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PROTECTING HEALTH IN DRY CITIES

FROM EVIDENCE TO ACTION

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OUR HEALTH

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WISH 2020 Forum on Healthy Dry Cities

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Climate change is one of the primary themes of the WISH 2020 research agenda. International co-operation will be key to helping health leaders better model the changes they wish to see, as well as drive improvements elsewhere.

As part of WISH's flagship report to equip health leaders with an understanding of the threats and opportunities that climate change creates for health, we invite health systems to join an ongoing WISH sub-community where they will be able to share lessons and ideas, and report back on their successes and challenges at the next conference in two years. Interested community members should express their support to wishclimateaction@qf.org.qa.

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FOREWORD

The world is at a crossroads. We face planetary transformations such as climate change, continuing urbanization, persistent public health challenges, and gaping inequalities in wealth and health. Policymakers have a choice – business as usual, or decisive action for a more sustainable planet.

Water scarcity – a long-standing reality in some parts of the world – is becoming increasingly severe and widespread with climate change, with the overexploitation of available water sources, and with increasing demand. This threatens public health. The idea of 'healthy dry cities' represents the intersection of two of the world's great challenges – urban health in the context of ongoing urbanization, and water resource management in the context of water scarcity. A healthy dry city is one that optimizes its physical and social environments and community resources in the face of water scarcity, to achieve the physical, mental and social wellbeing of all its inhabitants.

As co-chairs of *The BMJ* special collection on Healthy Dry Cities, we are pleased that some of the articles from the collection are being showcased in this report for WISH. This report complements the flagship Forum Report on Climate Change and Health (*Health in the Climate Crisis*) and *The BMJ* special collection on climate change and infectious diseases (*Unheeded warnings: Mitigating the impact of climate change on communicable diseases*). The articles draw attention to the health challenges of dry cities and make some recommendations for addressing those issues. They highlight the risks, while underscoring the fact that a healthy dry city is eminently achievable with the right policies, institutions, technologies, and the space for innovation. Together, they are meant to galvanize health professionals, policymakers, and members of the public to address the links between dry cities and the health of their residents.

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SECTION 1. A VISION FOR HEALTHY DRY CITIES

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Water has always been essential for cities to survive and thrive. The earliest cities, from 4000 BC, were founded near water sources. Conversely, water scarcity might have contributed to the demise of ancient cities such as Tikal in present day Guatemala and Angkor in present day Cambodia.[1,2] Water deprivation was also used as a weapon in ancient times; when Sennacherib of Assyria ransacked Babylon in 689 BC, he destroyed the city's water supply.[3]

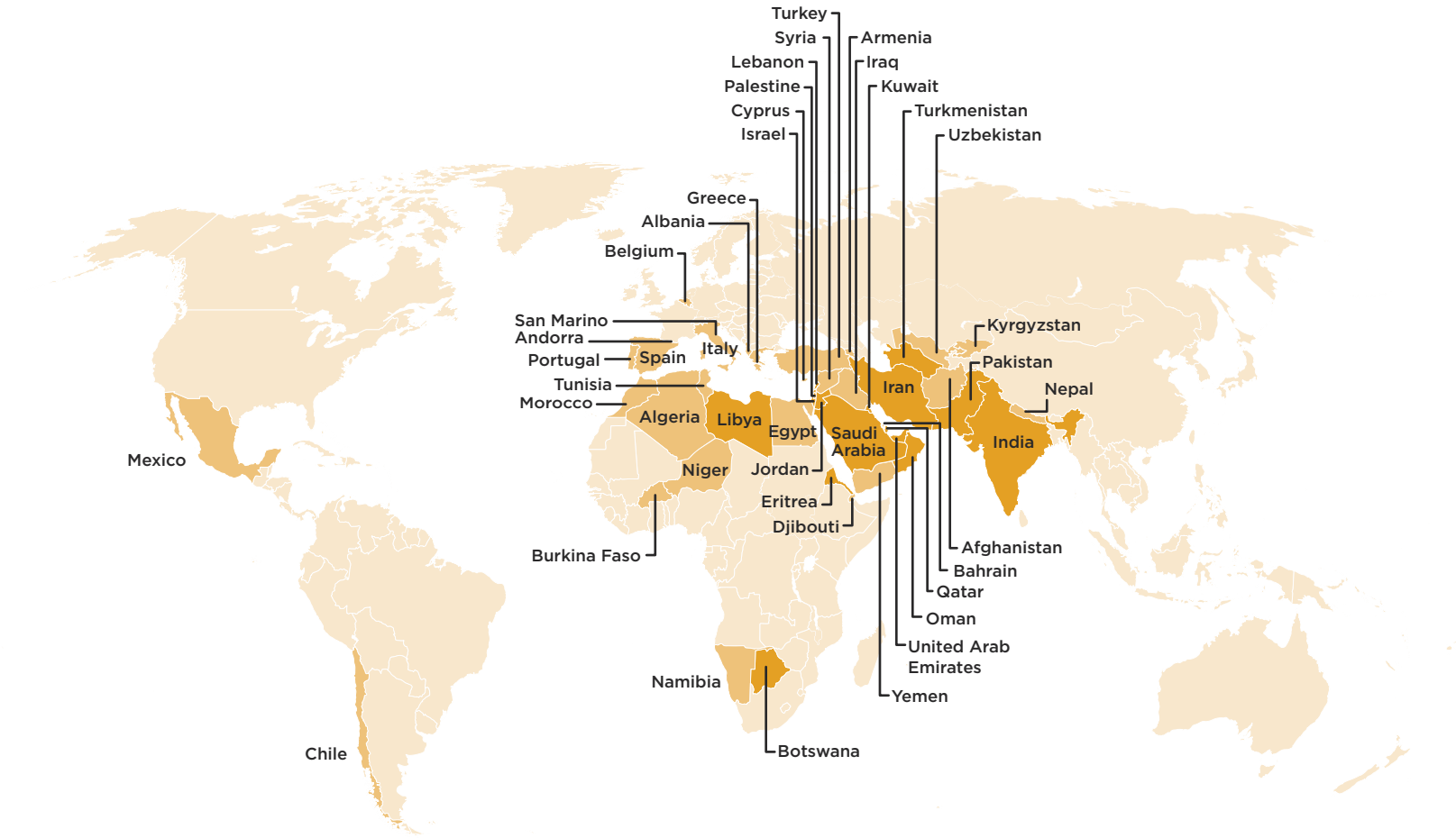
Dry cities present complex challenges in a dynamic world. The supply of water in many cities will increasingly fall short of demand, with diverse and potentially severe effects on health. In a world of pervasive inequalities, water scarcity is likely to hit the most vulnerable hardest. The challenge of achieving health in dry cities is intensified in the setting of resource scarcity, state and societal fragility, and weak institutions.

The interrelation between human health and the environment needs to be central to planning and management of water and health systems. Promoting health and wellbeing in dry cities is essential to achieving the United Nations Sustainable Development Goals (SDGs). Innovation will be key to progress; it requires foresight, strong institutions, and action from many people.

Today's global population is increasingly urban, and the world is increasingly hot, with dry regions becoming drier. Dry cities have scarce water relative to demand. An estimated 150 million people live in cities that have perennial water shortage.[4]

Some cities are dry because of their location in arid environments, with low levels of fresh water, precipitation, or both. In 2000, about 27 percent of the world's urban area was in drylands.[5] Many of the world's most water-stressed countries are in the Middle East and North Africa (Figure 1). Doha, Abu Dhabi, and Dubai in the Gulf region, and desert cities, including Cairo (Egypt) and Windhoek (Namibia), Antofagasta (Chile), Trujillo (Peru), Phoenix, and Las Vegas (US) are widely recognized as 'dry cities'.

Figure 1. The world's most water-stressed nations[6]



Other cities are dry because of a temporary scarcity of water, or drought, influenced by factors including local hydrology, climate, and human activities.[7,8] Semi-arid regions may have dry cities if drought strikes, if demand grows much faster than supply and/or if the city cannot keep pace owing to poor governance or inadequate infrastructure. Such cities include Cape Town (South Africa) and Gaborone (Botswana). Other cities, such as São Paulo (Brazil) and Chennai (India), historically have had ample water supply, but have recently confronted scarcity. Still others, such as Los Angeles (US) and Bangalore (India), are forecast to face water shortages in the coming years.

How to define a healthy dry city

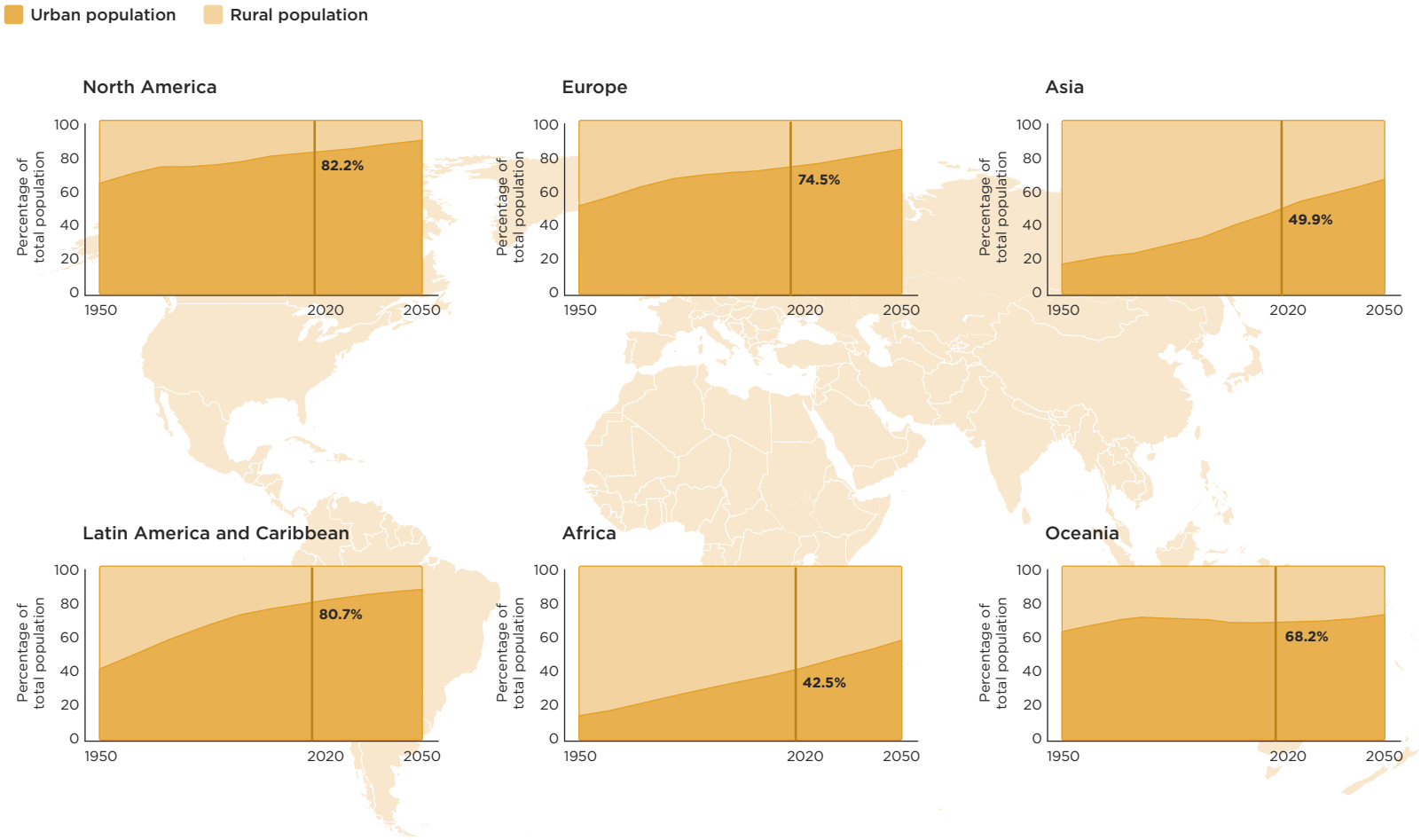
The COVID-19 pandemic shows how health crises can emerge in urban areas, and how water availability is crucial for good hygiene and containment of disease through handwashing and proper sanitation. A healthy city is "continually creating and improving those physical and social environments and expanding those community resources which enable people to mutually support each other in performing all the functions of life and developing to their maximum potential."[9] This definition emphasizes that health, at the urban scale, has both physical and social dimensions.

The physical dimensions include elements of the natural environment – ecosystems within cities and in their surrounding regions[10] – and aspects of the built environment. These include traditional characteristics of urban health – such as water, sewage and waste infrastructure, air quality, and housing – as well as urban design, transportation systems, food systems, and parks and green space, which have only recently resurfaced as public health concerns after decades of neglect.[11,12]

The social dimensions of healthy cities include the extent of poverty and inequality or access to health and social services and to employment, and also the sense of community and social cohesion. Healthy cities also provide opportunities for all inhabitants to assert their social identity, freedom, and autonomy, and to have voice in urban governance.[13]

All cities share health challenges, but dry cities have some unique challenges, as climate change and scarcity of water intensify rising heat and propel diseases of hot climates. A healthy dry city manages its physical and social environments when water is scarce to optimize the health and wellbeing of all its inhabitants. Healthy dry cities are achievable with the right policies and institutions, and with the space for innovation.

Figure 2. Growth of urbanization by world region 1950–2050[14,15]



Broader context matters

Dry cities, and their quest for health, exist in the setting of increasing urbanization, inequality, environmental hazards, and climate change, and the coexistence of different health risks.

Urbanization

More than half (at least 55 percent) of the world's population live in urban areas, and this level is projected to rise to two-thirds by 2050. This led the United Nations (in 2018) to identify urbanization as one of four "demographic mega-trends" – the others being population growth, aging, and international migration. Yet patterns of urbanization vary among and within countries. Asia and Africa are expected to see the fastest growth in urbanization (see Figure 2). A rise in absolute numbers of urban dwellers will also be concentrated in these continents.

