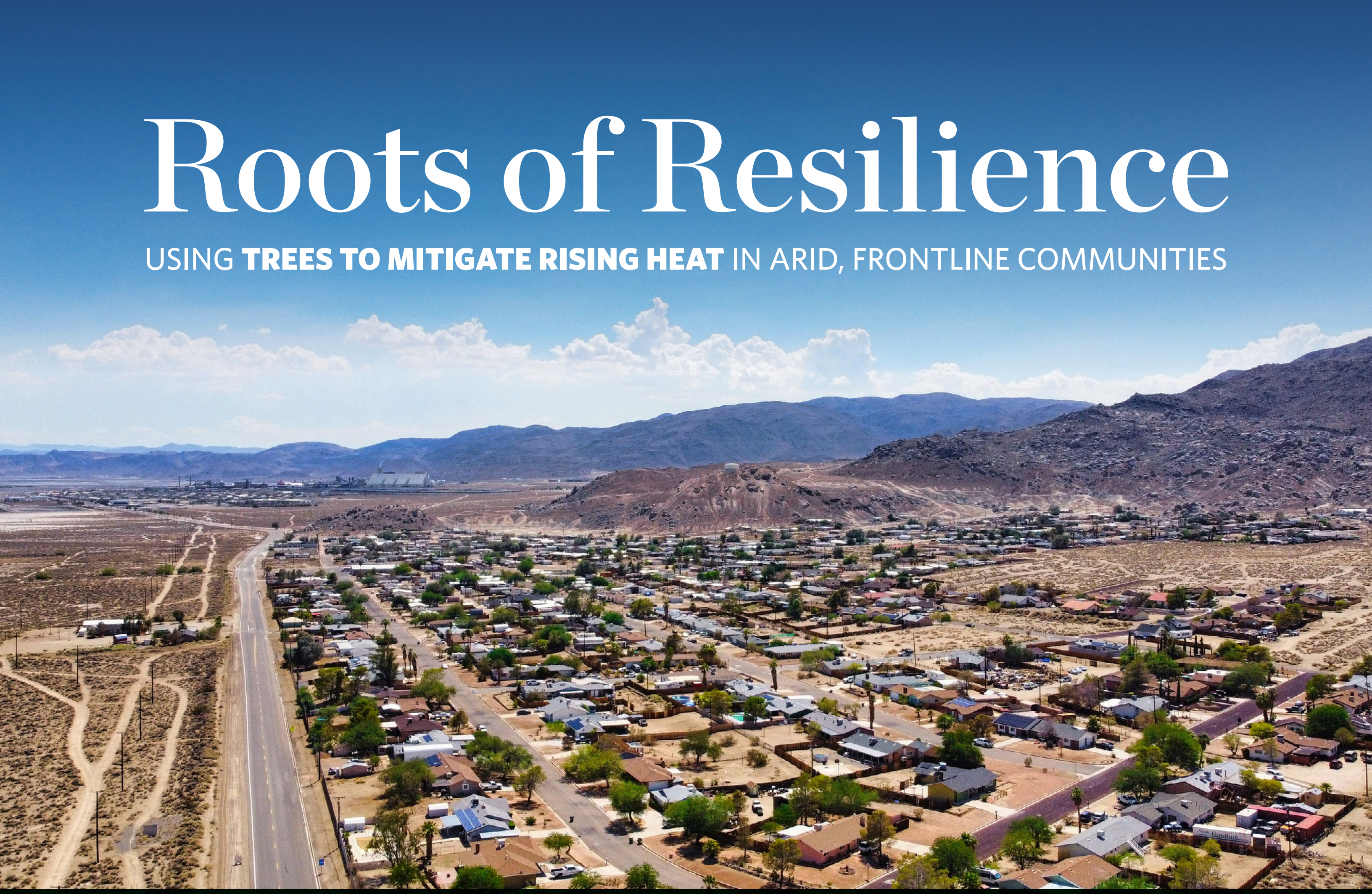
Roots of Resilience

USING **TREES TO MITIGATE RISING HEAT** IN ARID, FRONTLINE COMMUNITIES



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USING **TREES TO MITIGATE RISING HEAT** IN ARID, FRONTLINE COMMUNITIES

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TABLE OF CONTENTS

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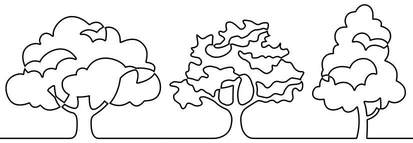
EXECUTIVE SUMMARY

The epic challenge facing frontline communities in arid cities

Science shows climate change will dramatically increase the frequency, duration, and intensity of heat waves, posing serious health and wellbeing impacts worldwide. According to the IPCC, life-threatening heat and humidity are expected to impact between half to three-fourths of the global population by 2100. Cities, which are currently home to more than half the world's population and will add another 2.5 billion people by 2050, will be exposed to double the intensity of heat stress compared to rural surroundings.

Cities and towns in arid, water-scarce areas face exceptionally daunting challenges. In many cases, these cities are already impacted by heat, and climate change will make the threat more acute. This report explores the potential for increased tree cover to serve as one potential adaptation to a warming world, as trees cool ambient outdoor air temperatures and provide shade. Arid cities also face another, often related challenge—water insecurity. Climate change is expected to increase the variability in precipitation and rates of evapotranspiration, reducing water availability for many cities during at least parts of the year. As these twin challenges—extreme heat and water insecurity—interact, the lack of water to support additional trees may limit their use as a nature-based solution for heat in urban areas.

Most at risk are frontline communities—that is, those that will be impacted first and most intensely by climate change. In this report, we operationally define frontline communities as neighborhoods with low economic resources and high surface temperatures. Frontline communities face more risk during heat waves for at least three reasons. First, they are more exposed to heat, as these neighborhoods usually have more impervious cover and hence higher surface and air temperatures. Second, these communities are more vulnerable because they have higher proportions of residents with pre-existing health conditions, such as heart disease, that can be exacerbated by exposure to extreme heat. These communities also are more vulnerable since they have lower economic resources and often must work or travel outside during heat waves. Third, they often have less adaptive capacity; for instance, a lower proportion of households own or can afford to use air conditioning or fans.



Back to Contents

Much has been writing about the potential for nature-based solutions (NBS) to help cities adapt to climate change, including increased heat risk. In this report we follow IUCN's NBS Standard, which defines NBS as actions that "address societal challenges through actions to protect, sustainably manage, and restore natural and modified ecosystems, benefiting people and nature at the same time." *This report quantifies the potential of NBS to help protect these frontline communities in arid cities from extreme heat, which is worsening due to climate change.*

This report identified approximately 415 million people globally who live in large urban areas (> 3 million population) with arid climates, and another 964 million people in large urban areas with semi-arid climates. We show that climate change will pose unique and serious challenges for those in arid cities. Globally, we estimate that there are 96 million people in frontline communities in large arid or semi-arid cities (8.0% of global urban population), although globally available information on socioeconomic status is limited, which makes this mapping imprecise. In the United States specifically, we estimate there are 66.3 million people in urbanized areas of all sizes in arid or semi-arid climates. Within these arid or semi-arid urbanized areas in the US, about 9.2 million people (13.1%) live in frontline communities. We can expect that the coming extreme heat may affect these frontline communities more intensely than other neighborhoods, for the three reasons previously described.

Making change happen

If NBS are to be a climate adaptation solution in these frontline communities, change must occur on the ground in the form of an equitable expansion of tree canopy, which poses several unique challenges. Frontline communities are often less politically and economically powerful, and have been historically marginalized, which makes them less able to advocate for tree canopy enhancement programs. Moreover, those in frontline communities (or those who represent them in political processes) may not have access to knowledge of the coming extreme heat, the risk it poses to health, and the role tree canopy could play in reducing this risk. Frontline communities may also have concerns about problems like lack of a sense of security in parks, crime, or lack of maintenance of parks and street trees. They may also be concerned that tree planting could be part of a series of events that lead to gentrification and rising rents, which, combined, could potentially displace residents. Further, the very history that has resulted in communities left with limited resources may also make community members less likely to trust the government or other organizations charged with leading tree planting initiatives. Any successful on-the-ground project for canopy enhancement must address these and other concerns.

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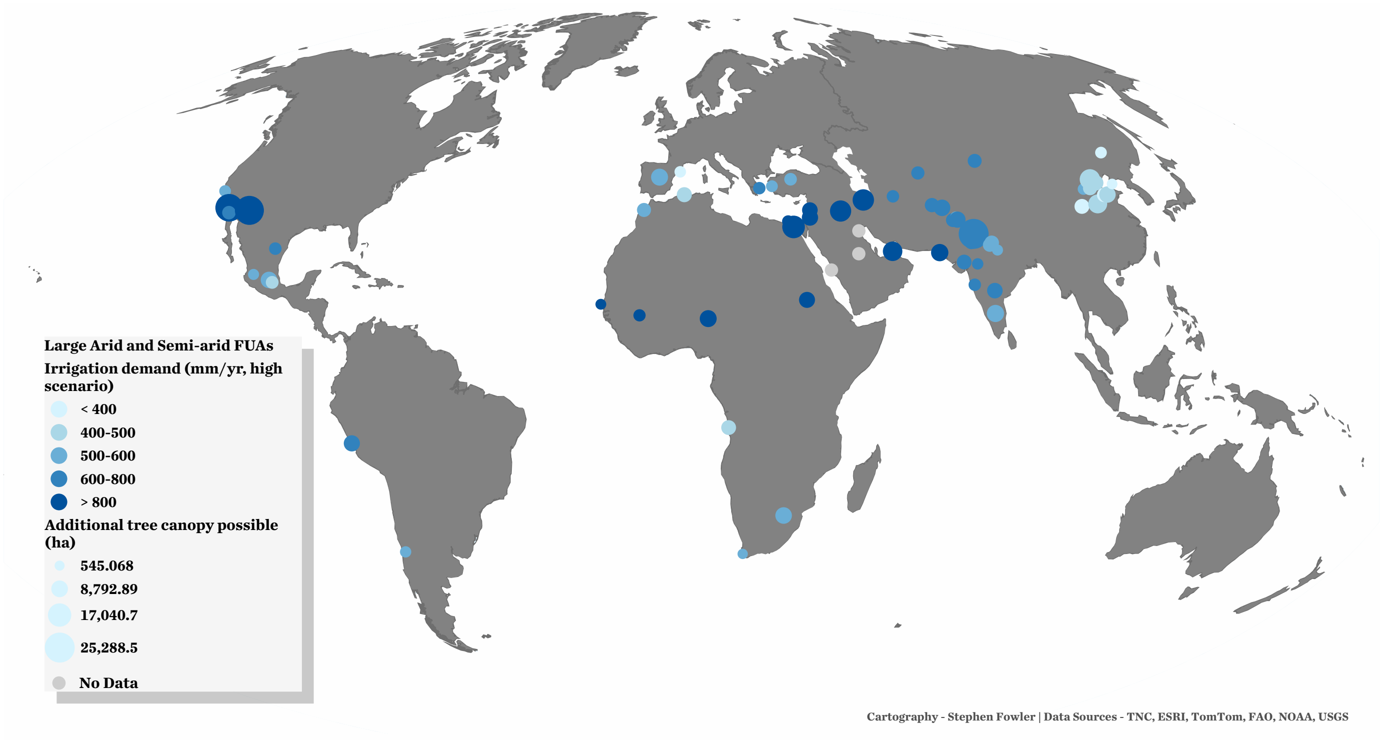
Yet we found many examples of frontline communities in arid regions that have overcome these challenges through policies, programs, and incentives. In our case study of the Phoenix, Arizona metropolitan area, we discuss how government and NGOs have worked to co-design solutions with local communities. And in our Athens, Greece case study, we describe how trees are both at threat from climate change but also an important solution to mitigate its effects.

Empowering frontline communities and partnering with them in developing urban greening plans appears to be key to the success of urban greening efforts. Some of the best practices our study uncovered were:

- Partner with frontline communities at the onset of urban greening plans and involve them recurrently throughout project implementation.
- Identify potential areas in frontline communities most suitable for urban greening, based on heat exposure, vulnerability, the location of plantable areas, and where regulations and local land-use permits greening.
- Select a portfolio of priority places for tree canopy enhancement based on cooling potential and a community's desires for their own neighborhoods.
- During and after planting, partner with frontline communities on the value of the cooling benefits trees provide to ensure buy-in and continued tree maintenance.

Back to Contents



Cartography - Stephen Fowler | Data Sources - TNC, ESRI, TomTom, FAO, NOAA, USGS

FIGURE 1. Tree canopy enhancement potential and irrigation demand rate for large (> 3 million) functional urban areas in arid or semi-arid climates.

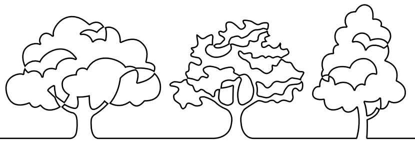
The global potential of trees

In the 61 large cities (> 3 million population) we assessed globally, the citizens of arid cities have, on average 1.5% tree cover in their neighborhood, while the average for citizens in semi-arid cities is 4.2%. We estimate that targeted urban greening programs could realistically increase this to 7.1% in arid cities and 7.3% in semi-arid cities. Implementing such a greening program in these arid cities would reduce air temperatures near people's homes by an average of 0.5˚C. The biggest potential decreases in air temperatures near people's homes are in urban areas like Kabul (1.2˚C) and Damascus (1.1˚C), which have arid climate and limited tree cover currently, and therefore have enormous potential for tree cover expansion. Note that there is far more variability within urban areas. For instance, in Athens (overall average population-weighted reduction of 0.6˚C), temperature reduction benefits in the 1 km^2 neighborhoods examined in this report ranged from close to 0˚C to 1.6˚C.

We estimate, however, that increasing tree canopy cover in these 61 large cities to this maximal potential would increase aggregate water demand by 3,200 million cubic meters per year. Therefore, any plans to increase tree canopy cover in these cities must provide viable options for overcoming potential water limitations and increasing tree equity. We show that the use of appropriate drought-tolerant species could reduce this water demand to 1,500 million cubic meters per year, with especially large water savings possible in semi-arid climates. In arid climates where irrigation for trees will be essential, emphasis must be placed on leveraging alternative sources of water, such as the reuse of wastewater or grey water.

Modelling the reduction in mortality during heat waves due to additional tree canopy cover is a complex task beyond the scope of this report. The most current epidemiology literature shows that the relationship between temperature and mortality during a heat wave varies by the city and its inhabitants' social and technological adaptations to heat as well as their underlying vulnerability to heat stress. However, we present some simple calculations that suggest potential mortality reductions in trees can potentially save thousands of lives during a major heat wave event.

