality of life**. There is clear evidence that human minds and bodies benefit from being exposed to nature, even man-made nature. In DSM, public greenspace is legally recognized. Authorities have various options to strengthen social and communal benefits of greenspaces: For example, urban river zones are valued for their flood protection function, but they are not managed as public greenspaces with recreation values. Also, **contract-based support could complement existing greenspace management efforts**: Mtaa-structures (i.e. sub-ward, street scale governance units) are well-placed for community greening initiatives.

8. **Urban greenspace can partly buffer the consequences of climate change**. By 2040, projections foresee that for almost one day in two, DSM will experience temperatures above 36°C. This will likely push energy demand (for air conditioning) and increase the public health burden. The significant cooling effects of urban trees, green spaces and green infrastructures therefore become all the more important. Health and energy authorities are encouraged to examine more closely the **opportunities for co-investing in urban greenspaces**. Similarly, disaster risk reduction efforts are likely closely linked with the maintenance of green space offering e.g. natural flood retention.

Acknowledgements

This Thematic Atlas is a collaborative effort. The following persons and institutions have supported its development and are gratefully acknowledged.

Funders

The INTERACT-Bio project supported the development of this Atlas. This project is funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) through the International Climate Initiative (IKI). The Urban Natural Assets for Africa: Rivers for Life (UNA Rivers) project funded a workshop of experts (June 2018), who provided critical inputs into the development of an updated spatial biodiversity layer for Dar es Salaam. The UNA Rivers project also funded the proofreading and a print run of this Atlas. The UNA River project is funded by The Swedish International Development Cooperation Agency (Sida) through SwedBio at the Stockholm Resilience Centre, Stockholm University.

Contributors

Hannah Kirschner (Helmholtz Centre for Environmental Research – UFZ) provided layout and co-developed the maps; Mthobisi Wanda (ICLEI Africa) supported map development; Florian Koch (HTW Berlin) provided inputs for the concept of the atlas; Ingrid Coetzee (INTERACT-Bio project manager, ICLEI Africa) provided overall guidance, and Tarryn Quayle (ICLEI Africa) gave inputs from an UNA Rivers project perspective; Alphonce Kyessi (Ardhi University) made substantial contributions to the section on livelihoods and urban agriculture; Nadja Martinussen (Brightstar Communications) ensured text editing.

In addition, the following people provided dedicated support and advice during the development of the Atlas: Amulike A. Mahenge (Department of Physical Planning, Ministry of Lands, Housing and Human Settlements Development), Andrew Perkin (Wildthings Eco-consultants), Elizabeth A. Mrema (Mapping Division, Ministry of Lands, Housing and Human Settlements Development), Grace Kyaruzi (Dar es Salaam City Council), Guido Uhinga (Ardhi University), Ivan Gayton (Humanitarian OpenStreetMap Team, Ramani Huria), Jafar Jongo (Ardhi University), Johannes Förster (Helmholtz Centre for Environmental Research – UFZ), Jutta Camargo (BORDA Africa), Larissa Duma (BORDA Tanzania), Mathias L. Serikali (Department of Physical Planning, Ministry of Lands, Housing and Urban Development), Nathalie Jean-Baptiste (Ardhi University).

Biodiversity expert input

The following individuals provided expert inputs and advice for the biodiversity map: Andrew Perkin (Wildthings Eco-consultants), Gillian Maree (Gauteng City-Region Observatory), Guido Uhinga (Ardhi University), Heather Terrapon (South African National Biodiversity Institute), Jafar Jongo (Ardhi University), January Ching'enya (Bird Environment Community Foundation), Jasson John (University of Dar es Salaam), Lenin Festo (Tanzania Forest Service), Lindsey West (Sea Sense), Omari Kibure (Tanzania Botanical Exploration Consultants).

Atlas validation

The following individuals provided critical feedback on a draft version of the Atlas: Alphonce Kyessi (Ardhi University), Ana Rocha (Nipe Fagio), Churchill Mujuni (Regional Administration, Dar es Salaam), Evelyn Herrera Lopera (BORDA Tanzania), Feada Magesa (Ilala Municipal Council), Grace Kyaruzi (Dar es Salaam City Council), Hilda Kigola (Town Planning Officer, Regional Administration), INTERACT-Bio Dar es Salaam Co-ordinating Committee (with representatives from the Dar es Salaam City Council, Kinondoni, Ubungo, Temeke, Ilala and Kigamboni Municipal Councils and the Dar es Salaam Regional Administration), Joyce Musira (BORDA Tanzania), Jutta Camargo (BORDA Africa), Leonidas Deogratias Bernado (BORDA Tanzania, Margareth Mazwile (Dar es Salaam City Council), Mariam Kitula (Regional Administration, Dar es Salaam), Navonaeli Omari-Kaniki (Nipe Fagio), Oscar Mbekenga (BORDA Tanzania), Theresia Dennis (Ilala Municipal Council).

INTERACT-Bio Project Co-ordinating Committee Dar es Salaam

The following individuals provided overall guidance: Barnabas M. Kisai (Ilala Municipal Council), Castory Alexander (Temeke Municipal Council), Churchill Mujuni (Regional Administration), Flora Msilu (Kinondoni Municipal Council), Grace B. Mbena (Dar es Salaam City Council), Hilda C. Kigola (Regional Administration), Hussein Omar (Ubungo Municipal Council), Margaret Mazwile (Dar es Salaam City Council), Maria Komba (Kinondoni Municipal Council), Masatu Ndanga (Ilala Municipal Council), Michael Ole-Mungaya (Regional Administration, Dar es Salaam), Nice Vahaye (Ubungo Municipal Council), Said Bakar Simu (Kigamboni Municipal Council), Said Swalehe (Kigamboni Municipal Council), Tumwamini Mbena (Temeke Municipal Council).

The project is endorsed by the Vice President's Office: Environment Division and it falls within the ambit of the Central Ministry: President's Office – Regional Administration and Local Government, as part of their role to empower Regional Administration and Local Government Authorities to improve the provision of quality life and services to the community.

We would like to extend a special thank you to Grace Mbena, Senior Town Planner, Dar es Salaam City Council, who, in 2017 focused our attention on the need to improve decision-making around city investment in urban greenspace. Ms Mbena continues to champion nature's benefits for urban citizens and the city.

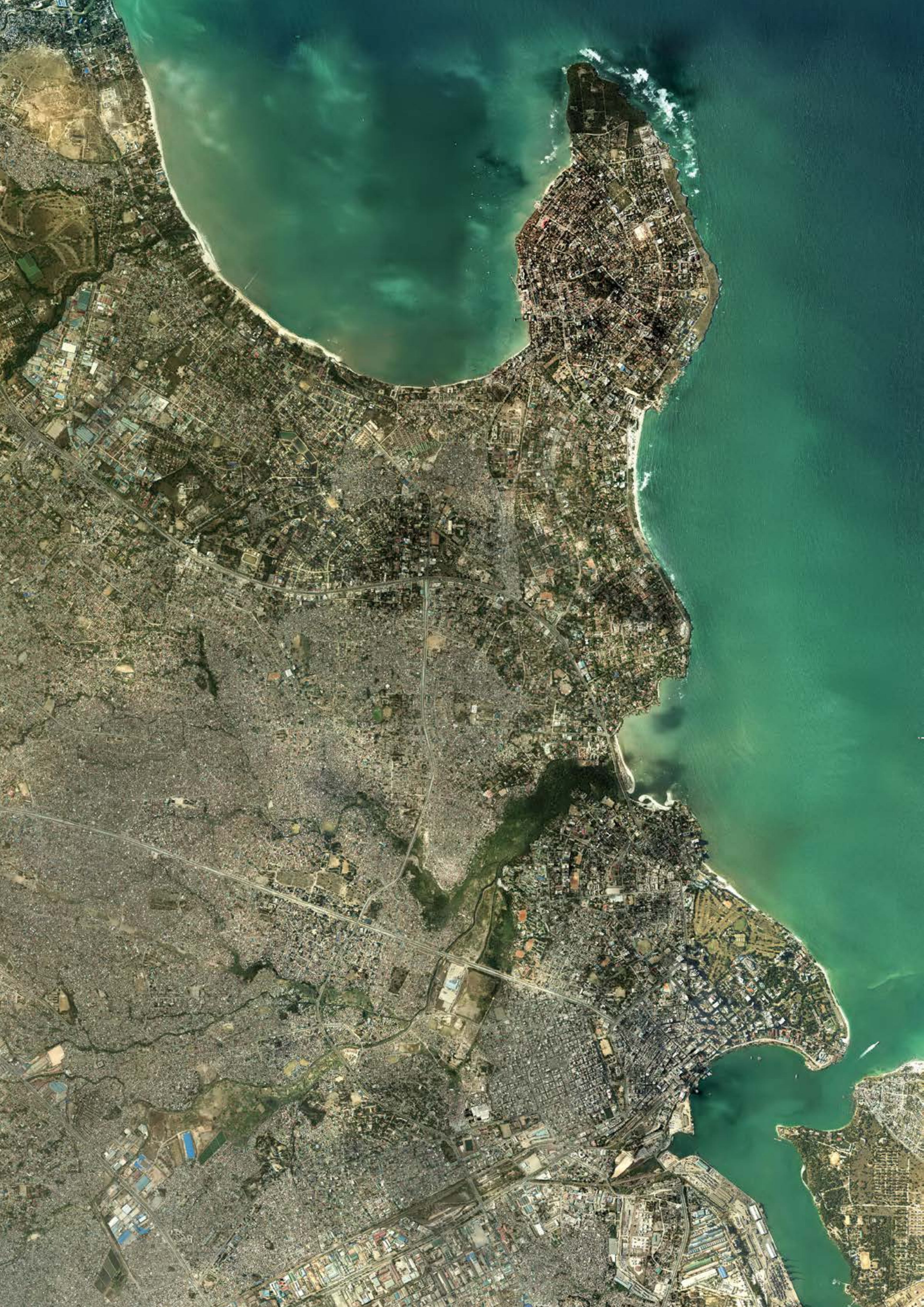
Preface

Sipora Liana
Director: Dar es Salaam City Council

Dar es Salaam is the cultural, trade and economic centre of Tanzania – and one of the most vibrant cities in East Africa. It is also one of the fastest growing metropoles in the world. How can we, as the city government, ensure that all citizens of Dar es Salaam live in a safe environment, enjoy a good quality of life and make a sustainable living? Increasingly, cities around the world have recognised that healthy and functioning ecosystems within and around urban areas provide solutions to challenges such as urban heat, flooding and other impacts of climate change, as well as enhance the quality of life of urban citizens. This Thematic Atlas shows how nature's benefits protect and sustain our city and make it liveable. It will help us prioritise our investment in urban nature. It will also enable Dar es Salaam's five municipalities to direct their plans to incorporate nature's contributions to enhance urban quality of life, livelihoods and the economy.

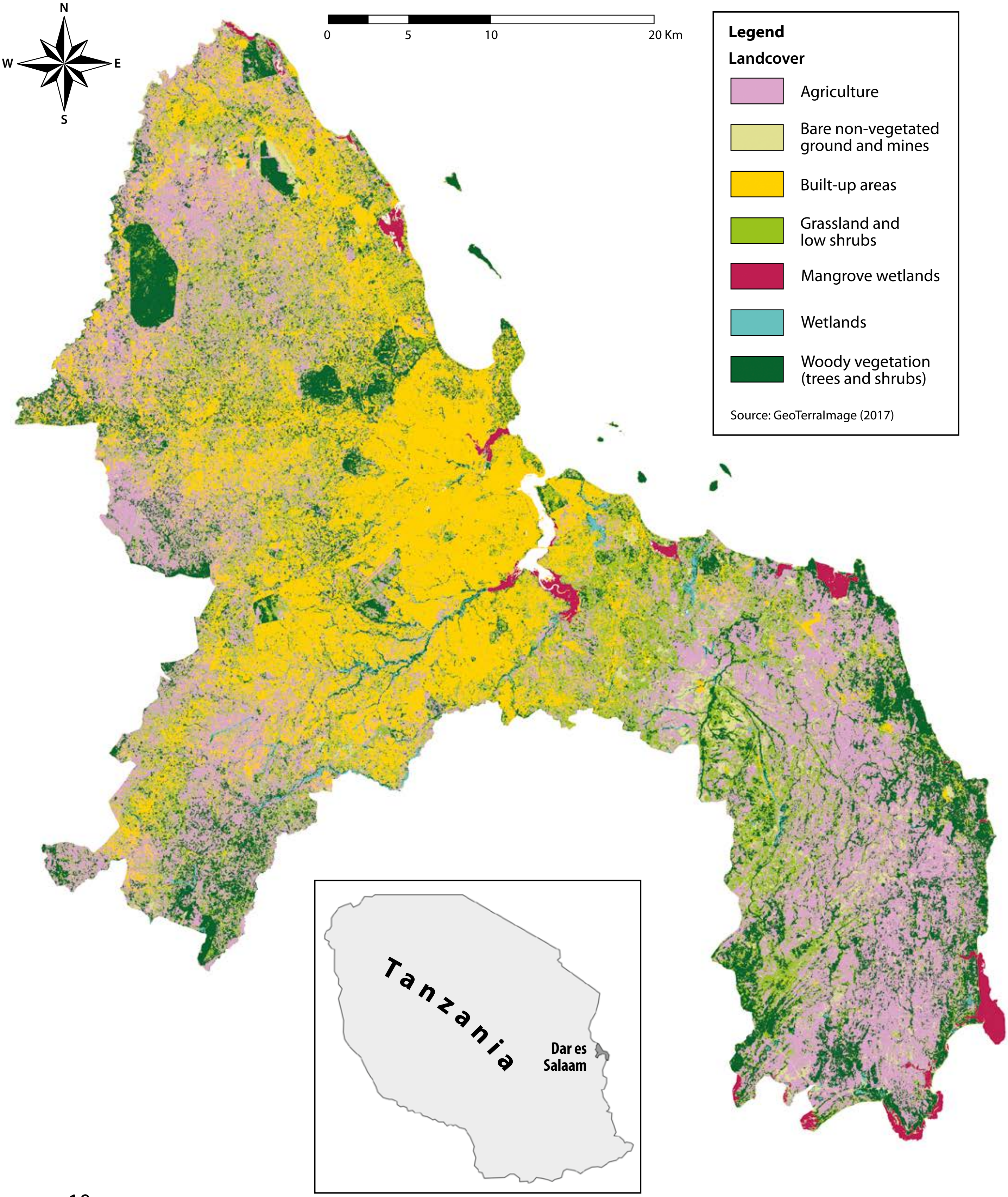
Kobie Brand
Director: ICLEI Cities Biodiversity Center

Cities across Africa are richly endowed with cultural and natural treasures. But cities can also be the means by which people become disconnected from the natural environment. As cities grow, urban citizens typically lose out on the connections and opportunities that are inherent in the relationship between nature and human well-being. Today, it is well known that the prosperity of cities critically relies on the ability of regional, city and municipal governments to protect and restore nature's benefits in order to make cities healthy and vibrant places to work, live and play. Now, more than ever, there is a need to unite and embrace nature and to reconnect communities with nature. City governments are the leaders that play a critical role in these developments. The Thematic Atlas for Dar es Salaam provides entry points for designing with nature. The tool can be applied by any city and it is our hope that it becomes well used by cities across the African continent, to create the sustainable cities of the future, CitiesWithNature.



Content

GREENSPACE IN DAR ES SALAAM



Dar es Salaam has diverse land use types ranging from highly compacted commercial and residential neighbourhoods to scattered settlements, and large areas dominated by agricultural activities. There are also sections of wildland. The map shows DSM's land cover pattern, including built-up areas, bare ground, various types of green, agriculture and water features. It has been compiled using remote sensing techniques (satellite imagery).

We apply an encompassing definition of greenspace or green structures within the urban area including public parks, street trees, private gardens, university and school grounds, cemeteries, river corridors, agricultural land, and beaches. Only 2% of DSM's total area is classified as public greenspace and as little as 0.1% classified as park. University and military areas together account for 3.4%, giving them considerable importance. DSM's tree cover (18%) is higher than in its primarily agricultural surroundings [2].

River corridors such as Msimbazi, Tegeta or Mbezi, which cover a small spatial extent of only ca. 1%, form the only green corridors in the city and are thus highly important for connecting habitats and for regulating services such as cleaning and cooling the air [2]. The broad range of benefits from mangrove forests (e.g. spawning grounds for fish, natural protection against erosion and sea level rises) shows their vital importance and urgent need for their de facto protection [3].

The Atlas also stresses the importance of agriculture for its valuable benefits both within and outside the urbanised area.

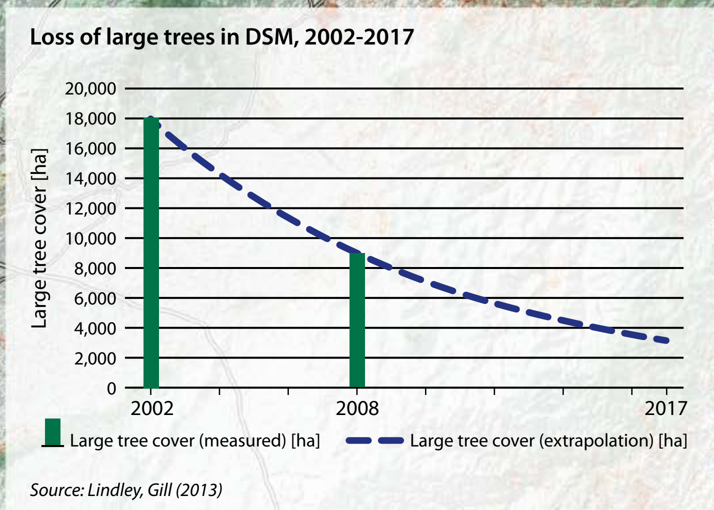
GREENSPACE UNDER PRESSURE:
Three Types of Change

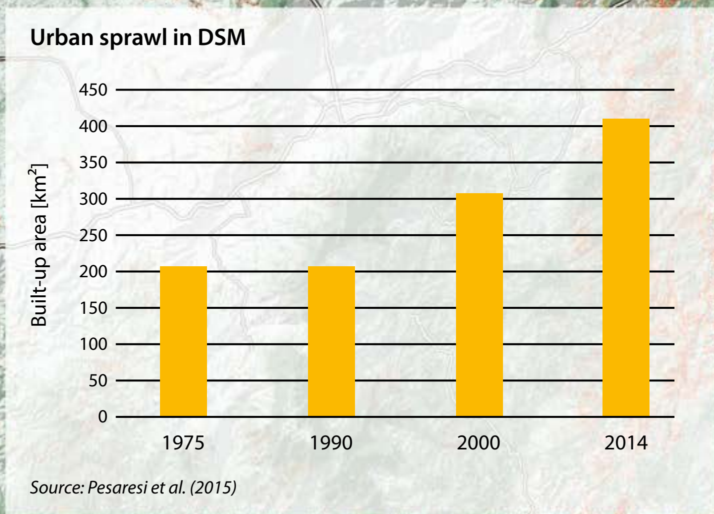
Many factors lead to the loss and degradation of green areas in and around DSM. The map illustrates three types of change:

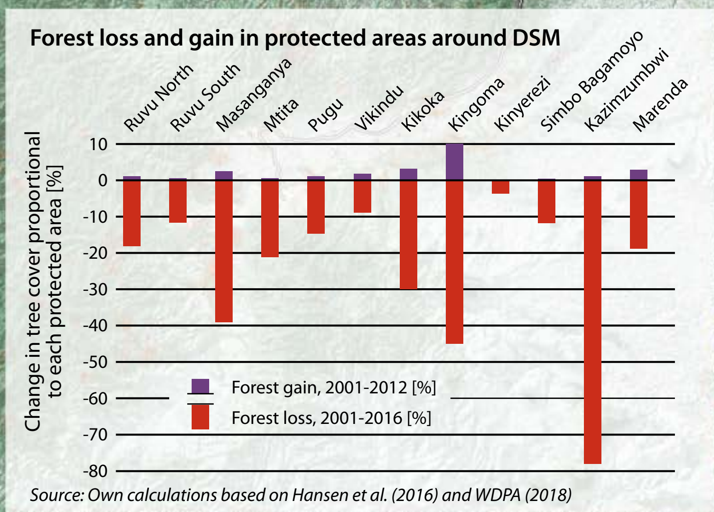
Type I, first radius: in built-up areas, densification leads to an increase in sealed surfaces (buildings, roads etc.). Trees and other vegetation are cleared to make space for new developments. This has caused high losses in the last decades, especially in the city centre and in dense informal settlements.