Much urban growth will be in arid regions. According to one estimate, urban areas in arid regions globally will nearly double in size by 2030, from just below 300,000 km^2 to almost 500,000 km^2.[16] With increased demand for water exceeding growth in supply, the number of people living in cities with perennial water shortage is projected to reach almost one billion by 2050.[17] Migration is a key driver of urbanization and is influenced in part by factors such as droughts and natural disasters. Migration can place pressure on cities that may already have water scarcity.

Inequality

Although cities and towns often offer opportunities for people, and have better infrastructure than rural areas, they are beset by high levels of inequality. Almost one-fourth of the world's urban population – more than a billion people – lived in informal settlements ('slums') in 2018, most in Asia and Africa.[18]

Slums are associated with poor-quality housing, water, sanitation, and other services, leading to, (among other outcomes), higher rates of disease and death, whereas rich households are often located in areas with piped water. During water shortages, they can build storage facilities, tap into underground wells, and pay for delivered water. Only 38 percent of households among the poorest fifth of India's urban population have access to indoor piped water, compared with 62 percent of the richest fifth.[19]

Environmental hazards

Urban residents are subject to diverse environmental hazards, including air and noise pollution, high levels of waste generation, and deprivation of green space and blue space (natural streamfronts, riverfronts, and coastlines). For instance, 97 percent of cities with more than 100,000 inhabitants did not meet air-quality guidelines in 2016.[20] Increasing pollution, especially in countries that are rapidly industrializing and have lax environmental controls, also threatens water quality.[21,22]

Waste generation is correlated with economic development and urbanization, and thus low- and middle-income countries, with the least capacity for sustainable waste management, are likely to see the largest increase in waste production.[23] Water scarcity can amplify the effects of urban environmental hazards – for example, by concentrating water pollutants and limiting provision of green space.

COVID-19 has highlighted particular health challenges of water scarcity and heat. Examples include: the difficulty of handwashing when water access is limited;[24,25] the difficulty of socially isolating indoors when the temperature is extremely hot; and the paucity of green space and parks in hot, dry places – important assets for restoration during the pandemic.[26,27]

Climate change

Climate change amplifies the challenges of dry cities in at least two ways: by reducing water availability; and by increasing heat. Reduced water availability results from reduced rainfall in regions that are already dry. Rising temperatures increase evaporative loss of surface water and reduce summertime flow in snowmelt-fed rivers.[28–33] Also, dry weather can be punctuated by sudden heavy rainfall, a well-recognized phenomenon in arid regions.[34,35]

An estimated 1.8 billion people are affected by abnormal rainfall (both high and low) every year.[36] This disproportionately occurs in developing countries, and particularly cities. Many coastal cities, including some in arid regions, are experiencing saline intrusion of their water tables, due to a combination of sea level rise, withdrawal of groundwater, and settling of the city.[37–40]

Dry cities are often also hot cities. Global projections of heating trends[41] and studies in dry cities such as Mashhad (Iran),[42] Delhi (India),[43] and in major Chinese cities[44] indicate that water scarcity and heat will intensify in tandem in many cities.

Double burden of health risks

Cities and towns, especially in low- and middle-income countries, are characterized by the coexistence of infectious diseases such as HIV/AIDS, tuberculosis, pneumonia, dengue, diarrhea, and COVID-19, and non-communicable diseases such as heart disease, cancer, and strokes – the so-called 'double burden'.[45,46] Additional health burdens such as violence and injuries, including road traffic injuries, and mental health problems, also exist.

Such coexistence is seen across the world in settings as diverse as Accra, Ghana,[47] Pune and Maharashtra, India,[48,49] and in many Chinese cities.[50] Some infectious diseases thrive in hot cities where water is scarce. Therefore, health systems, especially in low- and middle-income countries, have to be simultaneously prepared for diseases of both richer and poorer contexts. Dry cities also confront unique health hazards, some of which relate directly to water scarcity, whereas others are caused indirectly.

Specific health considerations

Dry cities confront unique health hazards, some of which relate directly to water scarcity, whereas others are caused indirectly (see Figure 3).

Figure 3. How dry cities affect health

Infectious disease

Waterborne and water-related infections, caused by bacteria such as *E. coli*, *Vibrio cholerae*, and *Salmonella Typhi*, and viruses such as rotavirus, hepatitis A virus, and poliovirus, are major causes of childhood deaths and malnutrition across the life span. Clean water, free of microbiological contaminants, is essential for infectious disease control.

When the water supply is unreliable, people resort to informal sources of water such as street vendors, and to home water storage, both of which are associated with water contamination. Household drinking water containers can be breeding grounds for mosquitoes such as *Aedes aegypti*, the vector of dengue fever,[51] which threatens 2.5 billion people worldwide and is on the rise.[52,53] Similarly, re-wetting after drought can alter water table levels, vegetation, and aquatic predators, all of which affect mosquito populations.[54] Access to water in healthcare facilities is essential, because shortages undermine safe childbirth[55] and hinder control of hospital infections.[56]

An additional link between water scarcity and infectious disease is the use of wastewater in agriculture. In arid countries in the Middle East and North Africa, water scarcity increases the use of black and gray water for crop irrigation – a useful adaptive measure, but a hazard if the water is inadequately treated.[57] Contaminated food may then enter the urban supply.

Non-communicable disease

Water scarcity and heat also affect the risk of non-communicable diseases. Severe heat exposure, especially without readily available water for hydration, has health impacts ranging from mild symptoms to more severe respiratory and neurologic difficulties, heat stroke, and mortality.[58]

Water scarcity, especially linked to high temperatures, may aggravate the risk of non-communicable diseases in other ways: stress (cardiovascular risk), reduced availability of fresh foods (metabolic syndrome), kidney damage, reduced sleep quality (cardiovascular risk), and reduced physical activity. Older people and those with pre-existing health conditions are especially vulnerable, as are those who are poor, socially isolated, and who lack access to facilities such as air conditioned public spaces ('cooling centers').[59,60] Groups at considerable risk are outdoor workers such as construction workers, police officers, and street vendors, and industrial workers in facilities that are not air-conditioned.[61,62]

Heat can also lead to increased ground-level ozone and air pollution from fine particulate matter. These exposures increase the risk of cardiopulmonary disease, including risks of symptom aggravation, hospital admission, and death.[63]

Mental health

Water scarcity threatens mental health in rural populations, related to economic losses from crop failures, humiliation and shame over financial struggles, and social isolation in times of drought.[64] Displaced rural

populations may bring these problems when they migrate to cities, compounding the mental health impacts of migration itself.[65] In addition, the constant stress of lack of clean water for domestic use, the burden of having to fetch water from public water points, and the threat of flooding, contribute substantially to anxiety and depression. This burden often falls mainly on women, who are responsible for managing water for domestic use. Furthermore, lack of sanitation and water affects women when they are menstruating, after childbirth, and during the menopause, often with deleterious consequences for their health and dignity.[66]

Violence and conflict

Some evidence links high temperatures with aggressive behavior, violent crime, and possibly suicide.[67–70] Such societal tension can escalate into armed conflict. In addition, several dry cities are in areas with already fragile states. The links between the scarcity of natural resources and armed conflict are controversial,[71] but some evidence suggests that intrastate or interstate competition for resources such as water may be increasingly associated with armed conflict.[72] Armed conflict, in turn, undermines the health of combatants and civilians in many ways.[73,74]

Child development

Evidence links childhood exposure to drought with poor growth throughout childhood[75] and with long-term effects on health, including disability, in adult life.[76] Several mechanisms may operate at once, including poorer nutrition due to reduced agricultural output, increased gastrointestinal and respiratory infections due to scarcity of clean water, and reduced resources for childcare and education due to poverty.[77]

Children's development can also be affected by sweetened beverages. When water is unavailable or expensive, parents may provide their children with sweetened drinks instead, increasing the risk of obesity, diabetes, and heart disease. One study found that providing filtered drinking fountains, water bottles, and advice to children at school led to increased water ingestion by 1.1 glasses a day and to a 31 percent reduction in their risk of being overweight.[78]

Promoting health in dry cities

Policy has a critical role in ensuring that cities do not suffer from being dry, and that the health of their residents is promoted. Although the health sector is central, many solutions are multisectoral.

Health systems

Health systems in dry cities, especially in low- and middle-income countries, can be strengthened by investing in leadership, governance, health workforce, information systems, essential medical products and technologies, service delivery, and financing.[79] For example, health infrastructure and equipment should be adapted to drier and hotter conditions, the health workforce should be trained for morbidity exacerbated by drought, health information systems should be timely and include drought-related health indicators, and accessible healthcare should be provided.[80] A study that examined adaptation of the health system to heat and water scarcity in 13 low- and middle-income countries identified further examples of resilience, including a malaria early warning system in Kenya and safe reuse of wastewater in Jordan.[81]

Urban governance

The most successful systems approaches to urban governance are based on collaborative, cross-sectoral planning and implementation.[82] Decentralization permits cities to raise their own resources and plan and implement policies.[83] Municipal policymakers need to invest in institutions that will facilitate better management of water demand and supply. These include water utilities, health infrastructure, and regulatory and enforcement agencies.

Another characteristic of good urban governance is accountability to residents, with city governments making information publicly available, investing in public education, and strengthening citizens' voices. Civil society has a critical role in urban governance, facilitating government–citizen collaboration. Non-governmental organizations (NGOs) are often also service providers, policy analysts and advocates. Cape Town's recent water crisis shows the importance of integrating equity and justice issues as part of water and health governance.[84]

In India, NGOs successfully promoted large-scale toilet blocks in informal urban areas, including community-based schemes where users maintain the facilities based on a sense of ownership. Intersectoral partnerships and stakeholder engagement, including local communities, are fundamental in the healthy cities movement and promote community empowerment and urban health.[85] Cities can provide help and incentives for innovations led by non-state personnel such as citizens' groups and the private sector. There are good models for urban water and health governance, but few examples in the context of dry urban environments.[86]

Improve supply and manage demand

Water resource management includes technical and administrative solutions. Strengthening the resilience of a city's water supply requires reducing water demand, diversifying available water sources, and incorporating technologies that allow the whole water cycle to be managed as an integrated, flexible, and adaptive system.[87,88] For example, recycling wastewater and harvesting stormwater provide alternative sources to substitute or supplement scarce drinking water supplies, while also creating a range of additional environmental benefits.[89] For example, by 2010 Melbourne recycled more than 20 percent of its wastewater, providing 3 percent of its annual municipal demand through recycled wastewater and captured stormwater. These developments were encouraged by government targets to reduce pollution discharges to waterways, and to provide alternative water supplies during Australia's millennium drought. Tight regulation ensures that water quality protects public health.[90,91]

Storage options such as aquifer recharge and rainwater tanks retain water for later use during dry periods. Desalination has also been an important tool for many cities, but has some disadvantages.[92] Desalination requires large amounts of energy, which often comes from fossil fuels; it produces large quantities of brine;[93,94] and it removes iodine from seawater, which may contribute to iodine deficiency disorders.[95]

Regional approaches

Even as cities take initiatives in managing water scarcity, regional approaches are needed because watersheds do not respect political boundaries. Competition between urban and rural areas for water is common and is often politically charged.[96] Yet, there are also examples of equitable distribution of water resources and of water sharing between geographical areas.[97–99] For example, a complex legal and administrative structure in the US state of Arizona governs the allocation of water between agricultural irrigation and domestic use in cities.[100] Policy on water tariffs and pricing is political and highly contested. Some argue that it brings market discipline to a typically underpriced commodity, whereas others maintain that it disadvantages poorer people and makes a commodity of something better viewed as a human right.[101,102]

Assess risk

Assessments that identify hotspots of high vulnerability to water shortage and disease can be an important tool for decision-makers in prioritizing measures toward better management of healthy dry cities. For example, an assessment in Brazil calculated vulnerability based on poverty, education, and access to piped water.[103] Another assessment in China included additional indicators such as the length of water supply pipelines, number of beds in healthcare institutions, built-up areas, and population density.[104] The COVID-19 pandemic presents an opportunity to develop new tools and methods for better assessments.

Behavior change

Water scarcity and the extreme heat that often accompanies it require city dwellers to adapt to protect health and conserve water. Some of this change can directly protect health, such as avoiding outdoor exertion during hot times of the day, carrying water, staying hydrated, and being alert to signs of dehydration and hyperthermia. Other behavioral changes benefit health indirectly by conserving water.

The general principles of social marketing – simple, clear messages, repeated often – and from a variety of trusted sources – are highly applicable.[105] Messaging should be evidence based,[106] involving target communities and offering practical advice that increases self-help.[107] Messages are most successful when there are high levels of social cohesion and trust[108] – a basic requirement for community health resilience. The most effective media to use – for example, newspapers, radio, television, social media – will vary across and within cities and subpopulations.[109]

Nature-based solutions

Solutions based on natural or modified ecosystems provide benefits for biodiversity and human wellbeing.[110] For example, street trees, vegetation, irrigated green space, and green technologies (such as biofilters, and constructed wetlands) can cool urban microclimates through shading and evapotranspiration, and can control stormwater pollution and flows.[111–113] Trade-offs need to be made explicit and addressed – for example, trees may provide shade that reduces the need to air-condition buildings, but at the cost of increased water demand.[114] Nature-based solutions also provide opportunities for physical activity, passive recreation, and social connection, which may contribute to the prevention of non-communicable diseases and improve mental health.[115]

Key recommendations

- Strengthen health systems in dry, hot areas, including their ability to engage in multisectoral adaptation planning.
- Develop national policies that give greater autonomy to cities, and policies in dry cities that build systems that are inclusive, transparent, and accountable to residents.
- Invest in better management of water resources, including better technology and management of demand and supply.
- Invest in better tools and diagnostics to guide water system management.
- Develop effective social marketing, which can drive change in public behavior, to protect health and conserve water.
- Invest in nature-based solutions, which provide foundations for sustainability and wellbeing.