Our results stress the importance of targeting tree planting in cities where they provide the most benefit to health during heat waves—that is, in frontline communities that most need the tree canopy. It is important to avoid spending money and using precious water resources to establish trees in places where they provide limited benefit, especially in water-scarce cities. In general, denser neighborhoods as well as denser cities have smaller potential for canopy



Back to Contents

enhancement and health benefits, as it is harder to plant trees in dense areas with ubiquitous impervious surfaces. But, in these instances, the cooling benefits could be greater, because each tree planted often shades more impervious surfaces and there are more people who live in close enough proximity to benefit from the cooling effects.

Realizing this potential

As part of a broader heat action plan for a community, NBS play an essential and cost-effective way to reduce risk during heat waves. It is, however, important to consider how NBS can be incentivized or funded. Municipal actions play a key role; in many cities, most trees in densely populated frontline communities are planted and maintained by municipal agencies. We urge municipalities to set ambitious tree canopy enhancement goals, focusing both on new tree planting and on supporting valuable older trees and urban forests. Cities will increasingly need more robust tree maintenance budgets and area-specific maintenance plans that take into consideration extreme high temperatures and water scarcity, which increase tree stress and makes them more susceptible to pests and diseases. Community groups that work in partnership with municipalities and local NGOs are key in helping co-design solutions that are in the interest of frontline communities.

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Often municipal forestry activities are funded by general tax revenues. However, there is a real need for more innovative financing mechanisms to achieve large increases in tree canopy described in this report. For instance, one such mechanism is green bonds in which cities borrow money to fund projects that have climate adaptation benefits, where such potential benefits exist. Another innovative option is to use funds for stormwater mitigation to help create NBS that achieve both stormwater and heat mitigation. The appeal of this approach for cities in arid environments is that increasing stormwater infiltration can increase soil water availability for trees, thereby decreasing their water requirements. For instance, the Storm to Shade program in Tucson, Arizona (US) creates such dual-purpose NBS and is funded through a small fee on every resident's utility bill, based on their water consumption. Stormwater mitigation funding streams are less available in developing countries, but the principle of jointly planning for stormwater and heat risk reduction is still crucially important in arid frontline communities in these regions.

National-level policy and funding will also be essential in utilizing trees to their full potential. In the US, for example, the Inflation Reduction Act is estimated to provide $1.5 billion for tree planting in urban areas, much of it targeted to frontline communities that currently have low tree cover. International policy will also be essential, especially for funding climate adaptation in the least-developed nations. Whatever the source of funding, our results emphasize that explicitly targeting action to frontline communities will be essential.

The moment to act

The world's first climate crisis, already being felt, is extreme heat. The coming extreme heat will impact water-scarce cities hardest, threatening them with twin threats—deadly heat and less precipitation. Despite potential water limitations, this report shows trees and NBS have roles to play in reducing heat if water demands are minimized and water recycling is promoted. As those most at risk, frontline communities must be explicitly made the focus of funding and action. Such action is urgently needed today, as it takes years for trees to mature into a robust canopy. Climate change is already here, and every year we wait to green frontline communities is a missed opportunity to save and improve lives.

Back to Contents

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GLOBAL CHALLENGES AND CONTEXT

Climate change is already impacting communities around the globe, and these impacts will intensify, worsening floods, threatening water security, raising temperatures to dangerous extremes, and otherwise disrupting many systems on which communities depend. Communities in arid, water-scarce communities face unique challenges from climate change, and the range of viable solutions is narrowed. This report focuses on water-scarce communities, which we define operationally as places where the ratio of precipitation to water demand by vegetation is low—from semi-arid areas like coastal southern California and the Mediterranean to arid deserts like the Sonoran Desert around Phoenix or the Sahara Desert near Cairo.

One challenge from climate change for water-scarce communities will be water security, as the average water supply available decreases, due to higher temperature and greater evapotranspiration, and precipitation patterns become more variable, with drought periods becoming drier and rainfall events becoming more intense. If reservoirs do not have enough capacity and/or supply, this can lead to water shortages and cause challenges for the management of stormwater and associated combined sewer systems.

Another challenge for these water-scarce cities will be extreme heat. These cities are already prone to periods of extreme heat now, as semi-arid and arid areas tend to have higher summer temperatures. Already, heat stress kills roughly 6,100 Americans and 356,000 people globally every year [1]. Climate change will make heat waves more frequent and intense. The Intergovernmental Panel on Climate Change (IPCC) has warned that by 2100, up to 3 in 4 people globally (76%) will be exposed to extreme heat [2], and this fraction is likely to be even higher in water-scarce cities.

Frontline communities and inequality

Frontline communities are those that will be impacted first and most intensely by climate risks. The term originated in the US, and in this report, we will follow the definition offered by the Georgetown Climate Center:

- Frontline communities include people who are both highly exposed to climate risks (because of the places they live, and the projected changes expected to occur in those places) and...
- have fewer resources, capacity, safety nets, or political power to respond to those risks (e.g., these people may lack insurance or savings, inflexible jobs, or low levels of influence over elected officials).

In this report, we will use the term both for US frontline communities, as well as similar communities globally, including those in developing countries where there are unique challenges, such as in informal settlements. Our use of the term is meant to focus attention on which specific neighborhoods within urban areas are most at risk, although we acknowledge there is also inequality in climate risk among urban areas, particularly when comparing between developed and developing economies.

Frontline communities face more risk during heat waves for at least three reasons. They are more exposed to heat, as these neighborhoods usually have more impervious cover and hence higher surface and air temperatures. They are more vulnerable on average, with a higher proportion of people with pre-existing health conditions like heart disease that can be exacerbated by exposure to extreme heat. And they often have less adaptive capacity, with a lower proportion of households having access to air conditioning or fans.

Urban areas around the world have begun to use heat action planning as they prepare for a hotter world. By lowering outside ambient air temperature, urban trees and other greenery can be a key part of heat action planning. Trees cool in two ways. They provide shade, which reduces the solar energy that reaches pavement and other impervious surfaces that would absorb the energy and later radiate it out as heat (thermal energy). And they transpire water as they grow, which cools the air through evaporative cooling, much as people are cooled when sweat evaporates on a sweltering day. Taken together, these two factors mean trees can reduce surface temperatures by more than 20˚C, and, on average, reduce air temperatures by 1-2˚C [3]. Trees in cities in the US, for instance, are estimated to save 1,200 lives each year during heat waves [4].

Frontline communities, however, often have less tree cover than other, more affluent communities, so they receive less of nature's protective benefits. Research on urban tree cover shows it is unequally distributed. For instance, one survey of 5,723 municipalities in the US found that in 92% of communities, low-income neighborhoods have less tree cover than high-income neighborhoods, with low-income neighborhoods on average having 15.2% less tree cover and being 1.5˚C hotter (summer surface temperature) than high-income blocks [5]. Trees are saving thousands of lives every year in the US, but primarily in high-income neighborhoods that are predominantly non-Hispanic white.

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The potential limits to nature-based solutions in water-scarce cities

By definition, though, arid cities do not have much available water, which may limit plant establishment and maintenance. New or young trees in semi-arid climates often need more water while their root systems are growing, but in arid climates, trees may perpetually need watering to overcome a water deficit, the difference between potential evapotranspiration of a plant and the available precipitation.

It is an open question of how much water-scarce cities can use nature-based solutions (NBS) to adapt to heat risk. NBS have been defined various ways, but in this report we follow IUCN's NBS Standard, which defines NBS as actions that "address societal challenges through actions to protect, sustainably manage, and restore natural and modified ecosystems, benefiting people and nature at the same time." While any kind of vegetation in urban areas can decrease ambient temperatures, in this report we pay most attention to urban trees, which are particularly effective in cooling cities. Water may seem too precious to use for watering vegetation, but without the cooling benefits of vegetation, temperatures are even more extreme and life-threatening. The consideration of both water scarcity and the cooling benefits of vegetation is needed to make an analysis of the potential return on investment of trees as an NBS to heat.

In this report, we present this possible tradeoff between water and NBS for heat, focusing on the experiences of frontline communities. In the next section, we map where water-scarce cities are located globally, estimating how many residents in these cities are in frontline communities. Then, we present two detailed case studies of frontline communities in Phoenix and Athens that are working to equitably increase vegetative cover to reduce heat risk. Next, we estimate the global potential for tree planting in arid cities as an adaptation to heat, and how such plantings would impact water security. We end by offering some policy recommendations for governments at all levels to incentivize win-win solutions for water security and heat risk reduction.

GLOBAL MAPPING OF FRONTLINE COMMUNITIES IN WATER-SCARCE CITIES

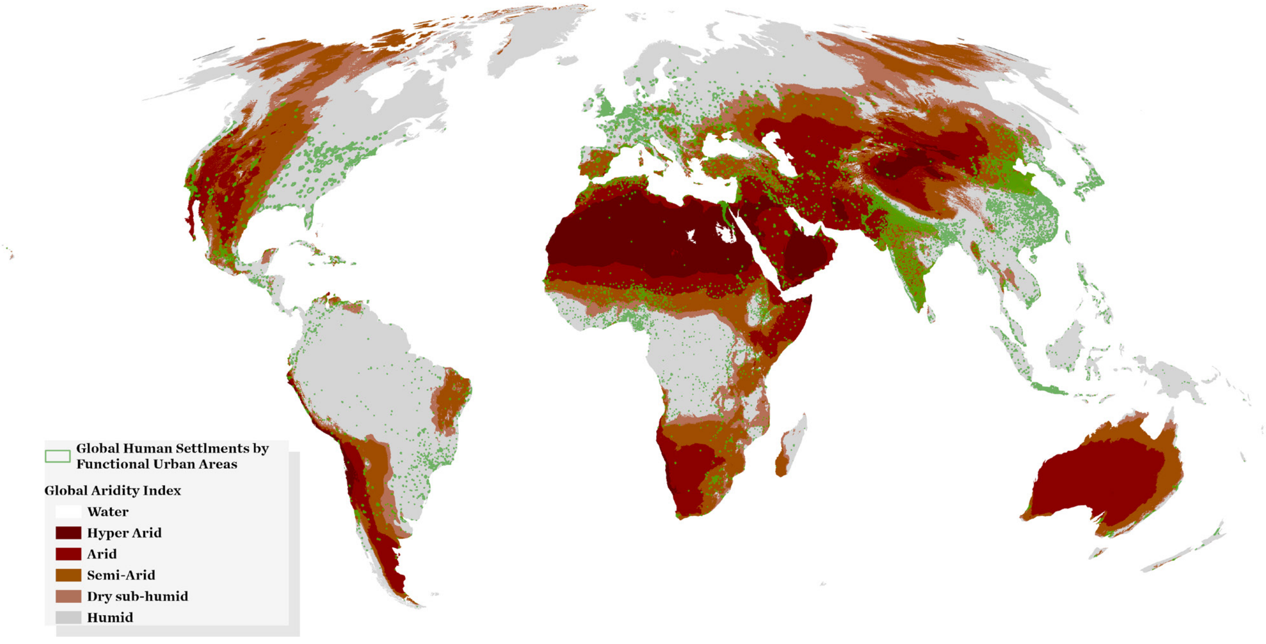
How many people are in arid cities, and where are they?

The climate of a city determines many aspects of how it is structured, from the shape and orientation of buildings and the technologies used to heat and cool those buildings, to the landscape planted around them. One important aspect of climate is how arid or dry a location is. In this report, we use the definition of aridity commonly used by the United Nations Environment Program. They define the aridity index as the ratio of precipitation to the potential evapotranspiration (PET), with high numbers indicating there is abundant water available relative to the demand for water from vegetation, while low numbers indicate demand for water far exceeds supply. The aridity index varies from near 0 (most arid) to around 1.2 (most humid). This aridity index is useful because it is readily measurable and describes how much water is available from nearby the city for all uses, from landscaping, washing, and drinking to agricultural and industrial uses. Climates can be arid (< 0.2 aridity index), or just semi-arid (0.2-0.5).

There are approximately 415 million people living in cities with arid climates (11% of urban dwellers), and another 964 million people in cities in semi-arid climates (25% of all urban dwellers) (Figure 2). Arid climates are widespread in areas of North Africa, the Arabic Peninsula, Australia, and the United States. Other places with aridity include the lands west of the Andes in South America and interior portions of central Asia. Semi-aridity is also widespread, affecting areas like the Sahel in Africa and the Cerrado in Brazil that have dry winters. To give another example, the so-called Mediterranean climate of southern Europe and the Californian coastline has dry, hot summers and is classified as semi-arid.

How will climate change increase heat wave frequency, duration, and intensity in arid cities?

Heat waves are often defined as periods of abnormally hot weather, lasting longer than two days [2]. "Abnormally hot" is often simply defined as being above some reference threshold, either defined in terms of a temperature (e.g., 30˚C) or a heat stress index that incorporates other factors



Data Sources - TNC, ESRI, TomTom, FAO, NOAA, USGS

FIGURE 2. The world's functional urban areas, overlaid on a map of climate zone as defined using the Aridity Index.

such as humidity, solar insolation, and wind. For example, the US EPA has set the threshold for heat waves at the 85th percentile of temperatures observed in a city historically.

Whatever the definition used, it is clear climate change has already shifted the distribution of global temperatures (Figure 3). Mean temperatures have been increasing over time and will continue to do so, shifting the curve to the right. The variation in temperature also appears to be getting more extreme—that is the curve is more spread out with thicker "tails," especially to the right.

This means climate change is increasing the frequency of heat waves. In the US, for instance, the average location has seen the frequency of heat waves per year increase from 2 to 6 between 1960 and 2021, and the duration of each heat wave has gone from 3 to 4 days over the same period [6]. Globally, the average location has seen the frequency of heat waves per year go from 2 to 4 between 1971 and today, with the average duration of each heat wave staying constant at around 4.5 days [7].

Climate change is also making heat waves more intense. The average heat wave intensity (the amount by which temperature exceed the reference threshold) in the US has risen from 1.1˚C to 1.4˚C [6]. Globally, the average heat wave intensity has not changed much from 1971 and today, in large part because as heat waves spread out to more dates with relatively low temperature just above the reference threshold, the average has not changed much [7]. However, the maximum temperature during each heat wave is clearly increasing in the US and globally. For example, in the summer of 2023 numerous high temperature records were set, including 48˚C in Phoenix and 43˚C in Rome [8].

