Food and Agriculture
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Urban forestry and urban greening in drylands

Improving resilience, health, and wellbeing of urban communities

A background document for the Green Urban Oases Programme

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Contents

Foreword

This document was produced in the framework of the Green Urban Oases Programme, which was launched by the Food and Agriculture Organization of the United Nations (FAO) in 2020 and whose overall objective is to transform dryland cities into 'green urban oases' by strengthening their overall resilience to climatic, health, food and economic crises for the improved health and well-being of urban communities.

The programme will support urban communities in drylands to develop their policy and technical capacities to plan and implement integrated urban forestry and urban greening strategies. It promotes multistakeholder engagement, and the integration of these participatory processes into the development of urban and territorial policies, governance and planning. It also helps cities to identify context-specific solutions to optimize the use of green public spaces and improve the provision of ecosystem goods and services to local communities.

This background document is intended to provide policy advisors, urban decision-makers, city planners, municipal and technical staff, local practitioners and other stakeholders with technical and scientific evidence of how trees and forests can contribute to increased resilience of urban communities in drylands.

The first part of the document offers an overview of the environmental, social and economic benefits that urban forests and trees have been proved to provide in arid cities. The second part focuses on challenges related to the planning, design and management of urban forests and urban green spaces in dry climates, providing numerous examples of how many cities have overcome these obstacles. For some subject areas, in was not possible to identify relevant case studies from drylands, so examples from cities in other climatic zones have been used to illustrate the points made in the text.

Executive summary

More than half the people on the planet currently live in cities. The urbanization rate is growing fast, especially in the global South, where 95 percent of the urban growth projected from now up to 2050 is expected to occur. Driven by a blend of natural demographic expansion and rural-urban migration – partly due to climate change and the consequent reduction in food production and livelihood opportunities – this inexorable process of urbanization is exacting a particularly heavy toll on drylands. Already some of the world's most vulnerable 'populations, i.e. people living in drylands, face particularly daunting challenges as a result of this trend.

Home to about 2 billion people, 90 percent of them in developing countries, drylands host just 1 percent of the world's built-up land, but have 35 percent of its largest cities and are home to 27 percent of the world's forests. Scarce rainfall and water supplies compound the negative impacts of rapid urbanization on drylands, leading to overexploitation of limited resources, increased land degradation and greater fragility for urban communities. This is particularly true in hot drylands, where high temperatures and projected temperature increases will more significantly affect evapotranspiration.

The implications of growing urbanization for public health in a dryland context are severe. With temperatures rising due to climate change, the effects are particularly acute in an urban setting, resulting in higher rates of respiratory and cardiovascular disease, with air pollution as an exacerbating factor. Increased demand for food and basic services as a result of soaring urbanization is exerting severe pressure on already stressed infrastructure and natural resources in many dryland cities, with major social, environmental and economic repercussions.

Urban forestry and urban greening present valuable opportunities for ensuring more sustainable development of dryland cities. Evidence has shown that incorporating green spaces, trees and forests into the urban fabric can support the provision of ecosystem goods and services that are critical for the livelihoods, health and well-being of urban populations, while increasing their resilience to global shifts, such as climate change. Nowhere is this potential more pronounced than in arid environments. In fact, in dryland cities where trees have been preserved or introduced as part of a deliberate urban planning policy, they have been shown to have a strong beneficial effect on the lives and health of people who live there.

Adequate design and management are essential prerequisites for urban greening in dryland cities, and this background document for the FAO Green Urban Oases Programme outlines important considerations to bear in mind from the outset. These include proper species-to-site matching and

appropriate planning and maintenance of green spaces, together with community participation to increase a sense of ownership.

With their proven capacity to cool ambient temperatures – and adjacent buildings – clean the air, sequester carbon and contribute to soil and water quality, as well as increased biodiversity, trees offer a cost-effective and efficient tool to help urban dryland communities address some of their main challenges. This document gives numerous examples of such benefits in the form of brief case studies from arid cities around the world, showing the benefits of planting trees in arid urban settings. It also reviews some of the key challenges that need to be addressed to ensure the success of any tree planting activity in drylands.

Policies to regulate and incentivize the planting of trees will be crucial to the successful outcome of urban greenery initiatives in arid cities, as will environmental education, public awareness campaigns and capacity development. Urban forestry and greening strategies have yet to be fully incorporated into urban development in many dryland cities, but this document presents compelling evidence that if properly planned and managed, such initiatives can make a powerful contribution to strengthening the resilience of dryland cities and supporting their sustainable development.

Urbanization in arid climates

Trends in urban growth and impacts on vulnerable populations

Since 1950, urbanization has been rapidly increasing (UNDESA, 2019). Today, more than half of the global population lives in cities, and the trend is expected to continue in the coming years. This is particularly true for the global South, in which 95 percent of urban growth is expected to occur from 2018 to 2050, mainly in Africa and Asia, with India, China and Nigeria anticipated to account for 35 percent of the total increase in urban population (UN Habitat, 2020). The fastest growing cities are the small and medium 'intermediate' or 'secondary' cities with less than 1 million inhabitants, which account for 59 per cent of the world's urban population (United Nations, 2018).

The main drivers of this unprecedented urban growth are natural demographic growth, rural-urban migration caused by increasing land degradation, a search for better living conditions, flawed expectations about urban life, the development of new urban settlements and the expansion of existing ones (UN Habitat, 2020; UNDESA, 2019). Most of the regions where the fastest rates of urbanization and urban population growth are occurring already struggle with scarce resources and poor living conditions (UN Habitat, 2020; UNDESA, 2019). Consequences of this rapid urbanization in less developed regions include high levels of inequality, social exclusion, homelessness, slum dwelling, overcrowding, unhygienic living conditions, land degradation and air, water and environmental pollution (UN Habitat, 2020). Poor urban dwellers, who represent a significant percentage of urban populations in the poorest regions, also face increasing food and nutrition insecurity, as cities generally have higher food prices and more limited opportunities for food production (FAO, 2019; UN Habitat, 2020; Voigtländer *et al*., 2008).

As a result of all these factors, urban dwellers in the global South – particularly in already sensitive areas such as drylands – are among the world's most vulnerable populations, as they are less able to cope with external shocks, including extreme weather events provoked by climate change (Voigtländer *et al*., 2008; Revi *et al*., 2014; UNDESA, 2019; UN Habitat, 2020). This calls for urgent action to bring about more sustainable and resilient urban development in those regions.

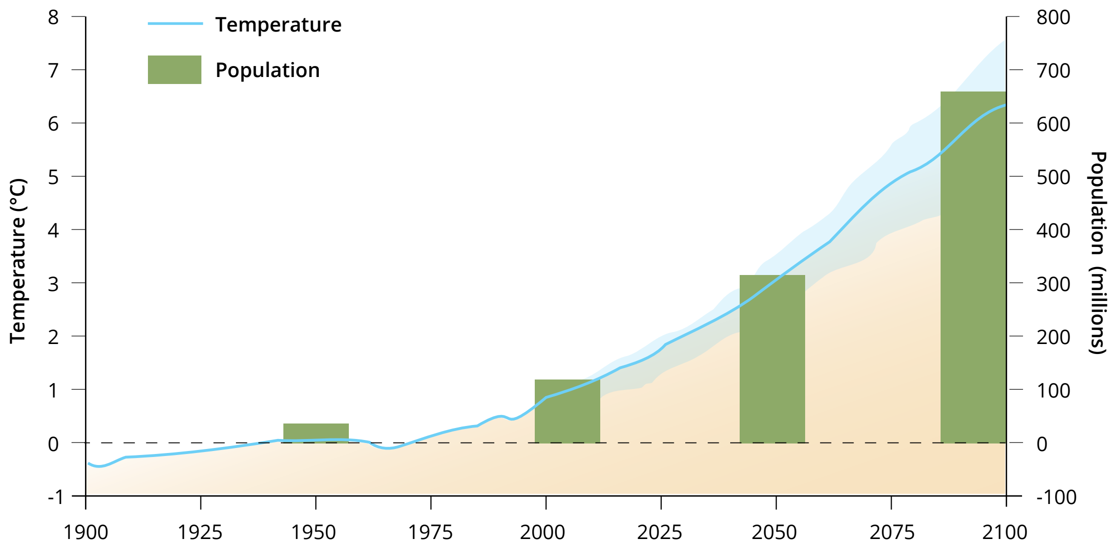
Drylands and their cities

Drylands are regions in which the aridity index (the ratio of annual precipitation and mean annual potential evapotranspiration) is no more than 0.65 (FAO, 2019). Their expected annual rainfall typically occurs in the form of a limited number of intensive, highly erosive storms (Safriel *et al.*, 2005). Drylands are commonly categorized according to an aridity gradient – hyperarid, arid, semi-arid and dry sub-humid – (Davies *et al.*, 2016; FAO, 2019) and are referred to as arid or desert lands. Drylands make up 41 percent of the Earth's land surface, housing about 2 billion people, of whom 90 percent live in developing countries, mainly in Africa and Asia (FAO, 2019). They host just 1 percent of built-up land (FAO, 2019); however, they house 35 percent of the world's big cities (cities with more than 300 000 inhabitants (WAD, 2019), including some of the world's megacities, such as Cairo, Mexico City and New Delhi (United Nations, 2011).