SECTION 2. CITY DESIGN FOR HEALTH AND RESILIENCE IN HOT AND DRY CLIMATES

Maya Negev, Haneen Khreis, Briony C Rogers, Mohammed Shaheen, Evyatar Erell

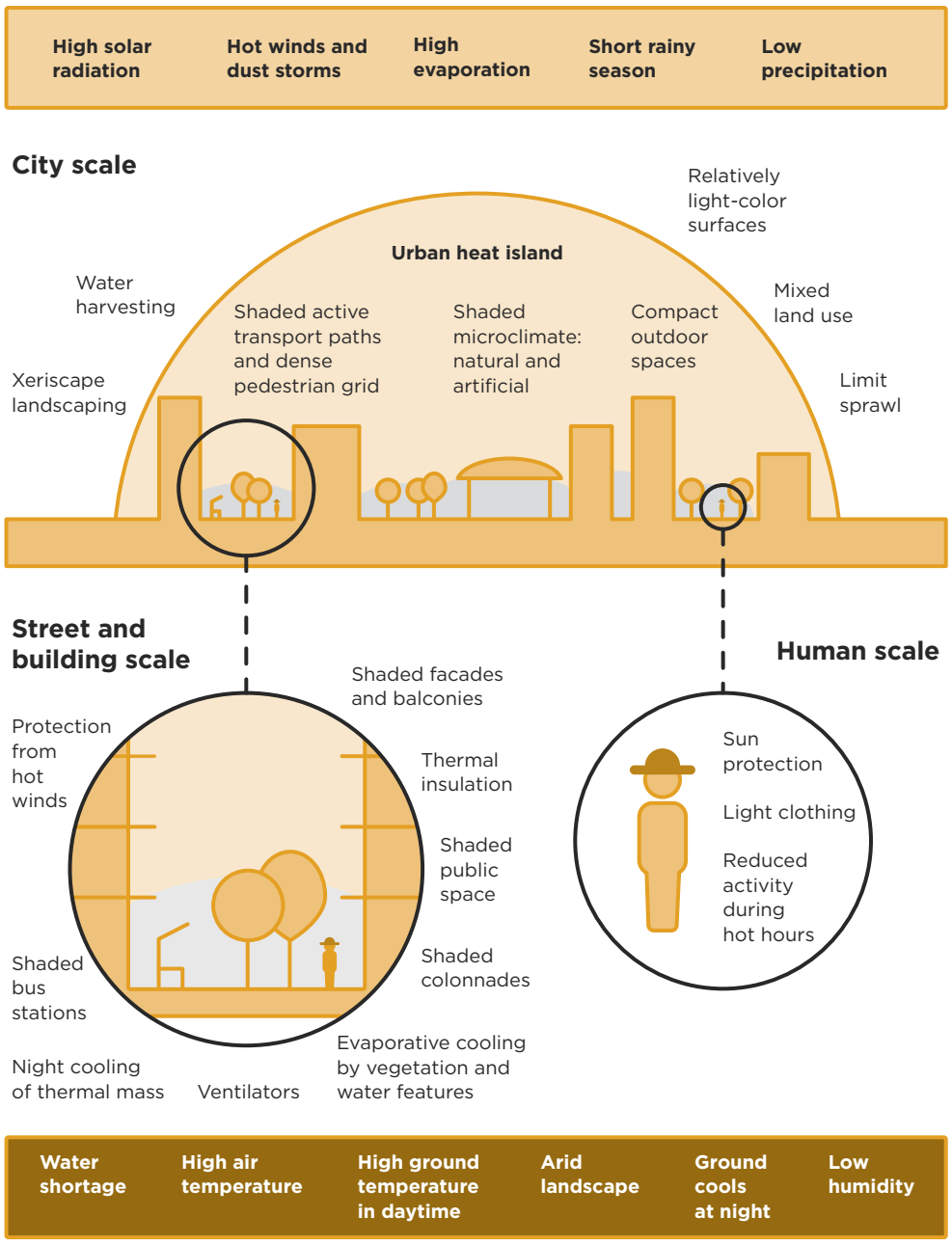
The health of people living in cities is affected by urban design elements, including density, distribution of land use, building design, transport infrastructure, green spaces, opportunities for social interaction, and accessibility to work, education, healthy food, and culture.[116,117] Several of these elements pose particular challenges when designing healthy cities in hot and dry regions such as the Middle East, where weather may constrain active transport, outdoor recreational physical activities and socializing.

Studies of the impact of urban design on health in arid regions is scarce,[118] with most research from the global north. A climate and culturally sensitive approach can, however, inform adaptation of evidence from temperate climates to hot and dry climates (see Table 1).

Challenges: Rising dryness and heat

Urban design can mitigate for the lack of water and high temperatures, which present a dual challenge to designing urban environments that promote public health (see Figure 4).

Figure 4. Designing healthy dry cities – city, street, building and human scale



Note: Environmental conditions in hot (light brown) and dry cities (dark brown) cities, and city, street and building, and human-scale means for designing a healthy city in hot and dry climate.
Source: created by Eran Kaftan for the authors

Extreme water shortages, long dry summers, and high potential evaporation are barriers to green spaces, which are a common feature of heat mitigation strategies in healthy cities in temperate climates, but are more difficult to establish and maintain in arid climates.

High temperatures and intense solar radiation can cause thermal discomfort and heat stress. High temperatures are also associated with increased morbidity and mortality;[119] even small reductions in heat stress can mitigate cardiovascular and respiratory morbidity.[120]

Cities in dry climates also have more intense nighttime urban heat islands than cities in temperate and tropical climates, though they often have modest daytime cool islands because they have more vegetation than the surrounding desert.[121]

These challenges are amplified by climate change, which has already resulted in rising temperatures and increased intensity, duration, and frequency of heat waves, as well as reduced precipitation in regions including the Middle East – trends that are expected to continue.[122] Climate projections suggest that heat-related mortality risk in this region will increase two- to three-fold in the near future.[123,124]

Cities can adapt to climate change through resilience strategies – for example, by designing urban spaces, transportation systems and buildings that increase their capacity to adapt to heat waves and recover from hazards such as droughts and floods, while maintaining essential functions (see Table 1 and Case study 1).[125]

Urban form for healthy hot and dry cities

Modern urban planning has been car-centric and has encouraged urban sprawl everywhere, but healthy desert cities should be compact, following tradition.[126] Compactness is especially important in desert cities because, unlike temperate or tropical climates, open space that is left unirrigated grows no vegetation and is a source of dust.[127] While strategies to create compact, dense cities are undergoing scrutiny because of the COVID-19 pandemic, hyperdense cities such as Hong Kong, Seoul and Tokyo showed that avoiding large outbreaks is possible with timely public health measures.[128]

Urban form affects physical activity,[129] and well-designed compact cities, such as Amsterdam and Portland, Oregon, promote outdoor physical activities and social interactions in ways that reduce people's exposure to infection risk indoors – for example, by expanding sidewalks and prioritizing cycling paths. Compactness and connectivity also increase access by foot or bike, reducing reliance on public transport.[130]

Nature-based solutions and water-sensitive cities

Nature-based solutions incorporate natural or modified ecosystems into urban design and, in temperate climates, have been shown to benefit human wellbeing, as well as biodiversity.[131,132]

Vegetation can provide cooling in several ways. Tree canopies create shade and reduce land surface temperature by intercepting solar radiation. Evapotranspiration releases water vapor into the atmosphere through a combination of evaporation from water surfaces and soil moisture and transpiration from plants, which lowers air temperature while increasing humidity.[133] Living in areas that are cooler and with more vegetation is associated with reduced risk for heat-related morbidity and mortality.[134]

Plants need a reliable source of water. This may be achieved through a water-sensitive city approach, which integrates water-cycle management with urban planning and design processes to maximize available water resources while generating additional community wellbeing and ecological benefits.[135] This visionary concept emerged in Australia in response to challenges with traditional water planning based on historic rainfall patterns that are no longer reliable. It also recognized the community's growing expectations for healthy, livable urban environments.[136]

Three key principles guide water-sensitive practices.[137] First, they access a range of water sources efficiently to ensure availability for public consumption and irrigation of open spaces, even in periods of drought. Second, they increase and protect ecosystems including waterways, wetlands, river basins, and coasts. For example, constructed wetlands and biofilters capture, retain, and treat stormwater in the urban landscape, providing local cooling, greening, and reduced run-off pollution.[138] Such amenities have multiple health benefits for mental and physical health by offering greater opportunities for physical activity, passive recreation, and social connection.[139] Third, water-sensitive communities value their city's green spaces and waterways, adopt behaviors that conserve water and reduce pollution, and support the policy and governance arrangements needed to deliver health and wellbeing outcomes through better water management. For example, Melbourne, Australia, aspires to be a water-sensitive city: it recycles wastewater and captures stormwater to supply water for non-drinking uses; biofiltration rain gardens have been implemented across the city; and its community feels strongly connected to water issues and policy decisions.[140]

Greening public space

In the hot and dry climate of the Middle East, many cities lack the water required for urban greening. Adopting nature-based and water-sensitive urban design solutions that were developed for a temperate climate may be unsuccessful because rain is concentrated in the winter, followed by six to seven months of no rain.

In dry cities, public green space must be designed judiciously to target benefits to places most likely to be enjoyed by as many city residents as possible.[141] Consideration should be given to underprivileged neighborhoods, which are often neglected, and to social and cultural norms – for example, providing zones for women.[142]

Smaller areas of green space compared with temperate climate cities reduce irrigation requirements. Because plants adapted to the desert minimize water loss by evapotranspiration, they have only a minor effect on air temperature, and improve thermal comfort primarily by providing shade or by reducing heat emitted from the ground surface in the form of infrared radiation. Both benefits are localized, so vegetation should be prioritized for main pedestrian and cycling paths, plazas and courtyards. Xeriscape gardening – landscaping that reduces or eliminates the need for irrigation – can substitute for water-intensive green spaces.[143]

Keeping cool in hot cities

Thermal comfort is not just about air temperature; it is also affected by radiant exchange, humidity, and air movement, and may be assessed by complex indicators such as the universal thermal climate index (UTCI).[144] Such indicators may be used to compare alternative designs for urban spaces to enhance resilience and to promote walkability and outdoor activity.[145]

In contrast to temperate cities, where exposure to sunshine is considered beneficial for mental health and vitamin D synthesis, cities in hot and dry climates should provide shade. Trees deliver cooling more efficiently, in terms of water use, than grass or other non-shading plants.[146] Artificial shading, such as fabric canopies, pergolas, or arcades, can provide solar protection in urban corridors and recreational spaces where vegetation cannot be planted. Shading reduces land surface temperature by intercepting solar radiation, and significantly improves human thermal comfort. It is preferable to highly reflective pavement which, despite being cooler than dark surfaces, increases the radiant load on pedestrians and has an overall negative effect on comfort.[147] It also reduces exposure to the ultraviolet light that causes sunburn and skin cancer.[148]

Promoting active and public transport

Urban transport affects mobility and access to social networks, jobs, education, goods, and services (including healthcare), all with links to public health. Encouraging shifts away from car travel to public transport and active alternatives (walking and cycling) can improve health in cities by increasing physical activity and exposure to green spaces. It can also reduce air pollution, noise, social exclusion, injuries, stress, and 'community severance' – that is, when physical or psychological barriers caused by busy roads actually limit mobility rather than facilitate it.[149,150] Health benefits from such a shift reduce greenhouse gas emissions outweigh potential adverse effects of sustaining injuries while walking or cycling, and exposure to air pollution.[151]

However, hot and dry climates present unique challenges for designing healthy transport systems. Although the connections between transport planning and policy and public health are well researched, best practices for application in hot and dry cities have not been synthesized.[152] For example, active and public transport may be difficult to implement in hot and dry cities.[153] Research shows that warm temperatures (24–30°C) and dry and sunny weather encourage walking and cycling over car travel, but higher temperatures and humidity have the opposite effect owing to thermal and mechanical discomfort.[154,155] Similarly, use of public transport, which often demands walking or cycling part of the route, is reduced in extreme weather such as very high temperatures.[156]

Evidence originates mostly from areas of temperate climate in Europe, North America, and Australia, although inhabitants of hot and dry climates may become acclimatized to different combinations of temperature, humidity, and solar radiation.

Evidence also indicates that women and older people are more sensitive to thermal comfort than men and younger adults. This is particularly relevant in Middle Eastern countries including Qatar, Iran, and Saudi Arabia, where women's clothing tends to be heavier and their skin more covered because of religious, social, and cultural factors. This might deter active transport and increase the existing gender divide in physical activity.[157] Restricted interactions between women and men are another barrier for women using public and active transport.

Public transport can be a healthy mode of transport, but it needs to be weather resilient. Transport hubs should be sheltered and accessible, service should be reliable and frequent, and buses, trams, trains, and indoor stations should be thermally comfortable.[158]

Improving car efficiency and electrification are additional measures to promote health through reducing greenhouse gas emissions and air pollution.[159] Electricity should be decarbonized and generated from solar energy.[160]

Designing healthy buildings

Modern societies spend about 90 percent of their time indoors,[161] so the design of buildings has major implications for health and well-being. Improved indoor environmental quality has measurable benefits: increased ventilation and optimized daylight and views increase sleep duration[162] and improve cognitive performance.[163] Poor indoor environmental quality – primarily indoor pollutants, often characterized as 'sick building syndrome' – is common in offices and schools owing to central air-conditioning, adversely affecting attendance and performance.[164]

All buildings create an indoor environment distinct from outdoor conditions. The walls and roof form an enclosure that may be sealed or permeable to various degrees, depending on weather conditions, allowing exchange of heat, light, and air. The exchange can be controlled by mechanical systems, as in many modern buildings, by passive means, as in traditional construction, or by a mixture of the two. All climatic solutions should also be sensitive to visual and acoustic privacy, which are affected by social and cultural norms that vary among societies.

Climate-sensitive building design seeks to maximize the advantages of local conditions and mitigate their drawbacks, while minimizing the use of non-renewable resources, (especially energy), to improve sustainability. In hot climates, this means limiting unwanted solar heating and integrating passive cooling to release excess heat to the environment, in addition to providing well-controlled daylight and plenty of fresh air.

