The Cities Alliance
Cities and Migration Programme

CLIMATE-RESILIENT URBAN EXPANSION PLANNING:
A TOOL FOR ADAPTATION AND MITIGATION OF CLIMATE RISKS IN SECONDARY CITIES

Schweizerische Eidgenossenschaft
Confédération suisse
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Swiss Agency for Development and Cooperation SDC

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CONTENTS

EXECUTIVE SUMMARY

Municipalities in secondary cities in rapidly urbanising countries face grave climate risks. With limited resources on hand, they will be forced to confront sea level rise, storm surge, extreme precipitation, drought, landslide risk, and other geophysical shocks. Social and economic dislocations will change migration patterns and, in some cases, could lead to large short-term refugee flows.

These challenges add to existing obstacles, including inadequate service provision, rapid urban expansion, and proliferation of informal settlements.

Rapidly growing cities are primarily expanding into peripheral areas, which are often poorly planned and disorderly. Fragmented growth patterns undermine the formation of metropolitan labour markets and can impede socioeconomic progress, particularly for rural-urban migrants.

Adequate resources for adaptation and mitigation are unlikely to manifest, but municipal governments can still take meaningful action to prepare for climate change. They can do so using the same methodology that is used to help secondary cities plan for rapid population growth – urban expansion planning.

Urban expansion planning is a lightweight technique to organise land in the peripheral areas of cities, where growth is likely to occur, by laying out arterial roads and protecting environmentally sensitive open spaces in advance of development. The approach is focused on acquiring land for infrastructure before development occurs and can be modified to incorporate data on likely climate risks on the urban periphery.

Municipalities can use urban expansion planning to create a framework for adaptation and mitigation investments by reserving land for drainage and resilient infrastructure, encouraging titling and formalisation of informal settlements, reserving land for flood control, protecting water supply areas, and enhancing connectivity and opportunities for the provision of public transit. Planned investments in urban infrastructure can be made more orderly and climate resilient, and land for future necessary adaptation investments can be reserved in advance of settlement.

In addition, urban expansion planning can help to guide growth away from high-risk areas by offering alternative sites along the arterial road network. This can help promote higher density and more compact development, making future adaptation programmes more cost effective, helping cities attract needed funds, and supporting mitigation targets in the transport sector.

Planning for adaptation on the urban periphery is also a socially inclusive strategy. Low-income residents are more likely to settle in areas where land is more affordable, which is almost always on the edge of cities. Adaptation plans must consider the needs of those residents, not only the needs of the urban core. Urban expansion plans already consider the needs of peripheral residents, including residents of informal settlements.

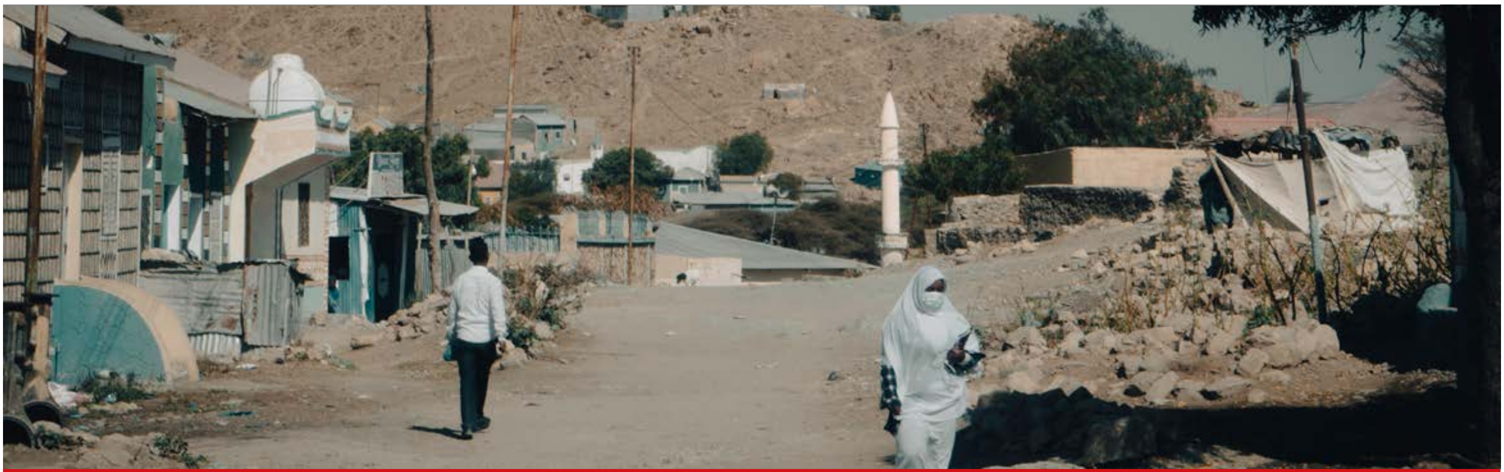
Urban expansion planning is a rigorous and pragmatic approach to planning that produces results on the ground. Climate-resilient urban expansion planning builds on this foundation by proposing a limited but feasible sectoral agenda. It does not purport to address all the adaptation and mitigation needs of cities or offer a comprehensive framework, but the limited activities proposed here will allow cities to approach the problem from an orderly foundation and take needed actions in the short term that will support longer-term investments in adaptation and mitigation.

INTRODUCTION

Climate risks pose a particular burden for secondary cities in rapidly urbanising countries, where a large share of global urban growth is occurring. These cities, already struggling to provide services to expanding peripheral areas and existing residents, have few resources to address adaptation and mitigation needs.

This paper explores options for synergising climate change adaptation and mitigation efforts with a methodology for managing urban growth in secondary cities in rapidly urbanising countries. The methodology, urban expansion planning, is an important tool for helping cities prepare for rapid rural-urban migration and urban spatial expansion. It is explored in detail in a new flagship report, *Managing Migration and Urban Expansion in Secondary Cities* (Lamson-Hall et al. 2022) and outlined in Box 1 for ease of reference.

Peripheral areas of cities – where most urban growth is occurring – will be more resilient and sustainable if urban expansion plans incorporate climate adaptation and mitigation needs. Climate adaptation and mitigation efforts will also be more robust if they consider long-term spatial trends in cities, and if urban expansion plans can help manage settlement in high-risk areas. Climate-resilient urban expansion planning will incorporate adaptation and mitigation efforts into the urban expansion planning process. The terms *climate-resilient urban expansion planning*, and *urban expansion planning*, are used in the paper to distinguish new climate-resilient aspects of the urban expansion planning process from its platonic form in Box 1.



BOX 1
URBAN EXPANSION PLANNING METHODOLOGY

URBAN EXPANSION PLANNING IS A SIMPLE METHODOLOGY THAT HELPS FAST-GROWING SECONDARY CITIES IN RAPIDLY URBANISING COUNTRIES MANAGE PERIPHERAL GROWTH. IT FOCUSES ON LAYING OUT AN ORDERLY GRID OF 30-METRE-WIDE ARTERIAL ROADS SPACED ONE KILOMETRE APART IN THE EXPANSION AREAS OF CITIES THAT ARE LIKELY TO DEVELOP IN THE NEXT 30 YEARS AND IDENTIFYING AND PRESERVING ENVIRONMENTALLY SENSITIVE AREAS AS FUTURE PUBLIC OPEN SPACES.

URBAN EXPANSION PLANS CONSIST OF FIVE ACTIONS THAT CITIES TAKE TO PLAN FOR GROWTH:

1. **PREDICT**
   Predict how much land is the city likely to need for urban expansion in the next 30 years.
2. **CONTROL**
   Identify where new urban areas will be located, and how the city can gain planning authority over this new expansion area.
3. **PRESERVE**
   Identify environmentally sensitive and high-risk places within the expansion area and determine how to protect them from development.
4. **PLAN**
   Plan a network of 30m-wide arterial roads, spaced 1 km apart, to make the lands in the expansion area accessible for development.
5. **PROTECT**
   Protect the arterial road rights-of-way against squatting and development, so that they are available in the future.

These five steps organise the urban periphery of the city into one square km macroblocks that can be developed over the next 30 years in response to demand. Road construction can proceed in stages, with a limited network of simple roads providing rural-urban linkages and the whole road network being developed gradually.