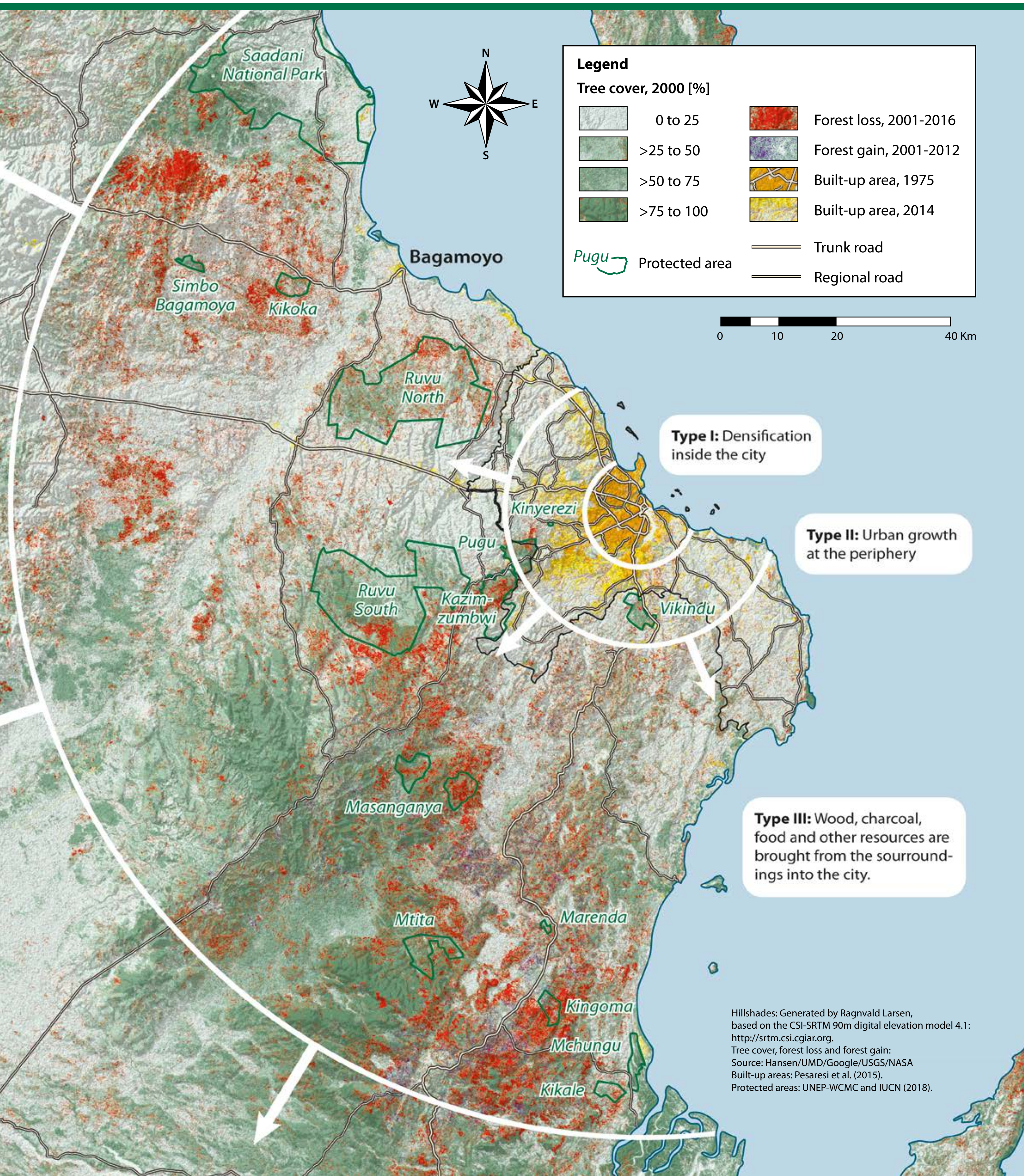
Type II, second radius: At the margins of the city, i.e. the 'urban fringe', natural and agricultural land is being converted into urbanised areas every day. This sprawl takes place especially along the main roads out of the city.

Type III, third radius: The impact on nature is not limited to DSM's urban area. The map shows how the forests around the city have been cut down for timber and charcoal. Other resources, such as food or building materials (e.g. sand) are also transported into the city from its surrounding areas. The city's impact on nature goes as far as 100km outside DSM boundaries (and beyond). As nearby resources are depleted, the impact distance grows.









Hillshades: Generated by Ragnvald Larsen, based on the CSI-SRTM 90m digital elevation model 4.1: http://srtm.csi.cgiar.org.
Tree cover, forest loss and forest gain: Source: Hansen/UMD/Google/USGS/NASA
Built-up areas: Pesaresi et al. (2015).
Protected areas: UNEP-WCMC and IUCN (2018).

GREENSPACE UNDER PRESSURE:
Three Types of Change

According to the Green City Index, Dar es Salaam (DSM) ranks below the African average for large cities. In 2004 DSM could only provide 64m² of greenspace per capita, compared to an average of 74m² for Africa [4]. Since then, DSM has lost much of its greenspace.

Between 2002 and 2008 one third of Dar es Salaam's green areas (here defined as woodland, riverine and grassland), was lost due to their conversion into agricultural land or settlements [2].

Different approaches for examining changes in greenspace make it difficult to directly compare data and research results. However, the general trend is clear: DSM is losing green and agricultural space at a rapid pace. Greenspace is being lost in the following three ways:

1. Densification within settled areas

Within DSM's boundaries, tree cover decreased by more than 10% each year between 2002 and 2008, mostly due to densifying urban areas [5]. The loss of trees is symptomatic of the general densification trend in the city, where houses, industry, offices and infrastructure sprout wherever space is available, including on vegetated land, riverine areas and mangrove forests. Riverine areas and mangrove forests face high development pressure. This leads to their fragmentation and even disappearance, even though their extraction/conversion is prohibited by law. Mangroves protect cities against floods, ocean storm surges and erosion [2, 6]. Their loss also incurs reductions in the provision of various other ecosystem services.

Of the 2,266ha of mangrove forests along the Tanzanian coast estimated in 1995, less than half remained in 2008 [5].

2. Conversion on the urban fringe

Land on the urban fringe typically experiences a two-step transformation.

In the first step, natural vegetation such as wood or bushland is removed to create arable land. In this way, many benefits from natural areas are being lost, such as firewood, natural water regulation systems and the biodiversity which sustains life in the wider landscape. Instead, agriculture is practiced on this land which generates other benefits, such as income to a large number of DSM residents and fresh, local food to the city.

In the second step, some of this agricultural land on the urban fringe is converted for the development of settlements and infrastructure. This entails a permanent loss of fertile land and permeable surfaces. These settlements at the urban fringe are relatively green, but this changes as the settlements at the urban fringe densify.

3. Urban footprint – Dar es Salaam's impact on ecosystems in the wider region

Metropoles such as DSM have an impact on ecosystems that goes far beyond their administrative boundaries. Resources such as water, energy and building materials are almost entirely drawn from outside the city. For example, the high demand for sand by the building industry has spurred illegal sand mining along the beaches and river beds [7]. Water abstractions from the Ruvu River compete with other demands for water in the basin, such as the Mikumi National Park and rural agriculture [8]. In addition, DSM has a high demand for wood for fuel and construction. The city accounts for 30% of the country's total charcoal and firewood consumption [9]. As charcoal production depletes wood resources adjacent to the city, the depletion of forests is further extended. In 2016, nearly half of the city's wood supply was obtained from more than 80km away, compared to 2000, when it was only 30%. Alarmingly, deforestation does also take place inside protected areas.

The entire territory of DSM has around 45% of greenspace remaining. This figure increases to 72.8% when agriculture is considered as 'greenspace' [11]. Many opportunities exist to slow down the further loss and degradation of (peri-) urban ecosystems. This Atlas provides suggestions as to how this can be achieved.

Of the 24 protected forests within a 100km radius of Dar es Salaam, 16 have lost 15% or more of their forest cover between 2001 and 2016, and Masanganya, Kingoma and Simbo Bagamoyo even more than 40% [9, 10].

Further reading

Taylor & Hochuli (2017) Defining greenspace: Multiple uses across multiple disciplines.

Lindley & Gill (2013) A GIS based assessment of the urban green structure of selected case study areas and their ecosystem services.

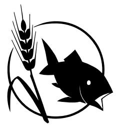
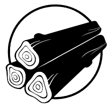
Hojas-Gascón et al. (2016) Urbanization and forest degradation in East Africa.

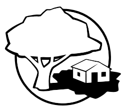
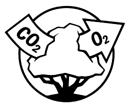
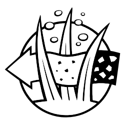
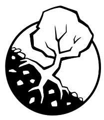
Continuous development of high-rise buildings in the city centre leads to further densification of Dar es Salaam. Picture: R. Karutz, UFZ

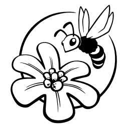
NATURE'S BENEFITS TO DAR ES SALAAM

ECOSYSTEM SERVICES:
A Systematic Overview of Nature's Benefits to People

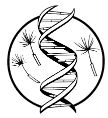
Healthy ecosystems can deliver a number of benefits to cities. Such benefits are also called *Ecosystem Services*. They can be grouped as provisioning, regulating, supporting and cultural services as shown in the table below.

1) Provisioning Services are the material outputs from ecosystems.	
Food: Ecosystems provide the conditions for growing food – in wild habitats and in managed agro-ecosystems.	
Raw materials: Ecosystems provide a great diversity of materials for construction and fuel.	
Fresh water: Ecosystems provide surface and groundwater.	
Medicinal resources: Many plants are used as traditional medicines and as inputs for the pharmaceutical industry.	

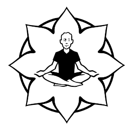
2) Regulating Services contribute to the stability of a landscape or ecosystem	
Local climate and air quality regulation: Trees provide shade and remove pollutants from the atmosphere. Forests influence rainfall.	
Carbon sequestration and storage: As trees and plants grow, they remove carbon dioxide from the atmosphere and effectively lock it away in their tissues.	
Moderation of extreme events: Ecosystems and living organisms create buffers against natural hazards such as floods, storms, and landslides.	
Waste water treatment: Micro-organisms in soil and in wetlands decompose human and animal waste, as well as many pollutants.	
Erosion prevention and maintenance of soil fertility: Soil erosion is a key factor in the process of land degradation and desertification.	

Pollination: Some 87 out of the 115 leading global food crops depend upon animal pollination including important cash crops such as cocoa and coffee.	
Biological control: Ecosystems are important for regulating pests and vector borne diseases.	

3) Habitat or Supporting Services underpin the functioning of all other services

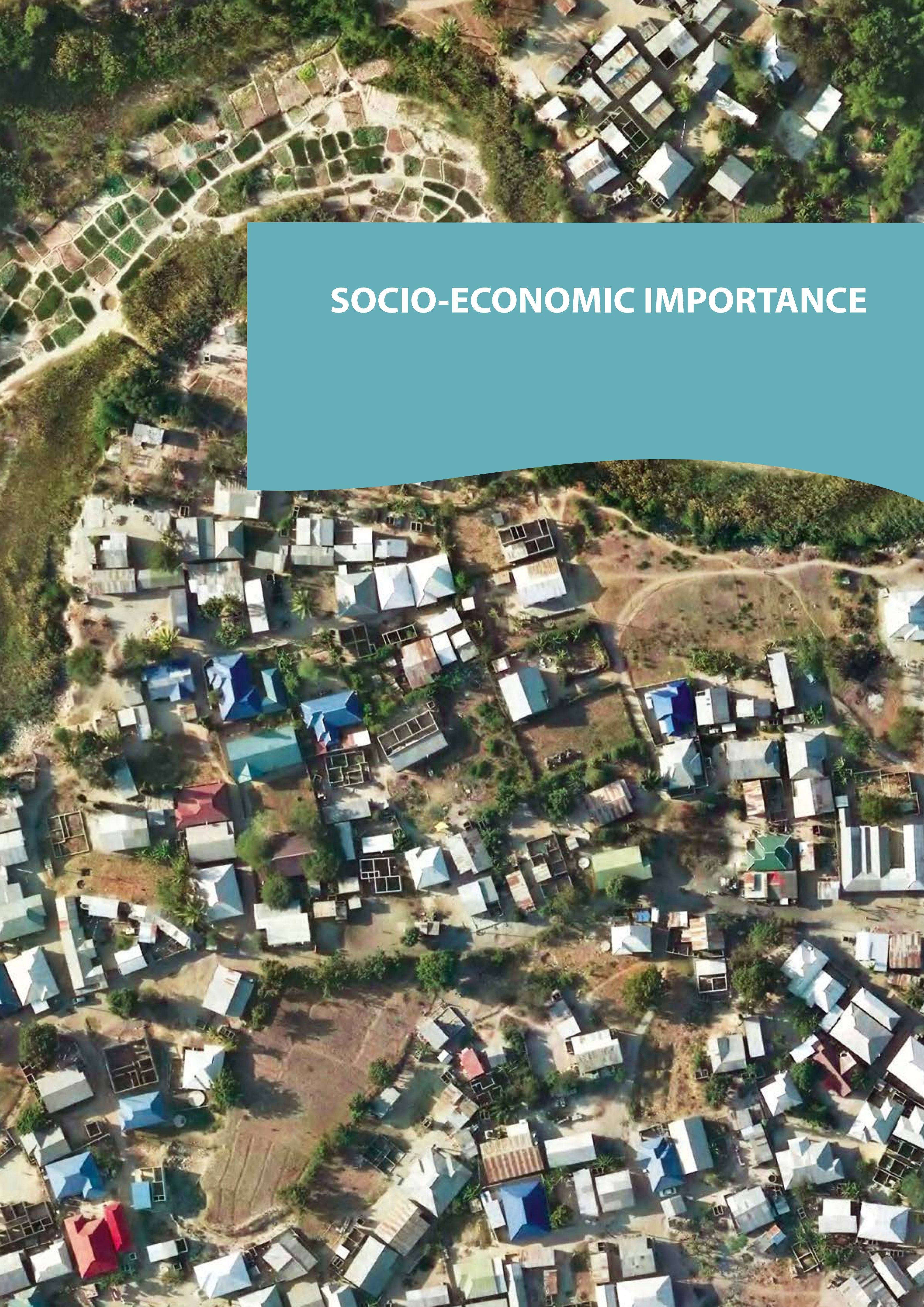
Habitats for species: Habitats provide everything that an individual plant or animal needs to survive. Migratory species need habitats along their migrating routes.	
Maintenance of genetic diversity: Genetic diversity distinguishes different breeds or races, providing the basis for locally well-adapted cultivars and a gene pool for further developing commercial crops and livestock.	

4) Cultural Services describe the non-material benefits people obtain from ecosystems

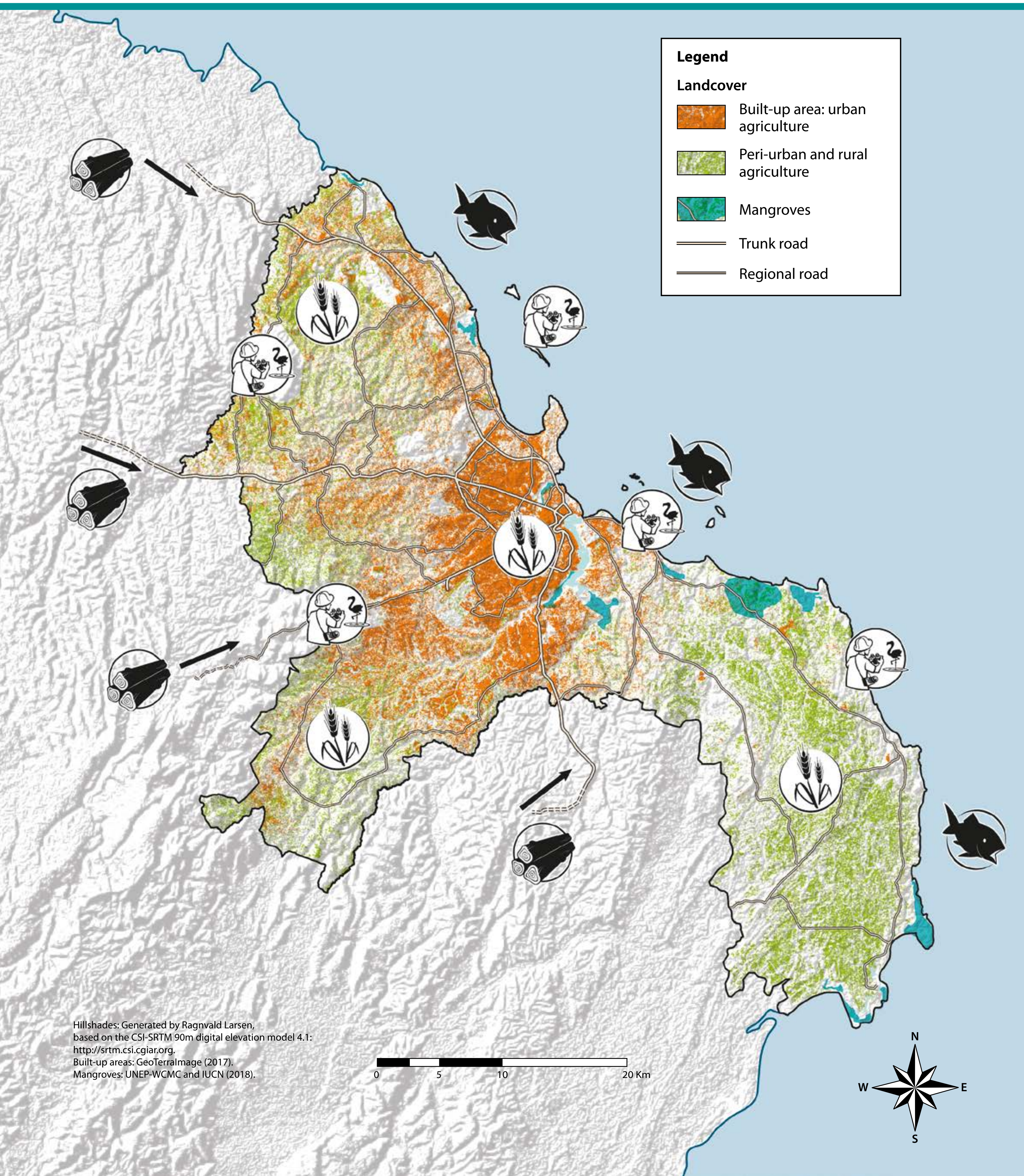
Recreation and mental and physical health: The role of natural landscapes and urban greenspace for maintaining mental and physical health is increasingly being recognised.	
Tourism: Nature tourism provides considerable economic benefits and is a vital source of income for many countries.	
Aesthetic appreciation and inspiration for culture, art and design: Language, knowledge and appreciation of the natural environment have been intimately related throughout human history.	
Spiritual experience and sense of place: Nature is a common element of all major religions; natural landscapes also form local identity and sense of belonging.	

The icons in the above table were developed by The Economics of Ecosystems and Biodiversity (TEEB). They indicate the benefits addressed in the maps on the following pages.

SOCIO-ECONOMIC IMPORTANCE



DAR ES SALAAM'S ECOSYSTEMS SECURE THOUSANDS OF LIVELIHOODS



Nature's benefits secure livelihoods both within DSM and beyond its borders. The map shows where some of the most important livelihood-securing benefits are located.

Agriculture plays the largest role in terms of supporting households. Urban agriculture is located within the built-up area and often practised in backyards or in open spaces. At the urban fringe, peri-urban agriculture takes place, which resembles rural agriculture.

Artisanal fishing, mostly practiced in shallow waters close to the coast, secures thousands of livelihoods.

Wood logging and charcoal production are also highly important sources of income, although they are increasingly found outside the city, where forests have not been cleared yet.

Nature-based tourism, another source of income, is conducted in several points in DSM, especially along the coast (beaches, bird- and turtle watching) and in the remaining natural forests.

Billions of people around the world are directly dependent on nature to generate an income and to sustain their livelihoods. Globally, 25% of all employment is in agriculture, and in Tanzania, the share is as high as 67% [12]. Marine and inland water bodies provide an income for more than 180,000 Tanzanian fishers and more than four million people in the entire sector [13, 14]. Ecosystems sustain jobs and livelihoods not only in the countryside: for example, urban farming can be found in cities around the world.

In Havana, Cuba, 90,000 urban farmers produce more than 60,000 tons of vegetables and 20,000 tons of fruit. Half of the city area is used for agriculture [15].

Numbers vary regarding the importance of agriculture to DSM's inhabitants. Estimates range from 22,000 households to 60% of the 'informal sector' [16]. What is clear is that in DSM, crop growing, horticulture, livestock raising, fisheries, charcoal production, bee-keeping, and jobs related to recreation and beach tourism constitute major economic activities – and they all directly depend on functioning and healthy ecosystems within the city and urban periphery.

Urban Agriculture in Dar es Salaam

Currently, farmland (i.e. field crops, horticulture and mixed farming) covers large areas in DSM, amounting to ca. 27.8% of the total municipal area in 2017 [11].

Farming is found in every imaginable location in and around the city. In the periphery (ca. 15-25km from the centre) it resembles rural agriculture and sustains around 35,000 households. Within the more densely urbanised area, hundreds of hectares are used for vegetable gardening etc., providing an income for over

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DAR ES SALAAM'S ECOSYSTEMS SECURE THOUSANDS OF LIVELIHOODS

4,000 urban farmers [2]. In urban backyards vegetable gardening is practised by those who own a parcel of land. It also takes place in urban open spaces, such as roadsides, along railroad tracks, under power lines and in river valleys and flood plains. All forms of urban agriculture are currently under pressure due to the city's ongoing sprawl and densification. [17, 18].

The rate of loss of agricultural land in the city is high and will continue to rise due to increasing land prices. Thus, growing competition over land and water will change the role of agriculture as a relatively secure source of income in DSM [5, 17].

In a recent survey, in DSM 24% of farmers interviewed had been forced to move from their lands due to land sale or development [19].

Urban agriculture generates income for many more people besides the farmers: It also supports economic activities along agricultural value chains: supply of seedlings and fertilisers, transport, processing, storage, local markets, etc. These activities not only sustain livelihoods, but also play a key role in the public life and local identity of communities and neighbourhoods [6]. Farmers in DSM earn more than double (ca. $60/month) the national average and the sector's gender distribution is well-balanced with ca. 52% of farmers being women [17].

The many urban farmers allow DSM to have an impressively high degree of food independence, which means that the city is less vulnerable when supply is unavailable from other regions. As an example, in the 1990s, DSM grew 90% of all of the leafy vegetables it consumed within its boundaries [20].

In 2007, Dar es Salaam produced 70% of the milk consumed by residents and 74% of the city's residents tended livestock [17].

In addition to income and food security for city dwellers, urban farmland also has regulating functions: air temperature and quality, water infiltration in case of heavy rainfall. It also beautifies the landscape and provides recreational and health benefits. On the other hand, urban agriculture can be environmentally harmful if practised unsustainably: groundwater abstraction and the use of pesticides and fertilisers must be adapted to the context and needs of densely inhabited city areas. In addition, it is vital to address the growing concern about the water quality of the rivers (especially the Msimbazi River) and associated contamination of locally grown produce. The same applies to vegetables grown along busy roads, where air pollutants may be absorbed and pose health risks when they are consumed with the food.

Further Examples of Nature's Importance in Securing Livelihoods

Fisheries: DSM has a long fishing heritage. However, the near-shore fishing practised by most fishermen is under pressure – dynamite fishing, international trawlers and pollution have depleted fish stocks and harmed local coral reefs. The deforestation of mangroves has degraded the spawning grounds essential for fish reproduction. Even though important steps have been taken such as in the regulation of dynamite fishing, the coastal waters are not as productive as they were previously and the fishers' livelihoods have been significantly affected [21].

Firewood and Charcoal: DSM's high dependence on firewood and its largely unregulated production of charcoal has led to massive deforestation in and around the city [3]. This is all the more serious as trees and forest patches regulate floods, provide water and filter and cool the air. While small-scale tree-cutting occurs within the city's boundaries, most wood is brought from the hinterland. Although the demand for firewood and charcoal provides ca. 1,500 lumbermen and charcoal producers with income, the required effort and resulting prices are rising, affecting the cost of living throughout the city. Typically, small groups of workers form harvest camps and cut and transport the wood into the city [11]. This practise is neither sustainable for the forests nor for the short-term employed workforce.