Scarcity of precipitation and freshwater availability (Arup, 2018) and the resulting high vulnerability to shocks and stresses combine to make cities in drylands even more vulnerable to the impacts of rapid urbanization. Indeed, rapid urban growth in these areas results in an overexploitation of already limited resources (Ameen *et al.*, 2020), increases land degradation and exacerbates the vulnerability of urban communities. In addition to a shortage of water supply (Ameen *et al.*, 2020), arid cities have average maximum summer air temperatures that are about 10 °C higher than cities in temperate regions (McDonald *et al*., 2016). They also face higher temperatures than their rural surroundings during the night (inverse urban heat island effect), which causes temperatures to be higher for longer periods (Chow and Brazel, 2012; Haddad *et al.*, 2019).

Dryland cities are particularly vulnerable to the increasing effects of climate change (Arup, 2018; IUCN, 2019). For instance, in the Sahel, temperatures are projected to increase by as much as 5–8°C by 2100; by that date, the population is expected to have increased threefold (Campbell *et al*., 2014). (see Figure 1).

FIGURE 1: Projected change in population and ambient temperature in Sahel (1900-2100)



Source: Adapted from Potts and colleagues: Campbell, M. *et al.* 2014. Population and climate change: Who will the grand convergence leave behind? *Lancet Global Health,* 2(5): 253-E254. https://doi.org/10.1016/S2214-109X(14)70021-X

The most severe impacts are expected to be on water, with substantial reductions in subtropical precipitation, and water stress is forecast to become particularly acute in arid zones (Ostad-Ali-Askari 2020; Wang *et al.* 2020). Both the quantity and distribution of water will be affected, and this is likely to accelerate land degradation and desertification, while reducing soil fertility and its ability to sequester carbon (IUCN, 2019). In turn, the increase in temperature caused by the changing climate is increasing the frequency and severity of droughts and the intensity of sandstorms (Revi *et al*., 2014), further reducing the resilience and adaptive capacities of dryland populations in both rural and urban areas (Wu *et al*., 2019).

It is estimated that climate change will severely reduce food production and livelihood opportunities by limiting access to water, food and fuelwood, thereby increasing poverty and health risks in rural drylands, which is likely to be reflected in an increase of rural-to-urban migration (Brown, 2008; Revi *et al.*, 2014; Wu *et al*., 2019). Indeed, increased migration to urban areas due to reduced rainfall and consequent loss of land productivity in rural areas is already being registered in some arid regions, particularly in Africa (Barrios *et al*., 2006; Brown, 2008; Hassan and Tularam, 2018; Bendandi, 2020).

Climate change is also increasing the vulnerability of urban populations to health-related problems in drylands. Exposure to high temperatures can have direct and indirect negative impacts on the health of populations of dryland cities. It can provoke mild conditions, such as cramps, fainting and exhaustion, as well as more acute conditions, such as heatstroke, which can lead to permanent damage or even death (McDonald *et al*., 2016). Exposure to high temperatures increases the risk of cardiovascular disease and there is evidence that extreme temperatures are associated with higher mortality rates (Revi *et al*., 2014; McDonald *et al*., 2016).

Air pollution, considered the greatest environmental risk to health worldwide, causes more than 3 million premature deaths globally every year (WHO, 2016a), and increased levels are taking a toll on desert city dwellers, as dust particles and dust storms are associated with a higher rate of respiratory and cardiovascular diseases (Revi *et al.*, 2014; McDonald *et al*., 2016; WHO, 2016b). Cities in drylands generally have a large concentration of air pollution, with a significant proportion of particulate matter (PM) coming from desert dust and sandstorms (McDonald *et al.*, 2016).[1] In particular, they have the highest levels of PM10 and PM2.5 (WHO, 2016b), representing 15–50 percent of cardiopulmonary deaths caused by atmospheric desert dust (Giannadaki *et al*., 2014).

All these factors increase the challenges that cities in drylands will have to face to accommodate their growing populations. Urban population growth also implies increasing demand for food and basic services, posing major infrastructural, social, environmental and economic challenges for local administrations, both in urban areas and surrounding hinterlands – where most resources are drawn from.

Population growth and booming urbanization, combined with the effects of climate change, are exerting severe pressure on already stressed infrastructure and natural resources in many dryland cities. Nonetheless, cities, even in harsh arid zones, are expected to continue to grow in size and quantity, while the time it will take to turn the surrounding areas into extreme desert is getting shorter (WAD, 2019). The current unsustainable development of such dryland cities leaves their population in a high state of vulnerability to climate change and economic shocks, with profound impacts on their health and well-being.

1 According to the World Health Organization (WHO): "PM is a common proxy indicator for air pollution. It affects more people than any other pollutant. The major components of PM are sulphate, nitrates, ammonia, sodium chloride, black carbon, mineral dust and water. It consists of a complex mixture of solid and liquid particles of organic and inorganic substances suspended in the air. While particles with a diameter of 10 microns or less, (≤ PM10) can penetrate and lodge deep inside the lungs, the even more health-damaging particles are those with a diameter of 2.5 microns or less, (≤ PM2.5). PM2.5 can penetrate the lung barrier and enter the blood system. Chronic exposure to particles contributes to the risk of developing cardiovascular and respiratory diseases, as well as of lung cancer." From: www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

Urban forestry and urban greening as part of the solution for increased resilience, health and well-being in drylands

There are many ways to incorporate sustainable development and climate action into urban environments. Urban forestry and urban greening are being increasingly recognized as some of the most promising approaches (Kuchelmeister, 1997; Yang *et al*. 2005, Conigliaro *et al*., 2014; Crabtree and Hall, n.d.; McDonald *et al*., 2016; Martinez *et al*., 2017; Salbitano *et al*., 2019; UN Habitat, 2020). Incorporating green spaces, trees and forests into the densely built urban fabric can support the provision of ecosystem goods and services vital for the livelihoods, health and well-being of urban populations (Wolf *et al*., 2020), while increasing their resilience to global changes. If properly planned and managed, urban forests and trees can help cities to better adapt to the effects of climate change, while contributing, on a wider scale, to mitigating the impacts of urbanization and even reversing its negative effects. Trees have the capacity to significantly improve the lives of urban dwellers and transform cities into more sustainable, resilient and healthy environments. The magnitude of these effects varies according to the city's climate, tree structure, form and tree cover density (Feyisa *et al*., 2014; Dronova *et al.*, 2018; Zhao, Sailor, *et al.*, 2018; Atwa *et al.*, 2020), as well as to the species chosen (Chow and Brazel, 2012; Feyisa *et al.*, 2014). In dryland cities, the contribution of urban forestry and urban greening can be even higher than in temperate zones and represents a valuable tool to help urban dryland communities address some of the main challenges in a cost-effective and efficient manner.

However, if inadequately designed and poorly managed, trees and forests in urban and peri-urban areas can pose direct and indirect risks to people. Some tree species produce allergens (substances such as pollen that cause allergic reactions in people); urban forests can provide habitat for fungi and insects that are potential vectors of epidemic or communicable diseases; and trees can drop limbs that may injure or even kill people and damage vehicles and infrastructure, especially during storms. Urban forests (especially those in peri-urban areas) that are not properly planned and managed can also be problematic in the case of rural/urban interface wildfires and, in the most severe cases, threaten people's lives, homes and businesses. They can litter sidewalks, lawns, roofs and streets with fallen leaves, flowers, nectar, pollen and fruits, and if planted too close to buildings and urban infrastructures, can provoke undesirable shading or conflict with them. Also, in many cities neglected urban green spaces may be host to crimes and be perceived as insecure areas for public use. In most cases, the potential risks generated by urban and peri-urban forests result from poor or wrong design, or limited or inappropriate care and maintenance, often as a result of inconsistent planning and poor management procedures.

Most of the risks that trees pose to society can therefore be avoided through proper species selection, and adequate design and management of green spaces that duly consider the urban ecosystem and its dynamics. The well-developed co-design of urban green spaces increases usage and generates a sense of ownership of public open spaces, strengthening social cohesion.

Environmental benefits of urban forests

The environmental benefits of urban forests and trees have been extensively studied. Due to the increasing impacts of climate change and related risks, special attention has been paid to their cooling effects, as well as to their ability to clean the air and sequester carbon, although they also contribute to soil and water quality and balance, and to increased biodiversity. As discussed in the next section, most of these benefits are particularly relevant in drylands. However, while several examples are available in the scientific literature for temperate cities in developed regions, experiences from drylands in developing countries are rarely reported and more difficult to find.