Urban expansion planning is a locally led effort. An urban expansion team made up of city technical staff is supported with international technical support and aid from regional and national government bureaus. This local team manages all stages of the plan, from forecasting to implementation.

It has been successfully implemented on the ground in cities in Ethiopia, and efforts are underway to plan for urban expansion in Somalia and Uganda. In Ethiopia, an investment of US$700,000 in technical support catalysed local infrastructure spending of over US$35 million and led to the creation of over 500 km of new arterial roads, creating space for tens of thousands of new residents and scores of new businesses. (Lamson-Hall et al. 2022).

SECONDARY CITIES IN RAPIDLY URBANISING COUNTRIES

Secondary cities can be defined by (1) population, (2) function, and (3) relationship to other urban areas. In their 2014 CIVIS report, Roberts and Hohmann arrived at the following definition:

A secondary city is largely determined by population, size, function, and economic status. Commonly, secondary cities are geographically defined urban jurisdictions or centres performing vital governance, logistical, and production functions at a sub-national or sub-metropolitan region level within a system of cities in a country. In some cases, their role and functions may expand to a geographic region or the global realm. The population of secondary cities ranges between 10-50 per cent of a country's largest city, although some can be smaller than this. They will likely constitute a sub-national or sub-metropolitan second-tier level of government, acting as centres for public administration and provision of education, knowledge, health, community, and security services; an industrial centre or development growth pole; a new national capital; or a large city consisting of a cluster of smaller cities in a large metropolitan region.

In this paper and its complementary flagship report (Lamson-Hall et al. 2022), we define secondary cities as cities that had 100,000 people or more in 2020 but are not primate cities, meaning the largest city in a country. This simplification is meant to overcome data problems for cities of less than 100,000 people. In 2010 there were 172 countries with cities of 100,000 people or more, creating a universe of 4,231 cities (Angel et al. 2016). Of these, 4,059 were secondary cities, comprising 96 per cent of all cities in 2010 and containing 77 per cent of the urban populations of cities of 100,000 people or more.

Secondary cities grew at an average annual rate of 2.33±0.07% per annum during the 2000-2010 period, a rate that would double their populations in 30 years. This rate was faster – yet not significantly faster – than that of primary cities during this period, 2.12±0.30%. Some secondary cities grew much faster. Eleven per cent of secondary cities grew at more than five per cent per annum, at an average rate that will double their population in ten years. An additional 17 per cent grew at 3-5 per cent per annum, at an average rate that will double their population in 18 years.

Rapid urbanisation occurs in a country when the share of total populations residing in urban areas grows rapidly. Since birth rates in rural areas are typically higher than in urban areas, the increase in the urban share of the population is driven by rural-urban migration (Lamson-Hall et al. 2022). Rapidly urbanising countries have the most rapid growth rates of their urban populations (see Figure 2).

We define rapidly urbanising countries as countries with urban populations that are projected to grow at an average rate of two per cent per annum or more during the next three decades (2020–2050), implying a doubling of the urban population in the next 36 years (see map in Figure 1).

According to the latest projections of the UN's *World Urbanisation Prospects*, 54 of these countries had more than one million people in urban areas in 2020. Of these countries, 39 were in sub-Saharan Africa, projected to add 810 million to their cities during this period; 7 were in South and Central Asia, projected to add 560 million to their cities during this period; 5 were in Western Asia and North Africa, projected to add 110 million to their cities during this period; and 3 were in Southeast Asia, projected to add 50 million to their cities during this period. Significantly, no countries from North America, Europe, Eastern Asia and the Pacific, or Latin America and the Caribbean were among these rapidly urbanising countries (United Nations 2018, File 3).

FIGURE 1

Rapidly urbanising countries are concentrated in Sub-Saharan Africa, South Central Asia, Western Asia, North Africa, and Southeast Asia.

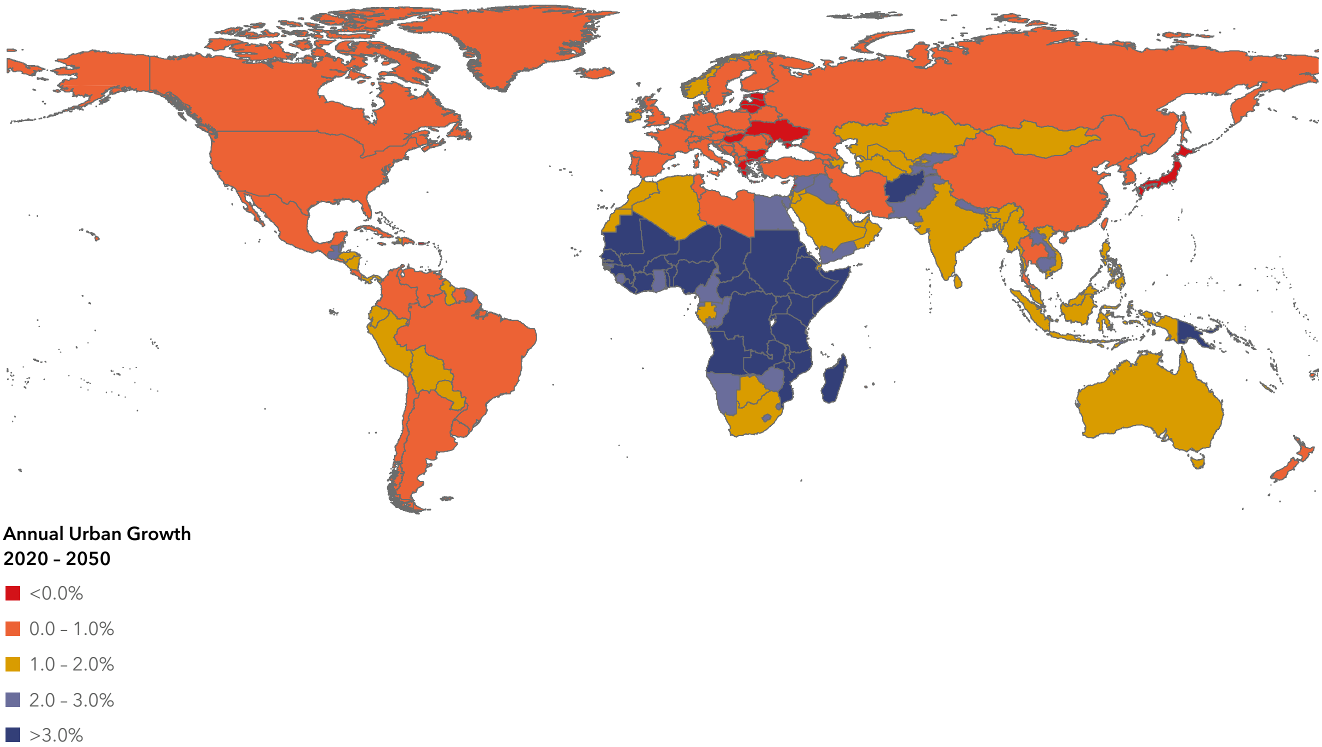
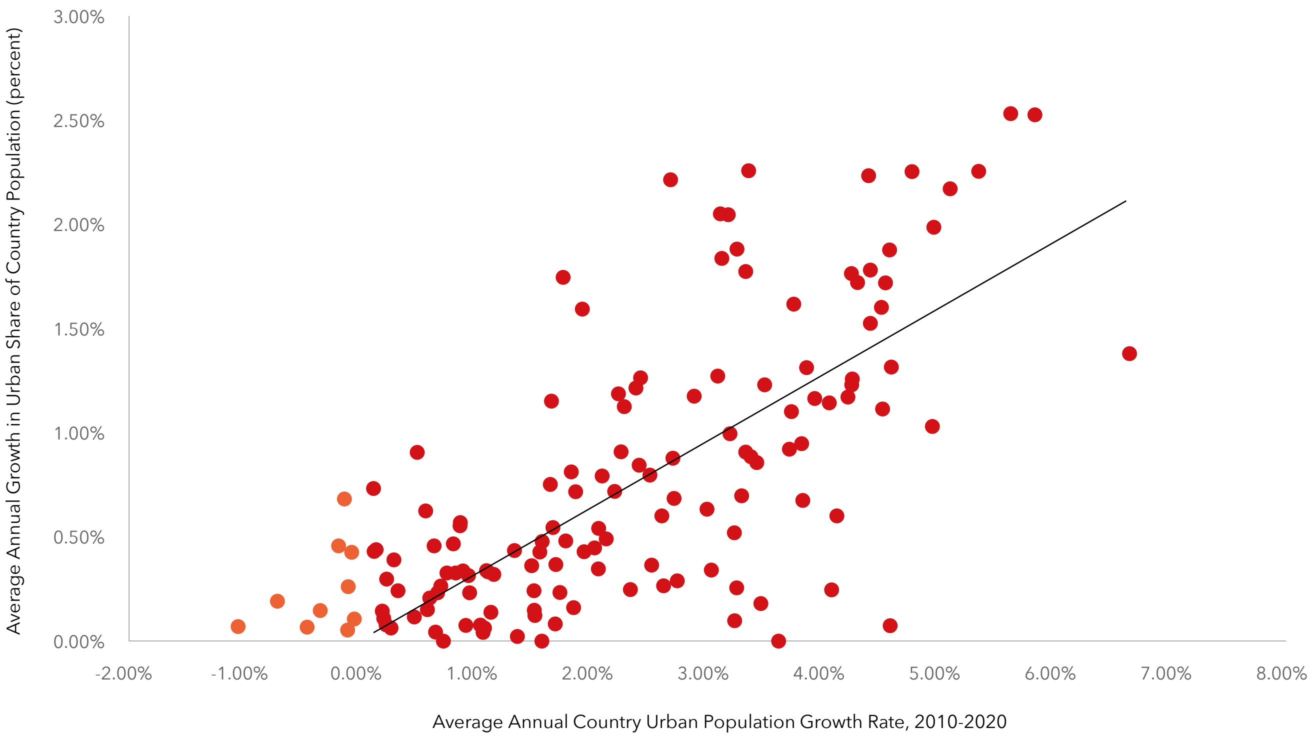