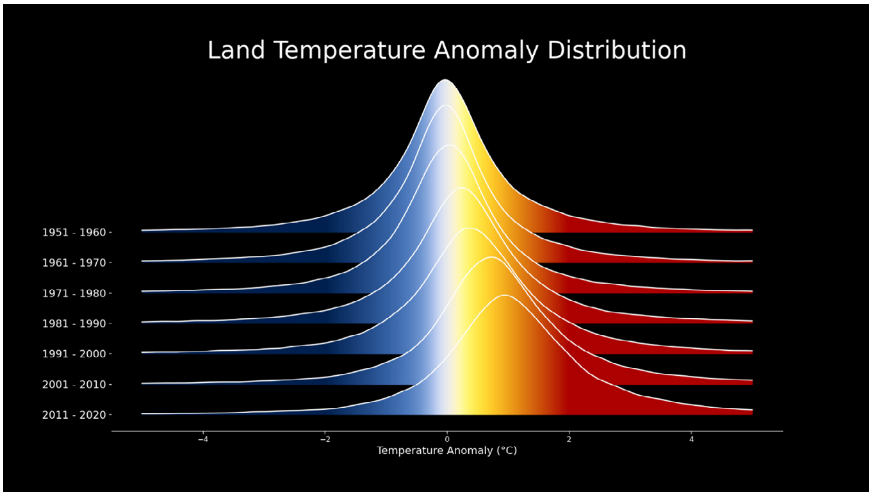
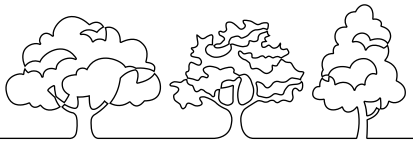


Figure 3. Change in the distribution of land temperature anomaly over time. The land temperature anomaly is the difference between observed the observed value and the long-term historical average. The distribution curve for each decade shows the frequency with which each value is observed. In the 1951-1960 decade, note that the most frequent observation is around 0˚C, identical with the long-term historical average. Over time, the most frequent observation has shifted right, and the distribution of observed values has gotten wider. Figure credit: NASA's Scientific Visualization Studio

Another way to understand how extreme climate change will be is through climate analogs [9]. By 2100, for example, Berlin's climate is expected to be like Madrid's today. Astonishingly, the climate of Warsaw in 2100 is predicted to be like that of Athens currently. These simple climate analogs focus generally on mean temperature and precipitation and do not fully capture the tendency for heat waves to become more frequent and intense. But climate analogs do give us a sense of how major a transition this will be for cities, as they will experience climates vastly different from the those for which they were designed.

The impact of climate change on heat waves is even worse for arid cities than for urban areas on average. According to one study, the population in cities exposed to extreme heat events (defined as > 30˚C in wet bulb temperature) has increased by almost 200% between 1983 to 2016 [10]. About half (52%) of this exposure increase is due to total observed urban warming (which can be due to climate change along with an increase in the urban heat island effect), with the remainder due to urban population growth. About 46% of all urban areas examined in this study had an increase in the number of days with extreme heat between 1983 to 2016. Across all urban areas, the average number of days with extreme heat increased by 22 over this period. Interestingly, the increase in the number of extreme heat days was slightly less in arid cities (16 days) than in semi-arid cities (21 days) or other more mesic cities (23 days). In other words, extreme heat is increasing as a risk in all cities, but it is increasing slightly faster in more mesic cities that tend to be at higher latitudes.

Climate change will also increase evapotranspiration (ET). Higher temperatures lead to higher ET (all else being equal), as the more energetic movement of molecules at higher temperatures increases the rate at which water molecules break away from the liquid water to become water vapor. Changes in precipitation patterns are complex to forecast, and vary by



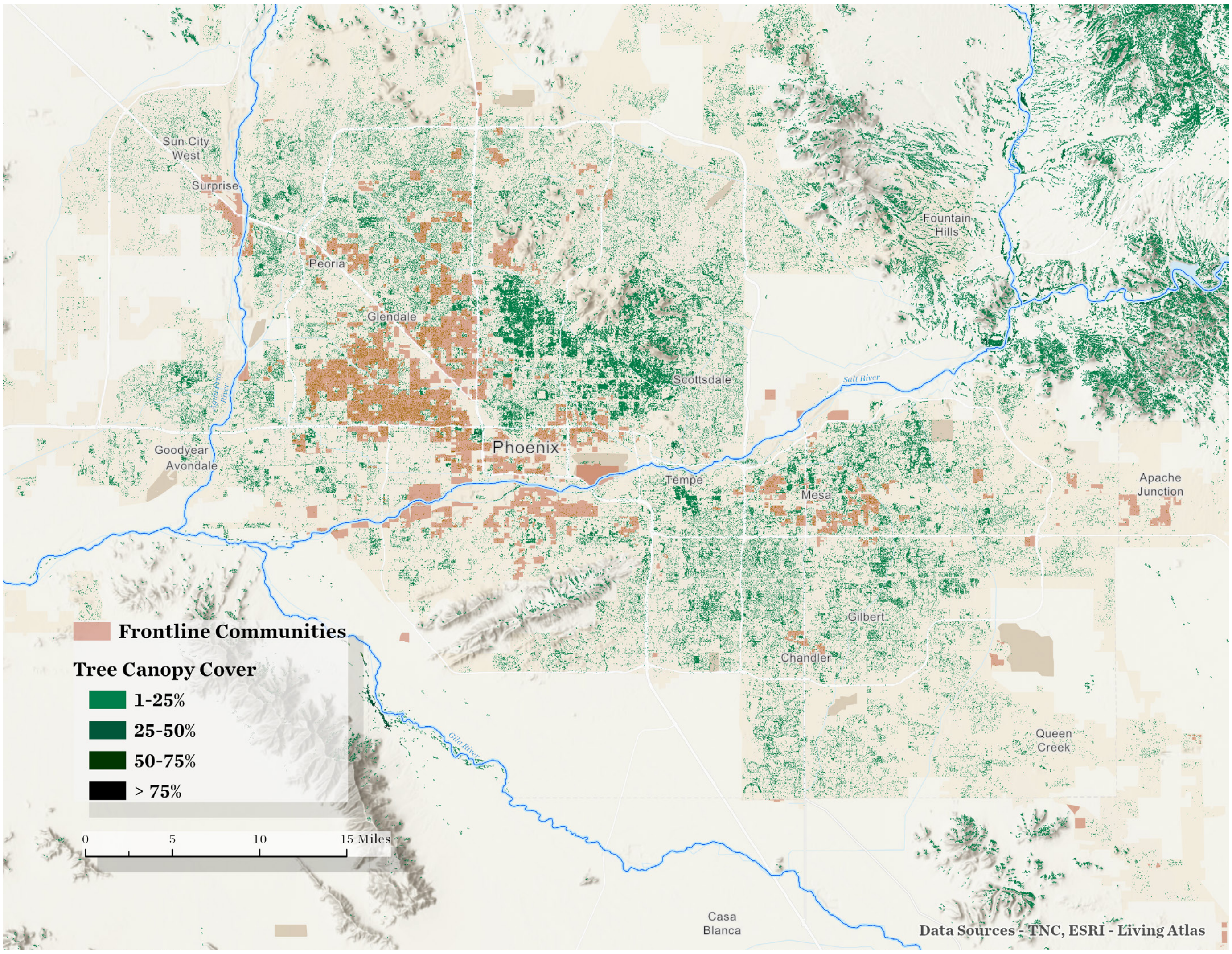
Back to Contents

region, but on average, globally, there is a trend toward more intense rain events but also more intense drought events during dry periods [2].

The increase in ET is strong enough [11] that the aridity index will decrease (i.e., climate gets drier) in most places [12]. The increase in ET, as well as changes in precipitation, will further reduce water availability and decrease the aridity index (note, a lower aridity index implies a more arid climate). Globally, the aridity index is forecasted to decrease (i.e., the climate will get drier) by 0.1 units at 2˚C of average global warming, and a decrease of 0.2 units at 4˚C of average global warming. This implies the water available will be increasingly insufficient to maintain as much present vegetation, and that more cities may struggle with water insecurity. Interestingly, the largest absolute declines in the aridity index will occur in the northern high latitudes, in places that are not currently considered arid or semi-arid. Thus, while this report is focused on cities that are already arid or semi-arid, there will be an increasing number of cities globally that will experience greater aridity in the future.

Where are frontline communities in these cities?

Frontline communities include people who are highly exposed to climate risks and have fewer resources or capacities to respond to those risks. In the US, we will operationalize this definition with respect to heat by calling frontline communities those neighborhoods with average summer land surface temperatures (LST) in the hottest 25% for the city and that have an average household income in the bottom 25% for a city. LST is a simple, easy-to-measure proxy for heat risk that is correlated with air temperature and mortality risk. Similarly, income is a common measure of the capacities of households to respond to stresses,



Data Sources - TNC, ESRI - Living Atlas

Figure 4. Frontline communities in Phoenix that face high temperature and have lower economic resources.

including climate disasters. Internationally we do not have the same kind of spatial data on income available for all cities. Rather, we focus our analysis on the global gridded relative deprivation index, defining frontline communities as those areas within the city that fall in the bottom 25% of this index and that also have an average summer LST in the hottest 25% for the city.

Phoenix can be a useful example of the geography of frontline communities (Figure 4). Low-income and minority communities in the US tend to live in neighborhoods with higher population density, often in row homes or multi-family apartment buildings. These dense neighborhoods have a greater proportion of surface areas covered with pavement and concrete, and hence a lower proportion of area with trees or other vegetative cover. In arid communities, the maintenance of trees and other vegetation often requires ongoing watering; and therefore low-income neighborhoods with generally less vegetation tend to use less water than high-income neighborhoods.

Using the definition of frontline communities listed above, we estimate that there are 4.9 million people in arid or semi-arid frontline communities in our national sample of 6,000 cities, towns, and other places (Table 1). Extrapolating to all urbanized areas in the US, ranging from small towns to big cities, we estimate 9.2 million people live in frontline communities. On average, frontline communities have 46% lower annual household income than other communities and are 2.6˚C hotter in terms of surface temperatures. In absolute numbers, the largest frontline community population in an arid or semi-arid metro area in the US is in the Los Angeles urbanized area, a semi-arid metropolis with 2.2 million people in its frontline community, split among several locations. In our sample, the LA metro area also has a remarkably high proportion of residents who live in frontline communities (18.0%), second only to San Jose, CA (18.6%). The second largest frontline community population in absolute terms is in the arid Phoenix metro area, which has 520,000 people living in its frontline communities, or 14.2% of its overall metro area population.

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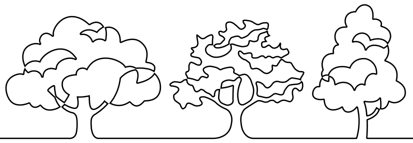
TABLE 1. The differential (frontline communities minus other communities) in key characteristics for large United States arid or semi-arid metro areas. A positive value means this characteristic is greater in frontline communities than in other communities, while a negative value means this characteristic is lesser in frontline communities. For instance, if frontline communities have a tree cover of 10% and other communities have a tree cover of 15%, then the tree cover differential is -5%.

Name	Tree cover differential (%)	Surface temperature differential (˚C)	Income differential (USD)	Population density differential (people/km^{2})
Albuquerque, NM	-4.1%	+2.3	-$14,703	+1,172
Austin, TX	-21.4%	+1.7	-$19,710	+1,567
Concord, CA	-12.0%	+2.2	-$26,260	+1,051
El Paso, TX—NM	-2.6%	+1.2	-$9,144	+404
Las Vegas—Henderson, NV	-2.3%	+2.3	-$16,820	+985
Los Angeles—Long Beach—Anaheim, CA	-4.4%	+2.6	-$25,601	+2,960
McAllen, TX	-0.6%	+1.1	-$7,200	+1,123
Ogden—Layton, UT	-7.4%	+2.1	-$9,924	+491
Oklahoma City, OK	-9.8%	+1.3	-$15,329	+925
Phoenix—Mesa, AZ	-4.2%	+2.1	-$20,724	+1,078
Riverside—San Bernardino, CA	-8.5%	+2.6	-$12,890	+143
Sacramento, CA	-10.4%	+1.9	-$18,668	+799
Salt Lake City—West Valley City, UT	-6.2%	+1.7	-$15,483	+850
San Antonio, TX	-12.1%	+1.2	-$15,191	+854
San Diego, CA	-3.2%	+3.1	-$22,635	+2,090
San Jose, CA	-8.1%	+2.4	-$35,679	+2,239
Tucson, AZ	-2.8%	+1.5	-$15,435	+582



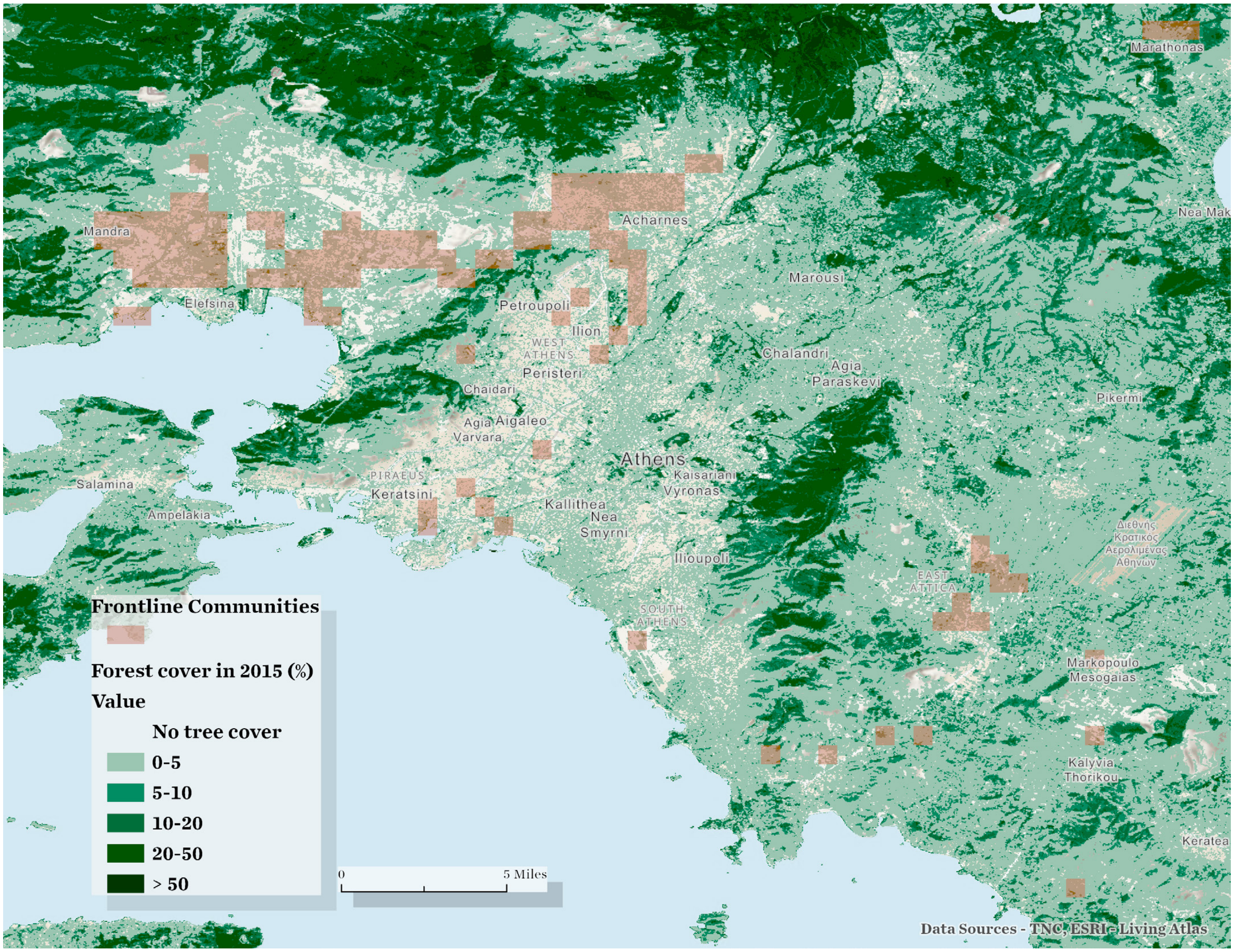


Figure 5. Patterns of forest cover and identified frontline communities. Forest cover is shown, as measured in 30m resolution Landsat imagery. Notice the chain of urban areas from Keratsini to Petroupoli with low tree cover. These areas also have high surface temperature. Using information on hot spots, as well as areas of relative deprivation, we identified frontline communities (in grey).