Temperature mitigation effects

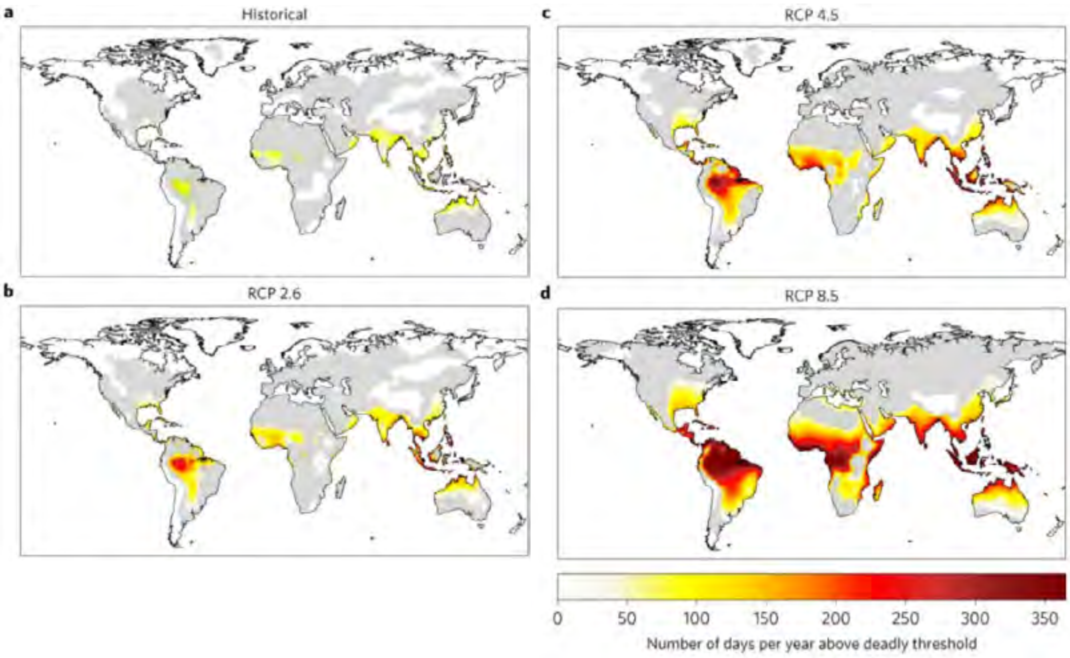
Climate change predictions estimate an increase in the number of days per year that will exceed the threshold of temperature and humidity beyond which climatic conditions can become deadly (Mora *et al*., 2017) (see Figure 2). Reducing air temperature in dryland cities is therefore of crucial importance.

Trees in arid cities can reduce temperatures through evapotranspiration, shading and regulation of atmospheric movement (Feyisa *et al.*, 2014; Dronova *et al.*, 2018; Gage and Cooper, 2017; Jiachuan Yang and Wang, 2017), thus reducing temperatures of the ground and air, and in the buildings that they shade with their canopies. Zhao, Yang *et al.* (2018) demonstrated that a single mature tree could cool one side of a building facade hourly by up to 2.3°C.

A cluster of two trees can increase the shading benefits in the central part of the facade with a temperature reduction of up to 6.6°C (Zhao, Sailor *et al.*, 2018). In other studies, it was found that the cooling effects of urban trees in parks and streets account for 3 to 4°C on average during summer middays in temperate and hot regions (Oke, 1989, Shashua-Bar *et al.*, 2000; Jansson *et al.*, 2007), and stronger effect in dry arid

regions reaching up to 5-6 °C cooler than urban open and bare areas during daytime (Miller *et al.*, 2006; Shpirt *et al.*, 2006).

FIGURE 2. a–d, Number of days per year exceeding the threshold of temperature and humidity beyond which climatic conditions become deadly (Fig. 1b), averaged between 1995 and 2005 (a, historical experiment), and between 2090 and 2100 under RCP 2.6 (b), RCP 4.5 (c) and RCP 8.5 (d). Representative Concentration Pathways 2.6, 4.5 and 8.5 (RCP 2.6, 4.5 and 8.5, respectively. RCP pathways represent contrasting mitigation efforts between rapid greenhouse gas reductions (RCP 2.6) and a business-as-usual scenario (RCP 8.5).



Source: Adapted from Mora et al., 2017. Global risk of deadly heat. Nature Climate Change, 7(7): 501–506. https://doi.org/10.1038/nclimate3322 Map complies with UN. 2020. Map of the world [online]

While cities in temperate zones often experience an urban heat island, cities in arid areas could act as day time urban cool islands. In Dubai and Abu Dhabi, for example, variations in net radiation between urban and rural land cover are mainly due to the sizeable differences in shortwave reflection and to the varying surface temperatures that control the longwave emission. In desert rural areas, albedo,[2] surface temperature, shortwave reflectance and longwave emissions are higher than in urban areas. That is why net radiation plays an important role in cooling desert and dryland cities. The higher net radiation in urbanized areas is a result of the high albedo in the desert and the lower albedo in urbanized areas themselves. Greening the city highly strengthens this effect (Frey, 2004). Finally, a recent global study found that the effect of population density on warming is more pronounced in desert cities (desert cities tend to display higher temperatures than other climates as their population grows) and that cooling strategies focused on using trees to reduce albedo are more effective in arid cities (Manoli *et al.*, 2019).

[2] Albedo is the fraction of light that is reflected by a body or surface. It is commonly used in astronomy to describe the reflective properties of planets, satellites and asteroids. It is an important consideration in climatology, since recent albedo decreases in the Arctic have increased heat absorption at the surface (www.britannica.com).

The generally limited number of trees in desert cities makes the effectiveness of such measures more pronounced. Furthermore, in arid environments, evapotranspiration from trees (although dependent of water availability) can also mitigate urban dry air (Czaja *et al.*, 2020).

In **Phoenix, United States of America,** the magnitude of tree cooling was shown to be significant both at a micro and macro scale, during day and night-time; eucalyptus, olea and to some extent acacia provided the greatest cooling effects (Chow and Brazel, 2012).

In **Enugu, Nigeria,** street trees reduced street temperatures by 8 and 5 °C respectively, during rainy and dry seasons (Enete et al., 2012).

Studies conducted in **Amman** have shown that trees can reduce the cooling load of buildings by up to 35 percent (Abdel-Aziz and Al-kurdi, 2014).[3]

A study in **Salt Lake City in the United States of America** found that neighbourhoods dominated by impervious surfaces were up to 2 °C warmer and drier than urban parks in both daytime and night-time (Gómez-Navarro et al., 2021).

A study conducted in **Cairo** showed that temperature in green spaces is lower than the temperature in non-green spaces by 3–4 degrees during daytime and night-time (AboElata, 2017).

The cooling effect of trees in urban environments translates directly into positive health effects, due to the improved thermal comfort within cities and reduced heatwaves affecting urban populations.

A study in **Toronto** found that heat-related morbidity (such as heat stroke) is reduced by 80 percent when tree canopy cover increases beyond 5 percent, and by 75 percent as hard surface cover decreases below 75 percent (Graham *et al.*, 2016).

In 97 cities of the **United States of America,** current relationships between temperature and health outcomes imply that urban tree cover is helping to avoid 245–346 deaths annually (McDonald *et al.*, 2016).

In **Gilbert, Arizona, in the United States of America,** the presence of trees in playgrounds significantly reduces children's heat stress, increases park usage and reduces sunburn (Vanos *et al.*, 2016).

In **Beijing**, tree cooling effects save 0.119 GWh of electricity annually, avoiding the emission of 41 701 tonnes/year of carbon dioxide (CO_2) (Yang *et al.*, 2005).

It has been estimated that, as well as sequestering 4.5–11 kg of carbon (as it would if growing in a forest), a tree planted in **Los Angeles, in the United States of America**, avoids the combustion of 18 kg of carbon annually through energy savings from shading. In this sense, one shade tree in Los Angeles is equivalent to three to five forest trees in terms of reducing carbon emissions (Akbari, 2002).

3 Cooling load is the rate at which sensible and latent heat must be removed from the space to maintain a constant space dry-bulb air temperature and humidity.

The cooling effect that trees have on urban environments also reduces the need for artificial cooling systems, and thus the need for energy consumption and carbon emissions (Yang *et al.*, 2005; Feyisa *et al.*, 2014; R. McDonald *et al.*, 2016). Reduced air temperature can further lower the activity of chemical reactions, which produce secondary air pollutants in urban areas (Nowak *et al.*, 2000).

Heatwave episodes have also consistently shown a synergistic link with air pollution, increasing the need to address both heat and air pollution in desert urban areas.

While in hot dry climates, tree shading can support mitigation of high temperatures, in cold dry climates trees can be planted and managed to stop cold winds. Simulations indicated that in cold climates, a 30 percent uniform increase in urban tree cover can reduce winter heating bills in urban areas by about 10 percent, and in rural areas by 20 percent (Akbari, 2002). It is estimated that urban forests in the United States of America help to save USD 3.1 billion per year in the form of reduced heating costs (Nowak *et al.*, 2017).

Air quality improvement

In drylands, the air quality of cities is often affected by sand and dust storms, and trees can be used not only as air filters, but also as physical barriers to such events (Kuchelmeister, 1997; Middleton and Kang, 2017; Salbitano *et al*., 2019).

Readings of PM10 before and after establishing a small-scale tree windbreak in **Dubai** showed a reduction of 19 to 22 percent of wind dust (Taleb and Kayed, 2021).

An analysis in **Northern Negev, Israel,** showed that peri-urban forests and trees produce a significant reduction in PM2.5/PM10 in urban areas during dust events (Uni and Katra, 2017).

Native trees and green belts in **Kuwait** contributed to a reduction in the annual rate of mobile sand by 94 and 95.3 percent, and that of dust by 64.5 and 68.4 percent, respectively (Al-Dousari *et al.*, 2019). The ability of urban and peri-urban trees to retain sand movement and reduce soil degradation helps to slow the expansion of desertification, leading to further mitigation of climate change.

Trees can improve urban air quality by preventing emissions of pollutants and greenhouse gases into the air, by reducing the need for air conditioning, by removing air pollutants from the atmosphere and by sequestering and storing carbon dioxide (Yang *et al*., 2005; McDonald *et al*., 2016). In addition to capturing particulate matter, trees sequester ozone through their stomata (Clifton *et al.*, 2020), remove pollution by intercepting airborne particles and serve as windbreaks for road pollutants (Middleton and Kang, 2017). In this regard, mature evergreen trees with thicker canopies are more efficient at reducing air pollution (Yang *et al*., 2005; Isaifan and Baldauf, 2020).