FIGURE 2

Rapidly urbanising countries are also countries with faster rates of growth of their urban populations.



Our focus on secondary cities in rapidly urbanising countries is mandated by the realisation that these are the cities that will benefit most from climate-resilient urban expansion initiatives. These cities are not only growing at a faster rate, the countries they are in are also generally poorer (see Figure 3). Poorer countries have more burdensome land use and construction regulations (Monkkonen and Ronconi 2015, 34) and exercise selective or weaker enforcement of these regulations (Monkkonen 2013; Ho 2001), hence allowing larger shares of their urban population to reside in informal settlements or 'slums' (see Figure 4). Rapidly urbanising countries also have less skilled human and financial resources for planning and preparing their cities for climate-resilient urban expansion. (Oborn and Walters 2020).

FIGURE 3

Rapidly urbanising countries are generally poorer.

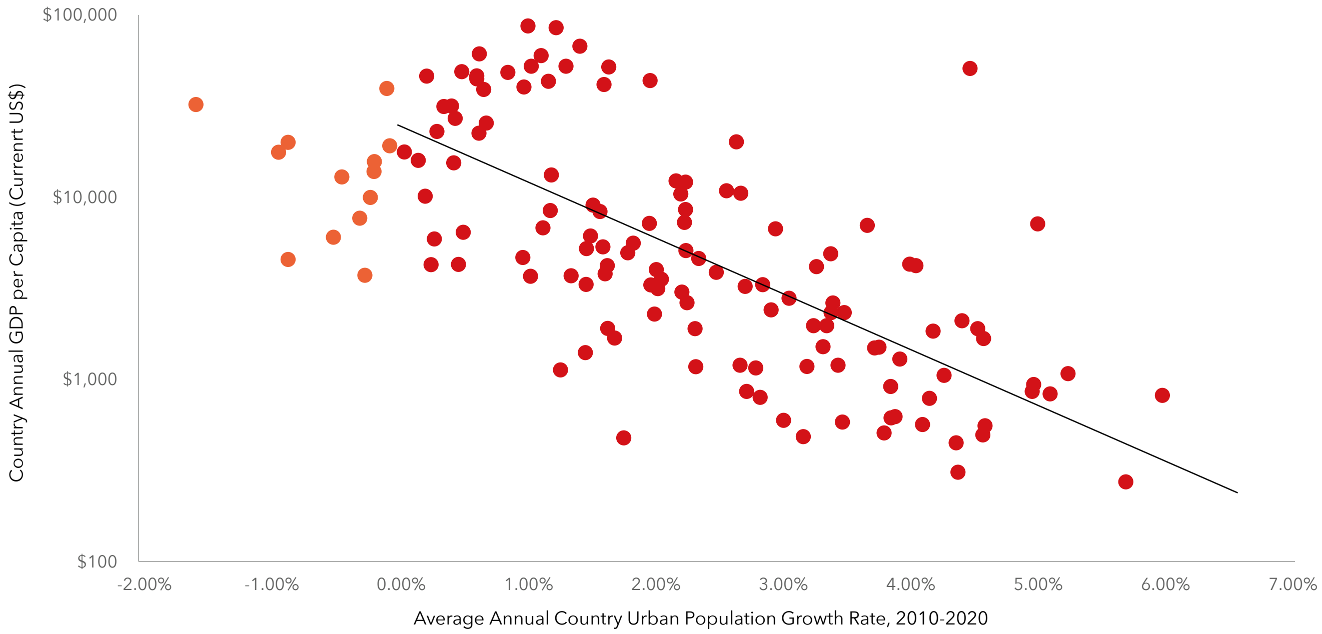
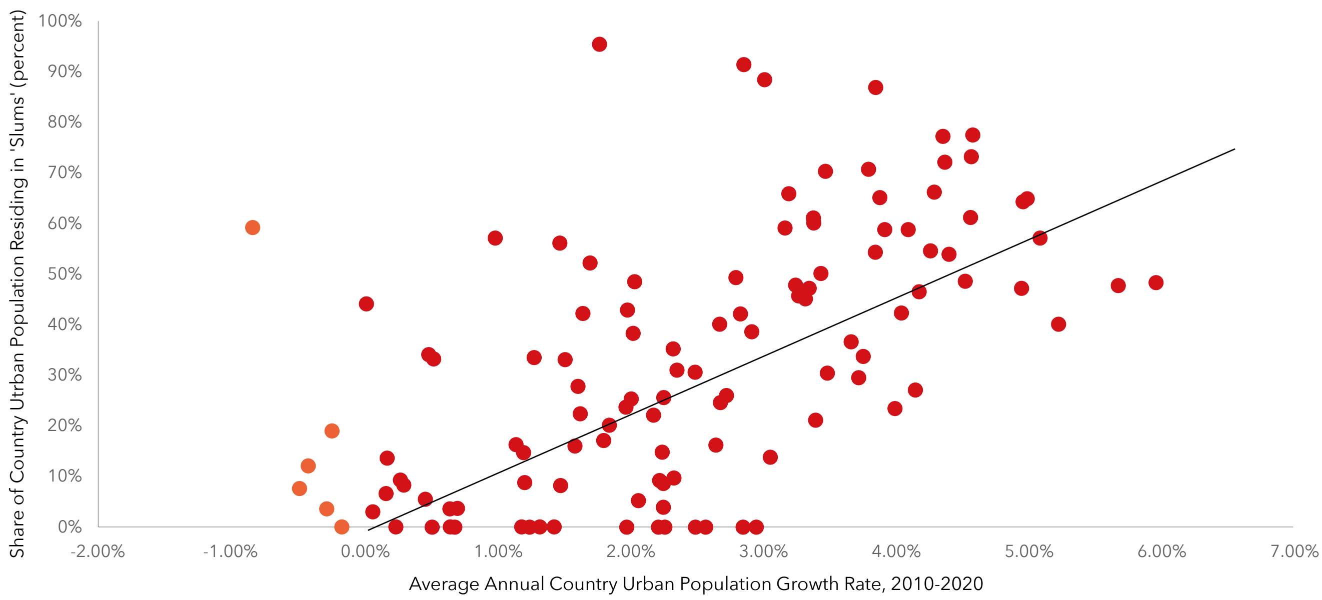


FIGURE 4

Rapidly urbanising countries have larger shares of their urban populations living in informal settlements or 'slums'.