In a well-designed house, a combination of internal thermal mass and external thermal insulation can keep indoor air temperature within a narrow band of 2–3°C without air-conditioning, even if the diurnal outdoor temperature range is 15–20°C.[165] Excess heat absorbed in the building during the daytime can be released to the environment at night by opening strategically placed windows to allow cross-ventilation.[166] However, as heat waves become more frequent and prolonged as a result of climate change, indoor conditions may exceed critical thresholds in many climates that rely on indoor cooling.[167] Many buildings constructed today will still be in service in 50 or even 100 years, so current building codes should be modified in response to modeled future climate.

The challenge for architects is to use innovative materials to reduce dependence on the ubiquitous air-conditioners that now give occupants greater flexibility and improved thermal comfort, compared with traditional vernacular passive cooling systems in buildings.[168] Well-designed modern buildings perform better in extreme weather, reducing morbidity and mortality, and improving resilience to power supply disruption.[169] By reducing dependence on air-conditioning, especially during heat waves, buildings can also reduce greenhouse gas emissions and can mitigate for energy poverty, which affects nearly 1.3 billion people globally who have no access to electricity (mostly in hot climates) or for whom it is simply too expensive.[170]

Table 1. Design strategies to promote health in hot and dry cities

Strategy	Health benefits	Adaptation to hot and dry cities
Urban form		
Increased built density and land use diversity[171]	• Encourages active transport (walking and cycling); improves accessibility to work, social networks, and health services	• Short walking distances to reduce exposure to hot weather and solar radiation
Dense network of pedestrian and cycling paths[172]	• Encourages active transport; improves accessibility	• Shade is essential for pedestrians and cyclists
Compact urban design[173]	• Encourages active transport	• Narrow streets and courtyards provide shade in the day but increase nocturnal urban heat island intensity
Diverse range of water sources, including recycled water and harvested storm water[174]	• Ensures water is available, even during dry periods	• Seasonal rainfall patterns need to be considered in developing water resources strategy
Urban design details		
Green space with tree canopies adjacent to main pedestrian and cyclist areas[175]	• Improves thermal comfort • Exposure to fresh air • Psychological wellbeing	• Modest size to conserve water • Water bodies are usually not possible owing to water shortage • Emphasis on shade trees
Spatial design that considers wind and natural ventilation[176]	• Encourages active transport	• Built form and shade elements should allow breezes to cool pedestrians and cyclists • Moderately non-uniform building heights promote ventilation without introducing wind hazards and mechanical discomfort

Strategy	Health benefits	Adaptation to hot and dry cities
Use of suitable colored materials in public spaces and on walking and cycling paths[177]	• Prevents surface heating and reduces heat emission	• Colors should be relatively light to avoid surface heating, but not very light to avoid thermal discomfort and glare from reflected sunlight
Restriction of vehicle access and defined pedestrian and cyclist-only zones[178]	• Encourages active transport	• Provide shade and green spaces in such zones
Priority given to cyclists and pedestrians over motor vehicles[179]	• Encourages active transport; reduces road travel injuries	• Convenient active transport reduces overexposure to heat and solar radiation
Transport planning and policy		
Increased accessibility and connectivity of public transport[180] Reduced distances from residential and work zones to public transport stops and connected walking and cycling paths	• Improves accessibility; potentially encourages active transport as a component of public transport trips	• Short walking distances to reduce exposure to hot weather • Shaded or cooled public transport stops
Zoning codes specifying maximum vehicle parking instead of minimum requirements[181]	• Discourages private vehicles	• No special adaptation
Appropriate cycling and walking signs; pavement marking and streetlights[182]	• Encourages active transport; reduces road travel injuries	• No special adaptation

Strategy	Health benefits	Adaptation to hot and dry cities
Building design		
Walls and roofs protect from climatic extremes[183–186]	• More resilience to disruptions in power supply and extreme weather • Less morbidity and mortality, especially during heat waves • Less dependence on air-conditioning • Mitigate for fuel poverty • Fewer greenhouse gas emissions	• Well-insulated walls and roofs • High thermal mass stabilizes indoor temperature • High-reflective roofs • Green roofs may require irrigation so are suitable only where water is plentiful • Passive cooling, especially night ventilation to flush daytime heat
Windows promote natural ventilation, daylight, and passive solar heating, but protect from unwanted heat[187,188]		• Moderate-sized windows on north- and south-facing walls, small ones on east- and west-facing ones. Large equator-facing windows if passive heating is required • Windows open to allow cross-ventilation • Operable external shading • Cool glazing provides light but reduces solar heat gain

Governance in healthy dry cities

Urban resilience is linked with most of the SDGs, particularly SDG 11: Make cities inclusive, safe, resilient and sustainable – focusing on healthy living, and ensuring availability and sustainability of water and sanitation.

Increasing resilience in hot and dry cities will depend on governance that ensures timely, collaborative, integrative, and adaptive processes with a long-term vision. Key barriers to adaptive and water-sensitive urban governance include sectoral silos, fragmented policy and regulations, lack of incentives, vision and leadership, limited practitioner capacity, inadequate funding and financing models, and remaining locked in to traditional practices.[189] Solving water shortages often requires national infrastructure. Innovative water storage and recycling requires capacity and often costly technology.[190]

Individual cities in the Middle East have taken local measures to increase urban resilience – for example, Saudi Arabian cities started adopting sustainable buildings, public transport, and urban greening strategies.[191] Examples include xeriscape gardening with natural elements in Riyadh, and green and blue spaces using recycled wastewater south of Riyadh.[192]

Region-wide initiatives in the Middle East have also sought to improve urban resilience (see Case study 1). Some of these include urban design measures to increase walkability and encourage green buildings. But mostly they are based on strategies from temperate urban areas adapted to the local climate and to climate change. To translate these plans into actions, cities might increase urban design and planning, co-ordinate between central and local levels of government, increase participation of all stakeholders, and allocate adequate resource.

Key recommendations

- **Climate-sensitive urban design:** Create compact cities with shaded public spaces, using trees and artificial shading.
- **Connectivity and accessibility:** Emphasize public transport with passive cooling in stations and in buses, trams, and trains. Provide shaded and safe pedestrian and bicycle lanes for access to work, leisure, and services. Encourage efficiency and electrification of vehicles, charged by solar energy.
- **Climate-sensitive buildings:** Design for indoor thermal comfort, fresh air, and well-controlled daylight and solar heating.
- **Redefine open space:** Use innovative arid landscape architecture for water-efficient and health-promoting parks and public spaces.
- **Culture-sensitive urban design:** Strategies should be sensitive to social and cultural norms.
- **Resilience and adaptation to climate change:** Design cities, buildings, and transportation that maintain their functions in a changing climate.

CASE STUDY 1. URBAN RESILIENCE INITIATIVES

Middle East

In 1990, the World Health Organization Eastern Mediterranean Regional Office (WHO EMRO) established a regional healthy cities network initiative, which 77 cities have joined, with a population of more than 22 million from 13 countries including Saudi Arabia, Iran, and the United Arab Emirates.[193] The network improves urban resilience in line with the Sustainable Development Goals. After joining the network, cities are required to implement 80 percent of 80 indicators in nine health and resilience domains, including emergency preparedness and response, health governance, water and sanitation, and social capacities. The city of Sharjah (United Arab Emirates) was the first to be awarded as a healthy city in the region, after meeting 88 percent of the indicators.[194]

The Rockefeller Foundation's 100 Resilient Cities initiative (2013–19) endorsed cities in the region including Ramallah, Amman, Beirut, Luxor, and Tel Aviv to develop strategic resilience plans. The Amman strategic plan, for example, sets out to improve the transportation system, promote walkability, apply green building guidelines, manage water resources efficiently, and institutionalize planning in the city. The Ramallah strategic plan includes urban design dimensions such as increasing green spaces and establishing a formal public transport system to improve mobility of women.[195] Tel Aviv adopted mandatory green building standards, pioneered bicycle and scooter rental schemes and developed an extensive network of dedicated riding paths, and is devising a climate change readiness plan that includes more shading and natural vegetation, cooling public facilities and spaces, and mitigation of the urban heat island.[196] Tel Aviv and Amman are also members of the C40 network of world megacities committed to addressing climate change.

SECTION 3. HEALTH IN DUST BELT CITIES AND BEYOND

Nick Middleton

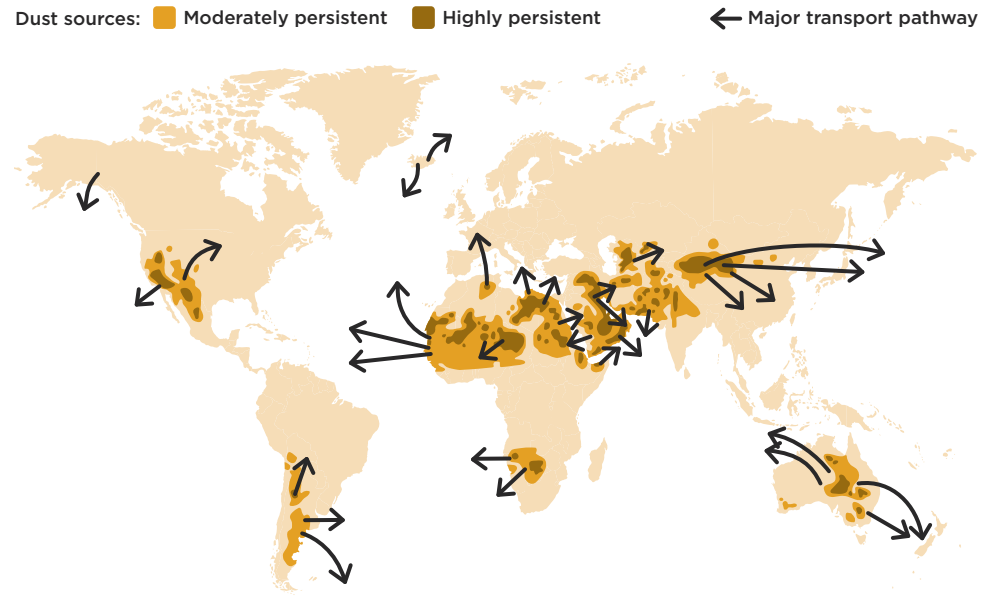
Every year, usually in December, the residents of cities in West Africa brace themselves for the Harmattan, an annual yellow haze caused by dust blown from the Sahara Desert (see photo below). It is a time of traffic accidents and flight delays, increased risk of wildfires and medical ailments – from respiratory complaints to skin problems.

Image 1. Dust storm engulfs Dubai

Credit: tobiasjo/iStock

The situation is similar across the string of deserts and semi-deserts stretching from the Sahara through the Middle East and central Asia to the Gobi Desert of China and Mongolia (Figure 5). The world's greatest dust sources are in this swathe of drylands, dubbed the 'dust belt', but airborne dust also affects dry parts of the Americas, Australia, and southern Africa.[197]

Figure 5. Map of dust sources



Source: Major global sources of desert dust and pathways of long distance transport (modified from Muhs et al. 2014)[198]

Globally, an estimated two billion tons of fine particles are raised by winds from the world's dryland soil surfaces each year. Urban areas in drylands are worst affected by these seasonal outbreaks, but fine soil particles are regularly blown over great distances, bringing dust haze to cities well outside areas considered dry. Desert dust is not just a desert problem; it has global ramifications. Dust comprises primarily mineral rock fragments with organic matter, a wide array of microorganisms, plus anthropogenic pollutants from the soil, or picked up in transit through the atmosphere.[199]

Health impacts

Soil particles entrained by turbulent winds can rapidly create a thick dust cloud. The worst cases involve abrupt and total loss of visibility at ground level, which can cause road traffic accidents, sometimes resulting in multiple vehicle pile-ups.[200] A series of severe dust events in northern India in May 2018 uprooted trees and damaged housing, leaving more than 125 people dead and many more injured in cities and rural areas of Uttar Pradesh, Rajasthan, Delhi, and Haryana.[201]

A large and growing body of research has looked at numerous infections and diseases associated with desert dust. Exposure to dust in the atmosphere can result in conjunctivitis and dermatological disorders, whereas inhalation can cause respiratory illnesses such as silicosis (also known

as desert lung syndrome). Many epidemiological studies show associations between exposure to high dust concentrations and increases in mortality and hospital visits and admissions owing to respiratory and cardiovascular diseases such as bronchitis, emphysema, and chronic obstructive pulmonary disease.[202,203] The effect of desert dust outbreaks on asthma has also attracted considerable research. However, dust is just one of a host of factors that might influence the development and expression of respiratory allergic diseases such as asthma.[204,205]

In the Sahel region of West Africa, outbreaks of bacterial meningitis are closely associated with the Harmattan season, although the exact nature of the association remains elusive.[206] In dryland parts of the Americas, dusty conditions are associated with an infectious disease known as valley fever.[207] In this case, a causal link is more clear-cut: People contract valley fever by inhaling spores of a soil-based fungus (*Coccidioides immitis* or *C. posadasii*) that become airborne during dust storms.

Air-quality guidelines

Once inhaled, the size of the dust particle is the main determinant of where it comes to rest in the respiratory tract. A distinction is typically made between particles less than 10 microns in diameter (PM_{10}), which can enter the lungs, and those with a diameter of less than 2.5 microns ($PM_{2.5}$), which can reach deeper into lung tissue.

Based on evidence, the World Health Organization (WHO) anticipates no minimum threshold for atmospheric concentration that would mean no adverse health effects,[208] but it still sets standards for acceptable air quality. National governments adopt WHO's limits or set their own similar guidelines.

Nonetheless, these limits are frequently exceeded during dust storms, sometimes by several orders of magnitude. The WHO guideline for the maximum acceptable 24-hour atmospheric concentration is a mean of 50 µg per cubic meter for PM_{10}. In Zabol, a city in southeastern Iran that frequently tops global league tables for atmospheric pollution, maximum PM_{10} levels during severe dust storms are more than 10,000 µg per cubic meter. Sometimes these storms continue for several days.