However, while trees generally intercept particles in the air, certain tree species can produce toxic elements, such as volatile organic compounds that contribute to ozone pollution and the formation of secondary particles, pollen allergenicity and asthma (Yang *et al*., 2005; Asgarzadeh *et al*., 2014; Selmi *et al*., 2016; Czaja *et al*., 2020; Wolf *et al*., 2020). Pollen allergies affect the health of urban dwellers and can increase health-care costs (Peper *et al*., 2007). Also, trees may indirectly increase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localized pollution by blocking the wind and preventing the dispersion of pollutants, in particular in areas where there are numerous pollutant sources below the canopy, such as roadways (Nowak *et al*., 2006; Selmi *et al*., 2016; Czaja *et al*., 2020). However, proper design and management, including ad hoc species selection, can minimize and prevent such risks.

The Nature Conservancy, in collaboration with C40, estimates that on average trees are currently providing 1.3 million people with at least a 10 µg/m³ reduction in PM2.5; 10.2 million people with at least a 5 µg/m³ reduction; and 52.1 million people with at least a 1µg/m³ reduction – a number that brings a real positive health impact for those affected (McDonald *et al.*, 2016).

In **Beijing**, even with 29 percent of trees in poor condition, 1 261.4 tonnes of pollutants from the air were removed by 2.4 million trees in 2002 (Yang *et al*., 2005).

Among cities in the continental **United States of America**, trees in **Los Angeles** – an arid city with long in-leaf season, relatively low precipitation and high pollutant concentration – had the highest pollution removal values per unit tree (Nowak *et al*., 2006).

Carbon sequestration

In drylands, the conversion of desert and croplands to urban areas has been shown to cause a loss in carbon (C) stock higher than was previously estimated, mainly due to the loss of carbon stored in the soil (Yan *et al*., 2015). In the city of Urumqi (China), about 82 percent of the ecosystem C loss observed from 1990 to 2010 was caused by the conversion of remnant desert and cropland into impervious surface area (Yan *et al*., 2015). Trees in cities can store carbon in their leaves, branches, stems, bark and roots, increasing the total amount of carbon storage in the area. Approximately half the dry weight of a tree's biomass is carbon and trees typically sequester carbon at a maximum rate between the ages of 10 and 30 (Johnson and Coburn, 2010). Large urban trees have been shown to play a key role as carbon sinks, compared with other types of vegetation (Schanrenbroch, 2012; Salbitano *et al*., 2019). For instance, in India, native trees such as *Azadirachta indica* (neem), *Tamarindus indica* (tamarind), *Ficus religiosa* (peepal) and *Madhuca latifolia* were found to have a high efficiency of carbon fixation (Ugle *et al*., 2010). Nowadays, most urban tree populations are composed of species with moderate ratings as carbon sinks (Schanrenbroch, 2012), but they still have a significant capacity for CO_2 removal. A study in the Republic of Korea showed that the

In the city of **Mendoza, Argentina,** a study was conducted to estimate the carbon storage of the dominant species, *Morus alba*. The total *M. alba* coverage was shown to accumulate 24 208 tonnes of carbon in urban areas and 43 000 tonnes of carbon in the suburban area, from which 1 998.6 tonnes of CO_2 and 4 118.8 tonnes of CO_2 respectively are removed annually by leaves. Each year, 13 000 tonnes of CO_2 are released into the atmosphere by the city's public and private transport (Carretero *et al.*, 2017).

The same 2.4 million trees in **Beijing** that removed pollutants from the air (see previous box) stored about 0.2 million tonnes of CO_2 in biomass form (Yang *et al.*, 2005).

In **Addis Ababa,** a study found that natural and planted forests and trees on the premises of Ethiopian Orthodox churches around the city each contained about 156 ± 92 tonnes per hectare of carbon stock (Yilma and Derero, 2020).

A study conducted in the **City of Tshwane, South Africa** in 2010 estimated that in the following 30 years, after planting 115 200 indigenous street trees during the period 2002–2008, around 200 492 tonnes of CO_2 equivalent would be reduced, and 54 630 tonnes of carbon sequestered (Stoffberg *et al.*, 2010).

In **Kumasi, Ghana** it was found that about 1.2 million tonnes of carbon are captured in aboveground components of urban trees, with a mean of 228 tonnes of carbon per ha (Nero *et al.*, 2018).

implementation of strategies to maximize the carbon budget of urban parks over their life cycle increased the net carbon uptake by approximately 9.2 times (Park and Jo, 2021).

However, if tree planting is not well managed, trees can have a negative effect on climate. This is due to the fact that high levels of respiration rates from trees can be linked to higher net carbon emissions. As temperature rises, so too does trees' rate of respiration. If temperatures go beyond a certain threshold – a specific temperature breakpoint – the faster rate of tree respiration can emit more carbon than trees can sequester (Czaja *et al.*, 2020). Trees' vulnerability to such events can diminish their effectiveness as long-term carbon sinks (Dass *et al.*, 2018). This should not discourage the planting of trees in dryland cities. It should, however, encourage the implementation of collateral interventions aimed at ensuring that temperatures within the city are kept under a certain threshold, above which the efficiency of trees in improving the urban environment may be compromised, and taking care that appropriate tree species are selected.

Soil quality and water balance

In drylands, soil undergoes various chemical and physical transformations that lead to soil degradation, causing compaction, water shortages due to surface runoff, high soil temperature, salinity, pollution, increased pH, and organic matter and nutrient deficiency (Czaja *et al*., 2020). Peri-urban forests in the upper watersheds help to stabilize and protect watersheds, and control downstream erosion. In fact, trees can provide environmental benefits through the improvement of soil quality and infiltration and filtration of rainwater. They can help to mitigate water shortage in the short and long term, as well as to provide access to safe drinking water. Particularly in drylands, trees can be used as tools for water catchment and infiltration, as well as to protect soils from erosion, thanks to the barrier effect of their canopies against winds and sandstorms. In many cities, water reservoirs are subject to sedimentation, and reforestation can provide a solution in combating soil erosion.

A study in **Manchester, United Kingdom of Great Britain and Northern Ireland,** found that while grass almost totally eliminated surface runoff, trees and their associated tree pits reduced runoff from asphalt by as much as 62 percent (Armson *et al.*, 2013).

The New York Municipal Forest Resource Analysis found that one tree can catch around 5 420 litres of water per year (Peper *at al.*, 2007)

A study in **Santa Monica, United States of America,** showed that rainfall interception varied seasonally, averaging 14.8 percent during a 21.7 mm winter storm and 79.5 percent during a 20.3 mm summer storm for a large, deciduous *Platanus acerifolia* tree (Xiao, 2002).

It is important to remember, however, that in arid climates there is always an inherent trade-off between tree cover (and the related ecosystem services) and water usage. Being aware of this trade-off is not sufficient in itself, and informed decisions on the optimal level of tree cover will mostly depend on the balance between the economic benefits of trees and the opportunity cost applied to irrigation. Bio-economic models can be a useful tool to assist urban planners in the decision-making process (Jones and Fleck 2018).

Biodiversity

Arid regions are characterized by relatively fewer species than more humid biomes. As a result, for each species lost from an arid region, the percentage of loss for the region's biodiversity is much higher than in more species-rich regions (McNeely, 2003).

Urban trees and forests offer a unique opportunity to enhance biodiversity, particularly if public awareness is raised regarding its benefits. The promotion and preservation of local (that is, native) biodiversity and the increased ecological connectivity provided by forests and trees can reduce the fragmentation of natural ecosystems surrounding cities (including peri-urban forests), while increasing their resilience to human pressure (Salbitano *et al*., 2019).

A study in the district of **Abidjan, Ivory Coast** identified that despite the poor state of urban green areas, strong biodiversity of ant species can be found, suggesting that those spaces present assets for the conservation of biodiversity (Kouakou *et al.*, 2018).

Research in **South Africa** found that, at street scale, there is a positive relationship between the richness of urban tree species and that of bird species (Shackleton, 2016).

In the city of **Xalapa, Mexico,** a study showed a positive relationship between the richness of species and size of green spaces, with higher levels of biodiversity being measured in larger green areas (MacGregor-Fors *et al.*, 2016).

As the first biodiversity park in the **United Arab Emirates,** Al Fay Park contains more than 2 000 native trees and bushes – including the national *ghaf* trees that have been replanted from desert nurseries into the park – all specifically chosen to strengthen biodiversity for both plants and wildlife and to maximize natural cooling throughout the park (World Landscape Architecture, 2021).

Social benefits

Urban trees provide a number of social benefits and can a have a positive impact on the cohesion, health and well-being of urban communities (Jennings and Bamkole, 2019). While there is limited research specific to drylands, it is assumed that the role of trees in improving the social dimension of urban environments also applies to drylands.

Studies have shown that urban green spaces have a positive impact on social capital by improving social cohesion and that this effect is further heightened by the presence of trees.

Tree planting and awareness-raising activities can also enhance community engagement.

In **Baltimore, United States of America,** Holtan *et al.* (2015) demonstrated that the green fabric of a neighborhood created by tree canopy also facilitates the social health that is vital to neighborhood functioning.

Historic and contemporary research in **Tunis** revealed that trees have become associated with different social values, from place-making to family practices and have become markers of local heritage (Bennour, 2014).