Athens, Greece, can be a useful example of the geography of frontline communities internationally. While low-income communities tend to be at higher population density than the metro average (i.e., housed in dense housing blocks), the negative correlation between LST and income is relatively weak, since there are central historical areas of the city that are quite affluent and prosperous. Nevertheless, as with the Phoenix example, low-income neighborhoods in Athens have less vegetation than the city average. Again, since trees and other vegetation in semi-arid areas like Athens often require watering, low-income neighborhoods tend to use less water but have higher LST.

Mapping frontline communities for all arid cities globally is made difficult by the incompleteness of many global datasets of income. In this report, we use the Global Gridded Relative

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Deprivation Index (GRDI) from the NASA Socioeconomic Data and Applications Center as a proxy for income. This index, while a helpful mapping of economic deprivation globally at a 1km resolution, is not a perfect analogy to income. For instance, several of the assumptions built into the GRDI assume that rural areas (including those within a functional urban area) will have greater deprivation and less income than more urban areas. While this is true globally, it does limit the utility of this index to capture urban areas of deprivation, such as informal settlements. Regardless, it is a useful example of how frontline communities might be mapped globally.

In the 3,595 functional urban areas (FUAs) in arid or semi-arid climates (total population 1.2 billion), we estimate that around 8.0% of residents, some 96 million people, are in frontline communities, defined here as in the top 25% of hottest areas within a FUA and within the 25% of areas that are most economically deprived. The ten arid or semi-arid FUAs globally with the largest population of people in frontline communities are shown in Table 2.


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Table 2. Estimated population in frontline communities for the Functional Urban Areas with the largest estimated frontline communities.

Name	Country	Aridity category	Frontline population
Karachi	Pakistan	Arid	2,926,801
Delhi	India	Semi-Arid	2,325,380
Mexico City	Mexico	Semi-Arid	1,231,752
Cairo	Egypt	Arid	1,185,469
Tehran	Iran	Arid	990,460
Bengaluru	India	Semi-Arid	961,913
Los Angeles	United States	Semi-Arid	818,700
Johannesburg	South Africa	Semi-Arid	738,031
Amman	Jordan	Arid	704,393
Toshkent	Uzbekistan	Semi-Arid	701,776

How much worse is heat risk already in frontline communities?

Frontline communities are already hotter than the average community in a city. More impervious surfaces, like pavement and concrete mean more energy from the sun is absorbed, warming those surfaces and later releasing it as thermal energy (heat). Less tree canopy cover (in US arid or semi-arid cities, 12.6% in frontline communities versus 17.1% on average) means less shade, which increases the amount of sunlight reaching impervious surfaces. These differences lead to significant variations in surface temperatures. For frontline communities in arid or semi-arid US cities, we estimate that their LST is 2.2˚C above the average in those cities. For frontline communities in arid or semi-arid cities globally, the land surface temperature in frontline communities is 2.4˚C above the average in those cities. Moreover, each degree of temperature difference really matters during a heat wave. For example, an epidemiological study in the US found that each 1˚F (0.6˚C) degree change in temperature leads to 2.5% greater mortality risk during heat waves [13].

Frontline communities also often have greater vulnerability during heat waves. Lower-income residents may have higher rates of preexisting conditions that make them more vulnerable during heat waves, and they may have less access to

Back to Contents

affordable medical care. Frontline communities often have less adaptation capacity. For instance, residents in frontline communities often lack air conditioning, or some households have an inability to run it frequently due to the cost of electricity. These types of factors make frontline communities more dependent on ecosystem services, like the cooling effect of trees.

How might climate change hit frontline communities more severely?

Climate change is expected to hit frontline communities during heat waves for at least three reasons. First, there is more *exposure* to extreme temperatures. Fewer trees and a greater amount of impervious surface area means increased storage of solar energy in pavement and concrete, which is later reradiated as heat, and less transpiration from trees to cool temperatures. People living near hot impervious surfaces will be exposed to increased air temperature, and since frontline communities are often at a higher population density than other, more suburban or rural communities, frontline communities contain relatively large populations exposed to elevated temperatures. This exposure will become even more dangerous as climate increases the frequency, duration, and intensity of heat waves.

Second, people living in frontline communities have greater *vulnerability* to impacts during heat waves. For instance, a higher rate of people in frontline communities have preexisting conditions that make them prone to heart disease or stroke or any of the dozens of medical conditions made worse by heat waves. Many people in frontline communities also have outside jobs (e.g., agriculture, construction), making them more likely to be impacted by heat. Therefore, as climate change ramps up the heat, we expect the impact on vulnerable populations in frontline communities will be greater than in other neighborhoods. As heat wave intensity increases, the risk of heat exhaustion and heat stroke will go up, particularly for those outside during the hot part of the day. Moreover, as heat wave duration increases and if nighttime temperatures stay elevated, the interior of houses could become dangerously hot.

Third, those in frontline communities often have less *adaptive capacity*. High-income households can afford to increase the use of air conditioners and fans, which also increases the aggregate municipal consumption of electricity. Low-income households may not own an air conditioner, or to be able to afford the extra burden of a rising electricity bill. As climate change increases the heat, an obvious adaptation will be for households to run air conditioners and fans more. By 2050, global capacity for air conditioning is estimated to be 2.7 times greater than today. And in developing countries, this factor is likely to be 15 times[14]. While this expansion in cooling capacity will occur in almost all communities, it is expected to occur at a slower rate in low-income communities. Thus, in this sense, frontline communities will likely continue to have less adaptive capacity than other neighborhoods.

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Back to Contents

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LOCALLY ACTING TO EQUITABLY INCREASE TREE COVER TO REDUCE HEAT RISK

In this section, we address how frontline communities in arid cities manage to plan for, implement, and maintain nature-based solutions to heat risk. Efforts at urban greening face unique challenges in these communities, and yet many of these communities manage to successfully implement urban greening projects. We first discuss some general strategies and principles for planning for urban NBS for equitable heat reduction. We then present two detailed city case studies, Phoenix and Athens, which are working to equitably increase vegetative cover to reduce heat risk.

Strategies to promote equitable greening

There are several diverse ways frontline communities work to promote community-led greening. One common first technical action is mapping exposure to heat, which pinpoints areas where this hazard is more intense. This can be quickly measured through land surface temperature (LST), which can be easily mapped off Landsat Thematic Mapper imagery, and, in some places, pre-existing LST maps already exist and are freely available. Communities can also use data from air temperature sensors, or even gather residents' perceptions of hot areas during community meetings. The goal should be to map where heat is experienced most intensely by residents during their everyday lives.

Another related first step is mapping vulnerability. Frontline communities are by definition some of the most vulnerable, but within their neighborhoods there are still gradients of vulnerability, varying across different scales due to varying drivers. Average household income, especially when available at fine spatial resolution, is one commonly used proxy for vulnerability, which is useful because it is commonly known and correlated to many aspects of vulnerability. More accurate is information on building characteristics, like the presence of air conditioning or ceiling fans, as well building material and insulation. And, of course, health indicators of vulnerability are important, such as residents' average age and preexisting conditions that could be exacerbated during heat waves.

With this sort of information, public health officials and municipal foresters can engage frontline communities to co-develop greening plans. Urban greening plans can take different forms depending on the decision context, but at their core, they are plans that describe *where* and *what* a scenario for urban greening looks like or will include. In the case studies that follow, we discuss components of a greening plan, sometimes referred to as a greenprint. Community involvement is key to ensuring these plans are desired and

Back to Contents

acted upon. All steps of the development of an urban greening plan require some sort of community input, although how this occurs varies by phase.

An important next step is identifying potentially plantable areas, which are places within the community where it is conceivable trees could be planted. One crucial factor is to identify where surfaces are sealed and impervious because of pavement or concrete. It is often expensive to remove such impervious surfaces, so it is logical to focus attention on the remaining pervious portion of the landscape. Other factors to consider are regulations (e.g., set-back requirements that sometimes apply to trees in some jurisdictions), infrastructure conflicts, or land-use limitations. Finally, community desires can be incorporated at this stage, putting certain areas “out of bounds” for urban greening effort plans based on feedback.

After potential areas have been mapped, communities should pick a portfolio of sites for action from the broader set of potentially plantable areas. A variety of factors come into play at this stage. Community members may perceive certain places are more in need of trees. There may also be certain political opportunities, such as when a particular government agency or landowner is willing to plant trees. Funding sources may also constrain planting to certain sites.

Sometimes it is helpful for building consensus for an urban greening plan to calculate the benefits if the plan were implemented. Estimating how the canopy area will increase is straightforward, given the number of new stems planted. It is then possible to translate these changes in tree canopy to changes in shade provision and air temperature. It is more difficult, without collaboration from epidemiologists, to estimate potential local health benefits. Regardless of the methods used, keep in mind most benefits that trees provide will occur within a couple hundred meters of their planting. Determining the *where* of planting therefore helps determine *who* will benefit.

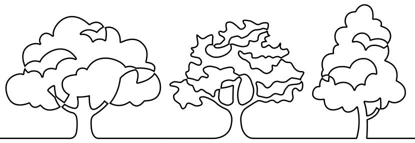
One common challenge to implementing greening plans is funding, and this can be particularly challenging in frontline communities that might have lower economic resources. (Note: this topic is discussed in more detail in the “Policy and Funding Options” section.) Since every situation is a different, each community should seek their own unique funding solution. In the case studies in this section, we have highlighted the diverse opportunities for funding solutions in these communities. As highlighted above, the source of finding often affects the *where*, and it is common for communities to have to cobble together various sources.

This report focuses particularly on challenges facing frontline communities in arid cities. Given this context, finding appropriate water for tree establishment also poses a challenge. Such challenges can occur on a political level when, for instance, municipalities are skeptical about investments in tree planting because of limited water resources or availability. Or they can arise at a programmatic level, when landowners express concerns about paying bills to water trees on their property, as is often required in arid and semi-arid cities. As discussed elsewhere in this report, the selection of the right tree species can reduce water needs, and there are other techniques to minimize the water required during establishment for ongoing tree maintenance at arid sites.

Another common challenge frontline communities face when planning for NBS may be concerns that a lack of tree maintenance over time could lead to trees that present hazards. For example, some may worry about the risk of trees that fall or drop branches during storms. This, however, is an unlikely occurrence, and planners can hopefully reassure communities they have budgeted for maintenance over time. Also, community members may express concerns that wooded areas will become sites for crime or become trash ridden. But with proper maintenance, this can be avoided, particularly if understories are cleared and sites include proper lighting.

Perhaps the biggest—or at least the most controversial—concern many communities express relates to potential gentrification. The concern is that planting additional trees may make a neighborhood a more desirable place to live and the increased demand to live there might lead to higher rents or housing prices. The reality is that while trees do affect prices, the effect is generally minor, around 5-10%. Moreover, this effect happens with *any* amenity, from playgrounds and schools to hospitals and improved mass transit access. Tree planting plans must be seen as one part of a community development plan, developed *with* the community, and these plans should address multiple goals, including those aimed at ensuring affordable housing.

To deal with these various community concerns, it is helpful to include an education campaign. By correcting misconceptions or apprehensions, such outreach can help increase community support. An education campaign can also spur support from political leaders. It is important the campaign is fact based and communicates the best science. Equally, effective campaigns must be designed by—and delivered by—community members or their trusted allies.