Tourism: DSM offers cultural, forest and beach tourism attractions and markets itself as a diverse, well-connected site for tourism. Popular tourist attractions include hiking in the Pande and Pugu Forests, bird-watching and turtle hatching on the beaches. The city's beaches also attract both residents and tourists for recreation. These activities do not only provide income for many people, but can also have important co-benefits when practised sustainably e.g. for the conservation of nature. For further information, see also [page 58].

Response Options

DSM is growing rapidly in population, with the result that the urban area is expanding at the same rate. And a large share of the population directly and indirectly depends on healthy and functioning urban and peri-urban ecosystems for their living [6]. This makes DSM's agro-ecosystems an extremely valuable yet highly threatened natural asset. It is essential that forests, farmlands and fishing grounds near the city are managed so that mid-term and long-term benefits are balanced with short-term needs and interests.

1. This calls for reforms of relevant by-laws and a better coordination of responsibilities across political entities, as well as better enforcement of existing legislation. Land tenure security is especially critical for farmers to sustain farming over the long-term on their land.

2. The planning practise of zoning land for agricultural use at the margins of the city should be enhanced and public land could potentially be given to farmers for certain time periods to counteract the loss of greenspace in other areas.

3. On a more practical level, farmers would benefit from extension services and technical support so as to better adapt to DSM's specific urban context [19, 22]. Here, targeted support schemes as well as innovation management are called for. This includes improved techniques (e.g. crop rotation), wise use of agro-chemicals, and support for establishing and maintaining cooperatives.

4. Furthermore, a better integration of urban agriculture into the city's economy could unlock new markets and increase and diversify value chains [18]. For example, alliances with the tourism sector could be considered.

5. Wood plantations in the urban periphery – and where feasible even in more central areas – should be advocated, so as to provide long-term access to the resource and more stable employment [2]. Awareness raising about the rapid loss of trees, and the implications thereof, is also required.

Further reading

Schmidt (2012) Getting the policy right. Urban agriculture in Dar es Salaam, Tanzania.

Halloran & Magid (2013) Planning the unplanned. Incorporating agriculture as an urban land use into the Dar es Salaam master plan and beyond.

IHSS (2017) The Impacts of Urban Agriculture on Food Systems and Human Security in Dar es Salaam.

WATER IS A HUMAN RIGHT

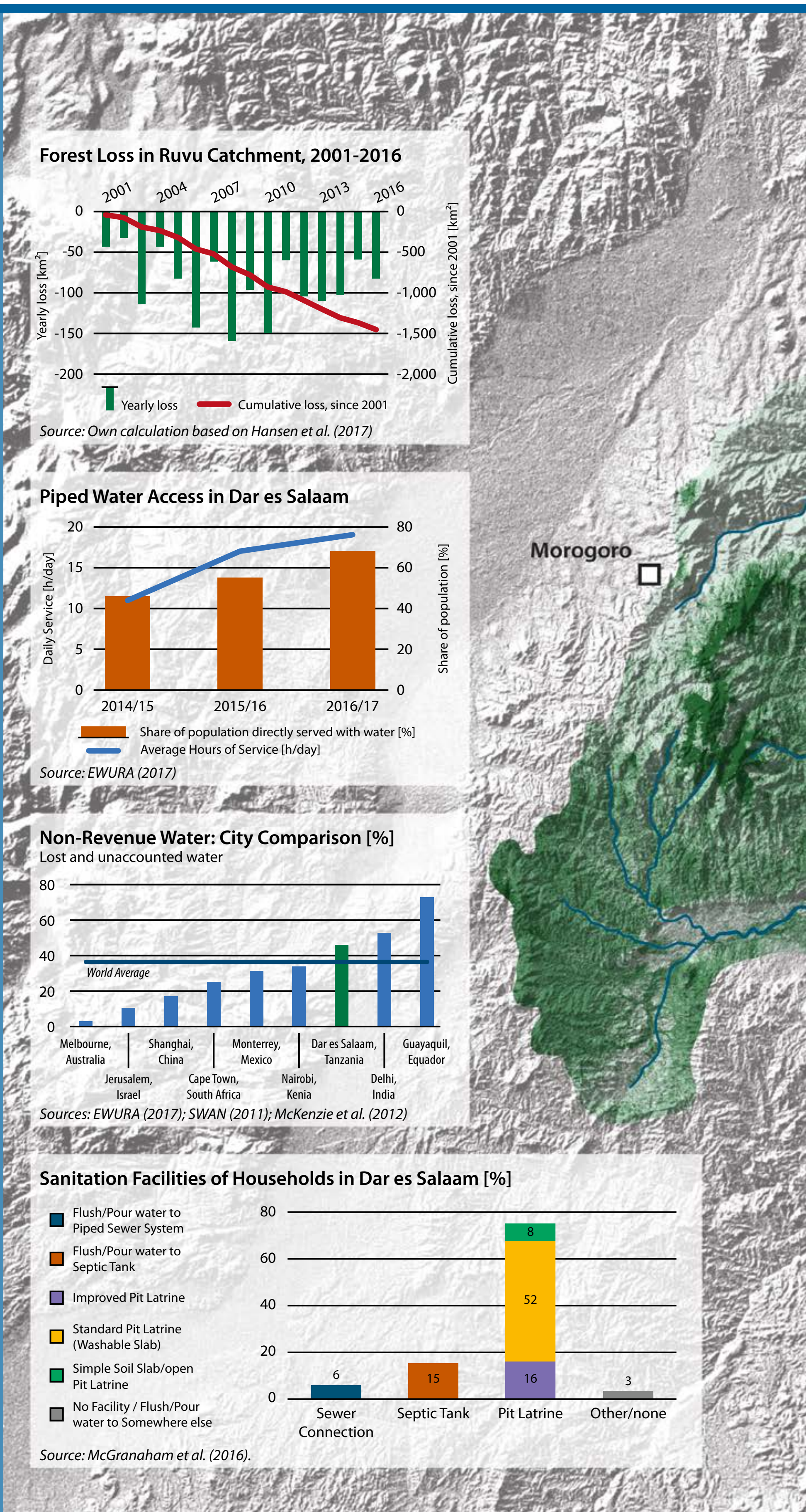
DAR ES SALAAM'S WATER SOURCES UNDER STRESS

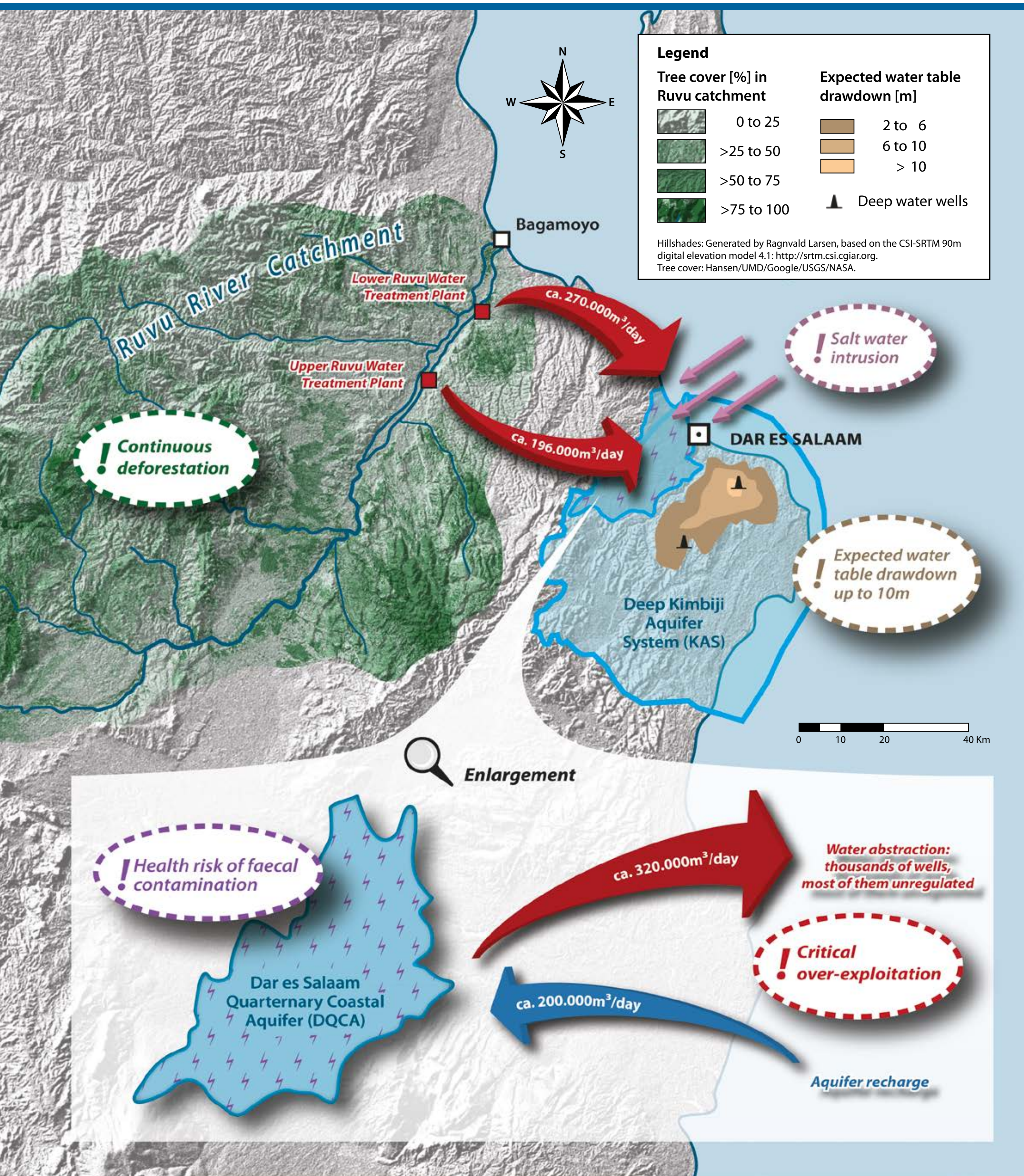
The map illustrates DSM's main water sources: the Ruvu River and its catchment, the Dar es Salaam Quaternary Coastal Aquifer (DQCA) below the city, and the Deep Kimbiji Aquifer System (KAS), on which deep boreholes are currently under development.

It shows the alarming pace of deforestation in the Ruvu catchment, which threatens the integrity of the river system, DSM's largest water source.

The DQCA is critically overexploited by thousands of (mostly unauthorised) wells and boreholes that have been built because millions of residents do not have piped water in their homes. It faces contamination problems from pit latrines, the dominating toilet design in DSM, as there is almost no sewerage network. Inappropriate use of pesticides in urban agriculture can also threaten the quality of drinking water of the DQCA.

A key challenge of the new KAS well-fields will be the lowering of the region's groundwater table. This is expected to dry out shallow wells and reduce its ability to recharge surface waters and wetlands.





Legend
Tree cover [%] in Ruvu catchment
0 to 25
>25 to 50
>50 to 75
>75 to 100
Expected water table drawdown [m]
2 to 6
6 to 10
> 10
Deep water wells
Hillshades: Generated by Ragnvald Larsen, based on the CSI-SRTM 90m digital elevation model 4.1: http://srtm.csi.cgiar.org.
Tree cover: Hansen/UMD/Google/USGS/NASA.
N
W
E
S
Bagamoyo
Ruvu River Catchment
Lower Ruvu Water Treatment Plant
Upper Ruvu Water Treatment Plant
ca. 270.000m³/day
ca. 196.000m³/day
! Salt water intrusion
! Continuous deforestation
DAR ES SALAAM
! Expected water table drawdown up to 10m
Deep Kimbiji Aquifer System (KAS)
0
10
20
40 Km
Enlargement
! Health risk of faecal contamination
ca. 320.000m³/day
Water abstraction: thousands of wells, most of them unregulated
! Critical over-exploitation
Dar es Salaam Quarternary Coastal Aquifer (DQCA)
ca. 200.000m³/day
Aquifer recharge

DAR ES SALAAM'S WATER SOURCES UNDER STRESS

Access to safe drinking water and sanitation is a global challenge. The Organisation for Economic Co-operation and Development (OECD) estimates that in Tanzania almost 24 thousand people died from unsafe water and around 18 thousand from unsafe sanitation in 2013 [23].

DSM is no exception when it comes to the health risks related to water supply and sanitation. In 2017, the city accounted for 256,290 domestic water connections, which – together with 314 functioning water kiosks – officially serviced 68% of the population with potable water [24]. Other reports suggest that the number of serviced residents is considerably lower, especially when informal areas are included [25]. Large system losses aggravate the city's water issues: half of piped water is lost or not accounted for (more than in most cities around the world) [26]. While progress has been made with regards some of these issues, such as massive expansions of the Ruvu water treatment plants, associated increases in bulk water supply to the city, and an expansion of the grid [25], the city's sewerage coverage remains minimal: only 17,089 (ca. 3%) of households are connected to the public sewerage network, leaving most residents dependent on septic tanks and pit latrines [24].

In this Atlas, two major challenges of the city's water system are examined more closely: The Ruvu River and the threats to its catchment, and the shallow aquifer below the city (Dar es Salaam Quaternary Coastal Aquifer), which is tapped into by many residents using boreholes and wells and therefore suffers from overexploitation and contamination. A recent development of potentially high importance is the plan to exploit the Kimbiji Deep Aquifer System (KAS), which is located south of the city and could contribute substantially to meeting DSM's increasing future water demand. Similarly, abstractions from the Rufiji River (Kitunda, Morogoro) are proposed and await realisation. Since these projects are still in the planning phase, they will not be focused on in the Atlas. Suffice it to say that the environmental assessments of these projects show that they may have considerable impacts e.g. in terms of lowered water tables around the wellfields of Kimbiji, or the reduced water supply of Selous Game Reserve Kitunda [27, 28].

Pressure on the Ruvu River Catchment

Every day, DSM abstracts around 470m³ of water from the Ruvu River, which makes it the most important source for the city, supplying 90% of the water provided by the Dar es Salaam Water and Sewerage Authority (DAWASA). This reliance is dangerous.

Because the city is increasing its consumption of water, the Ruvu River's limits will soon be reached. It is expected that there will be water shortages by 2030 if no additional sources are secured [25].

The Ruvu River originates in the Uluguru Mountains, which are part of the Eastern Arc Mountains (EAM). Collectively, the EAM rivers provide freshwater to ca. six million Tanzanians (including DSM, Morogoro and Dodoma) and to natural reserves such as the Mikumi National Park and the Selous Game Reserve. These rivers also provide more than half of the country's hydro-electricity [29, 30].

Although efforts are being made to protect the mountain forests, deforestation (for agricultural land, timber, firewood etc.) has caused the loss, fragmentation and degradation of large forest areas in the catchment [31]. While efforts to protect the Uluguru Natural Reserve are reported to function increasingly well, the general deforestation trend is alarming.

By 2000, already 17.5% of the mountain forests in the Ruvu catchment had been cleared [30, 32]. And the trend continues: between 2000 and 2016, an additional loss of ca. 8.5% was estimated [10].

Deforestation and the loss of woodlands have severe effects on the hydrological system of the Ruvu catchment area, impacting rainfall, local water storage levels and run-off. This leads to higher flow rates in the wet season and lower ones during dry months, increasing the risk of seasonal floods on the one hand and shortages on the other [30]. The protection of the Uluguru Mountain forests could be decisive for the city's future water security. Their biodiverse ecosystem makes conservation efforts even more meaningful [31].

Overexploitation of the City's Shallow Aquifer

Many people do not have access to piped water in DSM, and those that do have an intermittent supply. This forces people to explore alternative sources such as water vendors or private wells [3, 33].

Socio-economically disadvantaged population groups suffer the most from water scarcity [33]. DSM's informal settlements do not have piped water. Prices charged by vendors increase with distance to water access points. The United Nations Development Programme (UNDP) has noted prices up to 30 times higher compared to the DAWASA household tariff. For many people, high water expenses are a heavy burden [34]. Since water purchased from vendors cannot be reliably monitored, the risk of waterborne diseases poses additional risks.

It is therefore not surprising that DSM has innumerous private, mostly informal wells that tap into the DQCA [25]. Due to this massive, unregulated exploitation, the DQCA already shows signs of a lowering water table, contamination and salt water intrusion [25, 35].

More than three quarters of DSM's wells and boreholes are not registered by the Wami Ruvu Basin Office, the responsible agency [8].

Since informal wells and boreholes are typically constructed on small private properties, often very close to pit latrines or septic tanks, faecal contamination of the water source is also major concern. One study found that half of the tested wells were contaminated [36].

Response Options

DSM's complex water challenges cannot be solved by the management of greenspace alone. Instead, targeted utilisation of ecosystems may help as one element in a set of measures for the short-, mid- and long-term safeguarding of DSM's fragile water system. This is discussed below.

The protection of vital water catchments has been addressed by a number of legislative initiatives such as the Water Basins Management Approach as part of the National Water Policy and the Water Resource Management Act in 2009. Further support comes from intergovernmental agencies such as the UNDP [29]. Acknowledging DSM's high dependence on an intact catchment system, it can be argued that the City of DSM could engage as a partner in catchment conservation efforts, focusing especially on water-related issues. This could encompass:

1. Further support for the protection of mountain forests
2. Reforestation and renaturation of degraded riverbeds
3. Upscaling of existing watershed payment schemes for ecosystem services (e.g. it is suggested that downstream users such as DAWASCO pay opportunity costs for upstream users) [32]

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Since an expansion of the formal piped water network will take time, decentralised solutions will play a key role in the near future. Here, the potential of green areas to filter water and act as natural buffers around wells can be utilised. More specifically:

1. In central DSM, a focus on grid extensions, reliability and improved sanitation should be the priority.

2. In peri-urban areas, interim solutions are needed until the development of the main grid covers the whole city [25]. Affordable, private or community-run decentralised water systems are advocated by UNDP and supported by expert units from DAWASA and DAWASCO [25, 34].

3. The combination of informally dug wells and pit latrines in close proximity to each other urgently needs to be addressed to tackle water contamination and its associated health risks [36]. Wells and boreholes need to be monitored and protected against contamination.

4. Green buffer zones of a 30m radius around community boreholes and wells can serve as effective, low-cost solution to minimise the risk of faecal contamination. Such small greenspace patches would also foster rainwater recharge and provide further services (e.g. recreation and cooling) which will become increasingly valuable as peri-urban areas continue to densify.

5. Other measures may include the realisation of the Kimbiji deep aquifer development plans south of the city, a reduction of the system's high water losses, wastewater recycling, rain- and greywater use, improved well construction and awareness raising around water saving among more affluent users [6].

Further Reading

McGranahan et al. (2016) Universalising water and sanitation coverage in urban areas.

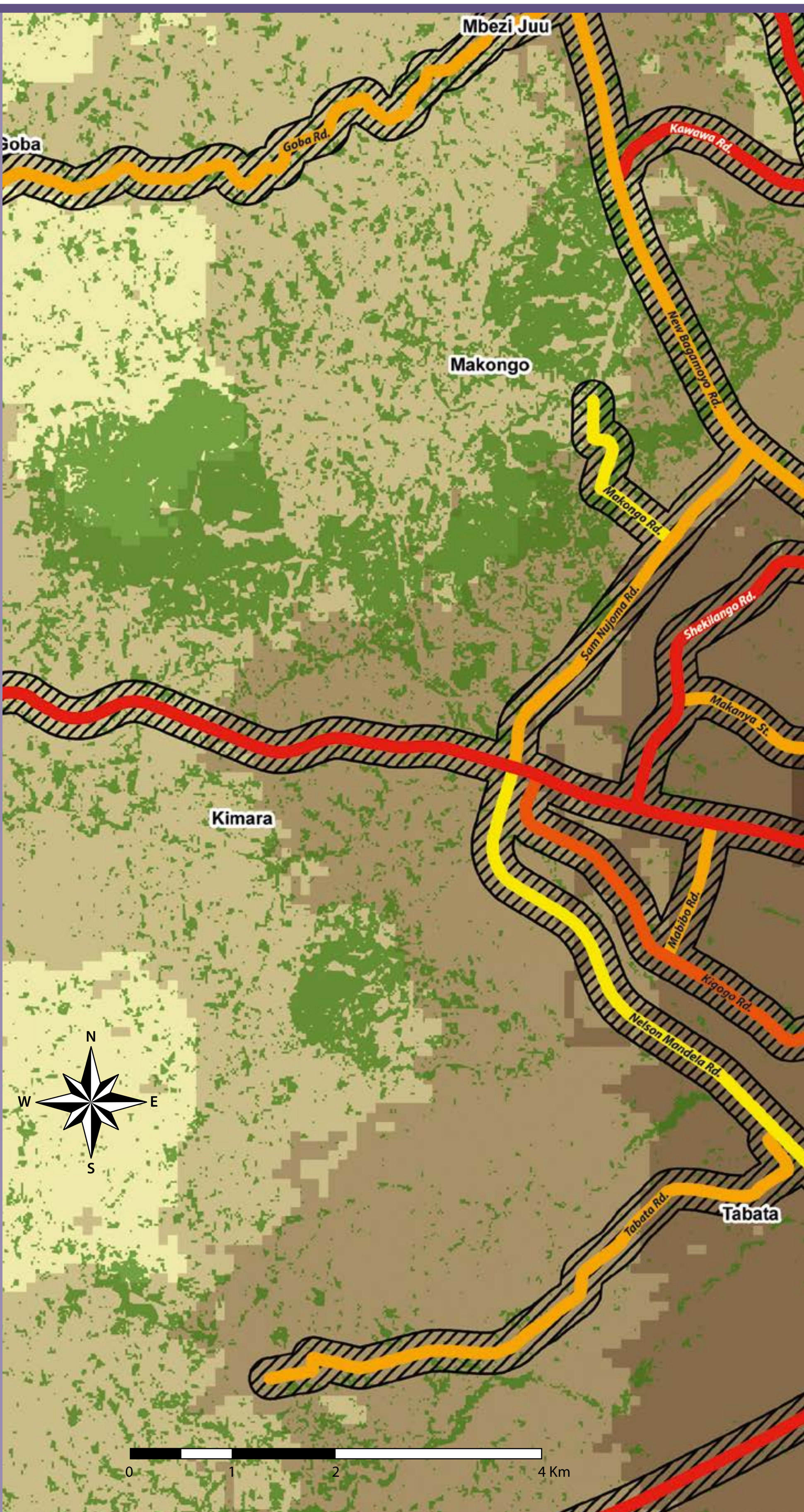
EWURA (2017) Water utilities performance report.