A study in the **Netherlands** found a strong association between the quantity and quality of streetscape greenery and perceived social cohesion at the neighbourhood scale (De Vries *et al.*, 2013).

In **Victoria, Australia,** attachment to the neighbourhood was found to increase significantly with tree coverage in three suburbs: where the sampled streets had higher levels of tree coverage, residents had higher levels of neighbourhood attachment compared with residents in areas where there was a lack of greenery (Abass and Tucker, 2016).

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During the Million Trees NYC programme, launched in **New York** in 2007, volunteers reported that the simple act of planting a tree was so transformative for first-time tree planters that it led them to become more civically involved in their community (US Forest Service, 2015).

A survey in **Benin City, Nigeria** found that knowledge of the importance of ecosystem services that trees provide was highly correlated to the communities' willingness to participate in voluntary conservation initiatives around the city (Arabomen *et al.*, 2020).

A review of community engagement in the Big Tree Plant programme launched in cities across the **United Kingdom of Great Britain and Northern Ireland** revealed that most participants perceived tree planting as a method for achieving a community-focused impact, generating a broadly defined local collective 'spirit' or 'pride' (Norris *et al.,* 2013).

Through a study in **Sydney, Wollongong,** and **Newcastle, Australia,** Astell-Burt and Feng, 2019, demonstrated that tree canopies have a greater influence on mental health than just green spaces.

In a larger study, in **Wisconsin, United States of America,** a 25 percent increase in the proportion of tree canopy in a neighbourhood was associated with a decrease in levels of depression. Reported mental health benefits included reduced stress, improved work productivity, increased self-esteem, enhanced attention span, and greater life satisfaction (Beyer *et al.*, 2014).

Urban forests can perform three health-related functions: 1) disease prevention; 2) therapy; and 3) recovery from illness. They can reduce the direct and indirect causes of certain non-communicable diseases and urban stressors, such as ultraviolet radiation and air and noise pollution, and they can help in cooling the environment. The presence of green spaces can have a positive effect on psychological well-being by reducing stress and improving mental health.

The presence of, and access to, green spaces can enhance the walkability and bikeability of streets and promote active lifestyles and regular exercise, thereby reducing the risks posed by obesity, type 2 diabetes, coronary heart disease, respiratory disorders and some types of cancer (Ohtsuka *et al*., 1998; Broekhuizen and Vries, 2013; Hartig *et al*., 2014; Grazuleviciene *et al.*, 2015). Physical activities, even in small amounts, can also increase mental health (Kabisch *et al*., 2017). Taylor *et al*. (2001) found that exposure to green space, chiefly spaces with trees, was found to be associated with children's mental health, alleviating the symptoms of attention deficit hyperactivity disorder and improving their concentration. A recent scope review on the relationship between urban trees and human health found that benefits are not age-dependent, but that urban trees have the capacity to influence the well-being of children, teenagers, adults and older people, although benefits vary from person to person (Wolf *et al*., 2020). The review further highlights recent studies that indicate a possible relationship between urban trees and a healthier human immune system, as well as between urban trees and higher birth outcomes (Wolf *et al*., 2020).

The same review reveals a large and rapidly growing body of research on the topic, in particular from 2010 onwards, illustrating public recognition of urban trees as an essential component of health-supportive environments (Wolf *et al*., 2020). This trend has developed further with the emergence of COVID-19. Since the onset of the pandemic, a growing body of literature has highlighted the significance of urban green spaces and trees, while reporting growing public recognition of the importance of such urban elements in promoting social, mental and physical health (for example, Kleinschroth and Kowarik, 2020; Schio *et al*., 2020; Ugolini *et al.*, 2020; Venter *et al*., 2020; Xie *et al*., 2020).

In a study in the city of **Burlington, United States of America,** 69 percent of respondents increased their visits to urban green areas following the COVID-19 pandemic and 80 percent reported their increased need of such areas (Grima *et al.,* 2020).

In **Oslo,** outdoor recreational activity increased by 291 percent during lockdown relative to a 3-year average for the same days, with intensified activity on trails with greener views and more tree canopy cover (Venter *et al.,* 2020).

Lastly, trees are correlated with social equity. Inequities in the distribution of urban tree cover may be a signal of pre-existing social injustice (Wolch *et al.*, 2014; Dronova *et al.*, 2018) and can result in high-income residents typically enjoying more of the benefits of urban trees than lower-income dwellers (Foley *et al*., 2018; Boyd, 2017). Well designed and distributed, urban forests can play key roles in increasing social equity, promoting a sense of community among residents, and ensuring the maintenance of local cultural values. By beautifying all areas in a city equally, for example, urban forests can help to reduce social, environmental and housing inequities. By providing residents with settings for local activities and events, green spaces can increase social cohesion and help to build stronger, more stable communities.

If not adequately planned and carried out, however, the creation or renovation of urban tree planting and parks may aggravate socioeconomic inequalities. Increased tree cover can result in higher property values and gentrification that, by forcing out lower-income residents (Wolch *et al.*, 2014; Donovan *et al.*, 2021), may polarize the use of urban parks between rich and poor, (Shi *et al.*, 2020; Xie *et al.*, 2020), and even enhance existing ethnic segregation. For example, a study in New York City on the impact of the Million Trees NYC programme demonstrated that a higher intensity of street tree planting resulted in a greater increase in the share of residents who were white (Li, 2019). In Milwaukee, United States of America, the distribution of urban tree canopy was found to be unevenly based on household income, housing market characteristics, and racial and ethnic factors (Heynen *et al*., 2006).

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Around the world, trees and tree groves have a strong spiritual connection with many cultures and religions, becoming a cultural symbol, as well as places of gathering for the community. *Ficus religiosa* trees, for example, are considered sacred and popular in countries where Buddhism is strong (Carter, 1993), playing an important role in social community structure and providing shade for social congregations and recreational activities (Salbitano *et al*., 2019).

The **date palm** plays a pivotal role in strengthening the connection between people and the land in the Arab region, and in 2019 the tree became a UNESCO Intangible Cultural Heritage of Humanity (UNESCO, 2019).	The *ghaf* is the national tree of the **United Arab Emirates** and symbol of combating desertification in the country (Give a Ghaf, n.d.).	The baobab – the national tree of **Madagascar,** but also found in Australia, India and a number of African countries – holds such important livelihood and cultural values that it is known as the 'tree of life' (Kumar, 2018).

Improved sustainability in desert cities can attract more investment and increase the well-being and health of urban dwellers, while the same time potentially enhancing cultural values and promoting a more resilient community.

Economic benefits

Environmental benefits aside, urban trees have strong potential for benefiting urban economies, and can represent a cost-effective management option to improve the quality of life in cities, especially in less developed countries (McDonald *et al.*, 2016). Such benefits are both direct and indirect, in the form of savings on resource expenditure and direct income.

For example, the cooling effects of trees can reduce the need for turf irrigation (Litvak *et al*., 2014), and reduce air conditioning and energy consumption during hot months (Berry, 2009; Crabtree and Hall, n.d.; Haddad *et al*., 2019; McDonald *et al.,* 2016). In arid cities, this can enable private dwellers and local administrations to save substantial amounts of money for the cooling of public and

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private buildings. In the United States of America, it is estimated that annual savings due to avoided mortality, morbidity, and electricity consumption through the presence of urban trees ranges from USD 5.3 to USD 12.1 billion (McDonald *et al*., 2020).

Estimates of the economic value of trees as carbon sinks show that tree planting can also save cities financial resources.

In **Phoenix, United States of America,** mature trees growing on the west, east or south sides of a house can reduce average annual household electricity consumption by about 4.6 percent (Berry, 2009).

Trees planted in **Tshwane, South Africa,** generated a CO_2 reduction valued at more than USD 3 million (Stoffberg *et al.,* 2010).

A tree plantation programme in **Phoenix, United States of America,** had an estimated present value of net benefits of around USD 681 000 (Berry, 2009).

Statistical models predicted that the 400 000 trees planted in **Canberra** prior to 1990 would have a combined energy reduction, pollution mitigation and carbon sequestration value of USD 20–67 million during the period 2008–2012 (Brack, 2002).

Trees also support the provision of food. Fruit tree cultivation by urban dwellers is widely reported in Asia, Africa and Latin America. In arid cities, where resources are naturally lacking, trees can represent an important source of food, particularly for the most vulnerable groups, such as the urban poor. In West Africa, urban forestry practices include collecting wild edible plants, planting fruit bearing trees (in the streets or new urban settlements) and establishing multifunctional or medicinal public parks (Fuwape and Onyekwelu, 2011). For example, foods such as baobab leaf, tamarind and processed parkia seeds are highly popular in large towns in the Sahel (Kuchelmeister, 1997).

In **Seattle, United States of America,** a strong movement of non-profit organizations, working together with local communities, is harvesting public and private urban fruit trees to improve the city's food security. From 2005 to 2009, volunteers from two organizations harvested 14.8 tonnes of fruit (McLain *et al.,* 2012).	A study in **Uchoa, Brazil** demonstrated that the municipality's street trees could have the capacity to provide up to 63.7 percent of the caloric deficit the city's inhabitants if they were used to their full potential (Vannozzi Brito and Borelli, 2020).	Using **Burlington,** in the **United States of America** as a case study, research on urban food forestry identified that 108 percent of the daily recommended minimum intake of fruit for the entire city's population could be met under the most ambitious planting scenario, if planted with *Malus domestica* – the common apple (Clark and Nicholas, 2013).