Back to Contents

Phoenix case study

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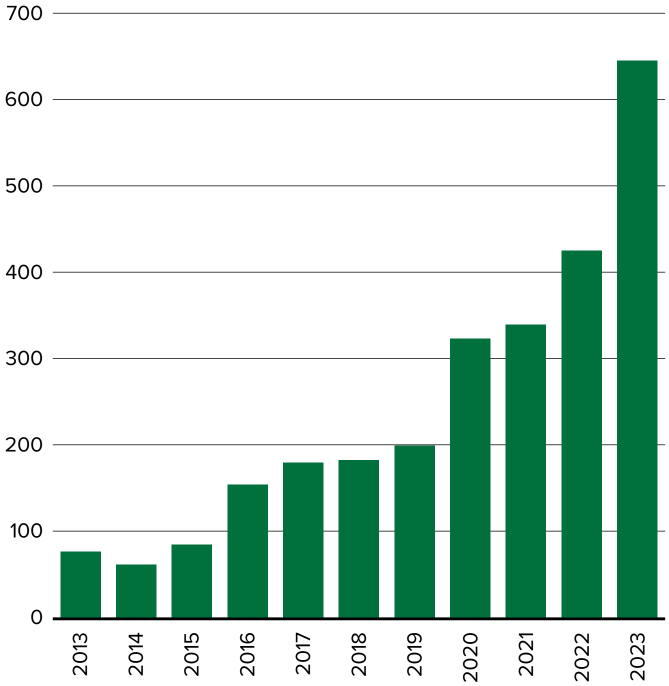


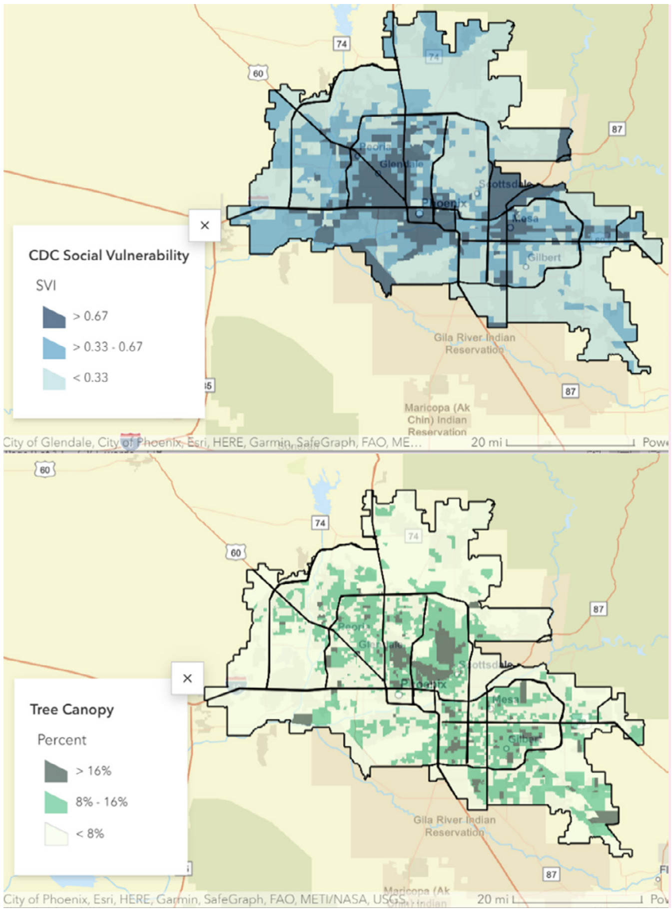
Figure 6. Heat deaths in Maricopa County over time. Data from the Maricopa County Department of Health.

Phoenix, Arizona (US), located in the Sonoran Desert, is known for its iconic cactus, the Saguaro as well as the region's dry heat. In July 2023, Phoenix endured the hottest month ever observed in a US city—31 days above 43°C. During the summer months, the pavement in Phoenix frequently registers a surface temperature above 71°C, hot enough to cause burns that require hospitalization. Common items like seatbelts, mailboxes, and safety railings can cause second or third-degree burns. Even water coming from garden hoses can scald skin by reaching temperatures close to boiling.

Phoenix is the hottest large metropolitan area in the United States and is projected to become even hotter. Apart from its desert climate, Phoenix also has a large urban heat island effect due in part to the metro area's urban design. The urban heat island effect is caused by roads and buildings absorbing heat during the day and re-emitting the heat at night. Phoenix is a fast-growing, lower-density city that has been built to prioritize travel by car. To accommodate the number of cars, streets are built wide, in many cases to fit seven lanes. Additionally, it is estimated that 10 percent of the region's land use is dedicated to parking spots. This enormous amount of asphalt absorbs heat and re-emits it at night, making the city's temperature much hotter at night than surrounding rural areas.

These factors, combined with a growing population and climate change trends, mean the number of days above 43°C is expected to more than double by 2060, putting this metro area of more than 4.5 million residents at extreme risk of heat-related death and illness. In addition to the threat extreme heat poses to public health, American Lung Association rated in 2023 Phoenix the fifth most ozone-polluted metropolitan area in the US. And from 2021 to 2022, there was a 25% increase in heat-related deaths in Maricopa County (Figure 6), the county that encompasses the Phoenix metro area. This alarming increase represents an upward trend in deaths that spans a decade.

Rising heat levels in Phoenix affect the entire population but have a disproportionally high effect of frontline communities. On some days, the air temperature in some neighborhoods is up to 13 degrees Fahrenheit hotter than others. The hottest neighborhoods have two factors in common: fewer number of trees and higher social vulnerability. Social vulnerability refers to the ability of communities to survive and thrive when confronted by external stresses on human health (CDC).



City of Glendale, City of Phoenix, Esri, HERE, Garmin, SafeGraph, FAO, ME...

City of Phoenix, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS,

Figure 7. The link between social vulnerability and tree canopy in Phoenix. Source.

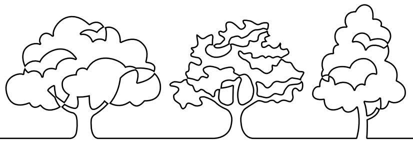
Neighborhoods with higher social vulnerability have higher poverty rates, homes without access to vehicles, and lower education rates (Figure 7). In Phoenix, for every $10,000 increase in neighborhood annual median household income, residents benefited from a decrease of 0.28˚C in surface temperature. Due to historical government-sponsored discriminatory practices, such as redlining, which created unequal lending and zoning based on race and immigration status, people of color are more likely to live in hotter and more polluted neighborhoods with less vegetation. The legacy of these practices in the Phoenix metro area today is that communities with the fewest resources and the least political capital are hotter, with less tree canopy and more heat-related illnesses than wealthier residents.

In 2010, the City of Phoenix adopted its first Tree and Shade Master Plan, which outlined a goal to achieve an average of 25% canopy coverage across the entire city by 2030. However, 14 years after the adoption of the initial Tree and Shade Masterplan, the city's tree canopy coverage remained at the same level as when the plan was passed in 2010 (approximately 11%). Current analysis shows that while the city planted nearly 33,000 trees on public property over 14 years, it also removed 21,000 leaving a gain of only 12,000 trees.

The key issues that led to insufficient progress toward 25% shade cover target were a lack of funding, high employee turnover, and unclear implementation procedures. In 2012, concern over the Great Recession froze city funding for the tree-planting program. Until the establishment of the city's Office of Heat Response and Mitigation in 2021, responsibilities for monitoring the tree-planting program shifted between city departments and, as a result, certain tree planting, maintenance, and monitoring responsibilities were inconsistently completed after 2014.

Affected residents concerned about insufficient action on the Master Plan goals helped bring about the creation of the Urban Heat Island/Tree and Shade Subcommittee to the City's Environmental Quality and Sustainability Commission in 2018. The committee included members of arboriculture, urban forestry, community health, commercial development, urban planning, environmental education, academia, and residents. Together they developed recommendations for the implementation of the city's tree and shade efforts, including the Cool Corridors Program that was introduced in 2021 and included a $1.4 million investment to the Street Transportation Department. With the Subcommittee's guidance, city staff and researchers identified where tree planting would be most valuable. To do this, researchers examined areas of the city with the highest neighborhood heat vulnerability, public transit dependency, pedestrian use, highest temperatures, and least shade. Since then, Cool Corridor projects have been completed, initiated, and planned in high-need areas throughout the city.

In June 2024, The City of Phoenix presented a comprehensive update to the city's Tree and Shade Masterplan called the "Shade Phoenix Plan" to reset the policy foundation for tree and shade initiatives in Phoenix and accelerate action. The new shade plan differs in several ways from its predecessor. First, it establishes a new set of core values to guide tree and shade programs, including priorities on equity and recognition of the physical environment, culture, and history of the region. It also presents a more detailed and robust set of tree and shade coverage metrics to establish baselines for understanding current patterns and tracking future progress. To address funding concerns, it is backed by a commitment of $50 million in local, federal, and private funds over the next five years. The estimated costs mean the city will budget $17 million for new trees, $15 million for maintenance,



$18 million for new built shade, and $2 million for workforce development and programming. In alignment with its core values, the Shade Phoenix Plan more explicitly focuses on vulnerable communities affected most by heat. The plan is focusing on low- and moderate-income level areas as well as high transit and pedestrian use areas, such as bus stops, playgrounds, and parks.

City governments have typically prioritized tree planting investments on public property, which generally accounts for a low percentage of the total land area of the city. In Phoenix, public land—excluding its large mountain preserves—accounts for less than 10% of plantable/shadeable space. The City of Phoenix has now developed new initiatives to expand the scope of its tree planting efforts to residential property and non-municipal public partners and non-profits, including schools, through federally supported grant programs.

The new Shade Phoenix Plan and many of its component actions draw inspiration from the Heat Action Planning Guide for Greater Phoenix, an initiative spearheaded by The Nature Conservancy's Arizona Chapter (TNC AZ) from 2017-2019. In collaboration with Maricopa County Department of Public Health, Arizona State University's Urban Climate Research Center and Urban Resilience to Extremes Sustainability Research Network, Central Arizona Conservation Alliance, Center for Whole Communities, Phoenix Revitalization Corporation, RAILMesa, and Puente Movement, TNC facilitated the creation of a participatory Heat Action Planning process in three metro-Phoenix neighborhoods disproportionally impacted by heat. In this process, residents identified areas in which they experience extra difficulty with heat and spoke about what is needed in their communities to decrease heat and improve safety. This program has catalyzed additional research and community engagement in Phoenix, and shaped public-sector tree and shade initiatives in multiple other municipalities.

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TNC AZ continued leading local efforts to improve heat planning and community engagement by collaborating with Phoenix Revitalization Corporation (PRC), a non-profit community development organization that works to facilitate improvement projects and advocate for equitable housing in Central City South. Together, they created the cohort-based Urban Heat Leadership Academy that engages in expert-led bilingual community discussions and interactive exercises that are focused on empowering residents to organize and advocate for cooler, greener, healthier neighborhoods. Their efforts encompass advocating for more trees, cool walkable corridors, and using rainwater for trees and vegetation in their communities.

Community buy-in

Residents are experts when it comes to their neighborhoods, making them the most qualified to identify the key heat-related challenges. One key equity tenant of TNC is supporting the voices and visions of local communities to co-develop conservation solutions focused on community-driven health and well-being outcomes. After attending the Urban Heat Leadership Academy, community members have new knowledge about sustainability challenges related to urban heat, air quality, and water. Upon graduation, residents possess the tools to mobilize their communities to advocate for a greener, cooler, and healthier Phoenix.

Planting and growing more trees in a water-scarce region

The City of Phoenix has a 2050 goal to provide clean and reliable 100-year supply of water. But drought, the variable flows of the city's primary source of water (the Colorado River), climate change, and population growth makes this goal difficult. Tree planting is aligned with Phoenix's goals if planting follows the "right tree, right place" guidance. "Right tree" refers to native species that are drought tolerant and use little water after being established. A 2017 tree irrigation study by the University of Arizona evaluated different watering strategies on native species and found that, after the initial establishment watering period, a dry irrigation strategy of 518 gallons per year produced healthy trees. Over the last 10 years, water usage in Phoenix has been relatively constant—around 100 billion gallons per year. As such, maintaining a million trees with 518 million gallons of water annually would only amount to about 0.5 percent of the city's annual water usage.

Back to Contents

Athens case study

Athens and its Acropolis are iconic symbols of democracy and of what we consider the classical ideals and values found in the Greek civilization that flourished more than 2 millennia ago. Today, the city is the capital of modern Greece and has a population of 640,000 people in the city proper and around 3.8 million people in the overall metropolitan region. While the population of the metro region is only slightly smaller than the Phoenix metro area, they have quite different climates. Athens traditionally has a Mediterranean climate with hot, dry summers, but cool, moist winters. Importantly, for the focus of this report, Mediterranean climates can support trees without additional watering once established *if* they are a species adapted to the climate. In the metro region more broadly, both greenspace and tree cover are inequitably distributed, as these areas are located primarily in the eastern suburbs of the metro area and less so in the western portions of the metro area.

The City of Athens has typical levels of greenness for a city in a semi-arid zone. Some 4.6 square kilometers out of 38 in Athens have some sort of 'green cover,' including shrubs and chaparral, representing some 12% of the total landscape. Most of this greenspace is found in parks and cemeteries or hillsides with less development (72%), while a smaller fraction is found in squares or along streets (22%). In total, the City of Athens metro area is estimated to have some 130,000 trees, with about 95,000 lining its streets. The primary species are mulberries (21%), Seville oranges (19%), and Acacias (8%).

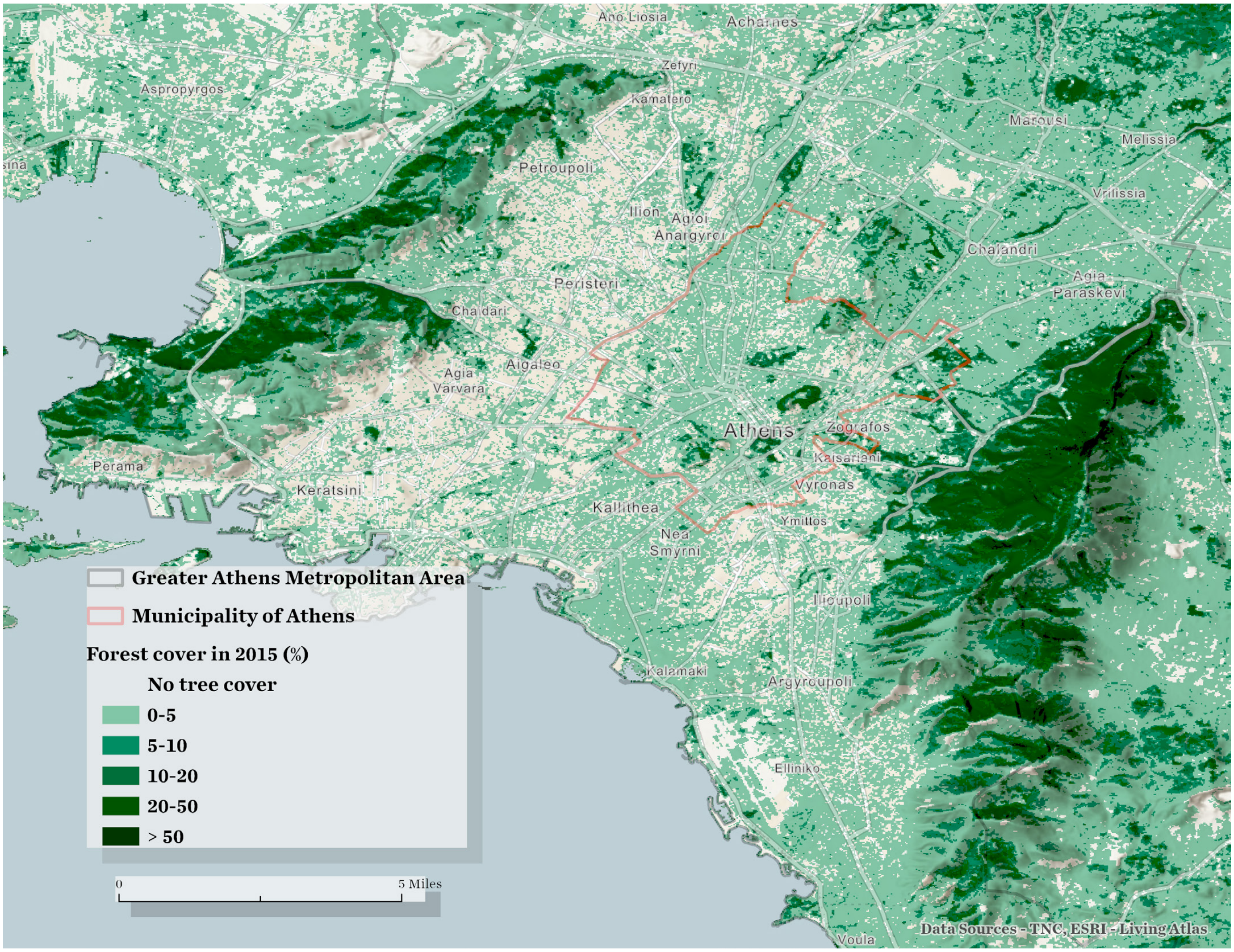

Figure 8. Forest cover in the Athens metro area.