Ngana et al. (2010) Ruvu Basin.

Smiley (2013) Complexities of water access in Dar es Salaam.

PUBLIC HEALTH

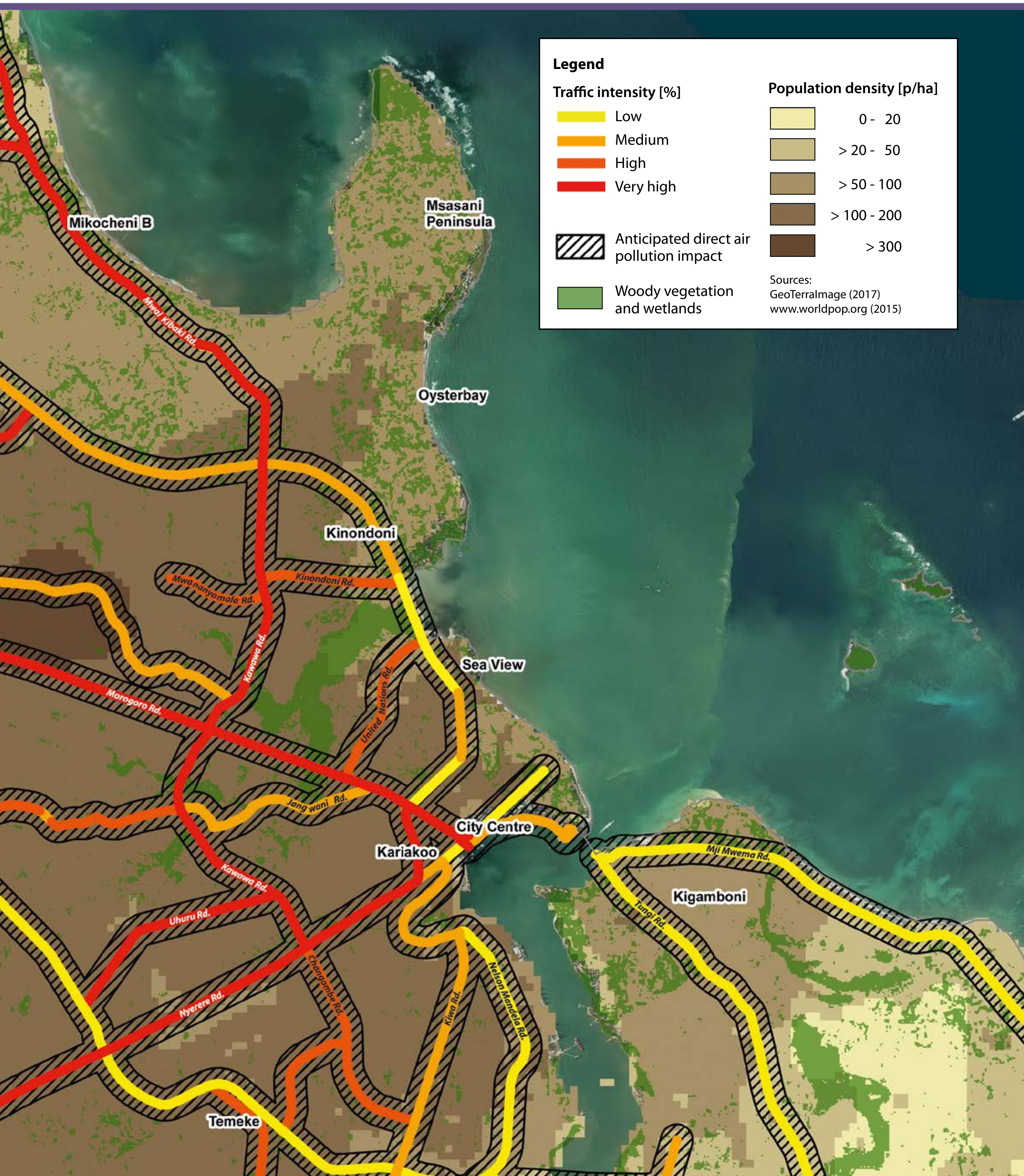
ROADSIDE GREENING FOR CLEANER AIR



The map shows the traffic intensity of DSM's main roads by number of vehicles.

The hatched areas around the roads indicate where high levels of traffic-induced air pollution are likely. Exact pollution levels depend on various additional parameters such as building structures and weather conditions.

The population density indicates those areas where high numbers of people are affected by traffic-induced air pollution around their homes.



Legend
Traffic intensity [%]
Low
Medium
High
Very high
Anticipated direct air pollution impact
Woody vegetation and wetlands
Population density [p/ha]
0 - 20
> 20 - 50
> 50 - 100
> 100 - 200
> 300
Sources:
GeoTerraImage (2017)
www.worldpop.org (2015)
Mikocheni B
Msasani Peninsula
Mwai Kibaki Rd.
Oysterbay
Kinondoni
Mwananyamala Rd.
Kinondoni Rd.
Kawawa Rd.
Sea View
Morogoro Rd.
United Nations Rd.
Jangwani Rd.
City Centre
Kariakoo
Mji Mwema Rd.
Kigamboni
Tungi Rd.
Kawawa Rd.
Uhuru Rd.
Chang'ombe Rd.
Nelson Mandela Rd.
Kilwa Rd.
Nyerere Rd.
Temeke

ROADSIDE GREENING FOR CLEANER AIR

Ambient air pollution is a growing concern in urban centres around the world. In Tanzania, it is estimated to have caused more than 3,800 premature deaths in 2014 [23]. The largest contributor to urban air pollution is road traffic: old vehicles, congestion and dust are responsible for up to 90% of air pollution [37]. Industrial activities (oil refineries, cement production and quarrying activities), domestic activities (biomass and waste burning) and natural effects (e.g. dust) are further sources [38].

The health impact of traffic air pollution along a busy road is comparable to 10 passively smoked cigarettes per day [39].

Cardiovascular diseases, lung cancer and low birth weights are especially associated with the effects of air pollution caused by traffic [39]. Depending on wind, housing structures and other factors, traffic air pollution extends beyond major roads into residential areas.

Focus on Dar es Salaam

As with many other cities around the world, DSM's traffic represents the largest contributor to air pollution [38, 40–42]. The number of vehicles is growing rapidly: in 2013, the City counted ca. 330,000 cars, three times more than 2005. In addition, there are 10,000 Dala dalas (minibus taxis), 30,000 Bajajis (three-wheel scooter taxis), several hundred thousand motorcycles and many other vehicles [43–45]. The resulting congestion (leading to frequent de- and acceleration and idling time) and old engines cause most of DSM's air pollution [40, 41]. These factors outweigh the emission reduction gains of any modern cars used in the city.

DSM loses 10% of its trees per year [5], which is concerning given their key role in supporting public health. Street trees reduce health risks associated with traffic air pollution.

Several studies have measured air pollution in DSM. The pollutants sulphur dioxide (SO2), particulate matter (PM) and lead (Pb) were found to exceed World Health Organisation (WHO) concentration guidelines. Carbon monoxide (CO), nitrous oxide (NO) and nitrogen dioxide (NO2) have also been registered. Generally, the city centre (e.g. Kariakoo, Gerezani) and transport hotspots such as the Askari Monument, Posta, Fire, have air pollution concentrations that are several times higher than the city-wide average [40, 41]. In Kariakoo, measured SO2 pollution levels were up to 70 times higher than recommended by the WHO [40, 46].

Response options

There are many ways to tackle urban air pollution. These include strengthening emission regulations and creating incentives for the use of public transport and bicycles. Roadside greening cannot replace the substantial efforts and investments in road infrastructure that are required to reduce traffic-related emissions. However, planting trees and shrubs can effectively complement such efforts.

Street trees remove thousands of tons of air pollutants in a city per year [47].

Roadside greening likely captures only a small fraction of a city's total air pollution (usually below 1%). However, the local effect of mitigating air pollution can be very significant, reducing up to 70% of the pollutants in a street [48]. In addition, street trees provide important further benefits (air cooling and shade, water retention, biodiversity, food trees...) [47, 49]. Therefore, it is recommended:

1. To compensate for DSM's rapid tree loss of 10% per year [5], substantial investments are needed. Initiatives such as Mti Wangu ('My Tree') are a great start that can be built on.
2. In more open structures, street trees with high leaf surface area should be planted and nursed to maturity. In narrow street canyons, shrubs, ground-based vegetation and green walls and roofs should be planted.
3. Increased collaboration with the Tanzania Electric Supply Company Limited (TANESCO) is required to maintain appropriate green infrastructure below power lines.
4. Incentives for the private sector and support programmes for communities should be developed to promote stewardship for street trees.
5. Horticulture, plant and flower vending along roadsides should be incentivised as a contribution towards local air quality improvement and the cultivation of indigenous plants should be promoted.
6. Brick making and other activities that affect the vegetative buffer along the roads should be redirected to other areas [2].

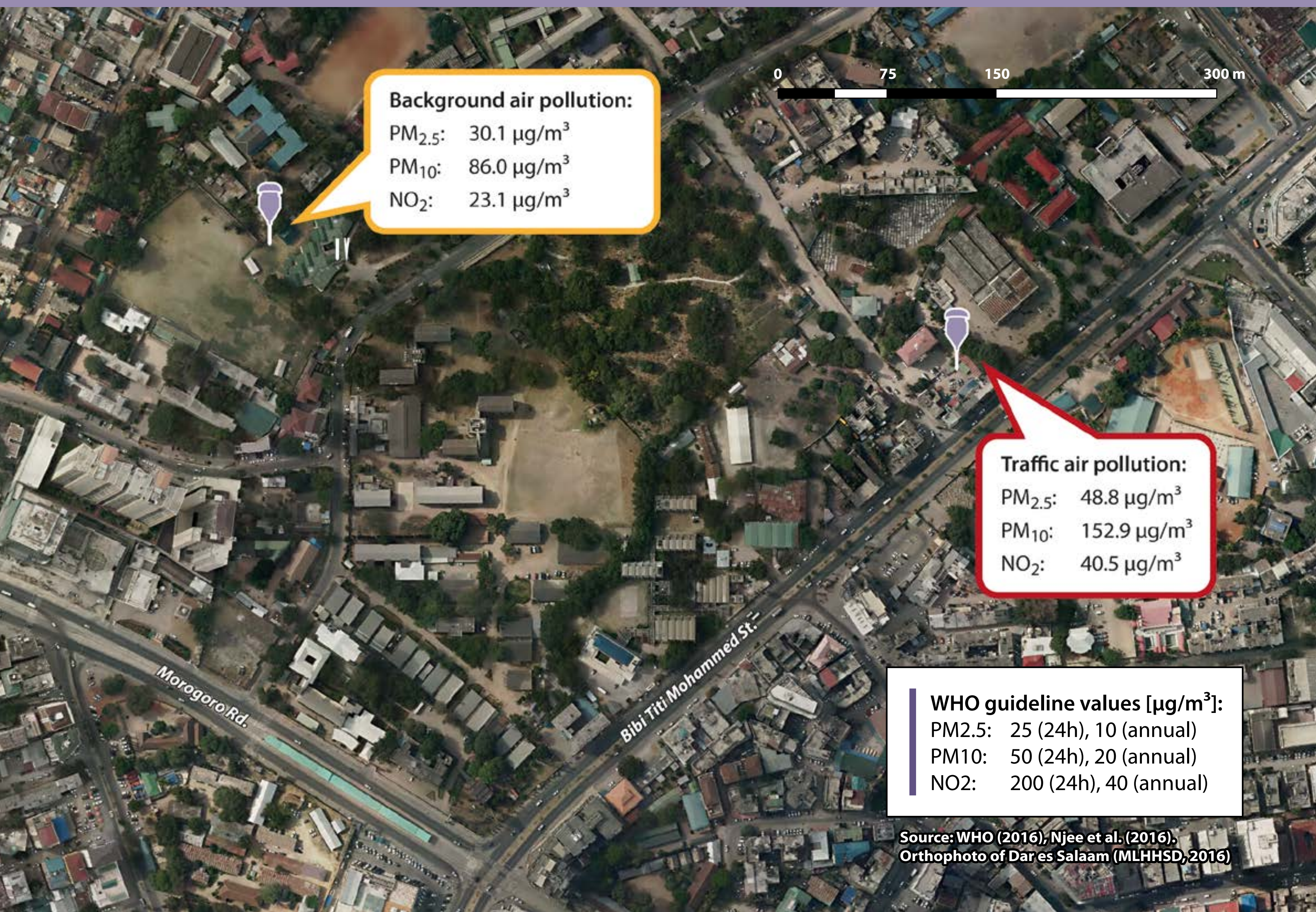
Further Reading

WHO (2016) Ambient (outdoor) air quality and health: Fact sheet.

Pauleit et al. (2013) Recommendations for green infrastructure planning in selected case study cities.

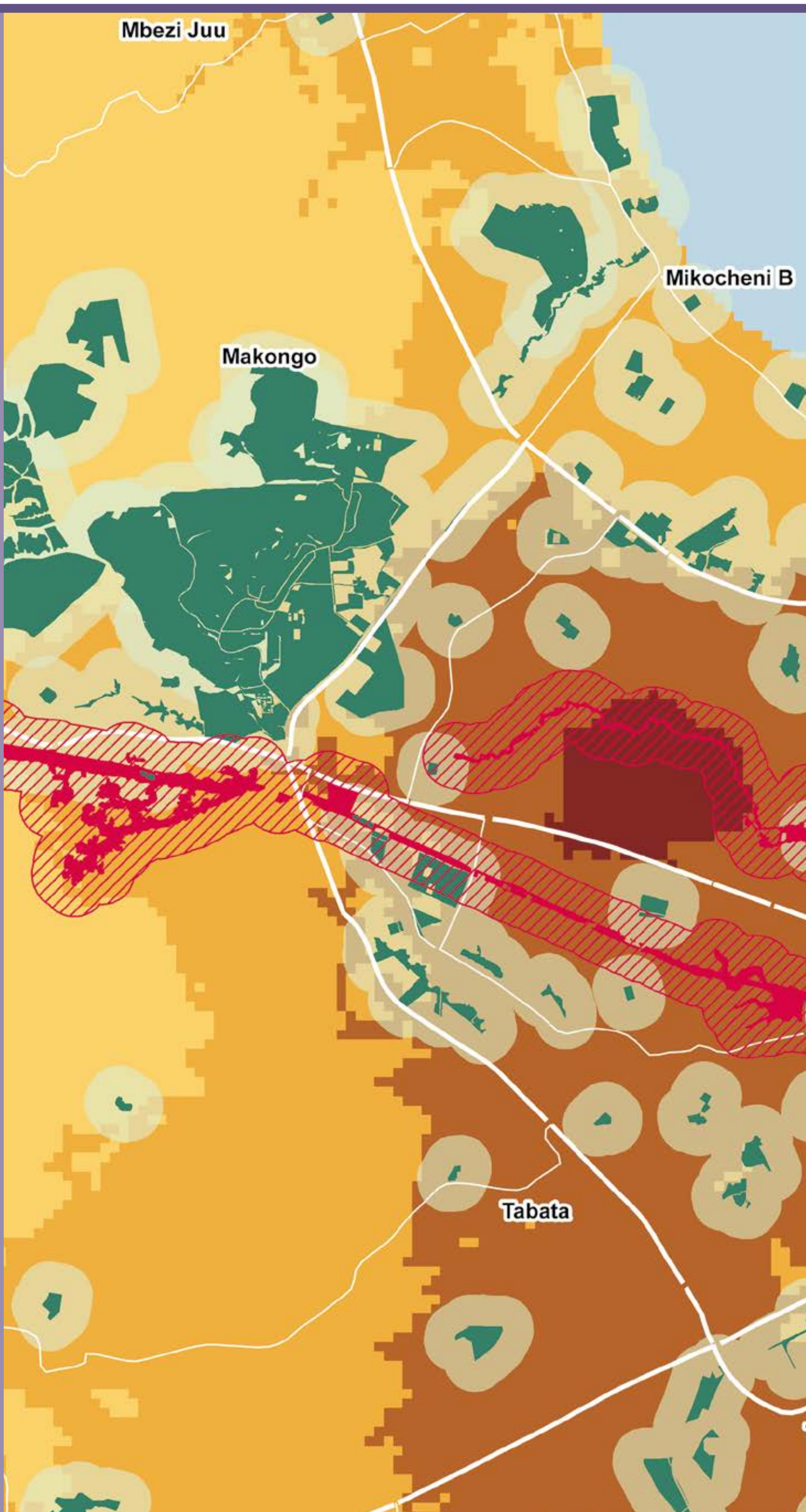
Nowak et al. (2006) Air pollution removal by urban trees and shrubs in the United States.

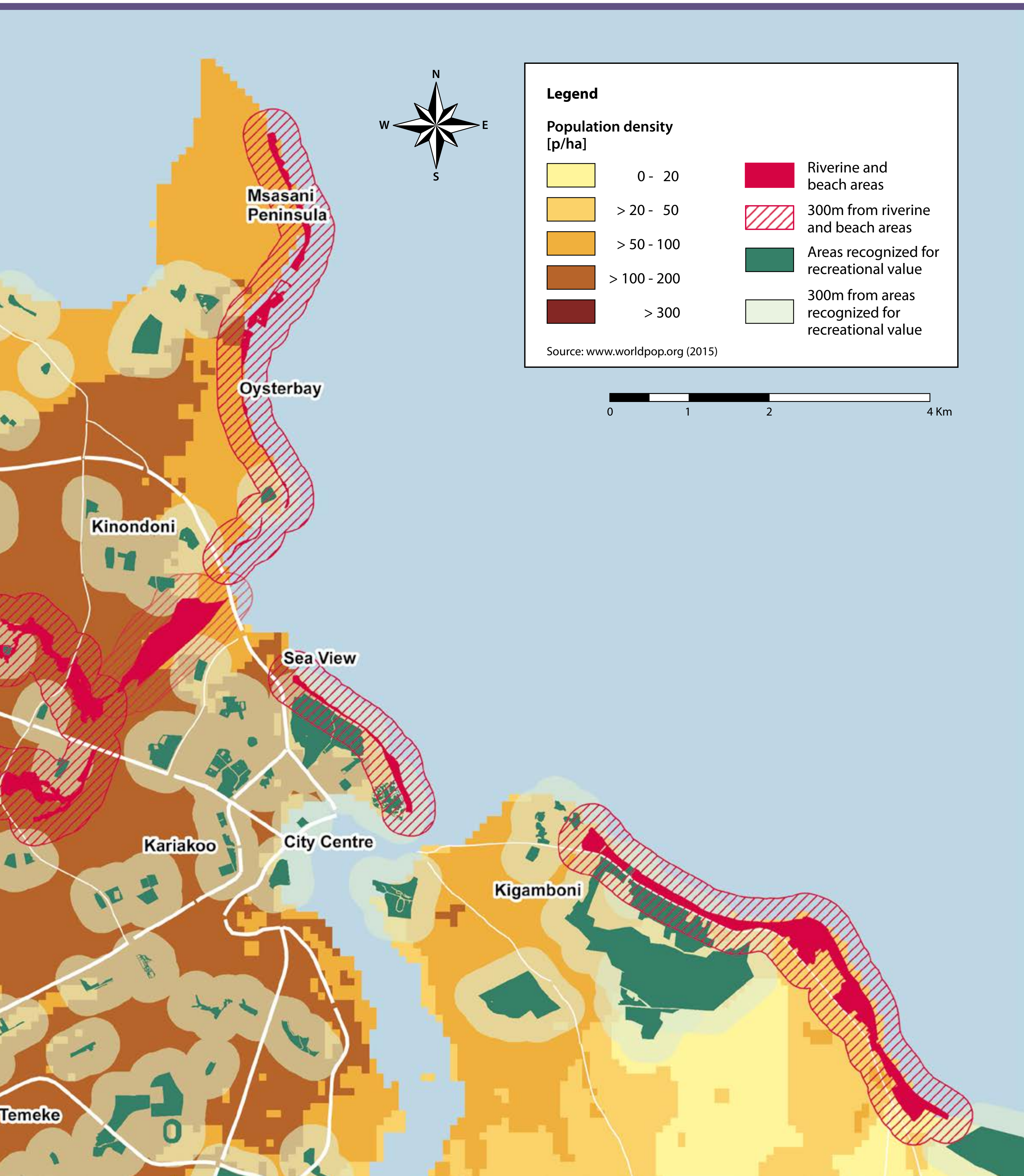
Roadside air pollution levels compared to urban background (within green structure) in central DSM, and WHO recommendations. Results based on six-week average of daily measurements (only working days). Source: Njee et al. (2016). WHO guideline values provided for 24h mean and annual mean.



GREENSPACE IS ESSENTIAL FOR HEALTHY COMMUNITIES

Public greenspaces for recreation in DSM include parks, sports and playgrounds, school yards and community gardens. In many cities, cemeteries are also included in this category. Although these public greenspaces offer an important environment for recreational activities, many residents do not have them close to their homes. This problem is depicted on the map, where buffer zones around public greenspace indicate the areas in which people are less than 300m (max. 15 minutes' walk) away from a greenspace with recreational value. This distance is a globally recognised indicator for acceptable greenspace access in cities. Many areas in DSM do not lie within these zones and thousands of residents do therefore not have access to green recreational areas. This issue should be addressed, especially in high density neighbourhoods, shaded dark red on the map. One possibility is to unlock the recreational potential of existing but inaccessible greenspaces such as beaches and riverine areas, marked in red on the map.





N
W
E
S
Msasani Peninsula
Oysterbay
Kinondoni
Sea View
Kariakoo
City Centre
Kigamboni
Temeke
Legend
Population density [p/ha]
0 - 20
> 20 - 50
> 50 - 100
> 100 - 200
> 300
Riverine and beach areas
300m from riverine and beach areas
Areas recognized for recreational value
300m from areas recognized for recreational value
Source: www.worldpop.org (2015)
0
1
2
4 Km

GREENSPACE IS ESSENTIAL FOR HEALTHY COMMUNITIES

Green recreation areas in the city enhance public health and community life.