In addition, urban trees provide wood, fuelwood and fodder. Agroforestry plantations and wooded parklands are often found in peri-urban areas, especially in Africa, and are frequently the result of private or community initiatives (FAO, 2012). In some arid zones, the need for fodder is so great that even amenity trees are lopped (Carter, 1993). In areas around refugee camps, the need for fuelwood has become a notable source of deforestation (Thulstrup and Indira, 2017). Establishing fast-growing tree plantations and agroforestry in such areas can help to halt the felling of native trees, protect the surrounding environment and biodiversity, and provide both fuel and food (Lynch, 2002; Thulstrup and Indira, 2017).

In Africa, many urban dwellers, especially those living on the urban fringes, and in slums and shanties, use urban and peri-urban timber for building (Fuwape and Onyekwelu, 2011). Particularly in drylands, planting and managing urban and peri-urban trees and forests for wood-related products and fodder production could help to protect the already scarce trees and forests from overexploitation and depletion, with strong benefits in terms of landscape protection and biodiversity conservation.


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In addition, the presence of trees in urban environments can provide tangible economic values. Studies of the impact of trees on residential property values found that trees add between 2 and 15 percent to the sale price of a property (Wolf, 2007).

In addition, street trees can provide business benefits, exerting a positive influence on consumer behaviour. A multi-study showed that consumers tend to travel greater distance and a longer time to visit a district that has high-quality trees, and they spend more (9 to 12 percent) on goods and more time there once they arrive (Wolf, 2005).

Tree planting, harvesting and management can also provide employment and income.

In **Doha,** trees were found to have a positive impact on property values. In terms of tree species, Acacia tortilis has a significantly higher annual increase in property value compared with Ziziphus spina-christi and *Phoenix dactylifera* since the shape of its canopy provides higher leaf surface area (Isaifan and Baldauf, 2020).

In **Minnesota, United States of America,** tree cover increased the sales price of properties that had trees within a distance of 100 and 250 m, but not beyond 250 m (Sander *et al.,* 2010).

A study in **Cleveland, United States of America,** revealed an increase of 7 percent in rental rates for commercial offices with high-quality landscapes and natural shade (Laverne and Winson-Geideman, 2003).

In **Jordan,** a project focused on improving green infrastructure to enhance conditions for social cohesion, public life, the urban climate and biodiversity, employed 3 000 workers in 10 municipalities and 14 rural areas (GIZ, 2017).

In **Ouarzazate, Morocco,** the plantation of a green belt dramatically increased nearby land value from USD 1 000 per ha to USD 60 000 per ha (UNEP, 2017).

In **Nairobi,** environmental organization the Green Belt Movement has assisted community associations in income generation by creating and operating nurseries to raise seedlings, creating jobs such as nursery attendants, promoters and Green Belt rangers for low-income residents (UNDP, 1995).

Establishment of urban forests and urban trees in drylands

An increasing number of desert cities (such as Phoenix in the United States of America, Abu Dhabi in the United Arab Emirates and Riyadh in Saudi Arabia) are integrating urban forestry, urban greening and nature-based solutions into their urban development plans. However, the development of urban forestry faces a series of constraints that limit its implementation. Some of these challenges are shared by most cities in the global South, while others are specific to drylands, as they are related to the extreme climatic and humidity conditions that characterize these regions.

Policy and governance

In urban settings, trees are forced to compete with the built form for natural and financial resources. Cities are often environments with limited space for nature, and planting trees in urban spaces can be perceived as problematic (Barret, 2017; Davies, 2020). Fuwape and Onyekwelu (2011) observe that many cities in Africa have seen the destruction of tree gardens, recreational parks and peri–urban plantations in a bid to create space for housing units and urban infrastructure. Åkerlund (2006) reports that in cities of Central Asia, such as Tbilisi and Yerevan, green areas are being torn down without authorization, for the placement of private buildings. Another crucial issue for the success of integrated urban forestry policies and governance is land tenure, here defined as the complexity of norms, by-laws and customary behaviours that rule the ownership and possession of (such as rental and leasehold) and access to (such as the right to enter and use) land. Legal ownership may be insufficient for determining land tenure in urban and peri-urban settings, and this is particularly true for public open spaces. Whether statutory or customary (or, in many cases, both), clear land tenure is essential for determining the potential of urban forests in a given location (FAO, 2016).

Policies regulating and incentivizing both new and existing urban trees are essential for the establishment of long-term urban greenery. Policies should encompass all aspects of planning, design and management of urban forests and green spaces, as well as environmental education and capacity development. Especially in drylands, land-use policies should give due consideration to urban forests and green spaces, and economic incentives made available for their establishment, just like any other feature of the city infrastructure. Knowledge sharing and evidence-based solutions should be encouraged, large- and small-scale programmes with community engagement should be implemented for planting and monitoring, and a comprehensive approach enabled.

In **Sacramento, United States of America,** an ordinance requiring 50 percent of parking lot areas to be shaded by trees within 10 to 15 years was passed in 1983 (McPherson, 2001). However, an analysis shows that this policy was not enough on its own. There was no system in place to monitor and evaluate tree health and maintenance, resulting in many trees not being planted, or being removed shortly after plantation (McPherson, 2001).

Port Augusta in **Australia** has developed a sustainable integrated street tree policy with 'Preferred Tree Planting Species for Port Augusta Environs', with the implementation of regulatory rules for tree ownership and planting, including determining tree setback to avoid conflicts with the built form, and rigid tree removal regulation (Schumann, 2004).

Another major, if not *the* main constraint for urban forestry implementation, is lack of appropriate governance (Fuwape and Onyekwelu, 2011; McDonald *et al*., 2016; Salbitano *et al.*, 2019). The unprecedented growth of cities, particularly in developing countries, leaves municipalities with little time to adjust to constant urban changes and pressures, while struggling to harmonize the goals, actions and needs of different agencies. This, added to the lack of awareness of the full potential of tree planting, often leads to urban forestry being left out of urban planning priorities. Failure to include the integration of trees and forests into the urban environment as a priority in urban planning agendas can leave little funding available for urban forests and urban trees in developing countries (Kuchelmeister, 1997; Åkerlund, 2006; Fuwape and Onyekwelu, 2011; McDonald *et al.*, 2016; Parivar *et al*., 2020). Governance issues, such as inadequate land policies, a long tradition of grey infrastructure and lack of knowledge on or interest in the subject (Ely, 2010; Brindal and Stringer, 2013; Foley *et al*., 2018), are also responsible for trees competing for urban space, water and other resources, along with improper tree planting and management.

In many countries, there is little community participation in urban forestry initiatives (Åkerlund, 2006). However, without public acceptance and engagement, tree maintenance and care is limited to municipalities (Cáceres Villanueva *et al.*, 2003). Many urban forestry projects do not achieve the expected results, or even fail due to lack of public engagement, as trees are a long-term and intergenerational solution (Kuchelmeister, 1997).

A broad, inclusive set of stakeholders is required for the establishment of urban forests and tree systems (Fuwape and Onyekwelu, 2011; McDonald *et al*., 2016; Foley *et al*., 2018; Salbitano *et al.,* 2019). It is important, therefore, to identify ways to ensure the integrated and transdisciplinary participation of diverse actors in decisions related to the governance of urban green spaces and

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green interventions. In fact, fostering the creation of socially inclusive public green spaces requires not only that all the different social groups are involved in decision-making, but also that opposing and diverse voices are heard and considered in the entire decision-making and implementation process (Borelli *et al*., 2021).

Public awareness and education campaigns can be an effective tool to garner citizens' support for tree planting and should be intensified. Education about the benefits of trees and awareness of the constraints and limitations of planting in arid climates can increase acceptance of xeriscaping[4] and local tree species, enhancing the quantity and quality of successful urban tree interventions. Cities can partner with their citizens to green their cities when they lack the funds or resources to conduct greening actions alone. Often, urban tree initiatives rely heavily on local volunteers for planting and maintenance.

Cities can provide funding opportunities through community grants or other mechanisms for tree maintenance, to improve tree survival on private property (Foley *et al.*, 2018) and also create public private partnerships to enhance public engagement.

The city of **Jeddah** partnered with King Abdul Aziz University to plant 60 000 trees in 165 locations, increasing the city's greenery (Arab News, 2020).

In **Ras al-Khaimah, United Arab Emirates,** the municipality has launched a Green Fines programme, giving companies the option to plant trees instead of paying environmental fees. (Barkawi, 2020)

Among the many efforts to green their city, the municipal government of **Ulaanbaatar, Mongolia,** reported more than 2 million trees planted by volunteers and community members from 2010 to 2017 (Altanzul, 2018).

[4] Xeriscaping is the process of landscaping, or gardening, which reduces or eliminates the need for irrigation.

Planning, design and management

Cities are complex habitats for trees. Proper planning, design and management of urban forests can enhance urban trees' survival rate and their integration within the city and community, and boost their benefits. Conversely, improper tree planting and management can lead to problems in cities' infrastructure (such as root damage to walls or structures) (Czaja *et al.,* 2020), contribute to tree damage and mortality, create hazards for citizens, and require the use of substantial resources. Air pollution, coarseness and compaction of soil with low availability of nutrients, high soil and air temperatures are all stress factors that harm tree growth and survival rates (Williams, 2003; Ely, 2010; Czaja *et al*., 2020). Pavements tend to act as a barrier to water infiltration, gaseous exchange and soil nutrients (Ely, 2010). Shortened life spans and tree deaths, resulting in removal soon after planting, are significant (Ely, 2010). However, the most common human-related contributions to tree deaths are poor stewardship and maintenance, and vandalism (Hilbert *et al*., 2019).