Secondary cities are vital parts of the urban system in rapidly urbanising countries. They are the focus of rural-urban linkages and cities of welcome for the rural-urban migrants who are driving urbanisation. These cities face enormous climate risks but are rarely offered appropriate and actionable solutions. Rapid urban growth is exacerbating exposure to those risks while causing a host of other social and economic problems.

Most international efforts are focused on forestalling the climate crisis by reducing emissions. Rapidly urbanising countries and countries that are adding much urban population are overwhelmingly not major emitters of greenhouse gases, but they are highly exposed to the risks of climate change. For the vast majority of cities in those countries, the most pressing concerns are to survive the existing instability in the climate system and to prepare for future disasters which are likely to occur due to previous emissions.

Municipalities in secondary cities in rapidly urbanising countries are typically responsible for planning, provision, and maintenance of public works such as roads, water supply, drainage, and public open spaces, as well as the regulation of building construction, land subdivision, zoning, and land use in the city as a whole.

Many municipal governments lack the necessary human, fiscal, and financial resources to fully meet these responsibilities. This results in sub-standard and intermittent services in most areas, and inadequate maintenance of the service system as a whole. In expansion areas, it can lead to the complete absence of even basic services such as municipally planned and constructed roads. Regulatory and planning failures also play a role in the creation of informal settlements and the construction of buildings that do not conform to building codes.

Climate-resilient urban expansion planning can help secondary cities in rapidly urbanising countries face some aspects of urban growth and climate risks through a single programme with a demonstrated record of success.

This paper considers climate mitigation and adaptation actions from the perspective of municipal actors. It mainly concerns itself with adaptation actions that can protect lives and property. Mitigation is discussed at the end, before the conclusion. Adaptation efforts focus on what can be done by governments in and around cities in the next five years, to prepare for the next 30 years of urban growth and climate risk using climate-resilient urban expansion planning.

The proposed agenda spans a range of climate risks and urban development needs and offers discrete and limited solutions for each. We risk exposing ourselves to criticism by proposing an agenda of great breadth but limited depth. However, successful urban expansion planning experiences have shown the benefits of such a limited agenda in making an impact on the ground. Experience has also shown the benefits of tying complementary agendas together, such as urban expansion planning and climate adaptation, rather than introducing new programmes or action plans. In the case of climate change in particular, delaying action until comprehensive solutions are available may expose urban residents to unnecessary risk. It is important for cities to act quickly to plan and protect the peripheries of cities, even if their actions are somewhat incomplete.

CLIMATE CHALLENGES CONFRONTING MUNICIPALITIES IN SECONDARY CITIES IN RAPIDLY URBANISING COUNTRIES

The world is currently on track to experience 3 degrees of global warming by 2100. The consequences will be severe and widely felt, including higher levels of sea level rise; more frequent flooding, droughts, and extreme precipitation events; and a higher probability of dangerous heat waves. The likelihood of these events is projected to increase significantly in the coming decades (IPCC 2021).

The rapid urban growth of secondary cities increases their exposure to physical risks from the changing climate, including rising sea levels and storm surges, heat stress, extreme precipitation, inland and coastal flooding, landslides, drought, increased aridity, and water scarcity (Revi et al. 2014a). Cities may also be exposed to high-risk, low-probability events considered in Box 2. These risks will strain infrastructure, create dangerous conditions in informal settlements, and make planning more difficult and costlier. Many of these risks are even more acute in expansion areas, where poor planning and underinvestment intersect with lower incomes to reduce resilience.

Geophysical climate risks are spatial, meaning different locations will be affected in different ways by a given risk (Farbotko 2018). Some areas will be directly impacted, and others will be affected through the impact on the city as a system, via disrupted transportation routes and infrastructure cutoffs, for example.

If cities are unable to make necessary investments and modifications to protect vulnerable areas, socioeconomic progress could stall or even move backward. This is especially perilous for rural-urban migrants. They and their households rely on cities for income and a form of self-insurance, but often have informal livelihoods that depend on fragile rural urban linkages. As new urban residents, they are also much more likely to settle in vulnerable informal areas, where land and housing are cheap (Lamson-Hall et al. 2022). Over one billion informal settlers are disproportionately exposed to climate risks (Cities Alliance 2021).

BOX 2

Low-probability events, such as sudden abrupt changes in the global climate system, can occur over relatively short time periods.

The climate system can be forced to a point where it suddenly flips into another state. These points are collectively known as tipping points and include the shutdown of the Gulf Stream in the Atlantic, the die-back of the Amazon tropical rainforest, stronger and prolonged El Ninõ Southern Oscillation (ENSO) events, and the collapse of ice sheets leading to large sea level rises.

Such events are unlikely, but the odds of their occurring will increase in the coming decades (IPCC 2021). These climate surprises would have dramatic consequences for society and the potential for massive demographic change. These 'Black Swan Events' (Taleb 2007) could involve abrupt population shifts that may increase a city's population several-fold.

Climate-resilient urban expansion planning is one way for cities to incorporate the possibility of low-probability events that can have an extreme impact on cities. As municipalities prepare land for orderly urban expansion, they should consider that the risk of erring on the side of estimating too much or too little land for expansion is asymmetric: as long as investments in preparing for such expansion are relatively low – e.g., obtaining the rights-of-way for arterial roads and planting trees along their future sidewalks – it is worth preparing too much land rather than too little.

Preparing too little land for expansion may create disorderly expansion or land supply bottlenecks that result in unaffordable housing – both costly outcomes. Preparing too much land, in contrast, is not likely to result in any negative outcomes, as the municipality has no obligation to service that land with infrastructure or to construct roads on vacant or lightly settled lands, and it may provide needed flexibility in the event of major disasters.

Urban planning is already considered an important tool for climate mitigation because of its effects on land and vehicle uses (Condon et al. 2009). The spatial nature of the discipline means that it also has an important role to play in adaptation efforts. Urban expansion planning, as the subset of the discipline that concerns itself with urban growth, can help cities make structural adjustments that will have long-term benefits.

Not all climate risks can be measured at the same scale. The scale of the risk is the initial consideration when determining whether a spatial plan can have a meaningful impact on a given risk category. In the case of urban expansion planning, the scope of the plan covers the expansion area of the city for the next 30 years of growth (typically three to five times larger than the existing area), and the scale of the plan is the macroblock (an area of one square kilometre).

Of all the climate risks that impact urban areas, the ones most easily spatialised at the scale of the macroblock are rising sea levels and storm surges, extreme precipitation and drought, inland and coastal flooding, and landslides, though they are still difficult to quantify at the urban scale (Revi et al. 2014a), partly because of high uncertainty in localising predictions. These risks can be directly addressed through climate-resilient urban expansion planning (Wilby 2009).

SEA LEVEL RISE

Sea level rise is a process of increase in mean sea level that occurs due to melting glacial ice and ocean warming. Tidal fluctuations mean that sea level varies depending on the time of year, month, and day. The relevant value for measuring sea level rise is median sea level, which refers to the average daily water level in a given location (Warrick and Oerlemans 1990, 257-281). For the purposes of inundation, mean high water should be considered. Areas that are regularly submerged at the time of mean high water can be considered uninhabitable, though some communities have adapted to these conditions by elevating structures or building protective barriers.

Sea level is rising worldwide at a rate of 1.5 mm per year. This rate is accelerating, and by 2100 sea level could rise by, on average, 63 cm over 2010 levels. These average values mask local variations which can be as much as 50 cm, meaning some areas are facing significantly greater amounts of sea level rise than others (Church et al. 2013, 1184).

The impact of sea level rise on a city will vary based on its location, past development patterns, topography, and access to resources. Past development will determine how much of the existing area of the city is subjected to sea level rise. Topography will determine how much additional area of the city is at risk of sea level rise, including in the expansion area. Cities where the elevation increases gradually as you move away from the sea will face more risk than those where elevation increases more rapidly. Access to resources will determine the ability of residents and the city government to make investments to adapt to rising seas, such as sea walls, pump stations, or resilient structures (IPCC 2014, 27).

In the long term, areas facing more frequent inundation will become difficult or impossible to inhabit. This is especially true of places that were not originally designed for inundation, such as places that were originally above the mean high-water level (Lawrence et al. 2020). One likely adaptive strategy for people and businesses in such places is to gradually relocate to higher ground, a process known as managed retreat from the sea. This is a decision that is usually taken at a household or firm level, but the public sector has a role to play in ensuring that adequate lands exist for resettlement (Hino et al. 2017).