As a signatory to the United Nations (UN) Sustainable Development Goals, the government of Tanzania is committed to ensuring the provision of "universal access to safe, inclusive and accessible, green public spaces, in particular for women and children, older persons and persons with disabilities" (Target 11.7; 50). This is especially necessary for rapidly urbanising areas like DSM where urban ecosystems are under high pressure and securing and sustaining public greenspace requires strong political and administrative support. By signing up to the UN Sustainable Development Goals, the Tanzanian government has joined 193 governments around the world which emphasise the need for 'green and public spaces.'

The benefits of urban greenspaces for citizens and visitors are manifold. The simple act of being exposed to greenspace has positive effects on health. Apart from mitigating air pollution, noise pollution and urban heat island effects, there is clear evidence that human minds and bodies benefit from being exposed to nature, even man-made nature. The mental and physical health benefits are further enhanced when people actively engage with nature [51–53] via sports, social activities, gardening and other outdoor activities. Next to the health and recreational benefits, public greenspaces also foster community relationships and contribute to peaceful and mutually supportive neighbourhoods [54, 55].

India's Keoladeo National Park inside the city of Bharatpur opens its gates very early every day for thousands of morning walkers to enjoy its beauty and refreshing air as they head to work [56].

In Detroit, Berlin and many other cities, the communities take care of their green spots and vegetable gardens and in Mexico City, more than 30 'pocket parks' have been developed in dense neighbourhoods as a way of helping people relax and socialise [57].

Public greenspace is not only about parks. It can include everything from reconverted former industrial sites to smaller patches of green which neighbours take care of jointly. The aim is to create and maintain enjoyable, safe, beautiful green spots and areas as part of the city. In a way, the green between streets, buildings and private houses is an expression of a city's culture.

Focus on Dar es Salaam

In DSM, the importance of public greenspace is widely recognised as evidenced in the Physical Planning Act and other regulations [2]. However, the provision of such spots is currently highly limited, especially in socio-economically disadvantaged areas.

The remaining greenspaces in informal settlements are constantly under pressure due to fuelwood demands and increasing housing density. As a consequence, the quality of life in informal settlements suffers from the loss of health, recreational and social benefits that greenspace provides.

Response Options

Access to greenspace should be of special priority for poorer neighbourhoods [58]. The following interventions, based on literature, are proposed in order to improve the quantity and quality of public urban greenspace [59, 60]:

1. Make existing parks and public greenspaces more attractive to citizens, especially in high demand zones. To do so, revise regulations, create new access points and increase public investments in maintaining them.

2. Facilitate public access to private greenspaces by negotiating management agreements with land owners (e.g. companies in the central urban areas).

3. Create new public greenspaces in high demand zones. In doing so, it is important to check for overlaps (co-benefits) with other nature benefits (see other maps) to increase overall value to the city.

4. Recognise beaches and river zones as public greenspaces due to their various other benefits. This will secure their maintenance and limit unregulated private development. Investments in public access, basic securities and amenities (beaches) are required.

5. Explore contract-based support. Mtaa-structures (i.e. sub-ward, street scale governance units) are well-placed for community greening or neighbourhood greening initiatives. These can be effective low-cost alternatives in informal settlements, where new greenspaces are often unfeasible.

6. Involve the public in the development of decentralised greening initiatives, e.g. through the introduction of a 'DSM tree planting day' or school competitions ('the greenest school'). These activities should be understood as being additional to existing initiatives.

Further Reading

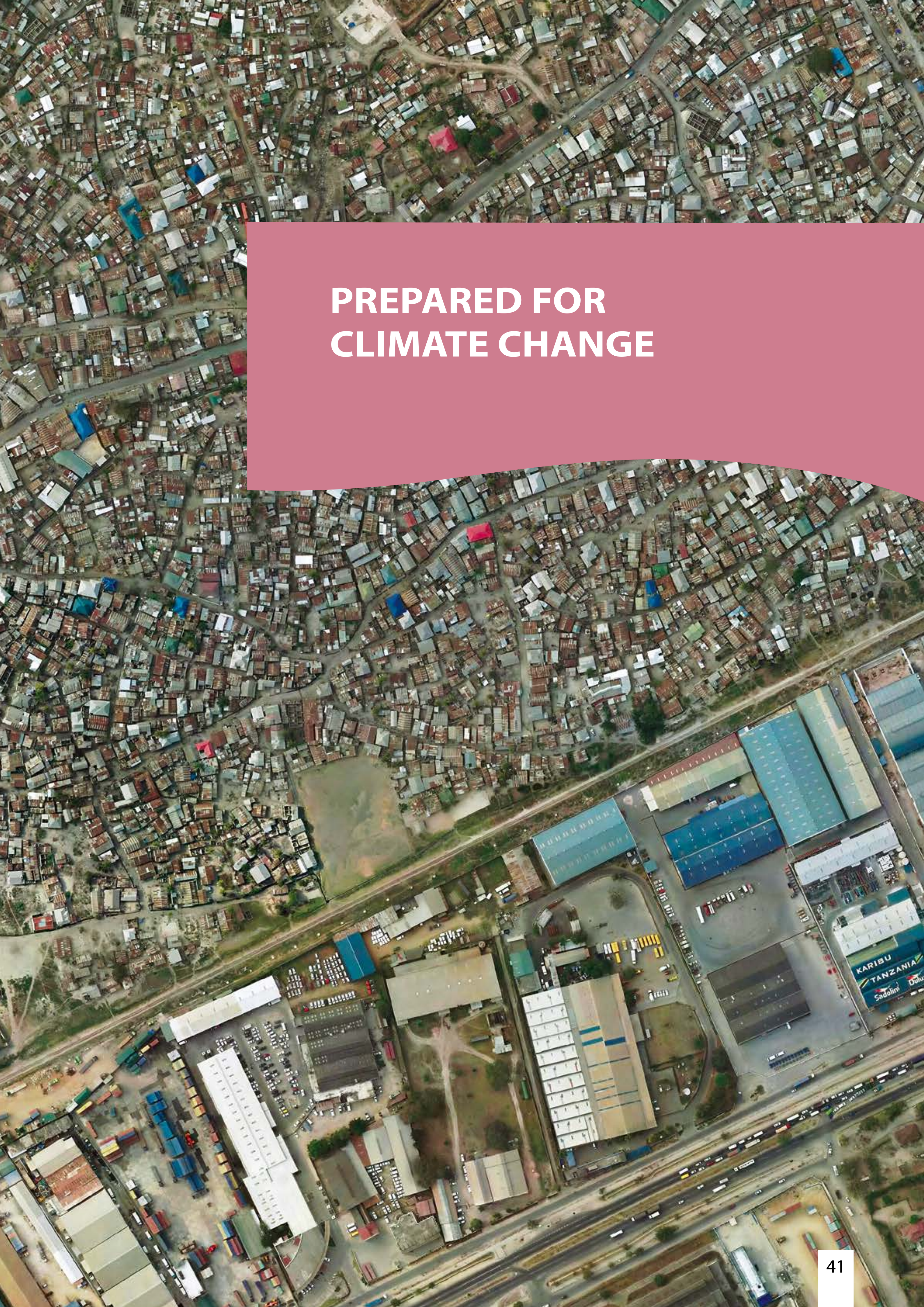
WHO (2016) Urban green spaces and health.

Grewal and Grewal (2012) Can cities become self-reliant in food?

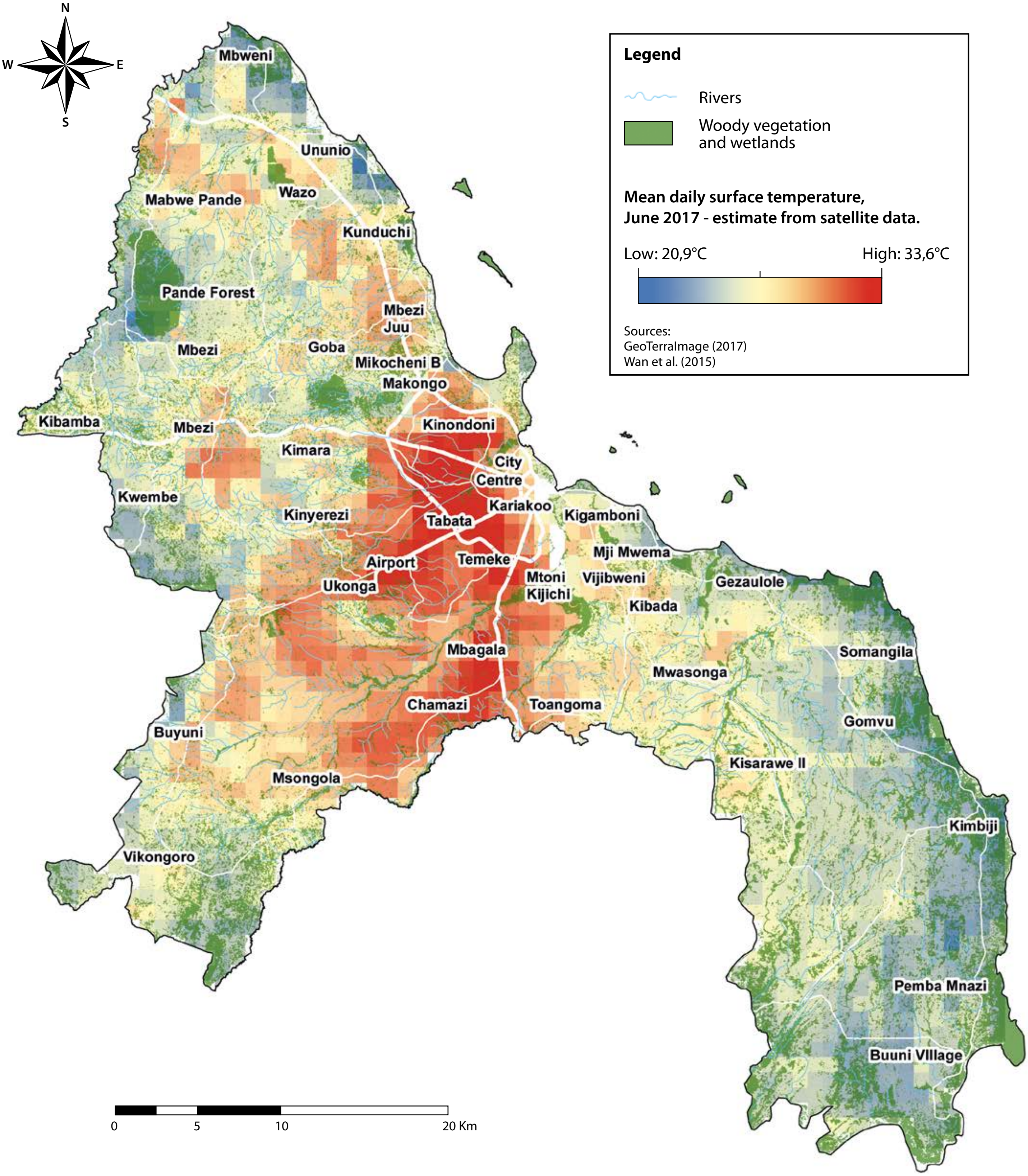
Handley et al. (2011) Providing Accessible Natural Greenspace in Towns and Cities.

Recreational activities and fishery at the beach in Dar es Salaam, June, 2018.
Picture: ICLEI

PREPARED FOR CLIMATE CHANGE



URBAN VEGETATION COOLS THE CITY



The map shows a satellite image of DSM's daytime surface temperature in June 2017. Surface temperatures in the city are up to 12°C warmer than in the surrounding landscapes. This so-called Urban Heat Island Effect (UHI) is a challenge to public health and to secure energy supply in many cities around the world. In DSM, the number of very hot days is expected to continuously rise over the coming decades.

The map also shows that surface temperatures tend to be cooler along the coast, as well as at the municipal boundaries, around greenspaces and river corridors. The map is a first approximation of DSM's UHI and should be further verified, e.g. by conducting systematic air temperature measurements.

Climate change is warming the Earth. East Africa already has 0.7°C higher mean temperatures than it did a century ago and this trend is expected to continue at an even faster pace [38]. In cities around the world, a local phenomenon, the Urban Heat Island (UHI) effect exacerbates the heat effect from climate change. Due to their sealed surfaces, an increase in heat storage in building materials and anthropogenic heat release factors (industry, cars, air conditioning etc.), cities around the world often have considerably higher air temperatures than their surroundings. The UHI intensity is defined as the difference between the highest urban and comparable rural temperature [61]. It can be as high as 12°C, for example in Tokyo [62].

High urban temperatures such as those induced by UHIs are a major concern for public health, especially during heat waves, as they can lead to severe health problems including an increased number of heat-related deaths [60]. Thermal stress increases both outdoors and indoors, particularly affecting low income dwellings without air conditioning [63]. The increased heat also has negative effects on labour productivity and brings secondary effects with it: higher temperatures foster the formation of air pollutants such as ozone, which can in turn cause secondary health effects [62]. The urban energy system is also affected, due to an increase in the demand for cooling and decreased power plant efficiencies. The electricity demand in Athens for example is estimated to be three times as high as it would be without the UHI effect [63].

Focus on Dar es Salaam

Dar es Salaam will likely experience warmer average temperatures (projected at a 2-4°C increase until 2100), and a higher number of extremely hot days (above 34.6 °C) and nights (above 24.5 °C).

»

URBAN VEGETATION COOLS THE CITY

By 2040, between 100 and 200 nights in DSM are expected to be warmer than 24.5°C and potentially half of the days will be above 34.5°C [64].

Despite its coastal location, which brings a cooling effect through the sea breeze, preliminary studies have confirmed the existence of UHI in DSM, with an up to ca. 2°C difference between urban and rural air temperatures. At night, near-surface air temperatures are especially elevated [2, 5].

Different types of UHI can be distinguished (see Appendix). For public health, near-surface air temperatures are critical since this is where people are mostly exposed to the effect.

In June 2017, surface temperatures between central DSM and its urban surroundings differed by up to 12°C during the day.

This is comparable to Sao Paolo, Brazil (14°C) or New York City, US (17°C) [61].

How does Urban Greening Influence Urban Heat?

Urban vegetation can mitigate the UHI effect by cooling the air. Typically, urban greenspaces (forests, parks, cemeteries, riverine corridors etc.) are between 1°C and 3°C cooler than their built-up surroundings [60, 65]. This cooling effect extends beyond the immediate green area: a park in Mexico City was found to provide cooling within a two kilometre radius [65]. The effect can be explained by evapotranspiration, shading, a low thermal storage capacity and less re-radiation of heat than built-up structures [66].

A single tree can have a cooling performance of up to ten standard air conditioners through transpiration alone. When other effects such as shading are included, the effect is even larger [48, 67, 68].

The potential is great: from an equity perspective, all urban areas, especially those with lower socio-economic profiles should be cooled by additional vegetation, since residents are more vulnerable to the effects of heat [60, 66]. Many informal settlements in DSM are sparsely vegetated and have a particularly high tree loss rate due to uncontrolled development.

Response Options

Greenspace: It is recommended that existing green areas in the city are retained and supplemented by the creation of additional greenspaces. The focus should be on vegetation with higher cooling capacity (i.e. forest patches rather than sparsely vegetated fields), especially in informal settlements.

Sea Breeze: The current development of high-rise buildings along the coast in downtown DSM is expected to block the cooling effect of sea breezes further inland in the city. It is vital to create and maintain corridors for sea breeze penetration [5].

Building Design: To improve indoor air temperatures without incurring a large energy demand and promote the release of heat in the city, well-insulated buildings and innovative building materials should be promoted. This includes the greening of roofs and facades. Here, the trade-off between demands for either water (irrigation of green roofs) or electric energy (air conditioning) need to be considered at the municipal scale.

Fuel substitution of vehicle fleet: The substitution of heat emitting combustion engines with public transport, electric cars and bicycles could bring significant improvements to DSM's air quality and temperature. They also facilitate the release of heat and counter air pollution, which is highly problematic (see page 34).

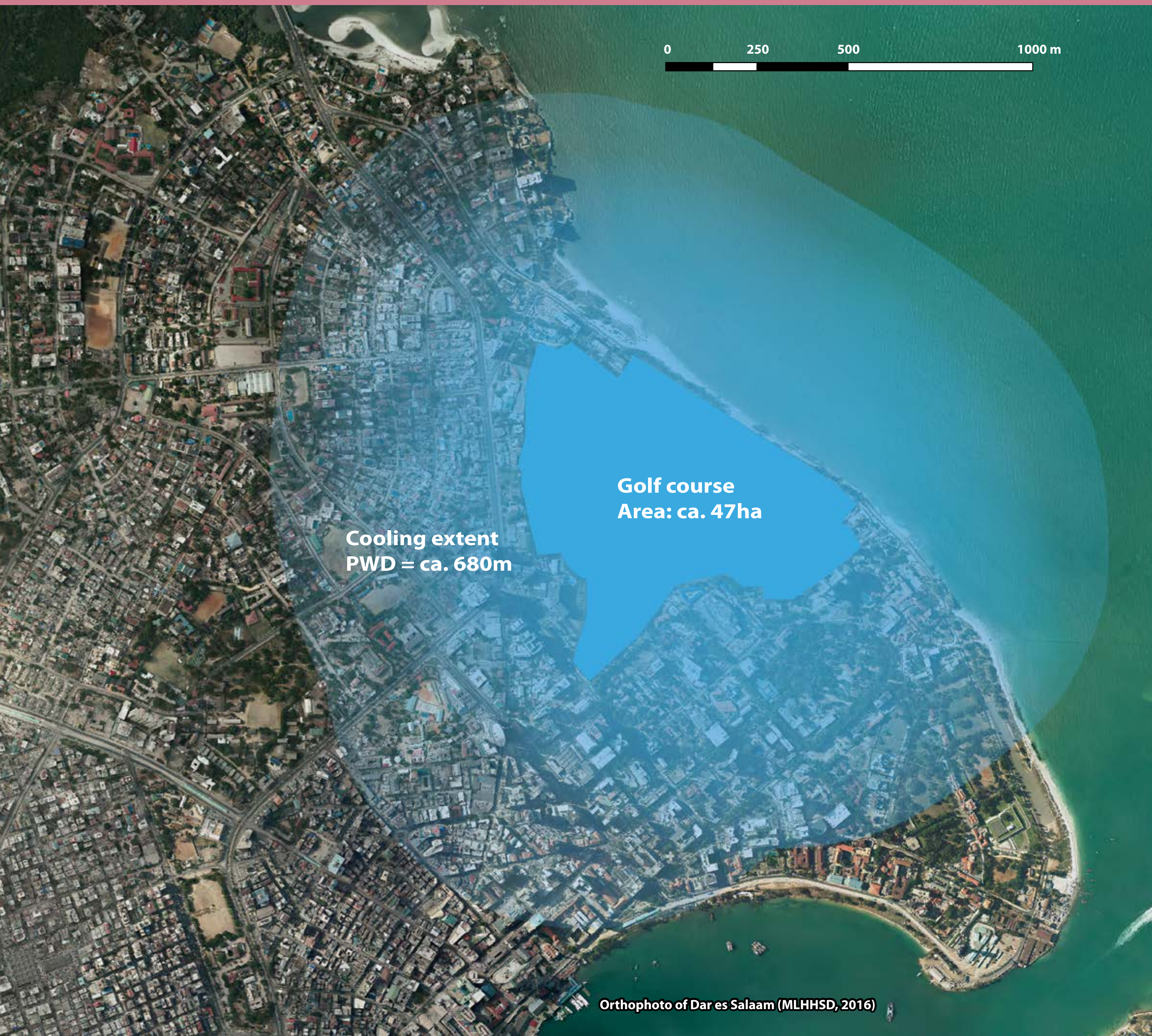
Further Reading

Ndetto & Matzarakis (2015): Urban atmospheric environment and human biometeorological studies in DSM.

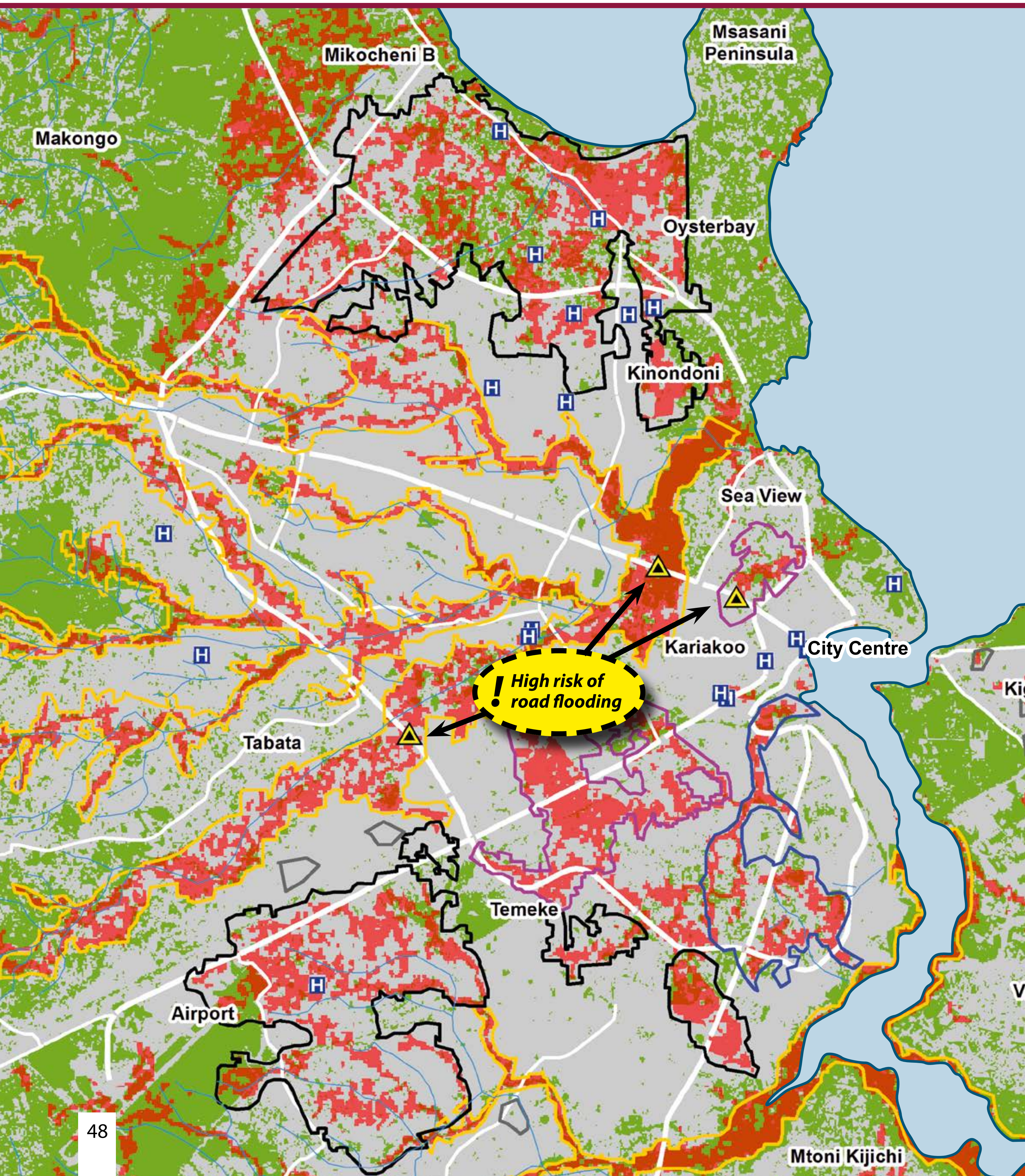
Roth, Oke & Emery (1989): Satellite-derived urban heat islands from three coastal cities.