Of course, the creation of new green space does not automatically lead to socially just and inclusive development. For green spaces to effectively foster social equality, the resulting co-benefits should be available and accessible to all members of the community, regardless of their socioeconomic level, ethnicity, religion, gender, age or disability (Borelli *et al*., 2021). Collaborative planning, design and management can empower local city dwellers, while incorporating the needs and interests of a wide range of stakeholders, in so doing overcoming a number of challenges that commonly affect the development of green spaces in dryland cities. These include poverty issues and overuse of natural resources – factors that often contribute to the depletion of green spaces in Africa, particularly in arid zones (Mensah, 2014) – and the mismanagement of solid waste and use of species that are associated with mosquito breeding in Latin America (Pérez Rubi and Hack, 2021). Design processes should actively involve all stakeholders (such as local administrations, technical partners, civil society organizations and end users), to ensure that the result meets their needs and expectations. In fact, urban forests and urban green spaces are ideal arenas for developing co-design processes and co-management programmes. Participatory processes can help to identify local knowledge on how to overcome climatic and social ecological constraints in vulnerable areas such as drylands, while providing a greater sense of ownership and stewardship, enhancing the prospects for the survival and success of trees and urban green spaces (Vogt *et al.*, 2015).

Urban greening interventions need to be planned and designed in a systematic manner. All urban forestry elements (street trees, parks and other green areas) should be spatially integrated and connected within themselves and with other urban infrastructure (City of Melbourne, 2012; Salbitano *et al*., 2016). In this manner, ecosystem services are more broadly distributed, amplified and perceived on a larger scale, while enabling more resilient and inclusive urban greening (City of Melbourne, 2012; Salbitano *et al*., 2016). Trees should be connected to parks and urban forests, as well as to other green elements. Trees planted in connection with other city infrastructure can add value and promote more multifaceted structures. Urban forest design can be combined with water-sensitive design, where trees do not only require less irrigation for their survival, but also act as a water management tool, intercepting incoming precipitation, enhancing infiltration and improving the overall performance of other green infrastructure (GreenBlue Urban, 2018).

The development of an urban forest master plan is a useful tool for the envisioning, planning and design of a spatially integrated urban forest. Such a plan can guide cities' greening efforts by prioritizing pressing demands, filling existing gaps, and building the capacity of technical staff and stakeholders, as well as identifying the physical challenges that are particularly important for dryland cities (City of Melbourne, 2012; Sacre, 2021). A number of cities worldwide have already started developing this strategy.

The City of **Palo Alto, United States of America,** developed an urban forest master plan in 2019, aiming to maximize the environmental and aesthetic benefits and the potential to achieve the greatest possible canopy equity, while minimizing conflicts with infrastructure and water conservation goals in each neighbourhood (City of Palo Alto, 2019).

The city of **Victoria, Australia** has drawn up an Urban Forest Master Plan that aims to reduce the number and severity of conflicts between urban forest and the built environment, while maximizing watershed health, biodiversity and community benefits to all neighbourhoods (Gye and Cullington, 2013).

Focusing on the design, size, shape and pattern of tree arrangements also has a significant impact on the behaviour and benefits of urban forests.

Any design should include an appropriate mixture and/or combination of species, as well as plants of different sizes, to enhance trees' benefits and limit disservices (Park *et al.*, 2017). Georgi and Dimitriou (2010) found that tree species with a higher level of evapotranspiration were the most effective in lowering heat discomfort. A combination of turf grass with dispersed, non-overlapping tree cover is also advised, as it reduces irrigation requirements, slows wind and provides heat relief and maximum cooling at night (Zhao, Yang *et al.*, 2018; Gómez-Navarro *et al.*, 2021).

In **Mendoza, Argentina,** a heterogeneous composition of green areas was found to be more effective for cooling the air than a homogeneous one (Stocco *et al.*, 2020).

In **Aurora, United States of America,** cooling benefits were greatest in buildings if taller trees were planted (Gage and Cooper, 2017).

In **Alexandria, Egypt,** it was noted that the layouts that provided the best cooling effect were double trees planted at equal intervals in the entire urban open space, or single trees at equal intervals planted along the four sides, with other trees planted randomly in the central area (Atwa *et al.*, 2020).

In **Riyadh,** a study found that *Faiderbia altissima, Zyzyphus spina-christi, Albizia lebbeck* and *Eucalyptus camaldulensis* are good pollutant-resistant trees (Alotaibi *et al.*, 2020).

In **Addis Ababa,** a study conducted on 21 urban parks found that although parks with a shape close to that of a circle are cooler than their immediate surroundings, more irregularly shaped parks have a greater cooling distance, with an overall more positive influence on thermal comfort (Feyisa *et al.*, 2014).

In **Tempe, Arizona, United States of America,** planting a single tree in the middle of the front yard and two trees at equal intervals on the sides produced the best outcome for both outdoor human thermal comfort and building shading, at both household and neighbourhood levels (Zhao, Yang *et al.*, 2018).


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With regard to air pollution reduction, there is a need for further studies, but the literature notes that tree species tolerant to pollution should be selected whenever possible, and trees with high levels of biogenic volatile organic compounds and high pollen emission rates should be avoided (Yang *et al*., 2005).

Appropriate consideration should be given to the space requirements of each species, both above and below ground – from root to canopy (Ely, 2008). Whenever possible, trees should not be planted in isolation, since the literature shows that interconnected tree plantations and urban tree systems with parks, street trees and other green spaces provide the best outcomes (Bell *et al.*, 2005). In dense and saturated urban areas, the reconstruction of streets can provide opportunities for street tree planting. Conflict between urban trees and built infrastructure can be avoided through the prohibition of inappropriate tree species, the establishment of tree setbacks – the practice of placing street trees behind the pavement and out of the right-of-way – and limitations to tree planting near buildings (Bell *et al.*, 2005). However, there are also many creative ways to find places to plant trees: on abandoned plots, traffic circles, street cut-outs and 'right-of-way' areas (strips of land between the street and private properties) (Shipek *et al*., 2016), through footpath widening, parking lane planting, and by planting trees in the streets as traffic calming devices (Jones, 2008).

The Buffalo Bayou Promenade in **Houston, Texas, United States of America,** created around and underneath freeways, transformed a former greyfield into a vibrant social space that sequesters 29.74 tonnes of CO_2 annually and increases the city's flood capacity (Ozdil *et al.*, 2013).

Space below ground level should not be neglected. For environments with a high presence of underground utilities, there are many possible solutions. An impermeable geo-textile membrane can serve as a root barrier, while other solutions include root paths, soil trenches, soil vaults, suspended pavement systems (pavements engineered to span an area of loosely compacted soil suitable for root growth) and structural soils (comprising a mixture of gravels, a hydrogen stabilizing agent and clay loam) (Ely, 2008; Urban, 2008; Davies, 2020).

Planting practices in drylands

There are a number of misconceptions regarding the abilities of trees to grow in arid lands. Davies, (2020) reports statements of general disbelief in the early 1980s regarding the idea of planting trees in arid landscapes. Essential ingredients for successful urban tree planting in arid zones involve knowing *what*, *when*, *how* and *where* to plant.

What to plant

The starting point for urban tree planting is identifying and selecting plant species, taking into account the site's constraints and climate and the purpose of tree planting (Symes and Connellan, 2013; Foley *et al*., 2018). In some countries, there are knowledge gaps on the appropriate selection of tree species for urban planting. For instance, Bateman (2020) and Al-Mashhadani and Rasheed (2006) pointed out that there was not enough literature on the United Arab Emirates' tree species, and on the specific requirements in terms of water and soil types. This gap, however, has since been filled through various studies (Bateman, 2020).

In **Abu Dhabi,** a recent urban forest project, Rem Forest, mapped 700 native trees, registering their water and sunlight needs (Bateman, 2020).

In arid **Port Augusta, Australia,** the list of tree species drawn up by the city not only includes appropriate tree species for urban environments, but also species that should be avoided (Schumann, 2004).

Trees should be chosen based on their availability, resilience to the climate, local conditions and the required benefits. For arid climates, an increased body of research notes the importance of implementing xeriscaping and planting indigenous trees (Chow and Brazel, 2012; Asgarzadeh *et al*., 2014; Shipek *et al.*, 2016; Wheeler *et al*., 2019). Designers with local knowledge should be involved in order to improve the life cycle of trees, increase the diversity of urban landscapes, avoid extra costs and ensure that the right tree is planted in the right location – without compromising either the tree or the urban environment (Asgarzadeh *et al*., 2014).

A number of guidelines for the use of xeric species in cities in drylands have been developed around the world. For instance, in 2014, the Government of Saudi Arabia produced a plant manual that includes details of more than 300 plants that are suitable for the climatic conditions of the city of Riyadh (High Commission for the Development of Arriyadh, 2014). This literature can broadly assist the selection of species for dryland cities and help to address lack of information in the area. Furthermore, if new tree species are introduced that are unfamiliar to local experts, and whose appropriateness has not been well tested, the tree behaviour and potential competition should be closely monitored, and the introduction process should be conducted slowly and gradually (Asgarzadeh *et al*., 2014).

Special attention should be paid to the creation and maintenance of nurseries. There is a need to support and establish local nurseries, to complement the information available on the practice of tree planting in urban environments (Asgarzadeh *et al*., 2014). Key considerations include the choice of the site based on criteria such as the projected demand for seedlings and the distance to the planting sites. Seedling production is a major expense of afforestation and every effort should be made to produce good quality seedlings at a reasonable cost (FAO, 1989).