STORM SURGE

Storm surge occurs when strong winds push water onto shore, causing coastal flooding. It is worsened by sea level rise, and higher temperatures increase the frequency and intensity of the types of storms that cause these surges. Storm surge is particularly dangerous because the height and force of the waves that are pushed on shore can be much more than normal, leading to impacts in areas that may not have been prepared for inundation. This can lead to sudden and violent destruction of buildings and loss of life. Areas impacted by storm surge may be uninhabitable until rebuilding can take place (Dasgupta et al. 2009.)

Many sophisticated models exist for estimating storm surge impact. In resource-scarce contexts, one method is to simply estimate storm surge height based on historical data from previous storms, with a correction for estimated sea level rise (ibid). Storm surge occurs erratically, at infrequent intervals, and it will most likely not be possible to present construction in areas at risk from this hazard.

WATER SHORTAGES AND EXTREME PRECIPITATION

With climate change, increased water shortages and extreme precipitation can occur in the same places at different times. Rising sea temperatures lead to increased evaporation. As air containing more moisture moves over land, it can cause more precipitation to fall within a certain amount of time (Donat et al. 2016), inundating some areas and depriving others. Disruptions in rainfall patterns can make it difficult for ground and surface water sources to recharge and providing year-round drinking water can become more difficult (Delpla et al. 2009), while simultaneously making flood management more challenging.

LANDSLIDE RISK

Landslide risk in the context of climate change is closely tied to changes in precipitation and extreme events. Greater precipitation totals and higher rainfall intensity can reduce the cohesion of soil on slopes. High winds from extreme events can uproot vegetation, removing roots that stabilise slopes (Crozier 2010). This is elaborated on in the example of Guatemala City, Guatemala, in Box 4.

ABSENCE OF LOCAL CLIMATE DATA

Cities seeking to create climate-resilient urban expansion plans may struggle to access localised information that will allow them to visualise and spatialise these climate risks. To amend this, cities that are engaged in planning for urban expansion should be supported in preparing urban climate risk profiles.

Considering the lack of capacity in many secondary cities, risk profiles generated for climate-resilient urban expansion planning may be the only city-specific data that city leaders receive on climate risk. The data should also be considered as a possible source of information for households and firms, who may be even less aware of the risks of climate change.

Risk profiles should start by developing a base of scientific evidence that identifies areas within the city that are at risk from sea level rise, storm surge, extreme participation, heat extremes, and inland and coastal flooding (Dickson et al. 2012, 15). It should include demographic and spatial forecasts, which can be developed by the local climate-resilient urban expansion planning team.

International partners can work closely with local leaders and technical staff to generate scientific data. Consultations to incorporate local and traditional knowledge can aid leaders in recognising, quantifying, and linking risks with which they are already familiar. This should include citizen science (for example, as in Paul et al. 2020). The goal of the exercise should not just be to deliver a completed report, but to build the capacity of the local leadership to understand and respond institutionally to climate risks. Local leaders can be supported in using the data for urban expansion planning and adaptation efforts, and different dissemination techniques for the data should be tested.

Cities will require downscaled data on sea level rise and storm surge, data on precipitation and extreme events, accessible and fine-grained elevation maps, and basic information on soil types. The availability of this data at the municipal level is unknown and should be explored (Dickson et al. 2012, 25–29).

Public and pre-existing datasets are available with this information, but many datasets are regional and may fail to consider important local variations that could have consequential impacts (Iturbide et al. 2020).

RECENT SOCIOLOGICAL EVIDENCE INDICATES THAT THE MOST EFFECTIVE WAY TO ENGAGE POPULATIONS IN CONSIDERING CLIMATE RISKS IS TO CREATE SPECIFIC SCENARIOS THAT WILL HELP ENVISION THE IMPACT OF THOSE RISKS IN THE LONG TERM

Climate resilience efforts in secondary cities in developing countries would benefit from investments in national climate projections (Skelton et al. 2019). These projections would ideally quantify the expected changes in precipitation, sea level, storm, and extreme events on a decadal basis over the coming 80 years, mirroring the timescale used in regional projections. Downscaled versions of these nationwide projections could be produced for every human settlement in the country and made available to local governments for use in planning.

National governments and international development agencies should also consider funding the creation of high-resolution topographic maps in secondary cities, especially the generation of light detection and ranging (LiDAR) data. This data would be most useful if it were generated for an area several times larger than the city itself, recognising that planning future expansion will require knowledge of the topography beyond the boundary of the existing city.

In the absence of perfect data, publicly available data can be used for rough topographic drainage and flood mapping, though short-term sea level rise and flood estimates may be imprecise (Courty et al. 2019). Local knowledge of soil types can help identify areas at risk of landslide, and the same expertise can be used to identify environmentally sensitive areas that should be preserved.

Risk profiles can also aim to support citizen action to address climate change. Many necessary investments in climate resilience and climate adaptation take place at the household or firm level, not at the level of the city government. This includes investments in resilient building materials, such as concrete structures, roof straps, etc.; redundancies for basic services (water storage tanks, backup generators); disaster recovery and rebuilding; and insurance to mitigate financial risk. These investments are neither financed nor managed by the government and are a critical part of ensuring that limited government resources are not overwhelmed when disasters occur. Risk profiles can help firms and households make critical decisions about adaptation.

Recent sociological evidence indicates that the most effective way to engage populations in considering climate risks is to create specific scenarios that will help envision the impact of those risks in the long term (Shaw et al. 2009; Mabon 2020). This 'scenario planning' exercise is essentially non-technical in nature, using narratives to present climate data in a way that is readily comprehensible to city residents. This is a critical part of the preparation of risk profiles and can only be managed by local leaders.

Climate-resilient urban expansion planning can incorporate urban climate risk profiling into the data generation stage of planning for urban growth. It will complement existing demographic and spatial analyses that are already used to help cities anticipate the amount of land needed for urban expansion. Demographic and spatial forecasts will also need to be modified to respond to changing conditions that result from climate change and that impact prospects for future growth. These changes will provide the foundation to successfully introduce adaptation considerations into urban expansion plans.

CONFRONTING CLIMATE DEMANDS ON URBAN EXPANSION PLANNING

Some knowledge of how much land a city will occupy in the future is an essential part of preparing to address urban expansion and climate change. Box 1 notes that the first step in creating an urban expansion plan is to estimate the additional lands that a city will need to accommodate growth for the next 30 years. These estimates consider demographic data, historical growth patterns, migration, natural increase, land availability and suitability, and economic changes that impact land and housing markets.

Climate change may disrupt the urbanisation process in some countries, shifting the trajectory and nature of people's movement to cities. The risks imposed on cities, including in their expansion areas, could render large areas unsuitable for settlement. The same risks could affect urban densities, promoting low-density sprawl or leading to crowding. Urban expansion plans for future settlement must consider each of these possibilities using available data that is often deficient. Plans for growth should also be realistic about current patterns of expansion in cities, which strongly favour peripheral growth over densification, as described in Box 3. This is one impetus for urban expansion planning in general, and it has real and important implications for climate resilience.