Lower-income neighborhoods in the Athens metro area are concentrated in places like the western part of Athens municipality, the western suburb of Tavros, and a north-western group of suburbs that include Aspropyragos, Fyli, Acharnes, and Kamatero. While wealthier neighborhoods are scattered throughout the metro area, there is a special concentration of wealth in areas in the city center such as near Lycabettus Hill. These upper-income areas in Athens are densely populated and do not necessarily have elevated levels of tree cover, although those directly adjacent to Lycabettus Hill have easy access to its hilltop park. However, there certainly are densely settled low-income neighborhoods in Athens where apartments lack air conditioning or the financial means to use it. In the past decade, 'energy poverty' has affected up to 25% of Athens' population.

Athens has already experienced around 1°C of warming, with its average annual temperature increasing from around 18°C in the 1990s to about 19°C today. By 2050, the city expects to have at least another degree of warming, and the number of heat wave days is expected to double from the current total to 15-20 days annually. During the same period, rainfall is expected to decrease by an average of 12%. Moreover, drought is affecting mulberry trees hard, as are wood-boring Tiger Longicorn Beetles (Xylotrechus chinensus), which can wreak havoc on these water-stressed trees. As in other tree species, it is possible there may be synergistic effects between climate change related factors that weaken trees, like droughts, and insect outbreaks.

In 2017, the municipality released its Athens Resilience Strategy for 2030, which considered several aspects of climate change and discussed changes in green infrastructure, the built environment, public health protection, and public information and awareness. One of the first actions implemented was the #CoolAthens campaign, aimed at raising awareness about heat risks. Another initial action was the designation of green corridors for heat-risk reduction.

In 2018, the Athens Resilience Strategy for 2030 anchored a 55 million Euro loan from the European Investment Bank (EIB) that was centered on resilience efforts. The loan included money for a Natural Capital Finance Facility—a tool that provided funding for the design and implementation of three green corridors in Athens. These corridors were designed to connect existing greenspaces and provide a cool route through neighborhoods that currently lack much greenspace. The initiative also included a Sustainable Water Management Plan for Lycabettus Hill—an iconic urban forest that is widely cherished by its residents and visitors.

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In 2021, Athens municipality, in collaboration with Arsht-Rock Resilience Center, appointed a Chief Heat Officer to coordinate municipal actions against the threat that heat poses as well as to collaborate and co-design solutions in tandem with the city's frontline communities. A more robust Heat Action Plan was established based on three pillars of actions: *Awareness* raising, *Preparedness* actions for protection of the most vulnerable during heatwaves, and Redesigning plans for a nature-positive and cooler city.

Among the Awareness and Preparedness solutions the city established was a heatwave categorization system, early heat-risk warnings, and a mobile app (the Extrema Global app), which provides personalized risk information and suggests nearby cool spaces in collaboration with the Hellenic Red Cross. Athens also created a hotline that dispatches vans that distribute drinking water as well as information about known hotspots, the cooling centers and cooler, cooler green corridors.

To categorize heatwaves, they developed a scientific system to classify the severity of heatwaves. To do so, they first quantified how past heat wave events increased mortality, and then they applied these models to short-term weather forecasts from the National Observatory of Athens and the website meteo.gr. The forecasted mortality risk is then translated to a simple-to-understand ranking of heat wave risk in the near term, and that, in turn, informs the Early Warning System messages that target frontline communities in Athens.

Finally, to create a cooler city, Athens municipality created a three-year program to renovate and restore existing green spaces by employing improved maintenance practices. This action created "pocket-parks" wherever possible and two large new parks in some of the most population-dense or hottest districts. Water is certainly also a resilience challenge for Athens, and greening projects have been designed with this in mind. Beyond the EIB-funded program focused on sustainable water management at Lycabettus Hill, another project aimed at using an untapped water source—a two-thousand-year-old monument, Hadrian's Aqueduct—to irrigate and green a 24km cool corridor. The Hadrian Cooling District has its own Heat Risk Reduction Guidelines, which explain how to use nature, water, and materials to lower temperatures in basic urban typologies, such as streets, squares, and parks. A planting palette was created so that tree planting is done with drought-tolerant species where possible, to further prepare for climate change.

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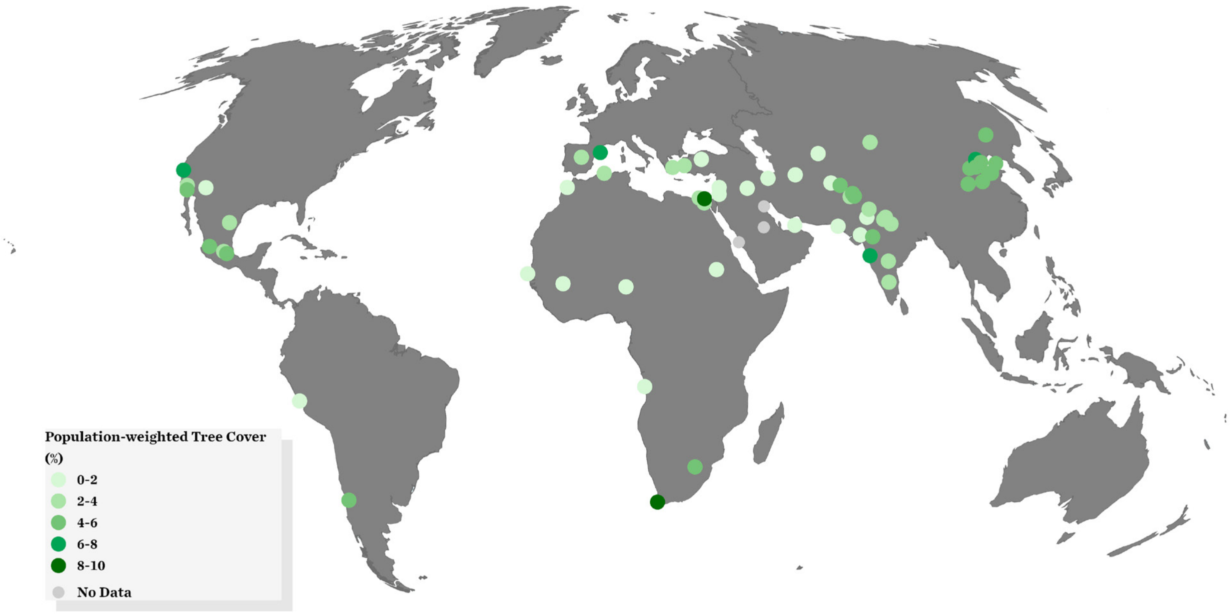
GLOBAL MAPPING OF POTENTIAL FOR TREES TO HELP

The previous sections laid out the scope of the problem facing arid cities, which will struggle with both higher temperatures and greater water insecurity in a climate-altered world. We then discussed how on-the-ground, frontline communities have expanded tree canopy to reduce their heat risk, focusing especially on examples from Phoenix and Athens. In this section, we return to a global scale and examine the global potential for tree planting in arid cities. Here, we examine how much tree canopy can realistically be expanded, how much that can reduce the impacts of extreme heat events, and what are the tradeoffs of this strategy in terms of implications for water security.

What is the current tree canopy cover in arid cities?

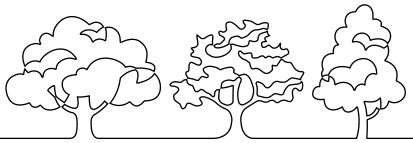
There are various methods for estimating tree canopy cover. Sometimes trees are directly surveyed on the ground, or humans interpret aerial photos at a set of control points to statistically estimate the percent of tree canopy cover. More commonly, tree canopy cover is assessed with classified remotely sensed imagery. In general, the amount of tree cover detected in urban areas is related to the resolution of the imagery. In this study, we use 30m resolution Landsat imagery (Tree Canopy Cover version 4), which has been processed to estimate percent tree cover in each pixel, and provides adequate estimates for most urban areas. This contrasts with some other datasets, including recent 10m categorical estimates of forest cover, where urban tree canopy is subsumed into an urban land cover category. Past studies [3] have shown that while 30m resolution data generally captures the major patterns of urban tree cover, it often underestimates its total extent. We caution that the numbers in this section likely underestimate total tree canopy cover.

The citizen of an arid city has on average 1.5% tree cover in their neighborhood, while the average for citizens in semi-arid cities is 4.2%. Note that this is the population-weighted average, so it measures the average where people live and gives less weight to sparsely populated portions of a FUA.



Data Sources - TNC, ESRI, TomTom, FAO, NOAA, USGS

Figure 9. The average tree cover in a 1km neighborhood around residents' homes, in Functional Urban Areas above 3 million people in population (2015). Tree cover was assessed using 30m resolution estimates of the % canopy cover, derived from Landsat imagery, and is an underestimate of the true tree cover, since small tree canopies are sometimes missed at this resolution.



The amount of tree cover varies widely among arid and semi-arid cities (Figure 9). Some of the highest average tree covers are in arid cities in the Southwest US and Southern Europe. Conversely, some of the lowest tree covers are in arid cities in developing countries, which are more densely settled than cities in developed countries and which have fewer economic resources to devote to something like tree planting. Tree cover also varies widely within cities. For instance, different neighborhoods in Athens vary from 0% tree cover to 26.5% in tree cover.

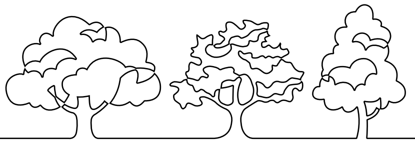
If we split neighborhoods in these arid cities into categories by aridity and by impervious surface cover class, and we can see more clearly the pattern (Table 3). Tree canopy is greater in semi-arid than in arid areas. This is to be expected, because it is easier to establish and grow trees when there is more rainfall. Tree canopy is also systematically less in neighborhoods that have more impervious surface cover—a trend that is typical in areas with higher population densities. We do not have spatial data on income for all these cities, but we know from studies in some countries that usually lower income (i.e., those in frontline communities) are in these higher population density areas.

Table 3. The average population-weighted forest cover for large functional urban areas (> 3 million), by climate and impervious surface cover category.

Climate	Impervious surface cover	Forest cover (%)	Population density (people/ha)	Average impervious (%)
Arid	> 50%	0.4	335	54.3
	25-50%	0.8	360	38.0
	10-25%	2.8	122	18.1
	5-10%	4.3	62	7.5
	< 5%	4.6	34	2.7
Semi-Arid	> 50%	1.6	390	56.6
	25-50%	3.8	210	36.7
	10-25%	5.3	101	18.1
	5-10%	5.9	48	7.6
	< 5%	6.1	24	2.4

How much tree canopy enhancement is feasible?

There are different methods for estimating how much tree canopy can be enhanced in a city, whether by new tree planting, allowing natural regrowth of trees, or increased maintenance that reduces mortality among existing trees. An upper bound is often set by looking at physical barriers to planting, such as buildings and impervious surfaces. While there are solutions to planting trees in such spaces (e.g., green roofs or removing pavement), they tend to be expensive and can disturb the existing land-use at a site. There are, however, due to regulatory, social, or cultural reasons, many other barriers to tree planting. For example, many municipalities have rules about planting trees near the edges of property lines or put restrictions on the height of trees that might block views. As it can be difficult to take account of all these different barriers, an approach sometimes used is based on the statistical distribution of existing tree cover in similar neighborhoods [3]. If, in each city in neighborhoods of a certain population density class (or impervious surface cover class), there are at least 10% of neighborhoods that hit a certain level of tree cover, then that tree cover would arguably be a realistic target for other neighborhoods in that population density class.



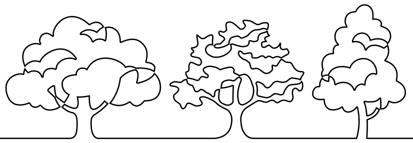
Back to Contents

For this project, we attempted to assess the planting potential for the world's largest (>3 million population) arid cities. First, we excluded impervious surfaces and other physical barriers, to set the upper limit of planting. Second, we set realistic targets at the 10th percentile observed in neighborhoods within a city at a similar level of impervious surface cover (see methodology appendix for details). The average citizen of an arid city lives in neighborhood with a realistic urban tree canopy cover target of 7.1%. The equivalent realistic urban tree canopy target for semi-arid cities is just a bit higher, at 7.3%. However, there is much variation among cities. Some of the greatest realistic potential increases in tree canopy cover are in cities like Kabul that currently has low population-weighted tree cover (0.2%) and could increase significantly (to 8.8%). Conversely, for some of the lowest potential increases are in cities like Cape Town, which already has relatively high population-weighted tree cover (9.1%); and the way our targets our set, may not rise too much more (to 9.9%). Note that our targets are set by looking at average tree cover for neighborhoods of similar levels of impervious cover across the 61 large cities in our sample. It is possible that individual targets could be set for cities like Cape Town that are already green, that would be more ambitious than what we use in this report.

Table 4. Current and potential realistic future tree cover for the arid and semi-arid cities in our sample. Note that because current tree cover is lower in arid cities, these cities have more space for potential tree canopy increase than do semi-arid cities.