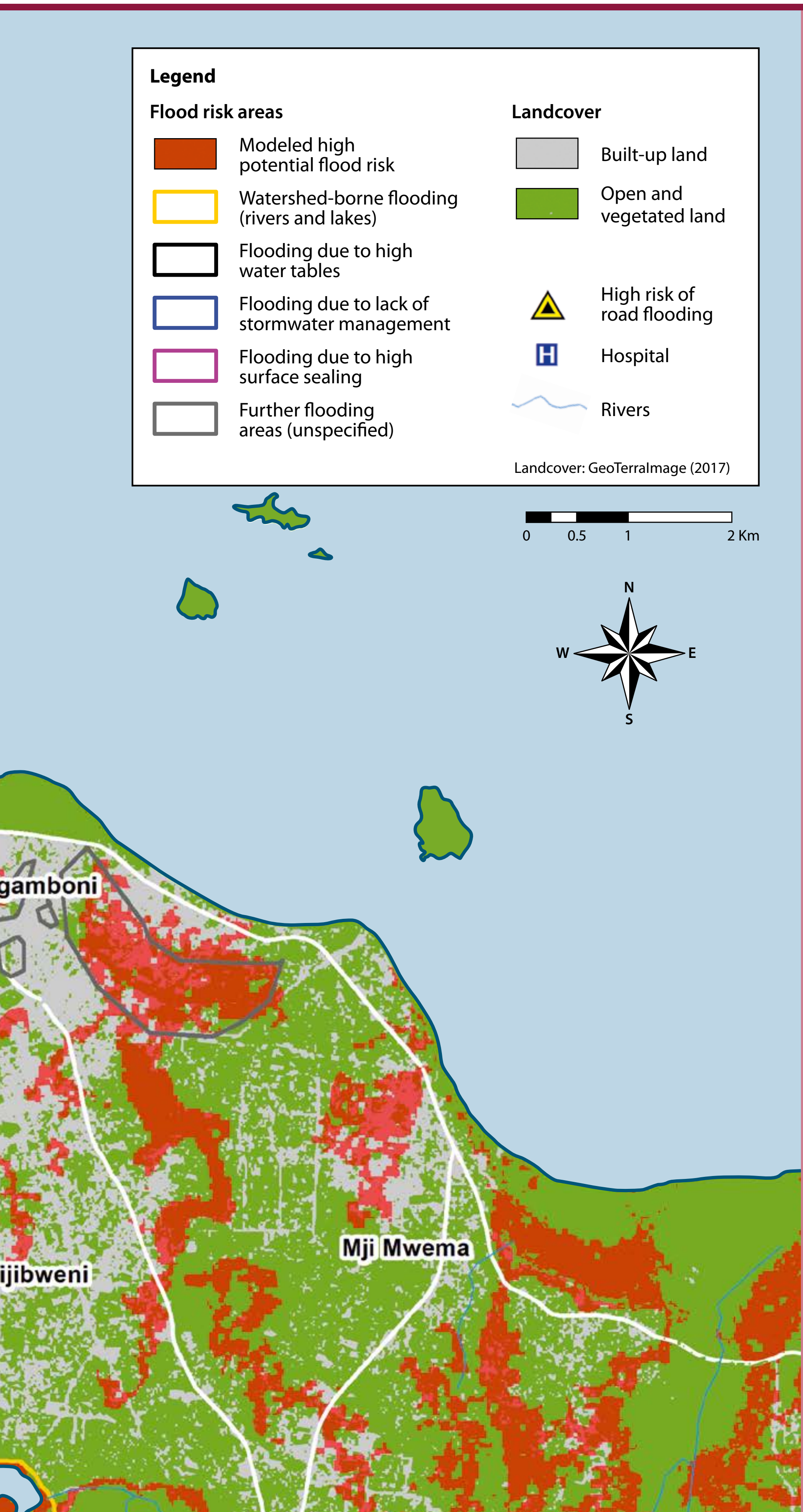
Lindley & Gill (2013): A GIS based assessment of the urban green structure of selected case study areas and their ecosystem services.

Schematic illustration of the cooling extent of an urban greenspace (here golf course in central Dar es Salaam). Further explanations can be found in the Appendix.



GREEN AREAS CAN REDUCE FLOOD RISKS AND PROTECT URBAN INFRASTRUCTURE





Many areas of DSM are prone to flooding during the rainy seasons.

The map combines modelling data and local knowledge for qualitative evidence on the city's flood-proneness. The following flood-risk types can be distinguished:

- **Type I: Flood-prone due to overflowing rivers**
- **Type II: Flood-prone due to high groundwater table**
- **Type III: Flood-prone due to missing or insufficient drainage infrastructure**
- **Type IV: Flood-prone due to high surface sealing and associated runoffs**

The map also depicts the city's main transport and health infrastructure and indicates where main roads are regularly being blocked due to flooding.

GREEN AREAS CAN REDUCE FLOOD RISKS AND PROTECT URBAN INFRASTRUCTURE

Dar es Salaam has experienced regular flood events, which will likely increase in frequency and intensity over the coming decades due to climate change and the further expansion of sealed surfaces in the city. Open, vegetated land in the right locations can help to reduce surface runoff and protect critical infrastructure and houses.

Heavy rainfalls in the wet seasons have led to regular flooding in many parts of DSM. In recent years, riverine and storm water flooding has caused high losses, both socially and economically, including traffic problems, damaged bridges and roads, flooding of homes and deaths [3].

In 2011-2012, a dramatic flood caused many deaths, the displacement of thousands of people and great damage. This was exacerbated by a lack of functioning drainage infrastructure and partly blocked natural drainage systems [69].

DSM's most flood-prone areas include the fast-growing Msasani in Kinondoni, the riverine areas of the Msimbazi valley (e.g. Suna) and Jangwani, as well as the Mikocheni district, which has especially poor storm water drainage systems. The city centre is also at risk, due to high surface sealing and outdated drainage systems [22]. Informal settlements are especially vulnerable to flood risks as they are inadequately prepared for these extreme weather events. This puts lives at risk.

DSM's storm water drainage system was initially installed in the 1950s and is highly undersized due to subsequent population growth. In addition, the pipes and canals are often blocked by solid waste due to poor waste management: in Temeke Municipality, only about 10 to 20% of the waste generated in informal settlements is disposed in landfills, while the rest is burnt on site or discarded, potentially ending up in rivers and drains [3, 6]. Expanding the conventional drainage system to remove storm water from the city into the sea as fast as possible is only part of the solution. The installation and maintenance costs would be high and the washing out of urban pollutants into the sea would pose problems to marine life and fisheries.

Infrastructure, especially main roads and the public transport system, need to be protected against inundation by flood water, to keep critical public services such as hospitals accessible [70]. The repeated flooding of the DSM Bus Rapid Transit headquarters, which has caused much damage, is a clear signal that immediate action is needed [71].

Green areas and sustainable urban drainage systems

Green areas offer a highly valuable ecosystem service: the regulation of extreme weather events. They are also valuable for their ability to slow down surface water and to absorb, store, evaporate and filter water, thereby reducing stress on conventional drainage systems and increasing the city's adaptive capacity [70]. The strategic design and use of green areas (or green infrastructure) in the urban landscape for storm water management is called Sustainable Urban Drainage Systems (SUDS). SUDS usually includes infiltration trenches, swales, dry and wet basins, and green roofs [72]. Often, green elements and built systems are combined into hybrid drainage systems. SUDS has been successfully used in small-scale, successful practices in DSM such as the widespread planting of elephant grass, which slows down storm water run-off and enhances infiltration [6].

In Birmingham, UK, the future benefits of implementing green infrastructure have been examined and found to possibly reduce overall run-off flow by 30%, depending on the nature of the rain event [6].

SUDS relies on many factors such as precipitation patterns, soil characteristics, vegetation transpiration performance, water tables etc. As a result, each city must conduct its own analysis on how SUDS can support existing drainage infrastructure. Initial studies on DSM have shown promising results.

SUDS need to be well designed to take into account any unintended side effects: for example, stagnant waters can foster the spread of diseases. In addition, the green elements of SUDS need to be well maintained to function according to purpose. However, SUDS is often cheaper than the expansion of conventional drainage systems, and offers a multitude of additional benefits. Parks can be designed to serve as storm water infiltration areas when required, and as recreational areas throughout the rest of the year. Green roofs not only slow down surface run-off, but have a cooling and air filtering effect and can be used for rainwater harvesting: One study found that DSM's roofs could supply about 5,000,000 m^3 of rainwater per year [6].

Copenhagen, Denmark, has implemented large-scale SUDS to protect the city against floods. Although the initial investments are substantial, the long-term cost savings are estimated to exceed US$1 billion [6].

Response Options

In light of the city's increasing exposure to flood risks, building green areas, implementing a SUDS and enhancing its adaptive capacity will be of major importance for city resilience in the coming decades. There have been calls to densify urban structures to reduce surface sealing, while others have advocated for improved grey infrastructure. To include SUDS in a mean-ingful way, the following recommendations are made:

1. Investments in modernising and expanding the conventional drainage system should build on a thorough analysis of the potential of green areas and combinations of different solutions as advocated by SUDS.

2. DSM's riverine green areas should be evaluated and protected in view of their role in regulating floods. Upstream retention areas at the urban periphery should also be identified and recognised for their flood protection potential.

3. Greenspace competes with real estate development and unplanned urban densification. It is recommended that the former be strategically considered to maximise the co-benefits of green infrastructure for storm water drainage. Combinations with urban agriculture, recreational use of greenspaces, as well as air quality and temperature regulation should be prioritised.

4. To develop its technical capacity and improve its understanding of local feasibility, DSM could pursue demonstration projects with local residents in highly flood-prone neighbourhoods and develop multi-use concepts for their benefit.

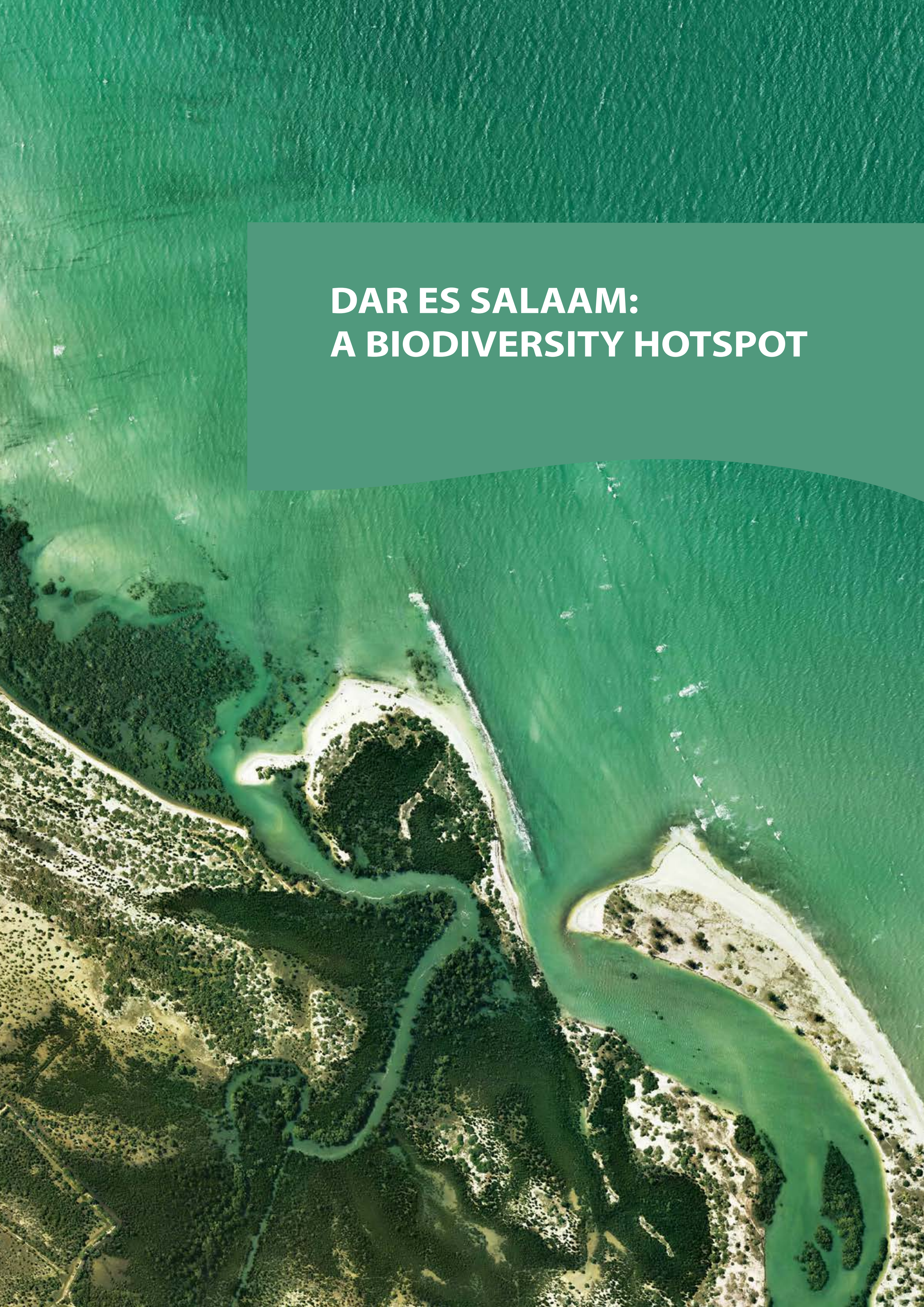
Further Reading

Fryd et al. (2012) A planning framework for sustainable urban drainage systems.

Mguni et al. (2016) Sustainable urban drainage systems. Examining the potential for green infrastructure-based stormwater management for Sub-Saharan cities.

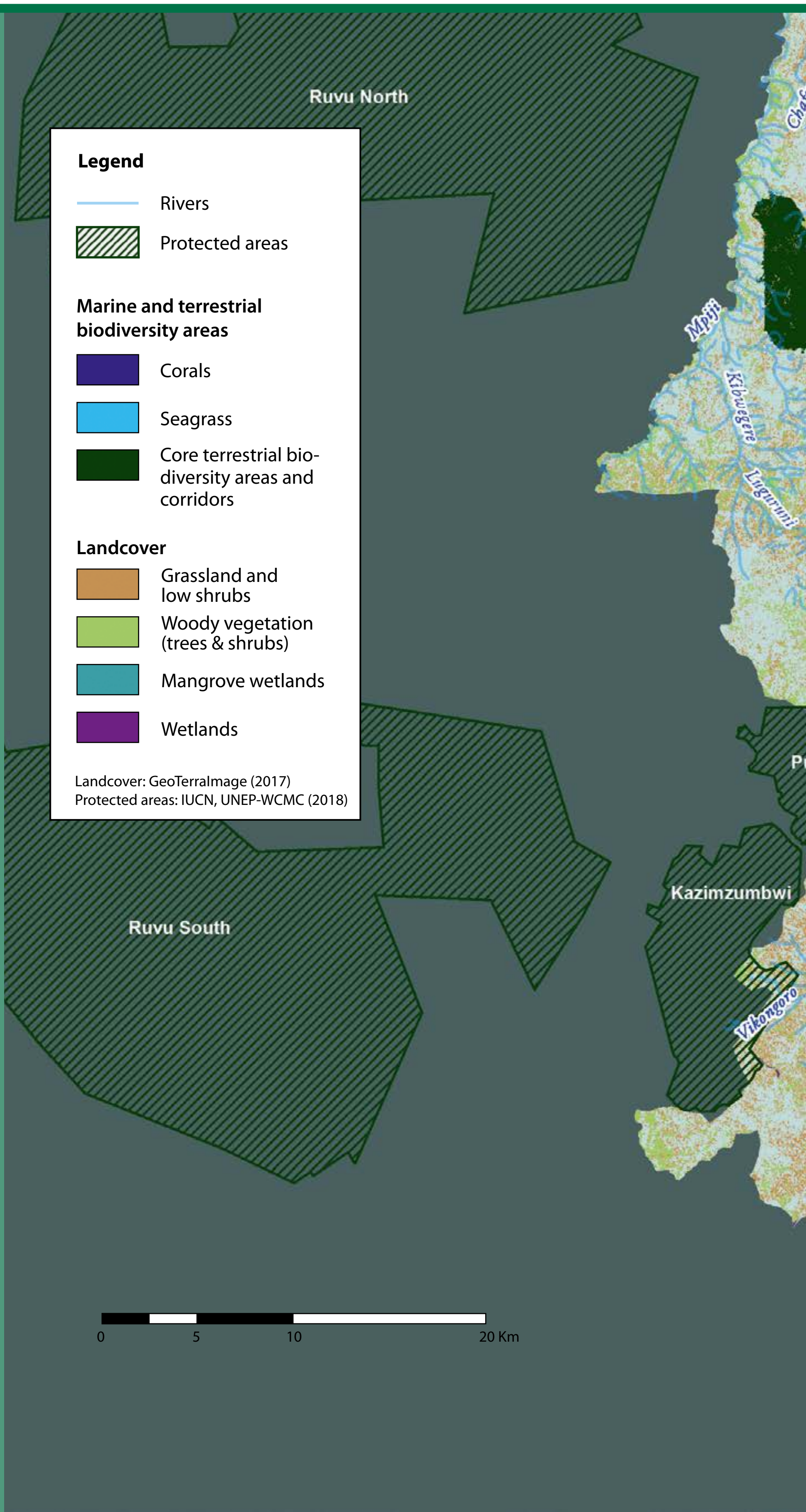
Mguni et al. (2015) Green infrastructure for flood-risk management in Dar es Salaam and Copenhagen.

DAR ES SALAAM: A BIODIVERSITY HOTSPOT



SAFEGUARDING THREATENED BIODIVERSITY IN AND AROUND DAR ES SALAAM

The map shows core areas of terrestrial and marine biodiversity in DSM and its adjacent areas. To the west, several remaining natural forests, such as the Pande and Pugu Forests, provide valuable habitat for large numbers of terrestrial species. These areas are partly connected to each other and to the coast by biodiversity corridors, which are often rivers (e.g. the Msimbazi River). Rivers and other inland water bodies have been found to often provide last 'islands of biodiversity' in increasingly built-up areas.
Both forests and natural corridors however, face strong pressure from development. Along the coast, seagrass and coral reefs provide habitat and grazing ground for various fish species and the (critically) endangered hawksbill and green sea turtles, which typically nest on the southern beaches of DSM. Weak enforcement of regulations in touristic and industrial development lead to high pollution levels of water, as well as noise and light pollution, which threaten fragile coastal ecosystems.



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Burumawe
Kalekwa
Nyakasangwe
Ndumbwi
Manyema
Tegeta
Pande
Mbezi
Mlalakuwa
Sinza
Kijitonyama
Ubungo
Luhanga
Kinyerezi
Kinyerezi
Zimbiri
Msimbazi
Temeke
Yombo
Mzinga
Uvumba
Bandarini
Mzinga
Kinyamwezi
Kizinga
Mirungu
Nguva
Ukoeni
Nyamaronda
Mirange
Mbugeni
Vikindu
Kurutini
Mlandika

SAFEGUARDING THREATENED BIODIVERSITY IN AND AROUND DAR ES SALAAM

Tanzania is biodiversity rich, hosting at least 14,500 species, many of which are endemic. The country not only provides a habitat for ca. 20% of Africa's large mammals, but also for thousands of different plant, bird and fish species. Today, ca. 40% of the country's total area is protected/conserved as a wildlife, forest, or marine habitat [73]. Much is unknown about wildlife in Tanzania, as biodiversity research here is still a small field. However, the country's importance as a global biodiversity hotspot is internationally recognised, especially its Eastern Arc Mountains and the East African Coastal Forests – both of which are partly located within or in proximity to DSM City. Together, these host 121 endemic vertebrates and 1,500 endemic plant species [74, 75]. Due to the growing value of wildlife tourism, which is already worth more than US$1 billion annually [76], biodiversity is increasingly important in Tanzania from an economic point of view.

The Tanzanian coast, especially Kigamboni, is rich in marine biodiversity and is characterised by mangrove forests, seagrass meadows and coral reefs. These areas provide important habitat for, for example dugongs (*Dugong dugon*), whale sharks (*Rhincodon typus*) and various species of sea turtles. In 2014, the central Tanzania coast was declared a 'Site of Regional Importance to Marine Turtles' under the Convention on Migratory Species to which Tanzania is a signatory state [77, 78].

Following a global trend, the country's biodiversity is under pressure: the Eastern Arc Mountains and Coastal Forests alone have been estimated to have already lost 93% of their original extent [74]. It is reported that the number of threatened species in the country almost tripled between 2004 and 2014 to a total of 914. According to Tanzania's national report on biodiversity [76], the main causes of species loss are:

- Habitat conversion, loss, degradation and fragmentation
- Over-exploitation of particular species
- Invasive alien species
- Environmental pollution or contamination
- Climate change

Focus on Dar es Salaam

Dar es Salaam is located in an area that is exceptionally rich in wildlife species. Despite the many challenges associated with urbanisation, wildlife can still be found in the city and within the built-up surrounding area.

DSM's botanical gardens and natural surroundings in the city centre are important nesting sites for birds and provide ideal conditions for many bat species.

Like Tanzania, DSM's biodiversity hotspots can also be grouped into three groups: terrestrial ecosystems (including natural forests), inland water ecosystems (rivers, lakes, ponds, wetlands/swamps, bwawa) and coastal/marine ecosystems (coral reefs, sea grass banks, mangrove swamps and beaches).