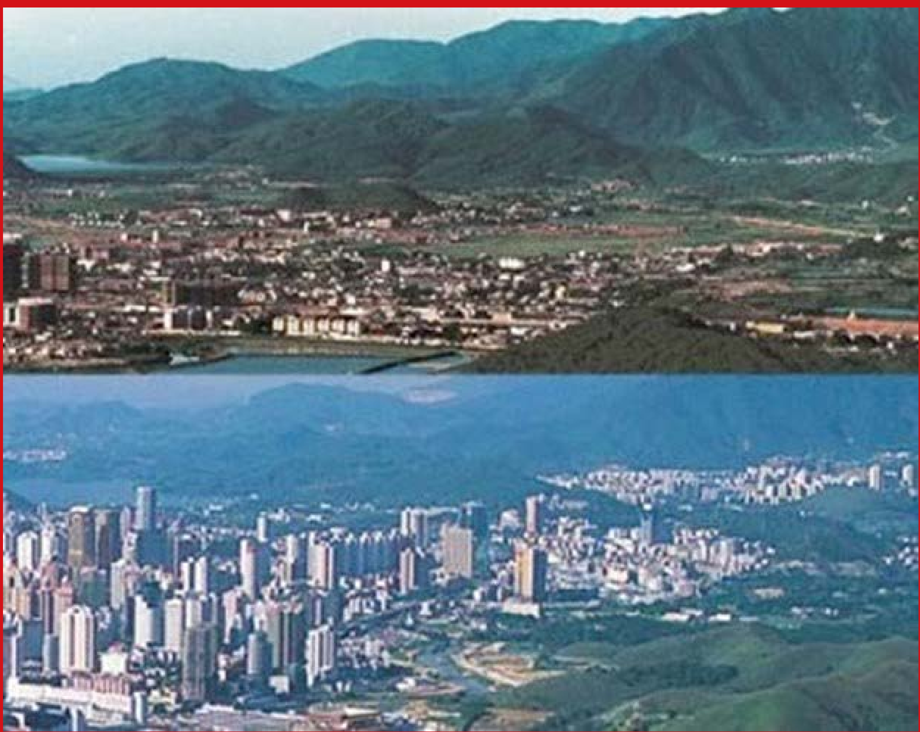
BOX 3
HOW CITIES ARE GROWING NOW

Cities add population through natural increase, urban-urban migration, and rural-urban migration. This new population has to live somewhere, either settling in the existing area of the city and contributing to densification or settling on the urban periphery and contributing to expansion (Figure 5).

A recent global study of a stratified sample of 200 cities, representing all of the cities on Earth with 100,000 people or more, found that, in the global sample of 200 cities as a whole, the share of the population added to cities during the 1990–2014 period that was accommodated within their 1990 footprint was 23 per cent. In comparison, the share accommodated in the expansion areas – the areas built and settled between 1990 and 2014 – was 77 per cent. These percentages varied from 0 and 100 per cent in the six cities that lost population or in the 50 cities that lost population within their 1990 footprints, to 40 and 60 per cent in cities that increased built-up area density within their 1990 footprints. In no category did the densification of the 1990 footprints of cities absorb half or more of the added populations. (Angel et al. 2022).

FIGURE 5

Shenzhen, China in 1982 (top) and 2007 (bottom). The city has grown through densification and expansion. Credit: Bartlett and Bartlett (1998).



Expansion is vastly preferred over densification. This is partly because land on the urban edge of cities is cheaper and therefore more accessible for new urban residents, and partly because most urban growth is occurring in rapidly urbanising countries, where existing settlements are small and unable to accommodate many new residents.

Secondary cities in developing countries could expand in area as much as ninefold in the coming three decades (Lamson-Hall et al. 2022). Urban expansion planning focuses on preparing land for expansion in peripheral areas, reasoning that these areas are more prone to informal settlement formation and will benefit more from orderly settlement. In addition, existing areas are already covered by existing plans.

ESTIMATING MIGRATION AND DISLOCATION

Migration is a major driver of urban growth and the driver of global urbanisation. Tacoli et al. (2015) estimated that one in three new urban residents in sub-Saharan Africa from 2010 to 2020 were rural-to-urban migrants. An improvement on their methodology that incorporates the differences in fertility rates between rural and urban areas (estimates from Lerch 2019) as well as forecasts from World Development Indicators (World Bank, 2020) and UN Population Division (United Nations 2018) finds that two-fifths of the total population growth in urban areas from 2020 to 2050 will come from migration from rural areas (Lamson-Hall et al. 2022).

New rural-urban migrants seek lives in cities for many reasons, and accommodating their lifestyle, social, and economic needs must be a major consideration for planners. Many migrants retain links to rural areas and are sometimes sent to urban and peri-urban areas by their families to diversify household income sources (Owuor and Foeken 2006; Lanjouw, Quizon, and Sparrow 2001). Migration to cities can drive increases in life expectancy, national income, household income, education levels, and more (Zimmer et al. 2020), but it can also strain the capacity of cities to provide basic services, as discussed in the introduction. Rural incomes and rural lifestyles may become less viable as predictable weather patterns become less certain. Climate conflict is also expected to increase in the coming years (Henderson, Storeygard, and Deichman 2017; Burke, Hsiang, and Miguel 2015). Climate-induced migration could increase the flow of migrants to cities, changing growth forecasts and requiring recalibration of growth estimates.

The available evidence suggests that climate change is one of many drivers of long-term or long-distance migration (Shukla et al. 2019). In its recently issued report *Groundswell Part 2: Acting on Internal Climate Migration*, the World Bank has concluded that internal migration due to climate change could reach 216 million people across all world regions by 2050, with 126 million of those migrants in South Asia and sub-Saharan Africa – the regions with the most rapid urban growth. Internal movements can be temporary and are often from one rural area to another (Clement et al. 2021). Still, assuming that *all* these people are *rural* dwellers who will settle permanently in urban areas, this climate-induced migration will increase the projected urban population by 10.6 per cent, likely within the margin of error of the population projections (United Nations, 2018). This evidence indicates that, on average, climate-induced migration should not alter urban population projections for the 2020–2050 period in predictable ways. Some forecasts in the Shared Socioeconomic Pathways do indicate major changes in global urban share, but this mainly results from economic and social changes under those scenarios, not from climate-induced migration. However, some areas of high risk will become hotspots for climate migration, and individual cities may experience sudden massive increases in their populations because of climate-induced rural-urban migration.

Climate-resilient urban expansion planning can help provide city leaders with information about likely climate risks in their area. The leaders should then be invited to consider the probability that these risks might lead to sudden inflows of people. This can be supplemented with community consultations and the incorporation of sociologists and other experts. Their local knowledge can take into consideration the sensitivity of surrounding rural areas to drought, the size of the adjacent rural population, and proximity to other urban centres that could attract growth. The high and low boundaries of estimates can be adjusted to incorporate this additional risk, and preferred estimates can be selected based on the principle of asymmetric risk laid out in Box 2.

CONTROLLING LOW-DENSITY SPRAWL

Low-density sprawl is conventionally defined as low-density suburban expansion on the urban fringe marked by fragmented development that leapfrogs over open spaces. This development pattern can lengthen commutes and increase car use, and thus energy use and greenhouse gas emissions. Low-density sprawl is usually too dispersed to make public transit viable, increasing reliance on private automobiles; as a result, it is largely a problem of developed countries.

Fringe development in secondary cities in rapidly urbanising countries takes place at higher densities and is typically served by public transport or by biking and walking. Fragmented leapfrogging development on the urban fringe of cities, even if it is not low density, is a concern in these cities, because it requires longer than necessary infrastructure lines. Municipal planners must understand, however, that such fragmentation is temporary and that vacant plots fill over time, often at higher densities than those of the initial settlements (Angel et al. 2022).

PLANNING FOR URBAN EXPANSION REQUIRES PREPARING ADEQUATE LANDS FOR EXPANSION, TYPICALLY FOR A 30-YEAR PERIOD. THESE PLANS, IN TURN, REQUIRE PROJECTING REALISTIC DENSITIES INTO THE FUTURE. SUCH REALISTIC DENSITY PROJECTIONS MUST CONSIDER EXISTING URBAN DENSITIES AND THEIR CHANGE OVER TIME, GIVEN THAT ECONOMIC DEVELOPMENT TYPICALLY RESULTS IN LOWERING DENSITIES.

Estimates of future land area are typically based on density trends that are derived from historical satellite imagery and population data (Lamson-Hall et al. 2018). But new downscaled global estimates that incorporate forecasts from the Shared Socioeconomic Pathways (O'Neill et al. 2017) show large variations in future urban land area, depending on the climate scenario under consideration. Estimates of the expected increase in urban area from 2015 to 2100 range from 53.8 per cent to 110.6 per cent worldwide. In rapidly urbanising countries, estimates of the increase in land cover range from 109 per cent to 574 per cent (Chen et al. 2020).

These estimates do not expressly consider density, but levels of urban population density vary dramatically from country to country and world region to world region (Angel et al 2016). Continued monitoring of regional density trends can help calibrate local density forecasts. Box 2 introduces a general principle to be applied in the event of competing forecasts; because the risk of under-planning is asymmetric, urban expansion plans should tend to incorporate the highest reasonable estimates available of future urban growth.