Climate	Impervious surface cover	Forest cover (%)	Canopy enhancement potential (%)	Target Forest Cover (%)
Arid	> 50%	0.4	2.6	3.0
	25-50%	0.8	5.0	5.9
	10-25%	2.8	6.8	9.6
	5-10%	4.3	7.6	11.9
	< 5%	4.6	8.4	12.9
Semi-Arid	> 50%	1.6	1.1	2.7
	25-50%	3.8	2.4	6.3
	10-25%	5.3	4.4	9.6
	5-10%	5.9	5.8	11.7
	< 5%	6.1	6.6	12.7

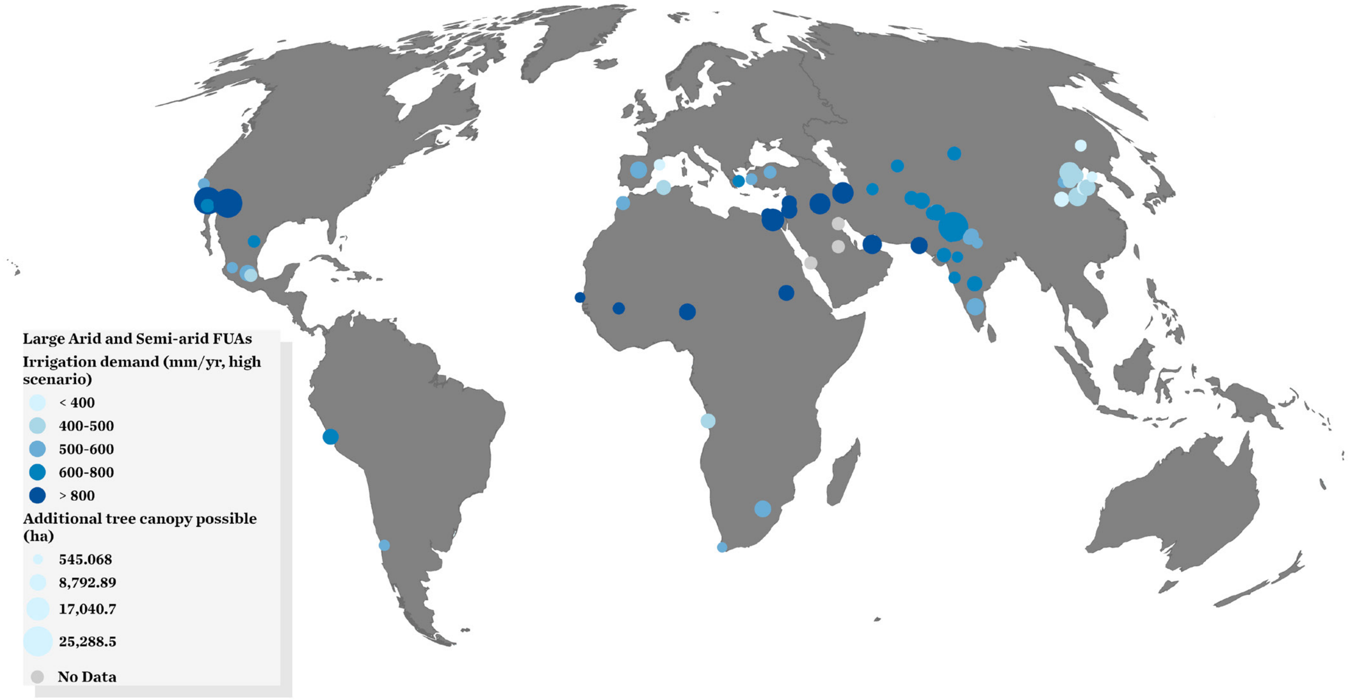
As before, we can gain insight into the patterns globally by dividing neighborhoods into groups based upon climate and impervious surface (Table 4). Semi-arid climates have higher realistic targets than do arid climates, simply because there are observed neighborhoods that have greater tree cover currently. This pattern is because the increased water availability in semi-arid climates compared to arid climates makes it easier to establish and maintain tree cover. Tree canopy targets are often greater in neighborhoods of lower population density than in those of higher population density. This is to be expected since there are fewer impervious surfaces there and land is less costly on average. Note also that globally, the tendency is that cities in less-developed countries have higher average population density and impervious surface cover than cities in more developed countries, which leads to generally lower realistic planting targets in cities in less developed-countries. Notwithstanding all these nuances, note that in all cases (whatever the climate or population density), the realistic targets we set for neighborhoods are greater than the current tree cover. This difference, between current vs. potential tree cover, is something we refer to as "canopy enhancement potential."



How much water would that take?

For a global study, it is difficult to realistically estimate the additional water demand from an expansion of tree canopy. More sophisticated plant physiology models are needed to consider factors such as tree species, the leaf area of an individual stem, soil water availability, and the climate—especially the rate of evapotranspiration. This is a complex topic, and calibrating an actual microclimate and ecohydrology model is well beyond the scope of this project. In this study, we instead arrived at an approximate estimate using global average values. Our methodology follows the Simplified Landscape Irrigation Demand Estimation (SLIDE) approach. In this methodology, the estimated water demand for an expansion of tree canopy is a product of the potential evapotranspiration (ET0), a plant factor (PF), and the leaf area (LA). For ET0, we use the high-resolution (30 arc-second) spatial mapping from the Global Aridity Index and Potential Evapotranspiration Database (v3), which implements a modified Penman-Monteith equation to estimate ET0 globally. The PF is set to either the average for trees (0.5) in our high scenario, or to the average for desert and semi-arid vegetation (0.3) in our low scenario. LA, the additional forest canopy, in square meters, possible under our maximal potential canopy enhancement scenario was already estimated above. From this estimated annual water demand, we subtracted annual effective precipitation to estimate the amount of irrigation water needed annually for maintenance. Note that this number does not account for additional irrigation water sometimes needed in the first few years as trees establish and expand their root network.

The additional water needed annually to achieve the realistic planting target varies widely among semi-arid cities (Figure 10). The annual rate of irrigation water needed under our high scenario (mm of water per year) to support tree canopy cover is greater in arid climates than in semi-arid climates (color of circles in Figure 10). Total additional irrigation water needed is then the product of this rate by the amount of new tree canopy possible under our maximal potential canopy enhancement scenario (i.e., the difference between current tree cover and the realistic target, shown with the size of circles in Figure 10). Cities with arid climates and a large canopy enhancement potential, like Phoenix, require more water to achieve this potential. Conversely, cities with a smaller canopy enhancement potential and semi-arid climates, like Dalian, need less additional irrigation water to achieve that goal. Keep in mind that even for a city like Phoenix, the additional irrigation water demand is a small fraction (<10%) of the overall municipal water use. The use of trees adapted to xeric climates can further reduce the irrigation water demand, and in some semi-arid cities reduces it to zero.



Data Sources - TNC, ESRI, TomTom, FAO, NOAA, USGS

Figure 10. Tree canopy enhancement potential and irrigation demand rate for large (> 3 million) functional urban areas in arid or semi-arid climates.

Back to Contents

If we look at total irrigation water needed by climate (Table 5), global patterns become more apparent. Per square meter of new canopy, it takes more water in an arid climate (the irrigation demand rate) than a semi-arid climate to establish and maintain a tree. Arid climates have lower targets of potential canopy cover, so the potential for tree canopy enhancement is greater in semi-arid climates. These two factors counteract each other, leading to similar total irrigation demand under our high scenario in arid and semi-arid climates. However, in our low scenario, where the use of trees adapted to xeric climates reduces water demand, irrigation water use falls faster in semi-arid climates, since often rainfall is sufficient in these climates to support xeric vegetation without any irrigation.

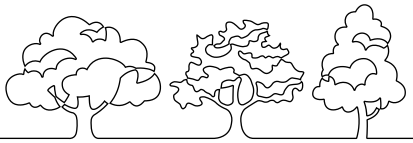
Table 5. Statistics on irrigation under maximal tree canopy enhancement for large arid and semi-arid functional urban areas.

Variable	Arid	Semi-Arid
Tree canopy enhancement potential (ha)	154,090	268,571
Irrigation demand- high scenario (MCM/yr)	1,617	1,577
Irrigation demand- low scenario (MCM/yr)	911	614
Irrigation demand rate- high scenario (mm/yr)	1,049	587
Irrigation demand rate- low scenario (mm/yr)	591	228

It is also helpful to examine irrigation water demand under maximal tree canopy enhancement as a function of density (Table 6). Neighborhoods with high impervious surface cover, which often have higher population density, have lower realistic targets for tree planting, and therefore the canopy enhancement potential is less, limiting additional irrigation water requirements. Conversely, neighborhoods with less impervious surface area and fewer people have higher realistic tree canopy targets, and so the canopy enhancement potential is greater, which, in turn, increases water requirements. Therefore, programs to enhance canopy need also to consider equity, so that any enhancements in tree canopy go preferentially to higher-density neighborhoods even though those neighborhoods may be logistically more difficult places to implement such efforts and have a lower maximum tree canopy potential. Our research shows that such efforts in these places benefits a larger number of people. Note the irrigation water needed per capita is less in neighborhoods of > 25% impervious surface cover than in less dense neighborhoods. These dense neighborhoods house 304 million people in large FUAs in arid or semi-arid climates (71% of total population). Therefore, the use of irrigation water to provide tree canopy that will benefit neighborhood residents in these cases is much more justifiable.

Table 6. Tree canopy enhancement potential and irrigation demand, as a function of impervious surface cover. Shown are data for large FUAs in arid or semi-arid climates.

Impervious surface cover	Tree canopy enhancement potential (ha)	Irrigation demand (MCM/yr)		Population (million)	Irrigation demand (m^3/capita)	
		High	Low		High	Low
> 50%	1,368	10.6	4.9	23.5	0.45	0.21
25-50%	88,390	722.4	360.6	280.8	2.57	1.28
10-25%	127,119	945.1	452.3	83.8	11.28	5.40
5-10%	76,469	552.9	259.1	21.2	26.11	12.23
< 5%	129,315	962.9	448.1	18.7	51.37	23.90



How much would that cost?

In our study, we used information regarding the cost of planting from Kroeger et al [15] and the Planting Healthy Air report [3]. These reports collected information on tree planting and maintenance costs from numerous cities. However, this data is primarily from the global north. We follow the approach of the Planting Healthy Air report and scale estimates of the cost of planting by country with country-level information on the cost of labor, since labor is typically the largest cost of tree planting. We have updated these cost estimates to 2023 USD. We then assume each 19.6 m2 of tree canopy requires one new stem, following the US level average reported by the US Forest Service. Note that is likely an overestimate of cost of planting, since it does not consider natural regeneration or how increased maintenance can enhance tree canopy, and it assumes all planting is done along streets rather than in large patches (which often have lower planting costs per stem).

We estimate that to achieve the targets we estimated for the 61 large water-scarce cities we studied, 217 million trees would be needed. This works out to around 0.5 trees per resident. While planting so many trees is a large endeavor, consider that our targets would bring the average neighborhood in these 61 water-scarce cities from 3.3% forested to 7.2% forested, slightly more than doubling the standing stock of urban trees. Roughly speaking, it takes 5-10 years to provide significant cooling benefits, so beginning to invest now in tree canopy enhancement is crucial if trees are to provide adaptation benefits in the 2030s and 2040s.

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We estimate that total planting and maintenance costs are about 4.4 billion USD per year. This is an annualized cost including maintenance, and with planting phased in over time. This is a more realistic way to think about this expense, since most cities can only implement large scale tree planting programs incrementally over many years, and then must pay to maintain that tree canopy over time. This annualized cost works out to around $10 per resident per year. This global average masks differences between countries. For instance, in the low-density San Diego (USA) functional urban area, our estimate of maximum realistic planting was 2.6 million trees for an annualized cost of 140 million USD, which works out to 53 USD per metro area resident per year. In comparison, in the denser Gujranwala (Pakistan) urban area, which is a similar total population, we estimate that at most 690,000 trees could be planted for an annualized cost of 4.3 million USD, which works out to $1.63 per metro area resident per year.

How much would it benefit climate resilience?

There are many methods for estimating the heat-risk reduction benefits of nature-based solutions, from the complex (e.g., running microclimate models off detailed local landcover, and then linking the output of these microclimate models to epidemiological models of human health response to heat) to the simple (e.g., using average values of air temperature reduction within a buffer distance of trees, and calculating the number of people who live or work within that buffer). In this project, we chose to estimate heat-risk reduction benefits using a simple methodology. We follow the approach of McDonald et al. (2024) for estimating the effect of tree canopy changes on land surface temperatures [16]. This study also has estimates of how changes in land surface temperature in arid biomes affect air temperature. Note also that different scientific studies find different rates of cooling due to a tree canopy increase [17], so our results in this report should be taken as only one possible estimate.

In our sample of water scarce cities, achieving the full canopy enhancement potential described above would reduce the land surface temperature where the average person lives by 1.5°C. Note that while this may seem modest, this is the average change over an entire 1 km^2 neighborhood. At a small scale of a few meters, shading an area of pavement by tree cover might reduce land surface temperatures of the pavement shaded by much more, by 15-20°C or more.

Achieving the full canopy enhancement potential that we estimated leads to an average population-weighted air temperature reduction of 0.5°C. Potential benefits of course vary by city, with the greatest reduction in air temperature in urban areas like Kabul and Damascus that are in arid climates and currently have relatively low tree cover. Potential benefits also vary widely by neighborhood within cities. For instance, in Athens (overall average population-weighted reduction of 0.6°C), temperature reduction benefits in the 1 km^2 neighborhoods examined in this report range from close to 0°C to 1.6°C. In general, dense neighborhoods (and dense cities) have smaller potential for canopy enhancement, as it is harder to plant trees in dense areas with lots of impervious surfaces than less dense neighborhoods, but for each tree planted the cooling benefits are greater, since trees often shading impervious surfaces and more people live close enough to benefit from the cooling benefits of the trees.

Modelling the reduction in mortality during heat waves due to additional tree canopy cover is a complex task beyond the scope of this report. The most current epidemiology literature shows that the relationship between temperature and mortality during a heat wave varies by city and its inhabitants social and technological adaptations to heat as well as by their underlying vulnerability to heat stress. However, some simple calculations suggest the potential mortality reductions due to tree canopy cover increases may be significant. McMichael and colleagues (2004) found in a literature review that for hot and dry climates—like those studied in this report—medical average all-cause mortality increases by 3.0% for each 1°C increase in mean daily temperature during a heat wave above a baseline safe temperature [18]. For instance, during a heat wave of 5°C above the average, all-cause mortality would increase on average by 15%. Across the 61 large arid and semi-arid cities we studied, the realistic maximum tree planting program would decrease air temperatures by 0.5°C. This implies a 1.5% reduction in the percent change in all-cause mortality during a heatwave. If, for example, trees reduced temperatures in our hypothetical from 5°C to 4.5°C above average, all-cause mortality would increase by "only" 13.5%, meaning the additional tree canopy would save 1 in 10 people who might have otherwise died. Individual heat waves can kill thousands, as was true during the European heave wave in August 2003, where, in Paris, average monthly high temperatures were 4.9°C above historical averages. The August 2003 heatwave killed an estimated 70,000 in Europe, so one can see how the effect of increasing tree canopy cover on mortality, while marginal, can potentially save thousands of lives during a major heat wave event.