Managing dust sources

Many dust sources are naturally devoid of vegetation, but some environments have become susceptible to wind action through human mismanagement. These situations include agricultural fields left bare after ploughing and harvests, and lake beds desiccated by society's overuse of water. Preventing emissions at source is the most obvious answer to problems presented by dust, and there are numerous tried and tested techniques to prevent wind erosion from agricultural soils.[209] Many of them involve maintaining or restoring some degree of vegetation cover to protect a surface.

Farmers use all sorts of technologies to control wind erosion. These include leaving crop residue in the field after the harvest, and erecting windbreaks at right angles to erosive winds. Such barriers might comprise fences made of dead palm fronds, for example, or living plants such as trees or bushes – windbreaks called shelterbelts. Other policy options include set-aside schemes – where plots of farmland are set aside or temporarily taken out of production – designed to allow protective vegetation to grow on former farmland.

Great efforts have been made to promote these techniques to farmers in some parts of the world. In the Canadian Prairie provinces of Alberta, Saskatchewan, and Manitoba, where wind erosion is especially prevalent during recurrent drought periods, numerous initiatives to develop and promote wind erosion prevention were made in the 1980s. A marked reduction in dust in the Canadian Prairies from 1990 onward has been attributed to the positive effects of these soil conservation campaigns implemented by both government agencies and private non-profit organizations.[210]

Other dust sources are more dependent on sustainable water management. The desert city of Zabol receives dust from a series of shallow, marshy lakes that become dry during times of drought, but also when water is taken from rivers for agriculture and municipal use.[211] The lakes, which straddle the border between Iran and Afghanistan, are a unique series of wetlands in an otherwise extremely arid region. They are fed by rivers that flow from the Hindu Kush mountains, but several of these rivers have been dammed on both sides of the border to provide water to irrigation schemes and for domestic use in the region's towns and cities. The best hope for improving Zabol's air quality is an international agreement between the governments of Iran and Afghanistan governing water use in the region.

The economic incentive to reach an agreement has been assessed on the Iranian side of the border. In the Zabol region, dust storms cost an estimated $25 million (£19 million; €21 million) a year in physical damage and loss of productive work hours.[212] Such economic assessments are few and far between. A rare valuation of dust-related medical costs in the US state of Arizona in 2007, showed that 1,735 hospital visits for valley fever resulted in $86 million in hospital charges alone.[213]

Impact mitigation

Preventing dust emissions at source is not always possible. Harmattan dust, for example, emanates from natural sources in the Sahara Desert, which are too large and remote to stabilize feasibly. In situations such as this, a range of monitoring, forecasting, and early warning measures can be implemented to mitigate the numerous effects of dust in the urban environment.

In northeast Asia, governments and their meteorological services co-operate to produce forecasts of transboundary dust events based on an ensemble of computer climate models from China, Japan, and South Korea. South Korea is outside the Asian drylands, but the season of yellow haze created by dust from China and Mongolia is common enough to have a Korean name: *Hwang Sa*.

The South Korean approach to managing the risks associated with Hwang Sa offers lessons for responses elsewhere. In the capital, Seoul, the metropolitan government issues dust forecasts in weather reports on the internet and through emergency broadcasts. It also has a guide on its website advising on what to do before, during, and after a Hwang Sa event.[214] Alerts are issued when an average hourly PM_{10} concentration of greater than 800 µg per cubic meter is expected to last more than two hours. The threshold concentration is noteworthy given that Seoul is over 1,000 km from the nearest dust source.

During an alert, people are advised to close windows and stay indoors and to avoid secondhand pollution by thoroughly handwashing before processing food and cooking. If people must go outside, they are advised to wear protective glasses, a mask, and long-sleeved clothes. Schools are told to cancel classes, if necessary, and to prohibit outdoor activities for kindergarten and elementary school students. Outdoor sports events and other open air activities should be stopped or postponed. When the yellow dust has dissipated, everything should be cleaned, and some facilities need to be disinfected.

Alerts of desert dust events are a simple way of reducing harmful health effects if they lead to behavioral changes that lower exposure. Studies of the large 'red dawn' dust storm in Australia in 2009, the worst in terms of reduced visibility to have passed through the city of Sydney since the 1940s, found the incidence of adverse health outcomes was reduced by public health messages and their widespread media coverage.[215]

A pressing matter

Dust storms do not typically result in the substantial destruction of infrastructure and the loss of life associated with other natural hazards such as floods or earthquakes. But the cumulative effects on society can be substantial, not least because dust events occur more frequently than most other hazards. While dust events can be important for ecosystem function, the disruption they bring to economic and social activity, including their diverse health effects, is an area of growing concern. The effects of climate change only heighten these concerns. Member states of the UN General Assembly have adopted resolutions on combating sand and dust storms each year since 2015 because they realize that these atmospheric phenomena present a severe obstacle to achieving the SDGs.[216]

Nevertheless, many gaps remain in our understanding of the relationship between desert dust and the wellbeing of urban residents. In West Africa, a critical knowledge gap lies in the precise nature of the association between meningitis outbreaks and the dry, dusty atmospheric conditions of the Harmattan. In more general terms, evaluating the detailed health effects of dust as an individual component relative to numerous other risk factors is another gap. Filling these gaps can only improve the ways we deal with desert dust in the city.

Key recommendations

- Protect ecosystems, promote agricultural practices that reduce soil erosion, and manage water resources judiciously in places with anthropogenic origins of this global environmental health problem.
- Conduct assessments of dust risk and vulnerability as part of the Sendai Framework for Disaster Risk Reduction.
- Implement dust monitoring, forecasting, and public health early warning measures to reduce dust exposure and harmful impacts.

A case study by WISH, separate from this report commissioned by *The BMJ*, on Qatar's efforts to tackle dust from construction related to the 2022 World Cup is available at 2020.wish.org.qa/topics/healthy-dry-cities.

SECTION 4. CONCLUSION AND RECOMMENDATIONS

All cities face obstacles in promoting the health of their citizens, and dry cities grapple with several unique health challenges, as outlined in this report and the full collection of articles. Promoting health and wellbeing in dry cities is essential to achieving the SDGs. Innovation will be key to progress. This requires foresight, strong institutions, and co-ordinated action across all key sectors.

We have developed several recommendations to guide policymakers in tackling the particular health challenges faced by dry cities (as shown in Figure 6). Policymakers should bear in mind the need to prepare for ongoing climate change and to future proof their plans.

1. Strengthen and adapt health systems

Health systems in dry cities, especially in low- and middle-income countries, can be strengthened by investing in leadership, governance, health workforce, information systems, essential medical products and technologies, service delivery, and financing – and empowered to engage in multisectoral adaptation planning.[217] Health infrastructure and equipment should be adapted to drier and hotter conditions, the health workforce should be trained for morbidity exacerbated by drought, health information systems should be timely and include drought-related health indicators, and accessible healthcare should be provided.[218]

2. Strengthen city autonomy and governance

Systems approaches based on collaborative, cross-sectoral planning and implementation are most successful.[219] Decentralization permits cities to raise their own resources and plan and implement policies.[220] Municipal policymakers need to invest in institutions that will facilitate better management of water demand and supply. These include water utilities, health infrastructure, and regulatory and enforcement agencies.

3. Make cities inclusive, transparent and accountable to residents

Another characteristic of good urban governance is accountability to residents, with city governments making information publicly available, investing in public education, and strengthening citizens'

voices. Civil society has a critical role in urban governance, facilitating government–citizen collaboration. NGOs are often also service providers, policy analysts and advocates.

4. Invest in tools and diagnostics to manage demand and supply

Water resource management includes both technical and administrative solutions. Strengthening the resilience of a city's water supply requires reducing water demand, diversifying available water sources, and incorporating technologies that allow the whole water cycle to be managed as an integrated, flexible, and adaptive system.[221,222] Storage options such as aquifer recharge and rainwater tanks retain water for later use during dry periods. Desalination has also been an important tool for many cities,[223] but has some disadvantages.

5. Improve regional co-operation for water management

Regional approaches are needed because watersheds do not respect political boundaries. Competition between urban and rural areas for water is common and is often politically charged.[224] Yet there are also examples of equitable distribution of water resources and of water sharing between geographical areas.[225–227]

6. Consider economic incentives to manage use

Policy on water tariffs and pricing is political and highly contested. Some argue that it brings market discipline to a typically underpriced commodity, whereas others maintain that it disadvantages poorer people and makes a commodity of something better viewed as a human right.[228,229]

7. Assess risk of water shortages and health impact

Assessments that identify hotspots of high vulnerability to water shortage and disease can be an important tool for decision-makers in prioritizing measures toward better management of healthy dry cities. The COVID-19 pandemic presents an opportunity to develop new tools and methods for better assessments.

8. Promote behavioral change

Water scarcity and the extreme heat that often accompanies it require city dwellers to adapt, to protect health and conserve water. Some of this change can directly protect health, such as avoiding outdoor exertion during hot times of the day, carrying water, staying hydrated, and being alert to signs of dehydration and hyperthermia. Other behavioral changes benefit health indirectly by conserving water.

9. Develop effective social marketing

Simple, clear messages, repeated often – and from a variety of trusted sources – are highly applicable.[230] Messaging should be evidence based,[231] involving target communities and offering practical advice that increases self-help.[232] Messages are most successful when there are high levels of social cohesion and trust[233] – a basic requirement for community health resilience. The most effective media to use – for example, newspapers, radio, television, social media – will vary across and within cities and subpopulations.[234]

10. Invest in sustainable, nature-based solutions

Solutions based on natural or modified ecosystems provide benefits for biodiversity and human wellbeing.[235] For example, street trees, vegetation, irrigated green space, and green technologies (such as biofilters and constructed wetlands) can cool urban microclimates through shading and evapotranspiration,[236-238] and can control stormwater pollution and flows. Trade-offs need to be made explicit and addressed – for example, trees may provide shade that reduces the need to air-condition buildings, but at the cost of increased water demand.[239] Nature-based solutions also provide opportunities for physical activity, passive recreation, and social connection, which may contribute to the prevention of non-communicable diseases and improve mental health.[240]

11. Use climate-sensitive urban design

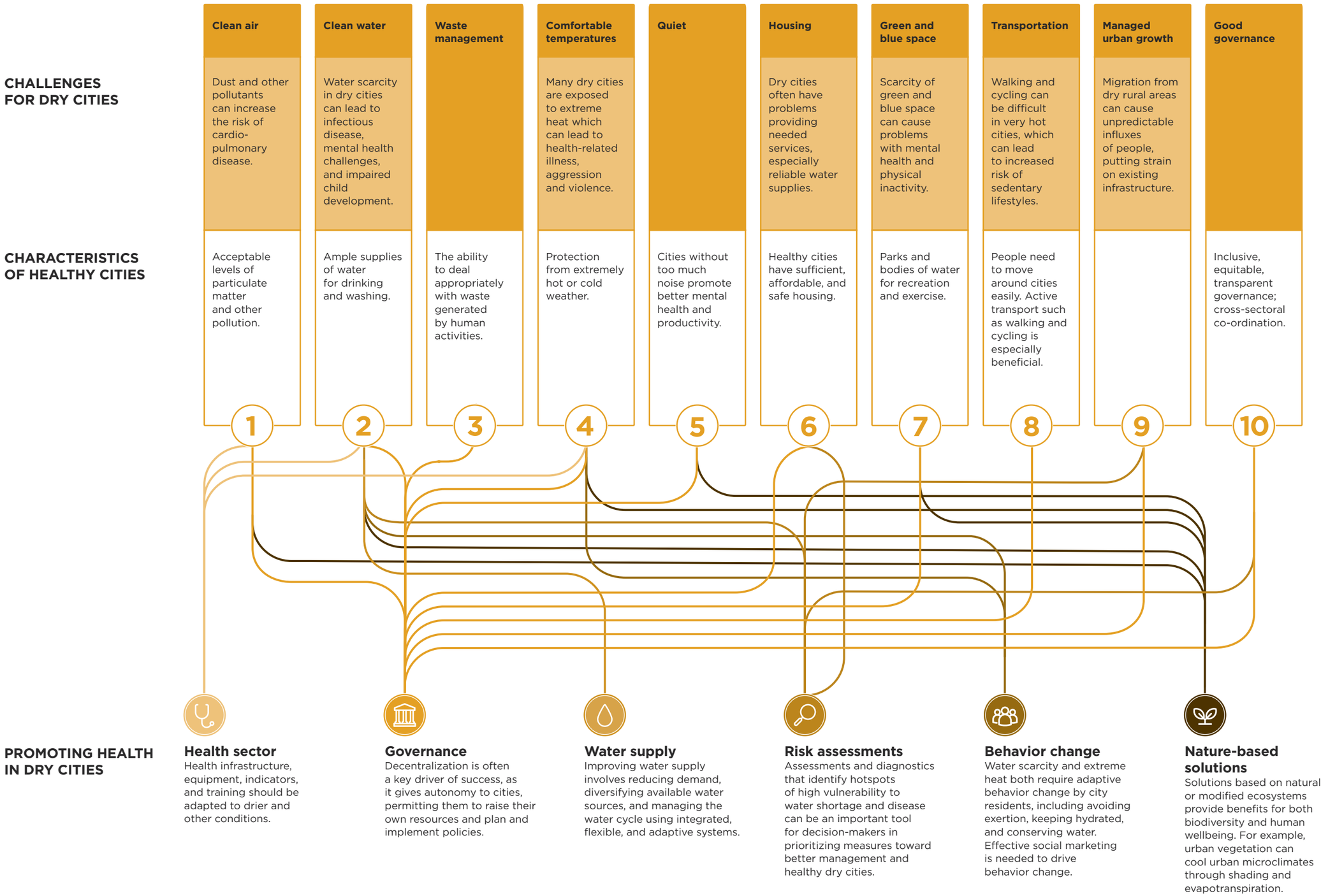
Create compact cities with shaded public spaces, using trees and artificial shading. Emphasize public transport with passive cooling in stations and cooling in buses, trams, and trains. Provide shaded and safe pedestrian and bicycle lanes, for access to work, leisure, and services. Encourage efficiency and electrification of vehicles, charged by solar energy. Design buildings for indoor thermal comfort, fresh air, and well-controlled

daylight and solar heating. Redefine open space: Use innovative arid landscape architecture for water-efficient and health-promoting parks and public spaces.