When to plant

Planting should normally be carried out during the rainy season, so that trees have sufficient time to establish themselves before the hot dry season (Schumann, 2004; Jones, 2008). Usually, planting is started as soon as a specified quantity of rain has fallen. The required amount of precipitation is judged on the basis of local knowledge. Planting can also be initiated when the soil is wet to a specified depth (for example 20 centimetres). A common mistake is to start planting too soon. On the other hand, if planting is started too late, it may be difficult to complete a large planting programme in the scheduled time, and the plants will lose the maximum benefit of rains after planting; this can be a serious matter where rainfall is low and erratic. (FAO, 1989).

How to plant

Although the selection of appropriate species can be an excellent approach for planting with minimal soil amendment, the need for soil improvement should be assessed before planting. Improvements can enable a wider choice of plants to be used and ensure better plant installation, and the use of organic matter is highly recommended (Jones, 2008). Due to the high temperatures and low rainfall in arid zones, the application of mulch is recommended to reduce evapotranspiration of soil moisture (Jones, 2008; Shipek *et al*., 2016). Tubes can also be used to provide tree and sapling protection (Jones, 2008). In areas where more than one tree will be planted (such as urban forests, parks), mixed plantations should be favoured (Afforest, 2019; Manuel, 2020; Shipek *et al*., 2016), as these promote biodiversity, reduce competition, prevent soil degradation and can enhance the capacity of trees to sequester CO_2 and other pollutants (Manuel, 2020).

Where to plant

The location of urban forests and trees is one of the most important decisions to be made when designing space in the built environment. The first step when planning to plant a tree or forest in or around a city is to establish the characteristics of the site where the trees will be planted. This means collecting structured information on: substrate, microclimatic aspects, available propagation material, soil improvement facilities, opportunities for implementing water harvesting systems, water conservation and reuse, technical capacity of workers, and actual economic availability. The information collected will influence all subsequent decisions. The urban context is a changing environment. For this reason, the planting site is often not chosen based on the needs of plants and the optimization of benefits for citizens, but on the basis of what has not already been occupied by buildings and infrastructures. Sound land governance requires the establishment of a database of available places/spaces to plant trees, as well as the creation of facilitation and support mechanisms, to enable both the public and private sectors to ensure the allocation of the right place to the right tree. Furthermore, trees frequently compete for space with other community services in urban and peri-urban environments, both above and below ground, including underground and aerial utility

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services, roads and pavements. This can influence the choice of tree species to be used, the extent to which the trees and forests will adapt to the site, and what management actions will be required to ensure adequate ecological resources for new plantations and neighbours.

Water management in drylands

Trees in urban arid environments face increasing water scarcity, long periods of drought, lack of soil moisture, high temperatures and dry air. Competition for water usage is particularly high. Indeed, urban forests and trees require irrigation, especially during their establishment, and water can be a major constraint. As a result, many trees in urban areas die due to lack of water, while competing with an increasing urban population for this resource (Åkerlund, 2006; Al-Mashhadani and Rasheed, 2006). Since the cost of water is higher in dry cities and the benefits of trees are often not fully understood, trees are often seen as an uneconomic solution. Dronova *et al*. (2018) also noted controversies being raised around shade tree planting efforts and water consumption in California.

There are several ways to address the environmental constraints that the climate imposes on tree planting and growth in drylands. However, those solutions can also have limitations. For instance, rainwater harvesting systems at household and small-scale urban agriculture and agroforestry level (a potential solution for water scarcity in arid climates) is often unaffordable for low-income families (Foley *et al*., 2018). Scarcity of water for urban trees can also be addressed through xeriscaping, although public perceptions regarding greenery vary among cultures and many people in drylands equate urban greening with turf-and-tree landscapes similar to those found in temperate climates (Wheeler *et al*., 2019) – that is, types of vegetation that require more water and are not resilient to dry climates.

However, the notion that trees in deserts need long-term irrigation is often a misconception, and should not be a concern if appropriate species are used (Shipek *et al.*, 2016). Native trees and other xeriscaping species are usually adapted to local rainfall patterns and have lower water requirements. In general, urban trees in arid environments may need to be watered up to their second or third year, but thereafter only during times of severe drought (Schumann, 2004; Shipek *et al*., 2016; Jones and Fleck, 2018).

The use of water-sensitive design can further reduce the water needs of urban trees. Trees can be incorporated into spaces with supplemental rainfall runoff from adjacent urban areas, such as bioretention systems that collect and filter rainwater: bioretention tree pits and bioswales (Ely, 2008; Shipek *et al*., 2016).[5]

In **Mendoza, Argentina,** a study found that the native *Acacia visco* could withstand lower irrigation quotas than those recommended (Martinez *et al*., 2011).	Luketich *et al*. (2019) shows that in **Tucson, United States of America,** structures such as bioswales have the best chance of providing additional deep (>20 cm) soil moisture from rain events, compared with natural environments, enhancing trees' accessibility to water.

Passive watering is also possible, through the diversion of stormwater runoff from the streets into tree pits through curb inlets, infiltration trenches and gravel-filled trenches (Ely, 2008).

If active irrigation is necessary, it is important to understand how much water the plant will need and determine the watering process accordingly, most likely with seasonal variations. The literature shows that if watering is planned on a yearly basis, trees are often overwatered in winter and underwatered in summer, consuming more water than needed (Shojaei *et al*., 2018). Conducting a soil moisture census and measuring the net rainfall reaching the ground, following interception by tree canopies, can help to understand the need for irrigation (Symes and Connellan, 2013). Hand watering and drip irrigation consume less water than other traditional active irrigation systems, and are therefore ideal for arid lands. When possible, hand watering should be favoured over drip irrigation, as it saves water while ensuring better monitoring (Shipek *et al*., 2016).

Recycled water or reclaimed water can be another solution for tree watering in dryland cities (Saputra, 2017; Li *et al*., 2019; Davies, 2020).

In **Australia,** the Adelaide Park Lands are fully supplied by the Glenelg Adelaide Pipeline Recycled Water scheme (Arup, 2018).	In **Urumqi, China,** it was found that the cities' reclaimed water is enough not only to meet the water demand of its urban landscape, but also to have remaining water stored in reservoirs, at minimum cost (Li *et al*., 2019).

In **Riyadh,** a recent project is seeking to green the city by using only recycled water. The city has recycled 1 million m^3 of water to plant 7.5 million trees in gardens, parks, the grounds of mosques, schools, health facilities and airports, and along most of the city's roads, streets, car parking spaces and valleys (RCRC, n.d.).

[5] Bioswales are channels designed to concentrate and convey stormwater runoff, while removing debris and pollution.

Lastly, in cases where tree plantations require watering, but active or passive irrigation systems are not possible (due to space limitations, tree quantity or water scarcity), new technologies are available. In recent years, there has been a surge in the development of innovative planting box technologies. Biodegradable or reusable, these boxes are essentially cocoons planted with trees that slowly provide water for 9 to 12 months, using less water than drip irrigation and significantly boosting survival rates (Groasis, n.d.; Land Life Company, 2016; Life Environment Project, n.d.).

The **United Arab Emirates** has planted the *ghaf tree, neem tree* and *sintra tree* using planting box technology, with a 90 percent survival rate (Land Life Company, 2016).	In **Spain,** the Green Deserts project planted more than 27 000 trees using cocoons, and found that survival rates in the different plots varied from 78 to 98 percent – significantly higher than in the control group, where the rate was 36 to 62 percent (Life Environment Project, n.d.).

The way forward

While several initiatives have been put in place to support the implementation of climate adaptation and mitigation strategies in dryland rural areas (such as the Great Green Wall in Africa and the Three-North Shelter Forest Programme in China), dryland cities face urgent challenges in integrating practical interventions with strategies aimed at enhancing the overall resilience of their urban communities.

Quality of life, especially of vulnerable groups in arid zones, can be significantly improved by integrating multipurpose urban trees and shrubs in urban design and urban development initiatives (Kuchelmeister, 1997). In this context, urban forestry and urban greening are valuable tools for strengthening the resilience of dryland cities and supporting sustainable urban development.

The literature shows a number of studies and experiences of municipalities that have successfully implemented tree-based solutions in arid environments and are enjoying their benefits. It has been proved that trees can improve air quality, reducing urban pollution, as well as providing an integral approach to managing greenhouse gas emissions, lowering air temperature and aridity, while providing social cohesion and increased well-being, promoting cultural values, enhancing livelihoods and generating further economic value. Factors directly connected with positive physical and mental health outcomes have been shown to have additional value in drylands. However, urban forestry and greening have yet to be fully incorporated into urban development in many drylands.

In arid landscapes, trees face additional resource limitations and environmental stress factors, such as harsh temperatures and scarce water supply, as well as cultural stigmas towards local species. These constraints can make implementation harder, but there is now sufficient knowledge available to overcome most problems. Tree planting in urban drylands shows potential for transforming arid cities from climate-vulnerable areas into valuable examples of sustainability, resilience and climate action in urban areas. The literature also shows a growing shift in how the human-nature relationship is perceived, demonstrating increased recognition of the importance of nature for human health and well-being.

The FAO Green Urban Oases Programme will contribute to this change by providing knowledge and technical support to dryland cities, making them greener, healthier and happier places to live.

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