A recent study of 5,723 US municipalities and other places (housing a combined 180 million people) modeled how an ambitious reforestation scenario in cities (with the target for maximum plausible reforestation set similar to this study) would affect air temperature and mortality [16]. The study found such an ambitious reforestation program would plant 1.2 billion trees and reduce population-weighted average summer temperatures by 0.38°C below current temperatures. This temperature reduction would reduce annual heat-related mortality by an additional 464 ± 89 people in these 5,723 US municipalities. Keep in mind this is an estimate of annual average mortality reduction, but avoided mortality would vary widely from year to year, depending on when and where heat waves occur.

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FUNDING AND FINANCING OPTIONS

As part of a broader heat action plan for a community, NBS can be an important and cost-effective way to reduce risk during heat waves. As previously highlighted, there is significant potential, even in arid cities, for NBS for heat risk reduction. However, we will not achieve this global potential without significant changes regarding how urban forests are incentivized or funded. In this section, we first take stock of commonly used policy options and funding mechanisms in use today. We then discuss potential new and innovative policy and financial ideas that could significantly accelerate the use of NBS for heat risk reduction.

Current policy and funding options

The current funding options for urban greening in cities are limited. There are three main ways cities try to support urban forests: Public revenue, municipal codes and policies, and partnerships [19]. There is also a growing set of funding sources at the national and regional level.

Public revenue: There are three types of revenue sources utilized by local governments to pay for investments in parks and land conservation, such as urban forestry or tree planting. These are, discretionary annual spending, dedicated funding streams, and debt financing. The funding options utilized by a government depend on a variety of factors, such as taxing capacity, budgetary resources, voter preferences, and political will. Significant, dedicated funding generally comes from broad-based taxes or the issuance of bonds, which often require the approval of voters. Once funding is secured, local governments are better positioned to secure scarce funding from state or federal governments or private philanthropic partners and to establish long-term conservation and forestry priorities. Other, less frequently used, mechanisms for municipalities include special assessment districts (e.g., business improvement district), real estate transfer taxes, impact fees, and income taxes. For example, the Urban Forest initiative in Melbourne, Australia, aims to provide critical ecosystem services, such as air and water filtration, shade, habitat, oxygen, carbon sequestration and nutrient cycling. The City of Melbourne established an Urban Forest Fund that disburses grants ranging from 7,000 USD to 200,000 USD to selected projects. The grants are funded through general taxation. In its first three years of operation the Fund disbursed a total of 675,000 USD. For example, Melbourne Skyfarm, a collaboration between Melbourne-based sustainability companies, received a 200,000 USD matching grant to transform a 2,000-square meter rooftop parking garage into an urban farm.

Municipal Codes and Policies: Many municipalities currently protect and expand urban tree canopy through the various policy mechanisms of managing land development. These mechanisms are important since they can affect urban canopy on privately-owned land, far beyond a municipality's direct reach. Zoning and building codes are local ordinances that designate the appropriate use, density and form of new development, regulate alterations to existing development, and typically establish a minimum amount of on-site open space or maximum building lot coverage ratio. These aspects of ordinances can help create the planting space required for tree planting. For example, Washington DC, has developed a Green Area Ratio requirement, in which new developments are scored based on the types of green landscape and design features they use and the area which they cover, and new developments must exceed a minimum score to be approved [19]. Similarly, voluntary private sector infrastructure standards like LEED (Leadership in Energy and Environmental Design) can also incentivize the use of trees and other vegetative elements into new developments. Some municipalities also have a tree code and/or municipal regulations dedicated to the preservation, maintenance, and planting of trees. The City of Portland, OR, for instance, updated its tree code in 2010 to streamline the process for tree planting on development sites and to improve the maintenance of existing trees on private property [19].

Partnerships: Partnerships are often key to leveraging municipal power alongside non-profit and business enterprises. The New York City Tree Trust, for example, is a public-private partnership established in 1994 between the City of New York, non-profit organizations, and private donors. It aims to expand and maintain the city's urban forest in streets, parks, and other public spaces. The partnership leverages private funding but also connects volunteers with tree planting and maintenance events. Similarly, Singapore's 1 Million Trees Movement is led by the National Parks Agency of Singapore and aims to plant one million trees throughout the country for urban heat island effect reduction. This movement also includes many private sector donors that contribute both funding and enable trees to be planted on their land in service of the agencies' goal. As these two examples illustrate, partnerships offer a way to bring other actors into urban forestry efforts, but their creation and maintenance take time and effort.

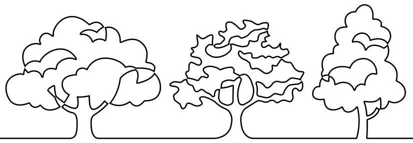
Inter-agency coordination and action: Presently, many cities face a "wrong pocket" problem. That is, the agency that plants and maintains trees (e.g., a parks agency) is different than the agency charged with maintaining climate resilience and health. If such agencies are not coordinated in efforts, they may end up with misaligned objectives and incentives for heat risk reduction. To effectively develop urban greening plans and enhance tree canopy, inter-agency coordination and policy development is needed. This includes coordination among different local municipal authorities and coordination between local agencies and regional and national ones, Identifying a heat champion—whether an individual like a Chief Heat Officer or a task force like a Heat-Health Task Force—to coordinate heat initiatives has been shown to lead to particularly effective and coordinated heat resilience efforts.

In general, tree planting and maintenance are often the responsibility of municipal authorities that have less capacity and resources than regional or national ones. United States national and EU level programs for NBS provide notable examples of such collaboration. Given the scale of the climate change challenge, it is increasingly clear that municipal actions alone will be insufficient. National-level programs must play a key role in financing NBS for heat risk reduction at scale. For instance, the Inflation Reduction Act in the US will mobilize $1.5 billion for tree planting and restoration for climate mitigation as well as human well-being goals, including tree equity and heat risk reduction. And in Europe, national government policies and incentives for NBS are supplemented by funding from the European Union.

Potential innovative finance ideas

While these governmental investments are impressive, they are not enough to reach the full potential for global tree planting in arid cities presented in the previous section. The full tree planting scenario we presented for the 61 cities studied might involve planting 217 million trees, slightly more than doubling the standing tree stock. This is estimated to cost around 4.4 billion USD in annualized investment, or $10 per person per year in these cities. This funding would be in addition to current contribution for urban forestry. Finding this extra funding is a daunting task, but one that can be achieved with innovative funding solutions.

Public sector: One potentially promising new funding source for urban forestry is linking funding for trees and parks to climate adaptation and health policy goals. If trees can play a significant role in reducing the threat to public health posed by urban heat in a climate-altered world, then why not consider a link between health funding and urban forestry? The value proposition for linking finance streams for nature and health is straightforward. Those whose mission it is to plant and maintain urban trees, which are delivering significant benefits in terms of heat risk reduction (but also other co-benefits, including benefits to mental and physical health more broadly), must devote funding and resources to this task. This helps government agencies charged with public health and climate adaptation achieve their goals. To complete the virtuous circle, the agencies should supply financial resources that help pay for the urban forestry efforts.



Another potential funding source is through stormwater mitigation monies. Many countries have laws designed to protect water quality, such as the Clean Water Act in the US. These laws often lead to requirements for municipalities to prevent stormwater pollution as well as limit combined sewer overflow events. In many cases there are funding sources for stormwater mitigation activities, such as the state water revolving funds in the US, which can be used to finance NBS. Municipalities can also raise new funds for tree planting through the initiation of stormwater utility fees, wherein property owners pay a fee to the stormwater utility, often based on the volume of unmanaged stormwater their property produces. Some municipalities have used stormwater fees to incentivize tree planting on private land. For instance, under the Treebate program of Portland, Oregon (US), a property owner's stormwater fee is reduced for each new tree planted.

Another related funding source is the use of funds to maintain watershed health. These funds often have multiple goals, including biodiversity maintenance and climate resilience, but quantitative goals typically pertain to water quality. For instance, water funds often pay for conservation activities that maintain raw water quality in reservoirs or reduce treatment costs for water utilities and industry. Payment from utility rate payers is the most common mechanism for water funds, as is the case in Quito (Ecuador), where, by municipal ordinance, the water utility contributes 2% of its annual budget to conservation activities. Unlike stormwater green infrastructure, however, these watershed resilience activities often occur in more rural landscapes and may be located too far from populated areas to deliver meaningful heat risk reduction benefits.

While there are other public sector models for funding, the key seems to lie in simple, transparent mechanisms that share funds from one agency that is focused on climate or health to another agency that can plant or maintain trees. Successful programs have clearly defined how the urban forestry activity will meet the goals of the climate or health agency. Then, once money is transferred and trees have been planted, there should be adequate monitoring to ensure climate adaptation benefits occurred. One straightforward way for funds to be transferred between agencies is for the climate or health agency to include a line-item in their budget for a transfer to the applicable urban forestry agency, which most likely receives money from the applicable city's general funds. Another source of public-sector funding includes grants from climate or health programs. Under the Inflation Reduction Act, for instance, communities must apply for grants in a competitive program.

Private sector: In many communities, corporate or philanthropic grants increasingly pay for part of the municipal forestry activities. Philanthropic donations in New York City, for example, financed part of the Plant a Million Trees program and its associated partner organizations. However, our study documented relatively little support for urban forestry from health-related foundations, with notable exceptions including funding from Robert Wood Johnson Foundation for work in the US. The same might be said for climate philanthropy, which has been overwhelmingly focused on mitigation rather than adaptation. Given our findings, philanthropic gifts are unlikely to pay for a substantial percentage of tree-planting conducted by municipal agencies, but such gifts can be helpful in paying for catalytic or outreach activities.

Green bonds and other similar debt obligations present another way to raise capital from the private sector for municipal activities. In one sense, green bonds are like traditional municipal bonds for parks and open space, but they often include more explicit environmental benefits. For instance, a climate adaptation bond might finance a suite of activities with measurable climate adaptation objectives. Capital for these bonds can be at the market rate for municipal bonds or can be below rate in so-called impact investing—when those lending are willing to take a lower interest rate when knowing their money is also contributing to the public good.

Finally, insurance-type mechanisms can play a significant role in funding NBS for heat risk reduction. In regions prone to extreme weather events, including heat waves, catastrophe bonds can be explored as a means of transferring risk. These bonds pay out when a specific trigger, such as a certain temperature threshold or duration, are met, providing such funds produce a financial "safety net" for the city. These and other parametric insurance mechanisms can potentially be helpful in financing responses to heat waves, but they can also be used to create adaptive NBS, including new trees. More ambitiously, the presence of NBS could be incorporated into insurance risk models and the premiums charged, creating a financial incentive to increase tree cover. Most heat risk, however, is uninsured, and developing heat insurance programs is complex, which does limit the scope of this more ambitious tactic.

Back to Contents

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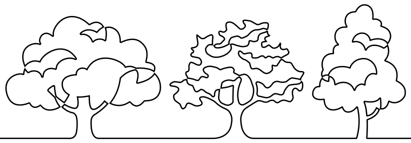
CONCLUSIONS AND RECOMMENDATIONS

Climate change will lead to more intense and more frequent heat waves, imperiling public health in communities around the world. Most at risk are frontline communities, which are those impacted first and worst by the impacts of extreme heat. These are communities of lower socioeconomic status that are most vulnerable to climate change and often least empowered to adapt. This report identified 96 million people in frontline communities in arid regions where the heat risk is extreme but where water availability may limit options. Current tree cover in these communities hovers around just 3%, but we estimate that targeted urban greening could plausibly increase this to 7%, which would meaningfully reduce temperatures and produce a positive impact for people around the world. This increase in tree cover would require an increase in water needed to irrigate trees, although there are strategies cities can use to sustainably find this water. However, reaching the full potential of urban greening will require major changes in the "rules of the game" that govern the extent and location of tree planting as well as a focus on frontline communities.

Governments at all levels must recognize that heat action planning is a crucial part of preparing for a hotter, climate-altered world. Heat action planning includes many components—including the creation of cooling shelters and bolstering the capacity of the medical system and facilities—but we believe nature-based solutions targeted toward frontline communities is an important part of the equation. Governments should consider new or strengthened policies to maintain current tree cover, which might include tree protection ordinances or the imposition of impact fees upon those who remove large trees. Incentives and policies can focus on trees on private land by protecting them from development and/or incentivizing new planting. But. equally, such government policies can achieve meaningful impact by focusing on land controlled by public agencies, such as the public right of way and parks, which can be sites to maintain and enhance tree canopy.



Whether on public or private land, increased funding is key to fully realizing the potential for trees to reduce heat risk. Since funding and water resources will always be constraining factors, conservation actions should target "high impact" planting sites, which are often found in frontline communities. Also, additional funding for urban greening comes from the public sector, especially from municipal budgets or bonds taken by municipalities. This report also described other innovative funding sources, like monies available from stormwater mitigation to build NBS that both manage stormwater and achieve heat reduction goals. We also described here several innovative private sector funding sources that can finance NBS for heat mitigation.

Most importantly, our research found that successful urban NBS projects are co-developed with frontline communities. Some of the best practices we identified were:

- Partner with frontline communities early and often and at the onset of urban greening plans and throughout project implementation.
- Identify potential areas in frontline communities most suitable for urban greening, based both on the prevalence of pervious surface areas and where regulations and local land-use permits greening and have a high potential for impact.
- Select a portfolio of priority places for tree canopy enhancement based on cooling potential and a community's desires for their own neighborhoods.
- To ensure buy-in and continued tree maintenance, partner with frontline communities during and after planting and continually reinforce the value of the cooling benefits that trees provide.

The world is already in the first climate crisis—extreme heat. Every summer from here on out only gets hotter. The increasing frequency and intensity of heat waves will hit frontline communities in water-scarce cities hardest, threatening them with twin threats: deadly heat and lack of water. This report indicates that trees and NBS have a role to play in reducing heat for these arid frontline communities. Increasing tree canopy will require additional water for irrigation, but this can be dealt with if water demands are minimized, and water recycling is promoted. The Nature Conservancy believes frontline communities, which are those most at risk, must be explicitly made the focus of funding and action. Action is urgently needed today, as it takes years for trees to mature into a robust canopy. Every year we wait to green frontline communities is a missed opportunity to save lives threatened by climate change.

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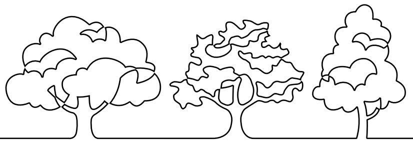

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