12. Reduce harms from dust

Protect ecosystems, promote agricultural practices that reduce soil erosion, and manage water resources judiciously in places with anthropogenic origins of this global environmental health problem. Conduct assessments of dust risk and vulnerability as part of the Sendai Framework for Disaster Risk Reduction. Implement dust monitoring, forecasting, and public health early warning measures to reduce dust exposure and harmful impacts.

Figure 6. Visual summary of healthy dry cities



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Section 1

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Section 3

Middleton N. Health in dust belt cities and beyond. *BMJ* 2020; 371: m3089

REFERENCES

1. Evans NP, et al. Quantification of drought during the collapse of the classic Maya civilization. *Science*. 2018; 361, P498–501.

2. Buckley BM, et al. Climate as a contributing factor in the demise of Angkor, Cambodia. *Proceedings of the National Academy of Sciences of the United States of America*. 2010; 107, P6748–6752.

3. Hatami H, Gleick PH. Conflicts over water in the myths, legends, and ancient history of the Middle East. *Environment: Science and Policy for Sustainable Development*. 1994; 36, P10–11.

4. McDonald RI, et al. Urban growth, climate change, and freshwater availability. *Proceedings of the National Academy of Sciences of the United States of America*. 2011; 108, P6312–6317.

5. McDonald RI, et al. Urban growth, climate change, and freshwater availability. *Proceedings of the National Academy of Sciences of the United States of America*. 2011; 108, P6312–6317.

6. Hofste RW, Reig P, Schleifer L. *17 countries, home to one-quarter of the world's population, face extremely high water stress*. www.wri.org/blog/2019/08/17-countries-home-one-quarter-world-population-face-extremely-high-water-stress [accessed 25 September 2020].

7. Zhang X, et al. Urban drought challenge to 2030 sustainable development goals. *Science of the Total Environment*. 2019; 693, 133536.

8. Ray B, Shaw R. Defining urban water insecurity: Concepts and relevance. In: Ray B, Shaw R (eds) *Urban Drought: Emerging water challenges in Asia*. Switzerland: Springer Nature; 2019; P1–15.

9. World Health Organization. *Health Promotion Glossary*. Geneva: World Health Organization; 1998.

10. Alberti M, Marzluff JM. Ecological resilience in urban ecosystems: Linking urban patterns to human and ecological functions. *Urban Ecosystems*. 2004; 7, P241–265.

11. Corburn J. Reconnecting with our roots: American urban planning and public health in the twenty-first century. *Urban Affairs Review*. 2007; 42, P688–713.

12. Jackson RJ, Dannenberg AL, Frumkin H. Health and the built environment: 10 years after. *American Journal of Public Health*. 2013; 103, P1542–1544.

13. Freudenberg N, Galea S, Vlahov D (eds). *Cities and the Health of the Public*. Nashville: Vanderbilt University Press; 2006.

14. Das MB, Espinoza SA. *Inclusion Matters in Africa*. Washington, DC: World Bank Group; 2019.

15. United Nations Department of Economic and Social Affairs. *World Urbanization Prospects: The 2018 revision*. New York: United Nations Department of Economic and Social Affairs; 2018.

16. Güneralp B, Güneralp İ, Liu Y. Changing global patterns of urban exposure to flood and drought hazards. *Global Environmental Change*. 2015; 31, P217–225.

17. McDonald RI, et al. Urban growth, climate change, and freshwater availability. *Proceedings of the National Academy of Sciences of the United States of America*. 2011; 108, P6312–6317.

18. United Nations Department of Economic and Social Affairs. *The Sustainable Development Goals Report 2019*. New York: United Nations Department of Economic and Social Affairs; 2019.

19. Desai S, Vanneman R, National Council of Applied Economic Research. *India Human Development Survey-II (IHDS-II)*. Inter-university Consortium for Political and Social Research; 2015.

20. United Nations Department of Economic and Social Affairs. *The Sustainable Development Goals Report 2019*. New York: United Nations Department of Economic and Social Affairs; 2019.

21. Damania R, et al. *Quality Unknown: The invisible water crisis*. Washington, DC: World Bank Group; 2019.

22. Landrigan PJ, et al. The Lancet Commission on pollution and health. *The Lancet*. 2018; 391, P462–512.

23. Kaza S, et al. *What a Waste 2.0: A global snapshot of solid waste management to 2050*. Washington, DC: World Bank Group; 2018.

24. Koop SHA, Van Dorssen AJ, Brouwer S. Enhancing domestic water conservation behaviour: A review of empirical studies on influencing tactics. *Journal of Environmental Management*. 2019; 247, P867–876.

25. Brauer M, et al. Global access to handwashing: Implications for COVID-19 control in low-income countries. *Environmental Health Perspectives*. 2020; 128, 57005.

26. Slater SJ, Christiana RW, Gustat J. Recommendations for keeping parks and green space accessible for mental and physical health during COVID-19 and other pandemics. *Preventing Chronic Disease*. 2020; 17, E59.

27. Hanzl M. Urban forms and green infrastructure – the implications for public health during the COVID-19 pandemic. *Journal of Cities and Health*. 2020; P1–5.

28. Güneralp B, Güneralp İ, Liu Y. Changing global patterns of urban exposure to flood and drought hazards. *Global Environmental Change*. 2015; 31, P217–225.

29. Carrão H, Naumann G, Barbosa P. Global projections of drought hazard in a warming climate: A prime for disaster risk management. *Climate Dynamics*. 2018; 50, P2137–2155.

30. Cook BI, Mankin JS, Anchukaitis KJ. Climate change and drought: From past to future. *Current Climate Change Reports*. 2018; 4, P164–170.

31. Liu W, et al. Global drought and severe drought-affected populations in 1.5 and 2°C warmer worlds. *Earth System Dynamics*. 2018; 9, P267–283.

32. Liang C, et al. Assessing urban flood and drought risks under climate change, China. *Hydrological Processes*. 2019; 33, P1349–1361.

33. Howard G, et al. Climate change and water and sanitation: Likely impacts and emerging trends for action. *Annual Review of Environment and Resources*. 2016; 41, P253–276.

34. Prama M, et al. Vulnerability assessment of flash floods in Wadi Dahab Basin, Egypt. *Environmental Earth Sciences*. 2020; 79, P114.

35. Wheeling K. *What causes flash floods in the Middle East?* eos.org/research-spotlights/what-causes-flash-floods-in-the-middle-east [accessed 25 September 2020].

36. Damania R, et al. *Uncharted Waters: The new economics of water scarcity and variability*. Washington, DC: World Bank Group; 2017.

37. Werner AD, et al. Seawater intrusion processes, investigation and management: Recent advances and future challenges. *Advances in Water Resources*. 2013; 51, P3–26.

38. Herbert ER, et al. A global perspective on wetland salinization: Ecological consequences of a growing threat to freshwater wetlands. *Ecosphere*. 2015; 6, ART206.

39. Shammi M, et al. Impacts of salinity intrusion in community health: A review of experiences on drinking water sodium from coastal areas of Bangladesh. *Healthcare*. 2019; 7, E50.

40. Rakib MA, et al. Groundwater salinization and associated co-contamination risk increase severe drinking water vulnerabilities in the southwestern coast of Bangladesh. *Chemosphere*. 2020; 246, P125646.

41. Pal JS, Eltahir EAB. Future temperature in southwest Asia projected to exceed a threshold for human adaptability. *Nature Climate Change*. 2016; 6, P197–200.

42. Naserikia M, et al. The urban heat island in an urban context: A case study of Mashhad, Iran. *International Journal of Environmental Research and Public Health*. 2019; 16, E313.

43. Sharma R, et al. Urban heat island and future climate change – implications for Delhi's heat. *Journal of Urban Health*. 2019; 96, P235–251.

44. Li Y, et al. Projecting future climate change impacts on heat-related mortality in large urban areas in China. *Environmental Research*. 2018; 163, P171–185.

45. Bygbjerg IC. Double burden of noncommunicable and infectious diseases in developing countries. *Science*. 2012; 337, P1499–1501.

46. Boutayeb A. The double burden of communicable and non-communicable diseases in developing countries. *Transactions of the Royal Society of Tropical Medicine and Hygiene*. 2006; 100, P191–199.

47. Agyei-Mensah S, de-Graft Aikins A. Epidemiological transition and the double burden of disease in Accra, Ghana. *Journal of Urban Health*. 2010; 87, P879–897.

48. Kroll M, Bharucha E, Kraas F. Does rapid urbanization aggravate health disparities? Reflections on the epidemiological transition in Pune, India. *Global Health Action*. 2014; 7, 23447.

49. Kholi R, Goli S, Doshi R. Epidemiological transition in urban population of Maharashtra. *Advances in Epidemiology*. 2014; 32810.

50. Liu M, et al. Epidemic transition of environmental health risk during China's urbanization. *Science Bulletin*. 2017; 62, P92–98.

51. Guzman MG, et al. Dengue infection. *Nature Reviews Disease Primers*. 2016; 2, 16055.

52. World Health Organization. *Global Strategy for Dengue Prevention and Control 2012–2020*. Geneva: World Health Organization; 2012.

53. Getachew D, et al. Breeding sites of *Aedes aegypti*: Potential dengue vectors in Dire Dawa, East Ethiopia. *Interdisciplinary Perspectives on Infectious Diseases*. 2015; 706276.

54. Brown L, Medlock J, Murray V. Impact of drought on vector-borne diseases—how does one manage the risk? *Public Health*. 2014; 128, P29–37.

55. Velleman Y, et al. From joint thinking to joint action: A call to action on improving water, sanitation, and hygiene for maternal and newborn health. *PLoS Medicine*. 2014; 11, E1001771.

56. Allegranzi B, et al. Burden of endemic health-care-associated infection in developing countries: Systematic review and meta-analysis. *The Lancet*. 2011; 377, P228–241.

57. Faour-Klingbeil D, Todd ECD. The impact of climate change on raw and untreated wastewater use for agriculture, especially in arid regions: A review. *Foodborne Pathogens and Disease*. 2018; 15, P61–72.

58. Gauer R, Meyers BK. Heat-related illnesses. *American Family Physician*. 2019; 99, P482–489.

59. Bao J, Li X, Yu C. The construction and validation of the heat vulnerability index, a review. *International Journal of Environmental Research and Public Health*. 2015; 12, P7220–7234.

60. Macintyre HL, et al. Assessing urban population vulnerability and environmental risks across an urban area during heatwaves – implications for health protection. *Science of the Total Environment*. 2018; 610–611, P678–690.

61. Levi M, Kjellstrom T, Baldasseroni A. Impact of climate change on occupational health and productivity: A systematic literature review focusing on workplace heat. *Work, Environment and Health*. 2018; 109(3), P163–179.

62. Flouris AD, et al. Workers' health and productivity under occupational heat strain: A systematic review and meta-analysis. *The Lancet Planet Health*. 2018; 2, E521–531.

63. Orru H, Ebi KL, Forsberg B. The interplay of climate change and air pollution on health. *Current Environmental Health Reports*. 2017; 4, P504–513.

64. Vins H, et al. The mental health outcomes of drought: A systematic review and causal process diagram. *International Journal of Environmental Research and Public Health*. 2015; 12, P13251–13275.

65. Bustamante LHU, et al. Stress, trauma, and posttraumatic stress disorder in migrants: A comprehensive review. *Brazilian Journal of Psychiatry*. 2017; 40, P220–225.

66. Das MB. *The Rising Tide: A new look at water and gender*. Washington, DC: World Bank; 2017.

67. Gamble JL, Hess JJ. Temperature and violent crime in Dallas, Texas: Relationships and implications of climate change. *Western Journal of Emergency Medicine: Integrating Emergency Care with Population Health*. 2012; 13(3), P239–246.

68. Hsiang SM, Burke M, Miguel E. Quantifying the influence of climate on human conflict. *Science*. 2013; 341, 1235367.

69. Burke M, et al. Higher temperatures increase suicide rates in the United States and Mexico. *Nature Climate Change*. 2018; 8, P723–729.

70. Gates A, et al. Short-term association between ambient temperature and homicide in South Africa: A case-crossover study. *Environmental Health*. 2019; 18, P109.

71. Mach KJ, et al. Directions for research on climate and conflict. *Earth's Future*. 2020; 8(7), E2020EF001532.

72. von Uexkull N, et al. Civil conflict sensitivity to growing-season drought. *Proceedings of the National Academy of Sciences of the United States of America*. 2016; 113, P12391–12396.

73. Klare MT, Levy BS, Sidel VW. The public health implications of resource wars. *American Journal of Public Health*. 2011; 101, 1615–1619.

74. Levy BS, Sidel VW. *War and Public Health*. 2nd ed. Oxford: Oxford University Press; 2007.

75. Bahru BA, et al. Drought and child undernutrition in Ethiopia: A longitudinal path analysis. *PLoS One*. 2019; 14, E0217821.

76. Dinkelman T. Long-run health repercussions of drought shocks: Evidence from South African homelands. *The Economic Journal*. 2017; 127, P1906–1939.

77. Bahru BA, et al. Drought and child undernutrition in Ethiopia: A longitudinal path analysis. *PLoS One*. 2019; 14, E0217821.

78. Popkin BM, D'Anci KE, Rosenberg IH. Water, hydration, and health. *Nutrition Reviews*. 2010; 68, P439–458.

79. World Health Organization. *Operational Framework for Building Climate Resilient Health Systems*. Geneva: World Health Organization; 2015.

80. Negev M, et al. Adaptation of health systems to climate-related migration in Sub-Saharan Africa: Closing the gap. *International Journal of Hygiene and Environmental Health*. 2019; 222, P311–314.

81. Ebi KL, Otmani Del Barrio M. Lessons learned on health adaptation to climate variability and change: Experiences across low- and middle-income countries. *Environmental Health Perspectives*. 2017; 125, 065001.