Urban population density can best be understood as the inverse of the *per capita* consumption of land in cities (OECD 2018). The role of city leaders in determining density is one-sided. Urban planners can remove restrictions on maximum density, but cannot practically mandate minimum densities, which would require them to directly control where individuals live, where firms are located, and how much land people choose to consume.

According to the standard urban model as articulated by Muth, Mills, and Alonzo, individuals and firms decide how much land to consume based on their needs, their resources, and the market price of land. The market price of land in urban areas is closely related to the market price of land in adjacent rural areas (Ng and Lo 2015). In fact, the physical edge of the urban area, all else being equal, is typically the point at which undeveloped rural land prices and undeveloped urban land prices converge (See, for example, Lai and Tsai 2008). The area of a city is therefore closely related to real estate decisions made by households and firms, and those decisions are closely related to rural and urban land prices (Bertaud 2018).

The fundamental theoretical relationship between density and climate change is this: Climate change will influence urban population density if climate risks, and the adaptive responses to those risks, impact the value of land within urban areas differently than the value of land outside urban areas.

Some climate risks can best be addressed through concentration of the population and physical capital of the city. These include risks that require major capital investments – such as flood or sea defense, district cooling, or drainage system upgrades – that will lead to higher land values within protected areas and lower land values outside the protected areas. Higher land values, along with the decreased risk of disaster impacts, will encourage households and firms to consume less land and lead them to live at higher densities within the protected areas.

In contrast, some climate risks can best be addressed through dispersion of the population and physical capital of the city to minimise the overall impact of a disaster (in the case of tornadoes, for example), or to facilitate nature-based solutions such as shade trees, soft-scaping of surfaces, or water impoundment and infiltration. The dispersion approach requires vacant land in order to work properly and will encourage higher consumption of land by households and firms, leading to lower urban densities.

CLIMATE CHANGE WILL INFLUENCE URBAN POPULATION DENSITY IF CLIMATE RISKS, AND THE ADAPTIVE RESPONSES TO THOSE RISKS, IMPACT THE VALUE OF LAND WITHIN URBAN AREAS DIFFERENTLY THAN THE VALUE OF LAND OUTSIDE URBAN AREAS.

CURRENT EVIDENCE DOES NOT CLEARLY INDICATE WHETHER CLIMATE CHANGE WILL CAUSE URBAN DENSITIES TO RISE, FALL, OR STAY THE SAME.

Three hypothetical examples illustrate this point:

EXAMPLE 1
As extreme temperatures become more common, life in the city centre becomes difficult. The high-density environment promotes the urban heat island effect, and temperatures are regularly 3-4 degrees Celsius higher than on the periphery. Families with the resources to do so will purchase houses on the urban edge with trees and gardens to protect themselves against this risk. These higher-income families will be replaced in the city centre by new migrants, but overall urban densities will decline.

EXAMPLE 2
Periodic extreme precipitation causes severe flooding several times a year in the hardscaped urban centre, where antiquated drainage networks are frequently overwhelmed. In newer suburban areas, drainage systems are scaled more appropriately and are closer to their outflows, and vacant lands help reduce the volume of stormwater by promoting infiltration. Flooding is less frequent in this area, and businesses and residences gradually shift outward, lowering urban densities.

EXAMPLE 3
Sea level rise and storm surge threaten the waterfront, and the government is investing in a large new seawall to protect the central areas of the city from this risk. The seawall does not extend into lower density suburban areas, because their lower densities make it very costly to provide adequate protection. Unprotected seaside communities flood regularly and many of their residents relocate to within the sea defense, raising urban densities.

DENSITIES CHANGE OVER TIME, EVEN IN THE ABSENCE OF CLIMATE CHANGE, BECAUSE OF SOCIAL FACTORS SUCH AS HOUSEHOLD SIZE, TECHNOLOGICAL FACTORS SUCH AS ACCESS TO TRANSPORTATION, AND ECONOMIC FACTORS SUCH AS HOUSEHOLD INCOME.

Densities change over time, even in the absence of climate change, because of social factors such as household size, technological factors such as access to transportation, and economic factors such as household income. In the slums of lower Manhattan, densities declined from 1,530 persons per hectare in 1910 to 400 persons per hectare in 2010, largely because of women's education (reducing household size), union wages (increasing household income), and the subway system (making it possible to live further from your place of work) (Angel and Lamson-Hall 2015). None of these things were under the control of the planners who laid out the neighbourhood, nor of the architects who designed the buildings.

The urban expansion approach laid out in this paper and articulated in other companion works is controversial in part because it is incorrectly perceived as a capitulation to sprawl. Despite this controversy, the approach is being actively used in Colombia, Ethiopia, Somalia, and Uganda to organise the peripheries of cities (Lamson-Hall et al. 2018; Cities Alliance 2020; Lamson-Hall et al. 2022), in part because it allows local authorities to exercise some measure of control over the trajectory of urban growth. The net effect of this added control, in theory, is to encourage more compact and, ultimately, higher density development on the urban periphery – a point which is articulated in more detail in the concluding section on mitigation.

A major strength of the urban expansion planning methodology is that it proceeds on an empirical basis, and this principle should be extended to forecasts of density. Current evidence does not clearly indicate whether climate change will cause urban densities to rise, fall, or stay the same. The present methodology for forecasting density relies on taking historical economic, land consumption and population trends in specific cities and regions and projecting them into the future. Density estimates produced using this methodology should be revised as new data becomes available to see if climate impacts affect trends.

The findings so far indicate that, on average, climate change will increase migration. In some hotspot areas, migration can be expected to increase substantially, but the timing of those increases is unpredictable, and the quantities may not be significant. Climate change will also influence density, but this depends not only on the types of risks that an area is facing, but how, when, and to what extent governments respond to those risks. We can conclude that some cities will almost certainly see both an increase in population and a decline in density as a result of climate change, above and beyond the increases in population and declines in density that are already occurring in many cities. These cities will see a corresponding increase in demand for urban land.

PROTECTING HIGH-RISK LANDS FROM SETTLEMENT

As cities grow through urban expansion, new areas may be developed that have different or exaggerated geophysical risks compared to in the urban core. Variability induced by climate change may also mean that familiar risks change or become more extreme. In general, climate risks are increasing, and the net effect of these changes in most cities will be to reduce the available supply of urban land that is considered low risk for development.

A KEY PRINCIPLE OF THESE PLANS IS THAT GROWTH CANNOT BE PREVENTED, ONLY GUIDED.

Urban expansion plans aim to be pragmatic, evidence-based, and to operate within the capacity of local governments. A key principle of these plans is that growth cannot be prevented, only guided. Growth in cities typically takes place in as compact a manner as possible, and efforts to prevent growth in areas that have good access to the rest of the city will usually fail, even if those areas are periodically subjected to disasters. We see no reason to believe that the exigencies of climate change will obviate this principle.

Urban expansion plans include areas of high environmental risk that are designated as protected from settlement. The resources needed to do so vary depending on how desirable an area is in terms of access to jobs. In highly desirable high-risk areas, protection can require active enforcement, which is politically and financially costly.

Some areas of high environmental risk can be protected based on the environmental services they provide to the municipality, such as the large bio-reserve of São Paulo, Brazil (Ramos-Ribeiro 2014) or the mangrove swamps of Mumbai, India (Everard, Jha and Russell 2014). Accounting for the value of these services can provide an impetus to invest in their protection.

In addition to environmentally sensitive areas, climate-resilient urban expansion plans may include land to support disaster management by providing space for temporary staging, evacuation, or longer-term resettlement. Disaster management areas can shift to other parts of the expansion area as the city develops outward and need not be serviced in advance. The land can be reserved, however, and disaster management plans can centre on the reserved lands. In the case of resettlement, such areas could be rapidly developed in the event of an emergency and would already be incorporated into the existing city using the arterial grid, ensuring that new climate migrants and refugees will have orderly access to the urban area.

The list of areas to be protected will have to be carefully managed. Policymakers must be extremely realistic about the resources that are needed to protect those areas, and difficult decisions will have to be made about which areas are truly worth protecting.

City leaders often withhold infrastructure from informal settlements as part of strategies to discourage their construction (Watt 2020). This strategy has always been inequitable and anti-poor. In the context of climate change, it is also dangerous. Examples from Ethiopia show that even extensive efforts to plan and prepare for urban expansion are unable to head off all informal settlement (Lamson-Hall et al. 2022), and it is highly likely that some degree of informal settlement will continue to occur in high-risk areas.