Due to encroachment (agriculture and human settlements) and charcoal-production, DSM's naturally forested areas are rapidly shrinking and degrading, despite their protected status. The forests serve as corridors to the Eastern Arc Mountains and have partly overlapping habitats for wildlife in the winter months. The last remaining patches are mainly located to the west of the city and include Pugu, Ruvu North and South, Pande and Kazimzumbwi, which are increasingly recognised for their species richness. The forests are home to a variety of endemic and/or endangered plants, endangered mammals such as the Rondo bushbaby (*Galagoides rondoensis*) and birds such as vultures and the African crowned eagle (*Stephanoaetus coronatus*). As a result, they attract a growing number of eco-tourists.

The inland water bodies in and around DSM serve multiple purposes and their importance is often underestimated. The rivers form corridors that connect forests with the sea, thereby fostering the migration of terrestrial and aquatic species. The brackish water at the estuaries supports species-rich mangrove forests. Riverine areas in Tanzania are protected by a 60m buffer zone within which development is not permitted. However, weak enforcement of this regulation has led to encroachment, pollution and degradation (e.g. through illegal sand mining) of the river banks, threatening the ecosystems and the safety of residents. The standing water bodies, of which some are seasonal, others permanent, have also been identified as 'islands of biodiversity', especially for amphibia and birds, such as the endangered migrant Madagascar Pond Heron (*Ardeola idae*). Since most of them are connected to the rivers, aquatic animals are able to migrate between them. Ponds and wetlands are often found in highly compacted neighbourhoods, and suffer drainage and encroachment.

While about 40% of Tanzania's land area is protected, only 6.5% of its territorial seawaters are gazetted as Marine Protected Areas (MPAs), despite the coast's astonishing species richness.

Along DSM's coastline, coral reefs and sea grass banks can be found, providing food and shelter not only for innumerous fish species, but also for endangered sea turtle species such as green (*Chelonia mydas*) and hawksbill turtles (*Eretmochelys imbricata*). These creatures nest along DSM's southern coast (Kigamboni) and migrate northwards along the coast. The beaches along the coast are also important for many migratory bird species. Sand mining and rapid beach development disturbs these habitats by polluting air and water and being a source of noise and light, which disrupts breeding of wildlife species.

Recommendations

Opportunities for habitat conservation and restoration are ample and the positive effects will extend beyond the ecological dimension. Many other themes discussed in this Atlas, such as tourism have strong co-benefits with biodiversity protection measures. The following recommendations were developed during a workshop of DSM biodiversity experts in 2018:

1. Generally, Tanzania and DSM have a large number of appropriate laws and regulations concerning biodiversity conservation. The main challenge however, is to sustain their continuous enforcement:

    - Waste water pollution of inland water bodies. The current elevated levels of pollution threaten the ecosystem of the water body affected, and impact downstream and coastal ecosystems e.g. the fragile coral reefs. Special attention should be given to the monitoring of industrial activities, in accordance with the respective Environmental Impact Assessments.
    - Beach protection laws, which are often ignored by residential, touristic and industrial development on the beach areas of Kigamboni. Light and noise pollution need to be minimised.
    - Regulations (e.g. 60m buffer zones around rivers) pertaining to riverine areas. These are vital corridors for urban wildlife and provide cities with cooling and improved air flow. They are also high flood-risk areas, which makes residential encroachment dangerous. For these reasons, resettlement should also be minimised. The remaining areas need stronger legal protection e.g. by giving them new status in the master plan ('park' instead of 'riverine').

2. The management of the various protected areas requires coordination between the authorities involved: The Ministry of Natural Resources and Tourism, the Vice President's Office for Environment, the Wami/Ruvu Basin Water Office, the Tanzania Forest Service Agency (TFS), the City Council of DSM, municipal governments etc. In addition,

    - responsibilities must be clarified and/or reassigned. For example, rivers within the city should be managed by the municipalities according to existing laws and regulations

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- the TFS should be strengthened as long-term bonds with the municipal governments are critical.

3. Available knowledge on local biodiversity is still sparse and should be increased by research projects e.g. on the determination of unknown species. The involvement of local students could raise awareness.

4. The existing tree planting programmes (e.g. Mti Wangu) should consider indigenous species as default options for new planting, especially those that are of special conservation significance (endemic and/or endangered).

5. A general focus should be placed on awareness raising of biodiversity benefits in local communities, in particular, potential economic opportunities associated with community conservation of biodiversity, for example through ecotourism (See box).

Further Reading

Burgess et al. (2007) The biological importance of the Eastern Arc Mountains.

Myers et al. (2000) Biodiversity hotspots for conservation priorities.

URT (2014) Fifth National Report on the Implementation of the Convention on Biological Diversity.

Local livelihoods benefit from sea turtle ecotourism:

The community based turtle nest monitoring and protection programme implemented by Sea Sense over the past 15 years has increased the survival rate of turtle eggs significantly. Consistently high hatching success rates have enabled the development of a sea turtle eco-tourism initiative at Tanzania's three largest nesting sites (Mafia, Temeke and Pangani). The initiative is being led by Conservation Officers and local 'Turtle Tour Guides' and is generating a sustainable source of revenue through visitor donations and turtle hatching viewing fees. Sea turtle ecotourism also creates awareness amongst local communities which improves knowledge and understanding of the value of conservation initiatives. Sea turtle ecotourism provides benefits to the wider community, beyond those individuals who earn direct income from the project. Half of all ecotourism revenue is donated back to local communities and this has in turn contributed to a number of community development projects. [77]

Sea turtle hatching on Kimbiji Beach, Dar es Salaam, June 2018. Picture: E.v. Wyk, ICLEI.

Abbreviations

BMU	German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
BORDA	Bremen Overseas Research and Development Association
DSM	Dar es Salaam
DAWASA	Dar es Salaam Water and Sewerage Authority
DAWASCO	Dar es Salaam Water and Sewerage Corporation
DQCA	Dar es Salaam Quaternary Coastal Aquifer
EAM	Eastern Arc Mountains
HTW	University of Applied Sciences - HTW Berlin
ICLEI	Local Governments for Sustainability
ICLEI CBC	ICLEI Cities Biodiversity Center
KAS	Kimbiji Deep Aquifer System
MPA	Marine Protected Areas
NO	Nitrous oxide
NO2	Nitrogen dioxide
OECD	The Organisation for Economic Co-operation and Development
Pb	Lead
PM	Particulate matter
Sida	The Swedish International Development Cooperation Agency
SUDS	Sustainable Urban Drainage Systems
SO2	Sulphur dioxide
TANESCO	Tanzania Electric Supply Company Limited
TEEB	The Economics of Ecosystems and Biodiversity
TFS	Tanzania Forest Service Agency
UHI	Urban Heat Island
UN	United Nations
WHO	World Health Organisation

Technical Annex: Metadata report and additional information

1. Greenspace in Dar es Salaam

DATA AND METADATA INFORMATION	
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INPUT DATA	
Data layer	**Description & source**
1. Agriculture	Raster format land cover image at 20m resolution; captured in 2017. *Source:* GeoTerraImage (2017) Generation of detailed, GIS compatible, digital urban land-use / land cover spatial data for the INTERACT-Bio project: Report and Meta Data. Pretoria, South Africa. Land cover class: *Cultivated smallholder farms.*
2. Bare non-vegetated ground and mines	Raster format land cover image at 20m resolution; captured in 2017. *Source:* GeoTerraImage (2017) Generation of detailed, GIS compatible, digital urban land-use / land cover spatial data for the INTERACT-Bio project: Report and Meta Data. Pretoria, South Africa. Land cover class: *Bare non-vegetated land, mines*
3. Built-up areas	Raster format land cover image at 20m resolution; captured in 2017. *Source:* GeoTerraImage (2017) Generation of detailed, GIS compatible, digital urban land-use / land cover spatial data for the INTERACT-Bio project: Report and Meta Data. Pretoria, South Africa. Land cover class: *Built-up commercial, built-up industrial, built-up formal residential, built-up other*
4. Grassland & low shrubs	Raster format land cover image at 20m resolution; captured in 2017. *Source:* GeoTerraImage (2017) Generation of detailed, GIS compatible, digital urban land-use / land cover spatial data for the INTERACT-Bio project: Report and Meta Data. Pretoria, South Africa. Land cover class: *Grass & low shrub vegetation*
5. Mangrove wetlands	Raster format land cover image at 20m resolution; captured in 2017. *Source:* GeoTerraImage (2017) Generation of detailed, GIS compatible, digital urban land-use / land cover spatial data for the INTERACT-Bio project: Report and Meta Data. Pretoria, South Africa. Land cover class: *Mangrove wetlands*
6. Wetlands	Raster format land cover image at 20m resolution; captured in 2017. *Source:* GeoTerraImage (2017) Generation of detailed, GIS compatible, digital urban land-use / land cover spatial data for the INTERACT-Bio project: Report and Meta Data. Pretoria, South Africa. Land cover class: *Wetlands*
7. Woody vegetation (trees & shrubs)	Raster format land cover image at 20m resolution; captured in 2017. *Source:* GeoTerraImage (2017) Generation of detailed, GIS compatible, digital urban land-use / land cover spatial data for the INTERACT-Bio project: Report and Meta Data. Pretoria, South Africa. Land cover class: *Tree & bush vegetation*

DETAILED NOTES
Purpose: To highlight the extent and coverage of greenspace land cover classes in DSM in 2017, and compare it to other land cover classes. **Methodology:** 1. The raster land cover images were converted into vector polygons and sorted by land cover attributes. 2. Land cover classes were merged for simplification as depicted above.

2. Greenspace under pressure: three types of change

DATA AND METADATA INFORMATION	
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INPUT DATA	
Data layer	**Description & source**
1. Hillshades	*Source:* Jarvis A., H.I. Reuter, A. Nelson, E. Guevara, 2008, Hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT), available from the CGIAR-CSI SRTM 90m Database: http://srtm.csi.cgiar.org. Hillshades generated by Ragnvald Larsen, www.tzgisug.org
2. Tree cover and forest loss	Tree cover in the year 2000, defined as canopy closure for all vegetation taller than 5m in height; encoded as a percentage per output grid cell, in the range 0–100. Global Forest Change 2000–2016, Version 1.4. raster data. Forest loss during the period 2000–2016, defined as a stand-replacement disturbance, or a change from a forest to non-forest state. Encoded as either 0 (no loss) or else a value in the range 1–16, representing loss detected primarily in the year 2001–2016, respectively. *Source:* Hansen MC, Potapov PV, Moore R, Hancher M, Turubanova SA, Tyukavina A, Thau D, Stehman SV, Goetz SJ, Loveland TR, Kommareddy A, Egorov A, Chini L, Justice CO, Townshend JRG (2013) High-resolution global maps of 21st-century forest cover change. Science (New York, N.Y.) 342(6160), 850–853. 10.1126/science.1244693. *Downloaded from* http://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.4.html. Access: 15. June 2018
3. Forest gain	Global Forest Change 2000–2016, Version 1.4. raster data. Forest gain during 2000–2012, defined as the inverse of loss, or a non-forest to forest change entirely within the study period. Encoded as either 1 (gain) or 0 (no gain). *Source:* Hansen MC, Potapov PV, Moore R, Hancher M, Turubanova SA, Tyukavina A, Thau D, Stehman SV, Goetz SJ, Loveland TR, Kommareddy A, Egorov A, Chini L, Justice CO, Townshend JRG (2013) High-resolution global maps of 21st-century forest cover change. Science (New York, N.Y.) 342(6160), 850–853. 10.1126/science.1244693. *Downloaded from* http://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.4.html. Access: 15. June 2018
4. Built-up areas	Global Human Settlement (GHSL) raster data. Multitemporal information layer on built-up presence as derived from Landsat image collections (GLS1975, GLS1990, GLS2000, and ad-hoc Landsat 8 collection 2013/2014). *Source:* Pesaresi M, Ehrilch D, Florczyk AJ, Freire S, Julea A, Kemper T, Soille P, Syrris V (2015) GHS built-up grid, derived from Landsat, multitemporal (1975, 1990, 2000, 2014): [dataset]. *Downloaded from:* http://data.europa.eu/89h/jrc-ghsl-ghs_built_ldsmt_globe_r2015b. Access: 15. June 2018

INPUT DATA	
Data layer	**Description & source**
5. Protected areas	World Database for Protected Areas vector data (selection). The map displays a selection of protected areas around DSM, focusing on forest areas. Mangroves are excluded. *Source:* UNEP-WCMC and IUCN (2018) Protected Planet: The World Database on Protected Areas (WDPA) [Online]: Version May 2018. Cambridge, UK: UNEP-WCMC and IUCN. Available at: www.protectedplanet.net.
6. Trunk roads, regional roads	Vector format polyline shapefile, date unknown, sourced from Ministry of Lands, Housing and Human Settlement Development.
Diagram: Loss of large trees, 2002-2017	Interpolation of remotely sensed data. *Source:* Lindley S, Gill S (2013) A GIS based assessment of the urban green structure of selected case study areas and their ecosystem services D2.8: CLimate change and Urban Vulnerability in Africa (CLUVA).
Diagram: Urban Sprawl in Dar es Salaam	Own calculations based on GHSL raster data (see above)[1] within municipal boundaries.
Diagram: Forest loss and gain in protected areas around Dar es Salaam	Own calculations based on Global Forest Change 2000–2016, Version 1.4. raster data (loss and gain) (see above) and World Database for Protected Areas vector data (selection, see above)

DETAILED NOTES
Purpose: To highlight the main types of greenspace change in and around DSM. **Methodology:** 1. The data layers were re-projected to coordinate system WGS_1984_UTM_Zone_37S. 2. For further analysis, layers 2-4 were polygonised to perform GIS-based area calculations.

3. Dar es Salaam's ecosystems secure thousands of livelihoods

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INPUT DATA	
Data layer	**Description & source**
1. Hillshades	*Source:* Jarvis A., H.I. Reuter, A. Nelson, E. Guevara, 2008, Hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT), available from the CGIAR-CSI SRTM 90m Database: http://srtm.csi.cgiar.org. Hillshades generated by Ragnvald Larsen, www.tzgisug.org
2. Built-up area: urban agriculture	Raster format land cover image at 20m resolution; captured in 2017. *Source:* GeoTerraImage (2017) Generation of detailed, GIS compatible, digital urban land-use / land cover spatial data for the INTERACT-Bio project: Report and Meta Data. Pretoria, South Africa. Land cover classes: *Built-up commercial, built-up industrial, built-up formal residential, built-up other*

INPUT DATA	
Data layer	**Description & source**
3. Peri-urban and rural agriculture	Raster format land cover image at 20m resolution; captured in 2017. *Source:* GeoTerraImage (2017) Generation of detailed, GIS compatible, digital urban land-use / land cover spatial data for the INTERACT-Bio project: Report and Meta Data. Pretoria, South Africa. Land cover class: *Cultivated smallholder farms.*
4. Mangroves	World Database for Protected Areas vector data (selection). The map displays a selection of protected areas around DSM, focusing on forest areas. *Source:* UNEP-WCMC and IUCN (2018) Protected Planet: The World Database on Protected Areas (WDPA) [Online]: Version May 2018. Cambridge, UK: UNEP-WCMC and IUCN. Available at:www.protectedplanet.net. The map displays a selection of protected mangrove swamps in and around DSM.
5. Trunk roads, regional roads	Vector format polyline shapefile, date unknown, sourced from Ministry of Lands, Housing and Human Settlement Development.

DETAILED NOTES

Purpose: To illustrate the main provisioning ecosystem services and their location in DSM, thereby depicting the importance of nature for securing livelihoods.

Methodology:
1. The data layers were re-projected to coordinate system WGS_1984_UTM_Zone_37S.
2. The GTI raster land cover images were converted into vector polygons, and sorted by land cover attributes.
3. Land cover classes were merged for simplification reasons as depicted above.
4. Relevant polygons were selected from the WDPA layer (mangroves).
5. Ecosystem service icons were placed on the map based on expert judgment.

4. Dar es Salaam's water sources under stress

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INPUT DATA	
Data layer	**Description & source**
1. Hillshades	*Source:* Jarvis A., H.I. Reuter, A. Nelson, E. Guevara, 2008, Hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT), available from the CGIAR-CSI SRTM 90m Database: http://srtm.csi.cgiar.org. Hillshades generated by Ragnvald Larsen, www.tzgisug.org

INPUT DATA	
Data layer	**Description & source**
2. Tree cover 2016	Tree cover in the year 2000, defined as canopy closure for all vegetation taller than 5m in height. Encoded as a percentage per output grid cell, in the range 0–100. Global Forest Change 2000–2016, Version 1.4. raster data. Tree canopy cover for year 2000 (treecover2000). Tree cover in the year 2000, defined as canopy closure for all vegetation taller than 5m in height. Encoded as a percentage per output grid cell, in the range 0–100. *Source:* Hansen MC, Potapov PV, Moore R, Hancher M, Turubanova SA, Tyukavina A, Thau D, Stehman SV, Goetz SJ, Loveland TR, Kommareddy A, Egorov A, Chini L, Justice CO, Townshend JRG (2013) High-resolution global maps of 21st-century forest cover change. Science (New York, N.Y.) 342(6160), 850–853. 10.1126/science.1244693. *Downloaded from* http://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.4.html
3. Ruvu River	Cartography by Hannah Kirschner, based on: Ngoye E, Machiwa JF (2004) The influence of land-use patterns in the Ruvu river watershed on water quality in the river system. Physics and Chemistry of the Earth 29 (2004) 1161–1166. Fig. 1. Cartography also based on the relief as represented by SRTM-hillshades.
4. Catchment contour	Simplified illustration, based on: Ngoye E, Machiwa JF (2004) The influence of land-use patterns in the Ruvu river watershed on water quality in the river system. Physics and Chemistry of the Earth 29 (2004) 1161–1166. Fig. 1.
5. DQCA contour	Simplified illustration, based on: Mjemah IC, Walraevens K (2015) Hydrogeological mapping and estimation of potential evapotranspiration and recharge rate of Quaternary sand aquifers in Dar-es-Salaam, Tanzania. International Journal of Geomatics and Geosciences 6(2).
6. KAS contour	Simplified illustration, based on: DAWASA (2017) Strategic Environmental Assessment of the Kimbiji Aquifer Development Plan: Final Report. Dar es Salaam.
7. Water table drawdown contour	Simplified illustration, based on: DAWASA (2017) Strategic Environmental Assessment of the Kimbiji Aquifer Development Plan: Final Report. Dar es Salaam.[2]
8. Abstraction numbers	*Source:* McGranahan G, Walnycki A, Dominick F, Kombe W, Kyessi A, Limbumba T, Magambo H, Mkanga M, Ndezi T (2016) Universalising water and sanitation coverage in urban areas: From global targets to local realities in Dar es Salaam, and back. IIED Working Paper. London.
Diagram: Forest Loss in Ruvu Catchment 2001-2016	Own calculation based on: Hansen MC, Potapov PV, Moore R, Hancher M, Turubanova SA, Tyukavina A, Thau D, Stehman SV, Goetz SJ, Loveland TR, Kommareddy A, Egorov A, Chini L, Justice CO, Townshend JRG (2013) High-resolution global maps of 21st-century forest cover change. Science (New York, N.Y.) 342(6160), 850–853. 10.1126/science.1244693. Year of gross forest cover loss event (lossyear) Forest loss during 2000–2016, defined as a stand-replacement disturbance, or a change from a forest to non-forest state. Encoded as either 0 (no loss) or else a value in the range 1–16, representing loss detected primarily in the years 2001–2016, respectively.
Diagram: Piped Water Access in Dar es Salaam	*Source:* EWURA (2017) Water utilities performance review report for the FY
Diagram: Non-Revenue Water: City Comparison [%]	*Sources:* EWURA (2017) Water utilities performance review report for the FY 2016/2017: Regional and national project water utilities. Dar es Salaam. Smart Water Networks Forum (SWAN) (2011) Stated NRW (Non-Revenue Water) Rates in Urban Networks: SWAN Research. Mckenzie R, Siqalaba ZN, Wegelin WA (2012) The State of Non-Revenue Water in South Africa (2012). WRC Report No. TT 522/12. Gezina, South Africa.
Diagram: Sanitation Facilities of Households in Dar es Salaam [%]	*Source:* McGranahan G, Walnycki A, Dominick F, Kombe W, Kyessi A, Limbumba T, Magambo H, Mkanga M, Ndezi T (2016) Universalising water and sanitation coverage in urban areas: From global targets to local realities in Dar es Salaam, and back. IIED Working Paper. London.[3]

DETAILED NOTES
Purpose: This thematic map is intended to illustrate the main water sources of Dar es Salaam (Ruvu River, DQCA, Kimbiji Deep Aquifer (potentially)) and their individual challenges.

Methodology:

1. For further analysis, the dataset 'Forest loss' was polygonised to perform GIS-based area calculations.
2. Tree cover was clipped on the catchment contour.

Additional information:

Of the estimated 500m³ of daily water that is provided by DAWASA, 466m³ is extracted from the Ruvu River, which will soon reach maximum extraction levels [3]. It has been shown that this reliance on the river not only increases the competition over the basin's water, but also poses challenges to DSM's resilience - from 2030 onwards, it is estimated that the river's water supply in dry periods will not cover demand anymore, potentially leading to shortages in 10% of the year [4], which would have to be compensated by tapping into the already overexploited DQCA or the Kimbiji deep aquifer. This would in turn potentially pose new sustainability challenges from these sources [3].

Simulations show that a conversion of the forests in the catchment area into cropland would result in higher overall water volumes in the Ruvu River of 5 to 6% due to lower soil infiltration. This increase however, would be distributed less evenly throughout the year with higher flow rates in the wet season and lower ones during dry months, increasing the risk of temporal shortages [5]. Expected aggravating effects are increased erosion and siltation of the river beds and a potential deterioration of the water quality [6]. An effect more difficult to quantify is the reduced interception of mist and fog by forest trees in the cloudy Uluguru mountains, which is known to be a constant source of water for the system [5, 6]. Modelling shows that, although much smaller in area, the mountain forests are more important for the catchment area than the woodlands, stressing the urgency of their protection.

The UNDP initiative (2015-2020) titled *Securing Watershed Services through Sustainable Land Management in the Ruvu and Zigi catchments* aims to protect the catchment area against degradation and increase the water quantity and quality [7].