82. Mitra BK, et al. Water-energy-food nexus: A provision to tackle urban drought. In: Ray B, Shaw R (eds) *Urban Drought: Emerging water challenges in Asia*. Cham: Springer Nature; 2019; P69–86.

83. Seto KC, Sánchez-Rodríguez R, Fragkias M. The new geography of contemporary urbanization and the environment. *Annual Review of Environment and Resources*. 2010; 35, P167–194.

84. Enqvist J, Ziervogel G. Water governance and justice in Cape Town: An overview. *WIREs Water*. 2019; 6, E1354.

85. Rydin Y, et al. Shaping cities for health: Complexity and the planning of urban environments in the 21st century. *The Lancet*. 2012; 379, P2079–2108.

86. Romano O, Akhmouch A. Water governance in cities: Current trends and future challenges. *Water*. 2019; 11, P500.

87. Dilling L, et al. Drought in urban water systems: Learning lessons for climate adaptive capacity. *Climate Risk Management*. 2019; 23, P32–42.

88. Wong THF, Brown RR. The water sensitive city: Principles for practice. *Water Science and Technology*. 2009; 60, P673–682.

89. Grant SB, et al. Taking the "waste" out of "wastewater" for human water security and ecosystem sustainability. *Science*. 2012; 337, P681–686.

90. Grant SB, et al. Adapting urban water systems to a changing climate: Lessons from the millennium drought in southeast Australia. *Environmental Science and Technology*. 2013; 47, P10727–10734.

91. Ferguson BC, et al. The enabling institutional context for integrated water management: Lessons from Melbourne. *Water Research*. 2013; 47, 7300–7314.

92. Jones E, et al. The state of desalination and brine production: A global outlook. *Science of the Total Environment*. 2019; 657, P1343–1356.

93. Jones E, et al. The state of desalination and brine production: A global outlook. *Science of the Total Environment*. 2019; 657, P1343–1356.

94. Darre NC, Toor GS. Desalination of water: A review. *Current Pollution Reports*. 2018; 4, P104–111.

95. Ovadia YS, et al. Can desalinated seawater contribute to iodine-deficiency disorders? An observation and hypothesis. *Public Health Nutrition*. 2016; 19, P2808–2817.

96. Garrick D, et al. Rural water for thirsty cities: A systematic review of water reallocation from rural to urban regions. *Environmental Research Letters*. 2019; 14, 043003.

97. Seto KC, Sánchez-Rodríguez R, Fragkias M. The new geography of contemporary urbanization and the environment. *Annual Review of Environment and Resources*. 2010; 35, P167–194.

98. Civitelli F, Gruère G. Policy options for promoting urban–rural cooperation in water management: A review. *International Journal of Water Resources Development*. 2017; 33, P852–867.

99. Zipper SC, et al. Socio-environmental drought response in a mixed urban-agricultural setting: Synthesizing biophysical and governance responses in the Platte River Watershed, Nebraska, USA. *Ecology and Society*. 2017; 22.

100. Eden S, et al. Agricultural water to municipal use: The legal and institutional context for voluntary transactions in Arizona. *The Water Report*. 2008; 58, P9–20.

101. Soto Rios PC, et al. Explaining water pricing through a water security lens. *Water*. 2018; 10, P1173.

102. Grafton RQ, Chu L, Wyrwoll P. The paradox of water pricing: Dichotomies, dilemmas, and decisions. *Oxford Review of Economic Policy*. 2020; 36, P86–107.

103. Sena A, et al. Indicators to measure risk of disaster associated with drought: Implications for the health sector. *PLoS One*. 2017; 12, E0181394.

104. Wang P, et al. Urban drought vulnerability assessment – A framework to integrate socio-economic, physical, and policy index in a vulnerability contribution analysis. *Sustainable Cities and Society*. 2020; 54, 102004.

105. Maibach E. Increasing public awareness and facilitating behavior change: Two guiding heuristics. In: Lovejoy TE, Hannah L (eds) *Biodiversity and Climate Change: Transforming the biosphere*. 2nd ed. New Haven: Yale University Press; 2019; P336–346.

106. Koop SHA, Van Dorssen AJ, Brouwer S. Enhancing domestic water conservation behaviour: A review of empirical studies on influencing tactics. *Journal of Environmental Management*. 2019; 247, P867–876.

107. Addo IB, Thoms MC, Parsons M. The influence of water-conservation messages on reducing household water use. *Applied Water Science*. 2019; 9, P126.

108. Miller E, Buys L. The impact of social capital on residential water-affecting behaviors in a drought-prone Australian community. *Society & Natural Resources*. 2008; 21, P244–257.

109. Das S. Television is more effective in bringing behavioral change: Evidence from heat-wave awareness campaign in India. *World Development*. 2016; 88, P107–121.

110. Cohen-Shacham E, et al. *Nature-based Solutions to Address Global Societal Challenges*. Gland: International Union for Conservation of Nature and Natural Resources; 2016.

111. Coutts AM, et al. Watering our cities: The capacity for water sensitive urban design to support urban cooling and improve human thermal comfort in the Australian context. *Progress in Physical Geography: Earth and Environment*. 2012; 37, P2–28.

112. Ma C, et al. Sustainable water systems for the city of tomorrow — a conceptual framework. *Sustainability*. 2015; 7, P12071–12105.

113. Livesley SJ, McPherson GM, Calfapietra C. The urban forest and ecosystem services: Impacts on urban water, heat, and pollution cycles at the tree, street, and city scale. *Journal of Environmental Quality*. 2016; 45, P119–124.

114. Wang Z-H, et al. Cooling and energy saving potentials of shade trees and urban lawns in a desert city. *Applied Energy*. 2016; 161, P437–444.

115. Braubach M, et al. Effects of urban green space on environmental health, equity and resilience. In: Kabisch N, et al (eds.) *Nature-based Solutions to Climate Change Adaptation in Urban Areas: Linkages between science, policy and practice*. Cham: Springer; 2017; P187–205.

116. Nieuwenhuijsen M, Khreis H. *Integrating Human Health into Urban and Transport Planning: A framework*. Switzerland: Springer Nature; 2018.

117. Dannenberg AL, Frumkin H, Jackson R. *Making Healthy Places: Designing and building for health, well-being, and sustainability*. Washington, DC: Island Press; 2011.

118. Al-Delaimy WK. Vulnerable populations and regions: Middle East as a case study. In: Al-Delaimy WK, et al (eds) *Health of People, Health of Planet and our Responsibility*. Cham: Springer International Publishing; 2020; P121–133.

119. Macintyre HL, et al. Assessing urban population vulnerability and environmental risks across an urban area during heatwaves – implications for health protection. *Science of the Total Environment*. 2018; 610–611, P678–690.

120. Loughnan ME, Nicholls N, Tapper NJ. When the heat is on: Threshold temperatures for AMI admissions to hospital in Melbourne Australia. *Applied Geography*. 2010; 30, P63–69.

121. Lazzarini M, et al. Urban climate modifications in hot desert cities: The role of land cover, local climate, and seasonality. *Geophysical Research Letters*. 2015; 42, P9980–9989.

122. Hochman A, et al. The seasons' length in 21st century CMIP5 projections over the eastern Mediterranean. *International Journal of Climatology*. 2018; 38, P2627–2637.

123. Ahmadalipour A, Moradkhani H. Escalating heat-stress mortality risk due to global warming in the Middle East and North Africa (MENA). *Environment International*. 2018; 117, P215–225.

124. Pal JS, Eltahir EAB. Future temperature in southwest Asia projected to exceed a threshold for human adaptability. *Nature Climate Change*. 2016; 6, P197–200.

125. Meerow S, Newell JP, Stults M. Defining urban resilience: A review. *Landscape and Urban Planning*. 2016; 147, P38–49.

126. Dannenberg AL, Frumkin H, Jackson R. *Making Healthy Places: Designing and building for health, well-being, and sustainability*. Washington, DC: Island Press; 2011.

127. Erell E, Tsoar H. An experimental evaluation of strategies for reducing airborne dust in desert cities. *Building and Environment*. 1997; 32, P225–236.

128. Organisation for Economic Co-operation and Development. *OECD Policy Responses to Coronavirus (COVID-19): Cities policy responses*. Paris: Organisation for Economic Co-operation and Development; 2020.

129. Kelly C, et al. The built environment predicts observed physical activity. *Frontiers in Public Health*. 2014; 2, P52.

130. Dannenberg AL, Frumkin H, Jackson R. *Making Healthy Places: Designing and building for health, well-being, and sustainability*. Washington, DC: Island Press; 2011.

131. Coutts AM, et al. Watering our cities. *Progress in Physical Geography: Earth and Environment*. 2013; 37, P2–28.

132. Cohen-Shacham E, et al. *Nature-based Solutions to Address Global Societal Challenges*. Gland: International Union for Conservation of Nature and Natural Resources; 2016.

133. Livesley SJ, McPherson GM, Calfapietra C. The urban forest and ecosystem services: Impacts on urban water, heat, and pollution cycles at the tree, street, and city scale. *Journal of Environmental Quality*. 2016; 45, P119–124.

134. Schinasi LH, Benmarhnia T, De Roos AJ. Modification of the association between high ambient temperature and health by urban microclimate indicators: A systematic review and meta-analysis. *Environmental Research*. 2018; 161, P168–180.

135. Wong THF, Brown RR. The water sensitive city: Principles for practice. *Water Science and Technology*. 2009; 60, P673–682.

136. Ferguson BC, Frantzeskaki N, Brown RR. A strategic program for transitioning to a water sensitive city. *Landscape and Urban Planning*. 2013; 117, P32–45.

137. Wong THF, Brown RR. The water sensitive city: Principles for practice. *Water Science and Technology*. 2009; 60, P673–682.

138. Water Services Association of Australia. *Health Benefits from Water Centric Liveable Communities*. Melbourne: Frontier Economics; 2019.

139. Nieuwenhuijsen MJ, et al. Fifty shades of green: Pathway to healthy urban living. *Epidemiology*. 2017; 28, P63–71.

140. Ferguson BC, et al. The enabling institutional context for integrated water management: Lessons from Melbourne. *Water Research*. 2013; 47, 7300–7314.

141. Mahmoud AHA. Analysis of the microclimatic and human comfort conditions in an urban park in hot and arid regions. *Building and Environment*. 2011; 46, P2641–2656.

142. Ahmed N, El Aziz A. Pocket park design in informal settlements in Cairo city, Egypt. *Landscape Architecture and Regional Planning*. 2017; 2, P51–60.

143. ARUP. *Cities Alive: Rethinking cities in arid environments*. Dubai: ARUP; 2018.

144. Fiala D, et al. UTCI-Fiala multi-node model of human heat transfer and temperature regulation. *International Journal of Biometeorology*. 2012; 56, P429–441.

145. Chokhachian A, Santucci D, Auer T. A human-centered approach to enhance urban resilience, implications and application to improve outdoor comfort in dense urban spaces. *Buildings*. 2017; 7, P113.

146. Shashua-Bar L, Pearlmutter D, Erell E. The influence of trees and grass on outdoor thermal comfort in a hot-arid environment. *International Journal of Climatology*. 2011; 31, P1498–1506.

147. Erell E, et al. Effect of high-albedo materials on pedestrian thermal stress in urban street canyons. *Urban Climate*. 2014; 10, P367–386.

148. Xiang F, et al. Incidence of nonmelanoma skin cancer in relation to ambient UV radiation in white populations, 1978–2012: Empirical relationships. *JAMA Dermatology*. 2014; 150, P1063–1071.

149. Nieuwenhuijsen M, Khreis H. *Integrating Human Health into Urban and Transport Planning: A framework*. Switzerland: Springer Nature; 2018.

150. Khreis H, et al. *Transportation and Health: A conceptual model and literature review*. Texas: Center for Advancing Research in Transportation Emissions, Energy, and Health; 2019.

151. Gouldson A, et al. *The Economic and Social Benefits of Low-carbon Cities: A systematic review of the evidence*. London and Washington, DC: Coalition for Urban Transitions; 2018.

152. Khreis H, et al. *Transportation and Health: A conceptual model and literature review*. Texas: Center for Advancing Research in Transportation Emissions, Energy, and Health; 2019.

153. Böcker L, Dijst M, Faber J. Weather, transport mode choices and emotional travel experiences. *Transportation Research Part A: Policy and Practice*. 2016; 94, P360–373.

154. Böcker L, Dijst M, Faber J. Weather, transport mode choices and emotional travel experiences. *Transportation Research Part A: Policy and Practice*. 2016; 94, P360–373.

155. Shaaban K, Muley D, Elnashar D. Evaluating the effect of seasonal variations on walking behaviour in a hot weather country using logistic regression. *International Journal of Urban Sciences*. 2018; 22, P382–391.

156. Miao Q, Welch EW, Sriraj PS. Extreme weather, public transport ridership and moderating effect of bus stop shelters. *Journal of Transport Geography*. 2019; 74, P125–133.

157. Shaaban K, Muley D, Elnashar D. Evaluating the effect of seasonal variations on walking behaviour in a hot weather country using logistic regression. *International Journal of Urban Sciences*. 2018; 22, P382–391.

158. Wei M, et al. The influence of weather conditions on adult transit ridership in the sub-tropics. *Transportation Research Part A: Policy and Practice*. 2019; 125, P106–118.

159. Gouldson A, et al. *The Economic and Social Benefits of Low-carbon Cities: A systematic review of the evidence*. London and Washington DC: Coalition for Urban Transitions; 2018.

160. Abubakar IR, Dano UL. Sustainable urban planning strategies for mitigating climate change in Saudi Arabia. *Environment, Development and Sustainability*. 2020; 22, P5129–5152.

161. Klepeis NE, et al. The national human activity pattern survey. *Journal of Exposure Science and Environmental Epidemiology*. 2001; 11, P231–252.

162. Boubekri M, et al. The impact of optimized daylight and views on the sleep duration and cognitive performance of office workers. *International Journal of Environmental Research and Public Health*. 2020; 17, P3219.

163. Allen JG, et al. Associations of cognitive function scores with carbon dioxide, ventilation, and volatile organic compound exposures in office workers: A controlled exposure study of green and conventional office environments. *Environmental Health Perspectives*. 2016; 124, P805–812.

164. Mendell MJ, Heath GA. Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature. *Indoor Air*. 2005; 15, P27–52.

165. Givoni B. *Man, Climate and Architecture*. 2nd ed. London: Applied Science Publishers, London; 1976.

166. Givoni B. Effectiveness of mass and night ventilation in lowering the indoor daytime temperatures. Part I: 1993 experimental periods. *Energy and Buildings*. 1998; 28, P25–32.

167. Baniassadi A, Heusinger J, Sailor DJ. Energy efficiency vs resiliency to extreme heat and power outages: The role of evolving building energy codes. *Building and Environment*. 2018; 139, P86–94.

168. Foruzanmehr A, Vellinga M. Vernacular architecture: Questions of comfort and practicability. *Journal of Building Research and Information*. 2011; 39, P274–285.

169. Baniassadi A, Heusinger J, Sailor DJ. Energy efficiency vs resiliency to extreme heat and power outages: The role of evolving building energy codes. *Building and Environment*. 2018; 139, P86–94.

170. González-Eguino M. Energy poverty: An overview. *Renewable and Sustainable Energy Reviews*. 2015; 47, P377–385.

171. Mouada N, Zemmouri N, Meziani R. Urban morphology, outdoor thermal comfort and walkability in hot, dry cities. Section A: Planning Strategies and Design Concepts. *International Review for Spatial Planning and Sustainable Development*. 2019; 7, P117–133.

172. Johansson E. Influence of urban geometry on outdoor thermal comfort in a hot dry climate: A study in Fez, Morocco. *Building and Environment*. 2006; 41, P1326–1338.

173. Erell E. The application of urban climate research in the design of cities. *Advances in Building Energy Research*. 2008; 2, P95–121.

174. Grant SB, et al. Adapting urban water systems to a changing climate: Lessons from the millennium drought in southeast Australia. *Environmental Science and Technology*. 2013; 47, P10727–10734.

175. Shashua-Bar L, Pearlmutter D, Erell E. The influence of trees and grass on outdoor thermal comfort in a hot-arid environment. *International Journal of Climatology*. 2011; 31, P1498–1506.

176. Ng E. Policies and technical guidelines for urban planning of high-density cities – air ventilation assessment (AVA) of Hong Kong. *Building and Environment*. 2009; 44, P1478–1488.

177. Yang J, Wang Z, Kaloush K. Environmental impacts of reflective materials: Is high albedo a 'silver bullet' for mitigating urban heat island? *Renewable and Sustainable Energy Reviews*. 2015; 47, P830–843.

178. Nieuwenhuijsen M, Khreis H. *Integrating Human Health into Urban and Transport Planning: A framework*. Switzerland: Springer Nature; 2018.

179. Nieuwenhuijsen M, Khreis H. *Integrating Human Health into Urban and Transport Planning: A framework*. Switzerland: Springer Nature; 2018.

180. Miao Q, Welch EW, Sriraj PS. Extreme weather, public transport ridership and moderating effect of bus stop shelters. *Journal of Transport Geography*. 2019; 74, P125–133.

181. Al-Fouzan SA. Using car parking requirements to promote sustainable transport development in the Kingdom of Saudi Arabia. *Cities*. 2012; 29, P201–211.

182. Muneerudeen A, Al Khani F, Furlan R. Urban revitalization of public spaces in the Pearl in Qatar. *American Journal of Sociological Research*. 2016; 6, P1–9.

183. Givoni B. Effectiveness of mass and night ventilation in lowering the indoor daytime temperatures. Part I: 1993 experimental periods. *Energy and Buildings*. 1998; 28, P25–32.

184. Baniassadi A, Heusinger J, Sailor DJ. Energy efficiency vs resiliency to extreme heat and power outages: The role of evolving building energy codes. *Building and Environment*. 2018; 139, P86–94.

185. Schweitzer O, Erell E. Evaluation of the energy performance and irrigation requirements of extensive green roofs in a water-scarce Mediterranean climate. *Energy and Buildings*. 2014; 68, P25–32.

186. Konopacki S, et al. *Demonstration of Energy Savings of Cool Roofs*. US Department of Energy, Office of Scientific and Technical Information; 1998.

187. Givoni B. *Man, Climate and Architecture*. 2nd ed. London: Applied Science Publishers, London; 1976.

188. Rezaei SD, Shannigrahi S, Ramakrishna S. A review of conventional, advanced, and smart glazing technologies and materials for improving indoor environment. *Solar Energy Materials and Solar Cells*. 2017; 159, P26–51.

189. Brown RR, et al. Fit-for-purpose governance: A framework to make adaptive governance operational. *Environment Science and Policy*. 2012; 22, P73–84.

190. Grant SB, et al. Adapting urban water systems to a changing climate: Lessons from the millennium drought in southeast Australia. *Environmental Science and Technology*. 2013; 47, P10727–10734.

191. Abubakar IR, Dano UL. Sustainable urban planning strategies for mitigating climate change in Saudi Arabia. *Environment, Development and Sustainability*. 2020; 22, P5129–5152.

192. ARUP. *Cities Alive: Rethinking cities in arid environments*. Dubai: ARUP; 2018.

193. Elfeky S, et al. Healthy cities programme in the Eastern Mediterranean Region: concurrent progress and future prospects. *Eastern Mediterranean Health Journal*. 2019; 25, P445–446.

194. Sharjah Health Authority. *Sharjah Healthy City Profile*. sha.gov.ae/en/sharjah_health_city [accessed 25 September 2020].

195. Ramallah Municipality. *Resilient Ramallah 2050*. www.ramallah.ps/userfiles/file/ir/Ramallah%20Resilience%20Strategy%202050.pdf [accessed 25 September 2020].

196. Tel Aviv-Yafo Municipality. *The Strategic Plan for Tel Aviv-Yafo: The City Vision, December 2017*. www.tel-aviv.gov.il/Residents/Development/DocLib1/City%20Vision%202017.pdf [accessed 25 September 2020].

197. Prospero JM, et al. Environmental characterization of global sources of atmospheric soil dust identified with the Nimbus 7 Total Ozone Mapping Spectrometer (TOMS) absorbing aerosol product. *Reviews of Geophysics*. 2002; 40, P1–31.

198. Muhs DR, et al. Identifying sources of aeolian mineral dust: Present and past. In: Knippertz P, Stuut J-BW (eds) *Mineral Dust: A key player in the Earth system*. Heidelberg: Springer Science and Business Media; 2014.

199. Goudie AS, Middleton NJ. *Desert Dust in the Global System*. Berlin: Springer Science and Business Media; 2006.

200. Li J, et al. Blowing dust and highway safety in the southwestern United States: Characteristics of dust emission "hotspots" and management implications. *Science of the Total Environment*. 2018; 621, P1023–1032.

201. Sarkar S, et al. Impact of deadly dust storms (May 2018) on air quality, meteorological, and atmospheric parameters over the northern parts of India. *GeoHealth*. 2019; 3, P67–80.

202. Zhang X, et al. A systematic review of global desert dust and associated human health effects. *Atmosphere*. 2016; 7, P158.

203. Querol X, et al. Monitoring the impact of desert dust outbreaks for air quality for health studies. *Environment International*. 2019; 130, 104867.

204. Ezeamuzie CI, et al. Asthma in the desert: Spectrum of the sensitizing aeroallergens. *Allergy: European Journal of Allergy and Clinical Immunology*. 2000; 55, P157–162.

205. Kanatani KT, et al. Desert dust exposure is associated with increased risk of asthma hospitalization in children. *American Journal of Respiratory and Critical Care Medicine*. 2010; 182, P1475–1481.

206. Koutangni T, et al. Compartmental models for seasonal hyperendemic bacterial meningitis in the African meningitis belt. *Epidemiology and Infection*. 2018; 147, 1–11.

207. Hector RF, Laniado-Laborin R. Coccidioidomycosis – a fungal disease of the Americas. *PLoS Medicine*. 2005; 2, E2.

208. World Health Organization. *WHO Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide: Global update 2005: Summary of risk assessment*. Geneva: World Health Organization; 2006.

209. Middleton N, Kang U. Sand and dust storms: Impact mitigation. *Sustainability*. 2017; 9, P1053.

210. Fox TA, Barchyn TE, Hugenholtz CH. Successes of soil conservation in the Canadian Prairies highlighted by a historical decline in blowing dust. *Environmental Research Letters*. 2012; 7, 014008.

211. Rashki A, et al. Dryness of ephemeral lakes and consequences for dust activity: The case of the Hamoun drainage basin, southeastern Iran. *Science of the Total Environment*. 2013; 463–464, P552–564.

212. Miri A, et al. Environmental and socio-economic impacts of dust storms in Sistan Region, Iran. *International Journal of Environmental Studies*. 2009; 66, P343–355.

213. Sprigg WA, et al. Regional dust storm modeling for health services: the case of Valley Fever. *Aeolian Research*. 2014; 14, P53–73.

214. Seoul Metropolitan Government. *A Guide to Measures in Case of Yellow Dust*. http://english.seoul.go.kr/policy/welfare-health-security/measures-in-case-of-yellow-dust/ [accessed 25 September 2020].

215. Merrifield A, et al. Health effects of the September 2009 dust storm in Sydney, Australia: Did emergency department visits and hospital admissions increase? *Environmental Health*. 2013; 12, P32.

216. United Nations. *Combating Sand and Dust Storms: Report of the secretary-general*. New York: United Nations; 2019.

217. World Health Organization. *Operational Framework for Building Climate Resilient Health Systems*. Geneva: World Health Organization; 2015.

218. Negev M, et al. Adaptation of health systems to climate-related migration in Sub-Saharan Africa: Closing the gap. *International Journal of Hygiene and Environmental Health*. 2019; 222, P311–314.

219. Mitra BK, et al. Water-energy-food nexus: A provision to tackle urban drought. In: Ray B, Shaw R (eds) *Urban Drought: Emerging water challenges in Asia*. Cham: Springer Nature; 2019; P69–86.

220. Seto KC, Sánchez-Rodríguez R, Fragkias M. The new geography of contemporary urbanization and the environment. *Annual Review of Environment and Resources*. 2010; 35, P167–194.

221. Dilling L, et al. Drought in urban water systems: Learning lessons for climate adaptive capacity. *Climate Risk Management*. 2019; 23, P32–42.

222. Wong THF, Brown RR. The water sensitive city: Principles for practice. *Water Science and Technology*. 2009; 60, P673–682.

223. Jones E, et al. The state of desalination and brine production: A global outlook. *Science of the Total Environment*. 2019; 657, P1343–1356.

224. Garrick D, et al. Rural water for thirsty cities: A systematic review of water reallocation from rural to urban regions. *Environmental Research Letters*. 2019; 14, 043003.

225. Seto KC, Sánchez-Rodríguez R, Fragkias M. The new geography of contemporary urbanization and the environment. *Annual Review of Environment and Resources*. 2010; 35, P167–194.

226. Civitelli F, Gruère G. Policy options for promoting urban–rural cooperation in water management: A review. *International Journal of Water Resources Development*. 2017; 33, P852–867.

227. Zipper SC, et al. Socio-environmental drought response in a mixed urban-agricultural setting: Synthesizing biophysical and governance responses in the Platte River Watershed, Nebraska, USA. *Ecology and Society*. 2017; 22.

228. Soto Rios PC, et al. Explaining water pricing through a water security lens. *Water*. 2018; 10, P1173.

229. Grafton RQ, Chu L, Wyrwoll P. The paradox of water pricing: Dichotomies, dilemmas, and decisions. *Oxford Review of Economic Policy*. 2020; 36, P86–107.

230. Maibach E. Increasing public awareness and facilitating behavior change: Two guiding heuristics. In: Lovejoy TE, Hannah L (eds) *Biodiversity and Climate Change: Transforming the biosphere*. 2nd ed. New Haven: Yale University Press; 2019; P336–346.

231. Koop SHA, Van Dorssen AJ, Brouwer S. Enhancing domestic water conservation behaviour: A review of empirical studies on influencing tactics. *Journal of Environmental Management*. 2019; 247, P867–876.

232. Addo IB, Thoms MC, Parsons M. The influence of water-conservation messages on reducing household water use. *Applied Water Science*. 2019; 9, P126.

233. Miller E, Buys L. The impact of social capital on residential water-affecting behaviors in a drought-prone Australian community. *Society & Natural Resources*. 2008; 21, P244–257.

234. Das S. Television is more effective in bringing behavioral change: Evidence from heat-wave awareness campaign in India. *World Development*. 2016; 88, P107–121.

235. Cohen-Shacham E, et al. *Nature-based Solutions to Address Global Societal Challenges*. Gland: International Union for Conservation of Nature and Natural Resources; 2016.

236. Coutts AM, et al. Watering our cities: The capacity for water sensitive urban design to support urban cooling and improve human thermal comfort in the Australian context. *Progress in Physical Geography: Earth and Environment*. 2012; 37, P2–28.

237. Ma C, et al. Sustainable water systems for the city of tomorrow — a conceptual framework. *Sustainability*. 2015; 7, P12071–12105.

238. Livesley SJ, McPherson GM, Calfapietra C. The urban forest and ecosystem services: Impacts on urban water, heat, and pollution cycles at the tree, street, and city scale. *Journal of Environmental Quality*. 2016; 45, P119–124.

239. Wang Z-H, et al. Cooling and energy saving potentials of shade trees and urban lawns in a desert city. *Applied Energy*. 2016; 161, P437–444.

240. Braubach M, et al. Effects of urban green space on environmental health, equity and resilience. In: Kabisch N, et al (eds.) *Nature-based Solutions to Climate Change Adaptation in Urban Areas: Linkages between science, policy and practice*. Cham: Springer; 2017; P187–205.

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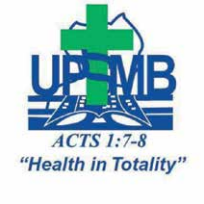
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