In some cases, the high prices of vended water result in water poverty (defined as more than 5% of income spent on water [8]). Since no comprehensive control mechanisms exist, water bought from vendors cannot be monitored reliably.

In its investigation of well water quality, the study noted that the majority of DSM's boreholes and wells are constructed less than 20m away from pit latrines or septic tanks and faecal contamination was found [9] in half of the tested wells.

Challenges in DSM's water and sewerage system are manifold and need to be addressed in spatially explicit ways, acknowledging socio-economic and water-specific differences. While for central, dense urban structures, a focus on grid extensions, reliability and improved sanitation might be a first priority, peri-urban areas urgently need better access to water [3]. The suggested radius of 30m (green buffer around wells) derives from the WHO's recommended minimum distance from pit latrines to wells and boreholes of 30m [9].

5. Roadside greening for cleaner air

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INPUT DATA	
Data layer	**Description & source**
1. Traffic	Vector format polyline shapefile, date unknown, sourced from Ministry of Lands, Housing and Human Settlement Development. Colour code based on historic traffic counts in DSM (2016) *Source:* URT, (2017) Dar es Salaam City Master Plan: 2012-2032: Draft version Feb. verified with OpenStreetMap data and Google traffic data 2018.
2. Anticipated direct air pollution impact	Vector format polygon shapefile for illustration.
3. Woody vegetation & wetlands (2017 land cover)	Raster format land cover image at 20m resolution; captured in 2017. *Source:* GeoTerraImage (2017) Generation of detailed, GIS compatible, digital urban land-use / land cover spatial data for the INTERACT-Bio project: Report and Meta Data. Pretoria, South Africa. Land cover class: *Tree & bush vegetation*
4. Population density	Raster format population data, dated 2015 *Downloaded from* http://www.worldpop.org.uk. Access: 15. June 2018. Linard C, Gilbert M, Snow RW, Noor AM, Tatem AJ (2012) Population distribution, settlement patterns and accessibility across Africa in 2010, PLoS ONE, 7(2): e31743.

DETAILED NOTES

Purpose: To highlight the areas where the direct impacts of air pollution intersect or diverge with natural assets in the form of woody vegetation & wetlands. Such pollution results from the high intensity of vehicular traffic and population density.

Methodology:

1. Traffic intensity data was created by joining polyline vector format traffic count data and average traffic intensity data from Google Maps as a high-level indicator.
2. A buffer was added to these polylines to show that the direct impact of air pollution extends some distance beyond the road reserve area.
3. Raster land cover images were converted into vector polygons and sorted by land cover attributes. Land cover classes related to woody vegetation and wetlands were extracted from the 2017 dataset provided by GeoTerraImage.
4. Population data sourced from Worldpop (which shows the estimated number of people that are located within each grid, with an extent of 1 hectare or 10,000 m^2) was added to the map.

Additional information:

Generally, vegetation can remove air pollution in several ways: while gaseous pollutants are taken up via leaf stomata and diffuse into the plants, particles are typically intercepted and deposited on the surfaces, where they may be resuspended to the atmosphere or washed off by rain or fall down with the leaf [10]. While generally positive on city scale, several factors determine, if and to what extent, roadside vegetation is a meaningful anti-pollution measure against high exposure to air pollution around the roads.

First, the location and structure of the vegetation is important to consider, as is the context of the urban morphology at the given spot. In street canyons, street trees may not be the optimal solution because their positive effect of pollution uptake may be counteracted by their reduction effect on air circulation, which would be important for pollution dispersion [11–13]. In open structures, street green should be high and thick enough for large deposition areas yet porous enough to allow airflow.

The kind of vegetation forms another important factor to consider: trees have been shown to be especially effective in removing pollution due to their leaves' high surface area and the turbulence caused by their structure, making them three times more effective in particulate matter (PM) filtering than grass (for example). It should also be noted that the uptake of air pollutants varies strongly between different tree species (e.g. coniferous trees have been shown to have higher filtering capacity due to their greater leaf surface and non-deciduousness. A recent study compared the PM2.5 removal potential of the 100 most common urban trees in the world, with the results revealing that Juniper species (e.g. Juniperus virginiana L., Cupressus sempervirens L.) were the best performers. Despite this, none of them are among the most planted trees in DSM [14]. In DSM, Mango (Mangifera inidica L.) is one of the most common trees [15], offers an average PM2.5 removal potential, has additional benefits for biodiversity and livelihoods and is well adapted to local conditions. Often, a combination of trees and surface vegetation is most effective [12]. Dense urban structures may call for other

DETAILED NOTES
greening strategies then trees, such as lower vegetation (shrubs), or building-integrated measures such as green walls or roofs. However, the strong correlation between traffic intensity and ambient air pollution calls for targeted interventions on several levels. These should include inter alia, the setup of a reliable, long-term measuring system across the city that can provide urgently needed spatial data, paving of dust roads, and stricter emissions standards and regulations for the import of second hand vehicles.

6. Greenspace is essential for healthy communities

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INPUT DATA	
Data layer	**Description & source**
1. Recreation areas	Dar es Salaam City Council 2012 landuse layer, consultation of OpenStreetMap (2017) data for verification.
2. Riverine & beach areas	Dar es Salaam City Council 2012 landuse layer, consultation of OpenStreetMap (2017) data for verification.
3. Access: 300m from recreation area	Illustration of 300m buffer around public greenspaces
4. Population density	Raster format population data, dated 2015 *Downloaded from* http://www.worldpop.org.uk. Access: 15. June 2018. Linard C, Gilbert M, Snow RW, Noor AM, Tatem AJ (2012) Population distribution, settlement patterns and accessibility across Africa in 2010, PLoS ONE, 7(2): e31743.
5. Trunk roads, regional roads	Vector format polyline shapefile, date unknown, sourced from Ministry of Lands, Housing and Human Settlement Development.

DETAILED NOTES

Purpose: To show where access to public greenspace in DSM is provided according to international standards, and where it is not. Furthermore, to show the potential of beaches and riverine areas to be unlocked as additional public greenspaces for recreational use.

Methodology:

1. Dar es Salaam City Council 2012 landuse layer was reprojected to Arc_1960_UTM_Zone_37S
2. Public greenspaces where selected according to the definition above and compared to the more recent OSM layers for verification. Where public greenspaces were missing from the Dar es Salaam City Council layer, these were added.
3. Each public greenspace was buffered by 300m.
4. Riverine areas and beaches were also buffered by 300m.
5. Population data sourced from Worldpop shows the estimated number of people that are located within each grid, with an extent of 1 hectare or 10,000 m².

DETAILED NOTES
Additional information: For this theme, public greenspace is understood to be a sub-group of open space. The term refers to land that has no building structures, is accessible to the public and is fully or partly covered by vegetation. It includes parks, community gardens, sports grounds and cemeteries and any other publicly accessible areas with vegetation such as grass, plants or trees [16, 17]. Since some functions of greenspaces are size-dependent (e.g. sports), the WHO recommends minimum areas for smaller (1ha) and larger (20ha) greenspaces [18]. We do not make this distinction on the map. Different indicators exist to measure greenspace access. One that is widely applied is the linear distance from any house to the next public greenspace. This is often set to 300m, which corresponds to ca. 500m walking distance along roads or pathways and less than 15min walking time [18, 19]. Other publications include a second buffer of 2km for greenspaces larger than 20ha in order to address the importance of larger green areas as well, where the increased attractiveness justifies farther access routes [20]. This is not done here. For greenspace density, the international minimum greenspace standard that has been recommended by WHO and the Food and Agricultural Organization (FAO) is 9m² greenspace per city dweller. Many developed countries have adopted values around 20 m² park area per capita. 9m² need to be considered as an absolute minimum [19].

7. Urban vegetation cools the city

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INPUT DATA	
Data layer	**Description & source**
1. Rivers	Vector format polyline shapefile, date unknown, sourced from Dar es Salaam City Council in 2018
2. Woody vegetation & wetlands (2017 land cover)	Raster format land cover image at 20m resolution; captured in 2017. *Source:* GeoTerraImage (2017) Generation of detailed, GIS compatible, digital urban land-use / land cover spatial data for the INTERACT-Bio project: Report and Meta Data. Pretoria, South Africa. Land cover class: *Tree & bush vegetation*
3. Daytime surface temperature (June 2017 average)	Raster format daytime (1:30pm) land surface temperature data at 1km resolution from MODIS Aqua satellite (MYD11A2), averaged for June 2017. *Source:* Zhengming Wan - University of California Santa Barbara, Simon Hook, Glynn Hulley - JPL and MODAPS SIPS - NASA. (2015). MYD11A2 MODIS/Aqua Land Surface Temperature and the Emissivity 8-Day L3 Global 1km SIN Grid. NASA LP DAAC. http://doi.org/10.5067/MODIS/MYD11A2.006
4. Trunk roads, regional roads	Vector format polyline shapefile, date unknown, sourced from Ministry of Lands, Housing and Human Settlement Development.

DETAILED NOTES
Purpose: To show the spatial extent of the urban surface heat island effect, and the cooling potential of natural assets in the form of woody vegetation, wetlands, rivers and the ocean.

DETAILED NOTES

Methodology:

In line with previous SUHI studies (e.g. 21, 22), we used NASA's MODIS-Aqua (MYD11A2) and MODIS-Terra (MOD11A2) products, which are level-3 global Land Surface Temperature and Emissivity 8-day composites at 1000 m resolution, provided in sinusoidal grid format (HDF-EOS) as the mean clear-sky LST during an 8-day time frame [23]. The data was downloaded, re-projected to the Universal Transverse Mercator (UTM) zone 37°S projection system (WGS84 datum), reformatted from HDF-EOS to GeoTIFF format, and converted from °K to °C. Then, all 8-day-images were averaged on pixel-basis into a consolidated map for the time frame (June 2017). Cloud-related null-values were not averaged.

2. Raster land cover images were converted into vector polygons and sorted by land cover attributes. Land cover classes related to woody vegetation and wetlands were extracted from the 2017 dataset provided by GeoTerraImage.
3. Polyline format vector data which shows the location of rivers and streams was supplied by Dar es Salaam City Council (date unknown).

Additional information:

The urban heat island effect (UHI) describes the effect of elevated urban air temperatures and compares it to the adjacent suburban and rural area [24]. A related, yet not directly proportional concept, is the Surface UHI (or: SUHI), which measures the difference in surface temperature (ground, roofs, vegetation etc.) in a city compared to its surroundings [21, 25].
Remote sensing of SUHI via satellite data allows for a visualisation of temperatures in a larger area (i.e. the whole city), [26]. As the results are qualitatively different from air temperature measurements, various intervening factors do not allow for direct correlation [21]. For example, the satellite does not capture vertical surfaces or any other structure anything below roofs, trees etc., irrespective of their relevance for air temperature. Typically, daytime SUHI intensities are higher than air temperature UHI, because of the faster response of surfaces (especially roofs) to irradiation compared to air [25].

Vegetation cooling

The cooling effects of vegetation, especially of larger greenspaces, are well-investigated, e.g. by [18, 24, 27, 28]. Although there are many factors that determine the cooling effectiveness of vegetation, a rough approximation of the cooling radius can be made. This is called the Park Width Distance (PWD), defined as the square root of the size of the greenspace. The cooling effect of a park with an area of one hectare would therefore be measurable up to ca. 100m distance. This approximation is used for the cooling radius around green space in the map.
The calculation behind the cooling performance of single large tree: one tree can transpire up to 450l/day [11].

- The latent heat transfer equals ca. 0.7kWh/l [28].
- This results in up to 315kWh cooling energy per day or up to 13 kW constant cooling
- 10 ACs (each 3 kW).
- Shading offers additional large cooling effects (up to 80% of total) [29]

8. Green areas can reduce flood risk and protect urban infrastructure

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INPUT DATA	
Data layer	**Description & source**
1. Rivers	Vector format polyline shapefile, date unknown, sourced from Dar es Salaam City Council in 2018
2. High risk of road flooding	Digitized vector format point shapefile, dated 2018, inputs sourced from DSM expert workshop in June 2018
3. Flood-risk areas (anecdotal)	Digitized vector format point shapefile, dated 2018, inputs sourced from DSM expert workshop in June 2018
4. High potential flood risk (modeled)	Vector format polygon shapefile, date unknown, sourced from GeoTerraImage
5. Land cover: built-up land	Raster format land cover image at 20m resolution; captured in 2017. *Source:* GeoTerraImage (2017) Generation of detailed, GIS compatible, digital urban land-use / land cover spatial data for the INTERACT-Bio project: Report and Meta Data. Pretoria, South Africa. Land cover classes: *Built-up commercial, Built-up industrial, built-up formal residential, built-up other*
6. Land cover: open and vegetated land	Raster format land cover image at 20m resolution; captured in 2017. *Source:* GeoTerraImage (2017) Generation of detailed, GIS compatible, digital urban land-use / land cover spatial data for the INTERACT-Bio project: Report and Meta Data. Pretoria, South Africa. Land cover classes: *Grass & low shrub vegetation; mangrove wetlands, wetlands, tree & bush vegetation, bare non-vegetated land*

DETAILED NOTES

Purpose: Many areas of DSM are prone to flooding during the rainy seasons, especially those that are close to rivers and those that have high degrees of sealed surface.

Methodology:

1. Polyline format vector data, which shows the location of rivers and streams was supplied by Dar es Salaam City Council (date unknown).
2. Flood-risk map comments provided to the team by Jafar Salehe Jongo and Guido Uhinga were digitized to create a vector format point shapefile showing where there is high risk of road flooding.
3. Flood risk area comments were provided to the team by Jafar Saleh Jongo and Guido Uhinga and were digitized to create a vector format polygon shapefile showing the types of flooding causes.
4. Polygon format vector floodplain models shapefiles date 2017 were sourced from GeoTerraImage.
5. Raster land cover images were converted into vector polygons, and sorted by land cover attributes. Land cover classes related to woody vegetation, wetlands, mangrove wetlands, water and grasslands were merged to create a single class 'open and vegetated land' from the 2017 dataset provided by GeoTerraImage.
6. Raster land cover images were converted into vector polygons and sorted by land cover attributes. Land cover classes related to built-up commercial, built-up industrial, built-up informal residential/urban, built-up high density informal/rural, cultivated commercial and mines were merged to create a single class 'built-up land' from the 2017 dataset provided by GeoTerraImage.

Additional information:

The principles of Sustainable Urban Drainage Systems (SUDS): In a rain event, the following water balance equation characterizes the distribution: $P = Q + E + AS$ (P is precipitation, Q is runoff (above and below terrain), E is evapotranspiration, and AS is the change in storage (e.g. in the soil or an aquifer)) [30]. In order to minimise flood risk, runoff needs to be reduced. While impermeable surfaces such as asphalt and concrete have very high runoff, the vegetated area runoff can be close to zero, since water infiltrates, is stored in the soil and the plants, is returned back to the atmosphere via evapotranspiration etc. This means that ca. 10% of precipitation can be expected to run off the surface, 50% to infiltrate and 40% to evaporate, all by natural means. The reverse occurs in urban areas: on average ca. 55% runs off the surface, 15% infiltrates and ca. 30% is transpired/evaporates. In addition, the runoff in cities typically reaches higher flow rates on the smooth surfaces compare to vegetated land. [30]

SUDS brings the superior stormwater-related attributes of natural areas into the city, an effect which is often enhanced by suitable grey infrastructure. In order to quantify the actual performance of SUDS, several

DETAILED NOTES
parameters need to be known, especially the characteristics of the soil and the conditions for evapotranspiration: The soil type determines the infiltration potential. It is typically higher in sandy soils than in soil with high clay deposits [30]. The evapotranspiration rate depends on the vegetation type and the local climate (hot dry climates lead to higher evapotranspiration rates than colder or more humid ones).

9. Safeguarding threatened biodiversity in and around Dar es Salaam

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INPUT DATA	
Data layer	**Description & source**
1. Rivers	Vector format polyline shapefile, date unknown, sourced from Dar es Salaam City Council in 2018
2. Protected Areas (WDPA)	World Database for Protected Areas (WDPA) vector data (selection). *Source:* IUCN, UNEP-WCMC (2018) The World Database on Protected Areas (WDPA) [Online]: Version May 2018. Cambridge, UK: UNEP-WCMC. *Downloaded from:* www.protectedplanet.net. Access: 15. June 2018.
3. Corals	Vector format polygon shapefile, date unknown, sourced from Lindsey West of SeaSense in 2018.
4. Seagrass	Vector format polygon shapefile, date unknown, soured from Lindsey West of SeaSense in 2018.
5. Core biodiversity and corridors	Vector format polygon and polyline data was created by digitizing biodiversity expert inputs drawn on physical map in June 2018.
6. Land cover	Raster format land cover image at 20m resolution; captured in 2017. *Source:* GeoTerraImage (2017) Generation of detailed, GIS compatible, digital urban land-use / land cover spatial data for the INTERACT-Bio project: Report and Meta Data. Pretoria, South Africa. Land cover classes: *Grass & low shrub vegetation, mangrove wetlands, wetlands, tree & bush vegetation*

DETAILED NOTES

Purpose: To integrate existing biodiversity spatial data into a consolidated biodiversity map, including core biodiversity areas and key natural assets such as woody vegetation, wetlands, rivers and marine biodiversity.

Methodology:

1. Raster land cover images were converted into vector polygons, and sorted by land cover attributes. Land cover classes related to woody vegetation, mangrove wetlands, water, and wetlands were extracted from the 2017 dataset provided by GeoTerraImage.
2. Vector format polygon and polyline data was created by digitizing biodiversity experts' inputs dated 2018. This shows the location of core biodiversity and corridors.
3. A 2km buffer along river corridors was created. An intersect function was performed between land cover classes related to woody vegetation, mangrove wetlands, water and wetlands and core biodiversity.
4. All layers were re-projected to the coordinate system WGS_84_UTM_37S.

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Project outline - INTERACT-Bio

Integrated subnational action for biodiversity: supporting the implementation of National Biodiversity Strategy and Action Plans through the mainstreaming of biodiversity objectives across city-regions.

INTERACT-Bio is a four-year project designed to improve the utilisation and management of nature in fast-growing cities and the regions surrounding them. It aims to provide expanding urban communities in the Global South with nature-based solutions that have associated long-term benefits. The project will enable governments at all levels – from local to national – to integrate their efforts to mainstream biodiversity and ecosystem services into core subnational government functions such as spatial planning, land-use management, local economic development and infrastructure design.

The project helps city-regions to understand and unlock, within their specific local context, the potential of nature to provide essential services and new or enhanced economic opportunities, while protecting and enhancing the biodiversity and ecosystems on which they depend. Engaging in these actions places participating city-regions on a more resilient and sustainable development path.

INTERACT-Bio is implemented by ICLEI – Local Governments for Sustainability. The ICLEI World Secretariat manages the project in close collaboration with the ICLEI Cities Biodiversity Center (CBC) which provides technical leadership. The CBC is in the ICLEI Africa office, one of three offices in ICLEI that is responsible for the regional implementation of INTERACT-Bio. ICLEI South Asia and ICLEI South America are the other two implementing partners.

At a glance:

- The Helmholtz Centre for Environmental Research – UFZ provides technical support for the ecosystem assessment components of the project. The Secretariat of the Convention on Biological Diversity is an endorsing partner
- The project is funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) through the International Climate Initiative (IKI)
- The duration of the project is from 2017 to 2020
- The project website can be found at: http://cbc.iclei.org/project/interact-bio/

Project outline - Urban Natural Assets: Rivers of Life

Urban Natural Assets for Africa: Rivers for Life (UNA Rivers) is a project that has been implemented by ICLEI's Cities Biodiversity Center to assist local African governments in the challenges they face protecting and revitalising their urban natural assets, and their river systems in particular. The overall objective is to increase the cities' resilience.

UNA Rivers achieves this by:

- improving co-ordination between key stakeholders to mainstream biodiversity and nature-based solutions into land use planning and decision-making processes
- increasing awareness of ecosystem benefits and services, and building local government capacity to proactively manage them
- aligning project activities with international policies and processes (such as the Convention on Biological Diversity's Aichi Biodiversity Targets and the Sustainable Development Goals) to mobilise them
- connecting local communities to nature to encourage appreciation, cultural activation and human wellbeing
- implementing community-based projects along urban river systems to improve river restoration and revitalisation efforts, and improve livelihood creation

At a glance:

- Funded by The Swedish International Development Cooperation Agency (Sida) through SwedBio at the Stockholm Resilience Centre, Stockholm University
- The duration of the project is from 2016 to 2019
- For more information, visit the project website: http://cbc.iclei.org/project/una-rivers-life

Kitabu cha ramani ya faida za mazingira Dar es Salaam

Sababu muhimu kwa kusaidia mimea na kwa kuhifadhi ecosystems mjini.

Dar es Salaam (DSM) ni kituo cha kitamaduni, kisiasa na kiuchumi nchini Tanzania - na mojawapo ya miji inayoshamiri zaidi katika Afrika Mashariki. Pia ni moja ya majiji yanayokua kwa kasi zaidi duniani. Hii inaleta changamoto: Ni jinsi gani ya kuhakikisha kwamba wakazi wote wa Dar es Salaam wanaishi katika mazingira salama, wanafurahia maisha mazuri katika jamii zao, na wanaweza kuwa na maisha endelevu? Mazingira yanayosabahiyana ndani na karibu na maeneo ya mijini yanatoa ufumbuzi wa changamoto kuu za miji. Miji duniani kote imeanza kutambua hili. Na hii ndicho kinacholengwa kuonyeshwa katika kitabu hiki cha ramani: Faida za mazingira asilia ni ulinzi wa miji, kuifanya iwe endelevu na kuifanya iwe ya kuishi maisha yaliyo bora. Kitabu hiki cha ramani kinasaidia safari ya Dar es Salaam kwenye mazingira asilia.

A Thematic Atlas of Nature's Benefits to Dar es Salaam

Critical reasons for greening the city and for keeping urban and peri-urban ecosystems intact.

Dar es Salaam (DSM) is the cultural, political and economic centre of Tanzania – and one of the most vibrant cities in East Africa. It is also one of the fastest growing metropoles in the world. How can the city government ensure that all citizens of Dar es Salaam live in a safe environment, enjoy a good quality of life and make a sustainable living? Increasingly, cities around the world have recognised that healthy and functioning ecosystems within and around urban areas provide solutions to important challenges such as these. This Thematic Atlas aims to show how nature's benefits protect cities, sustain them and make them liveable. More specifically, this Thematic Atlas supports Dar es Salaam's journey with nature.