Implementation of arterial grids in expansion areas can have a positive impact on the tendency to develop in well-located high-risk areas and the need to protect environmentally sensitive areas. An arterial grid on the urban periphery will increase the supply of urban land for development in low-risk areas and can improve access to good jobs for those areas. Urban expansion planning can reduce pressure on low-income households to settle in unplanned areas of high climate risk by ensuring that adequate lands with good access to urban job opportunities are available to households at all income levels.

CLIMATE-RESILIENT URBAN EXPANSION PLANNING MUST CONSIDER CHANGES IN THE RELATIVE RISK LEVELS OF LAND FOR DEVELOPMENT AND CAN ALSO BE A TOOL TO ENCOURAGE SETTLEMENT IN LOWER RISK AREAS. HOWEVER, THE ARTERIAL GRID SHOULD BE PLANNED AND CONSTRUCTED BASED ON LIKELIHOOD OF SETTLEMENT FROM THE PERSPECTIVE OF PROBABLE RESIDENTS, NOT THE CONVENIENCE OR DESIRABILITY OF DEVELOPMENT FROM THE PERSPECTIVE OF THE CITY. THIS RECOGNISES THE LIMITED CONTROL THAT LEADERS OF RAPIDLY GROWING SECONDARY CITIES IN DEVELOPING COUNTRIES HAVE OVER THEIR URBAN PERIPHERIES. A PRAGMATIC APPROACH WILL CONSIDERABLY ENHANCE THE REAL OPTIONS AVAILABLE TO CITY LEADERS IN THE FUTURE.

CONFRONTING CLIMATE DEMANDS ON INFORMAL SETTLEMENTS

Climate change has a disproportionate effect on the urban poor, especially poor households inhabiting informal settlements. Cities in rapidly urbanising countries have larger shares of their urban populations living in informal settlements or 'slums.' These areas require special consideration because of their heightened vulnerability.

Informal settlements are present in central and peripheral areas of cities, but new informal settlement formation is most rapid on the urban edge, where cheap vacant land is available. It has been estimated, for example, that in Ethiopia up to 80 per cent of the housing in peri-urban areas is informal (Kaganova and Zenebe 2014). A recent study in Lusaka, Zambia, found that 63 per cent of the city's population was living in informal settlements (Chiwele et al. 2022), and a global study of 200 cities found that, worldwide, around two-thirds of new residential areas were not planned before they were settled (Angel et al. 2016).

Urban expansion planning may help reduce informal settlement formation, but some informal settlements will continue to form in expansion areas. These settlements have a key role to play in welcoming rural-urban migrants and making room for new urban natives. Municipal governments can use urban expansion planning to ensure that residents of new peripheral areas (formal or informal) have access jobs and services (Lamson-Hall et al. 2022). A climate-resilient approach to urban expansion planning can also reduce pressure for informal settlement formation in areas of high climate risk, without marginalising the residents of those areas. In addition, it can include efforts to improve layouts in informal settlements, facilitating the provision of infrastructure. Municipal governments can also work to rapidly formalise informal areas to promote investment in higher quality buildings that are less vulnerable to disasters.

ASSESSING THE VULNERABILITY OF INFORMAL SETTLEMENTS

Climate change and the shock waves associated with it affect poor families in informal settlements disproportionally (Mitlin and Satterthwaite 2013), with compounding impacts at the household level, in neighbourhoods, and citywide. A 2015 World Bank report predicts that under a 'business as usual' scenario, "climate change could result in an additional 100 million people living in extreme poverty by 2030" (Hallegatte et al. 2015, 2).

Household impacts

Poor households in informal settlements are at higher risk from climate events because their health is more vulnerable (Hardoy and Pandiella 2009), they spend more on food and hence are disproportionally affected by rising food prices following adverse climate events (Tacoli 2013), and they have fewer assets and lower savings that can protect them from risk in emergencies. As a result, they typically take longer to recover from disasters, including repairing and rebuilding their homes (Moser and Satterthwaite 2008).

The homes of poor households are made of cheaper materials and are typically constructed without regard to building codes, with the result that they cannot withstand adverse climate events as well as homes in the formal sector (Hardoy and Pandiella 2009). Investment in housing in informal neighbourhoods is often compromised by insecure tenure or the threat of eviction.

Neighbourhood impacts

Denied access to formal land markets, informal neighbourhoods often occupy less desirable and vulnerable locations that are subject to inundation by extreme precipitation, river flooding and storm surges, as well as mudslides (Hardoy and Pandiella 2009). The infrastructure in these neighbourhoods – roads, water mains, sewers, and electric lines – is typically of inferior quality and often under-maintained, and therefore more likely to be damaged and washed away during extreme climate events (Moser and Satterthwaite, 2008). More specifically, these neighbourhoods do not have solid and well-maintained drainage works or adequate permeable green spaces that can absorb rainwater and delay flooding (Parkinson 2003).

The risk of landslides in particular is greatly reduced by the provision of proper drainage infrastructure, retaining walls, foundation piles, and the placement of vegetation to stabilise slopes. These investments can be substantial, and many of them belong to parcel owners, not the government (Lin et al. 2020). The successful deployment of these tools will also depend on local conditions. Formalising the development of steep slopes with adequate arterial road access will facilitate the provision of critical public sector infrastructure and encourage private investments that will minimise landslide risk.

Some areas will be subjected to repeated disasters of the same type, such as storm surge exacerbated by sea level rise. In those areas which will eventually be permanently uninhabitable, it is important to consider that the threat of future loss will not necessarily prevent people from building there in the near term. In fact, a decision to exclude otherwise well-located lands from the urban expansion plan will almost certainly lead to informality in those areas. An important job of the government in those areas is to provide people with information about the risks that they are taking by settling there.

Citywide impacts

Informal neighbourhoods are frequently denied municipal infrastructure services that may increase their resilience (Watt 2020), often because of their questionable tenure status or their failure to conform to municipal subdivision, zoning, and land use regulations and building codes. Residents of informal neighbourhoods are typically also politically weak vis-à-vis better-off ones (Fraser 2017). Even when municipalities do engage in infrastructure improvements that are intended to increase their city's resilience to climate change, poor informal neighbourhoods generally find themselves at the end of the queue (Chu et al. 2019).

When disaster strikes in those areas, other parts of the city will also be affected, and city leaders will be forced to respond. City leaders should identify areas with good access to the job market and provide arterial roads even in high-risk areas if there is a possibility the land will be settled, including by informal settlers. Those areas should be provided with urban infrastructure and formalised through the provision of land tenure. When local disasters such as flooding, landslides, and storm surges do occur, the arterial grid connections in those areas can serve as evacuation corridors to rapidly move residents who are in danger to higher elevation areas, minimising loss of life.

Some municipalities may use the rationale of improving their cities' resilience to climate-related disasters to accelerate evictions and forced resettlement of informal communities. Recent evidence from the United States suggests that "disasters increase evictions and lead to significant disruption for many low-income tenants for years after the disaster" (Brennan et al. 2021). A more pertinent example is the threat of mass eviction in Guatemala City, Guatemala, following its devastating 1976 mudslides (Box 4).

The IPCC, Cities Alliance, and others have called for increased infrastructure provision to informal settlements as a strategy for building resilience to climate risk (Revi et al. 2014a; Cities Alliance 2021), along with improvements in the quality of housing in those areas. Previous research has shown that providing land titles in those areas increases investment in housing (Galiani and Schargrodsky 2010) and makes homes more climate resilient.

MUNICIPALITIES PLANNING FOR CLIMATE-RESILIENT URBAN EXPANSION SHOULD NOT ASSUME THAT CLIMATE DISASTERS, EVEN THE WORST ONES, WILL DISCOURAGE PEOPLE FROM REBUILDING THEIR NEIGHBOURHOODS OR CREATING NEW NEIGHBOURHOODS IN LOCATIONS WITH SIMILAR ENVIRONMENTAL RISKS TO THOSE DESTROYED BY EXTREME CLIMATE EVENTS.

Instead, cities should focus on reducing risk and supporting informal households and neighbourhoods.

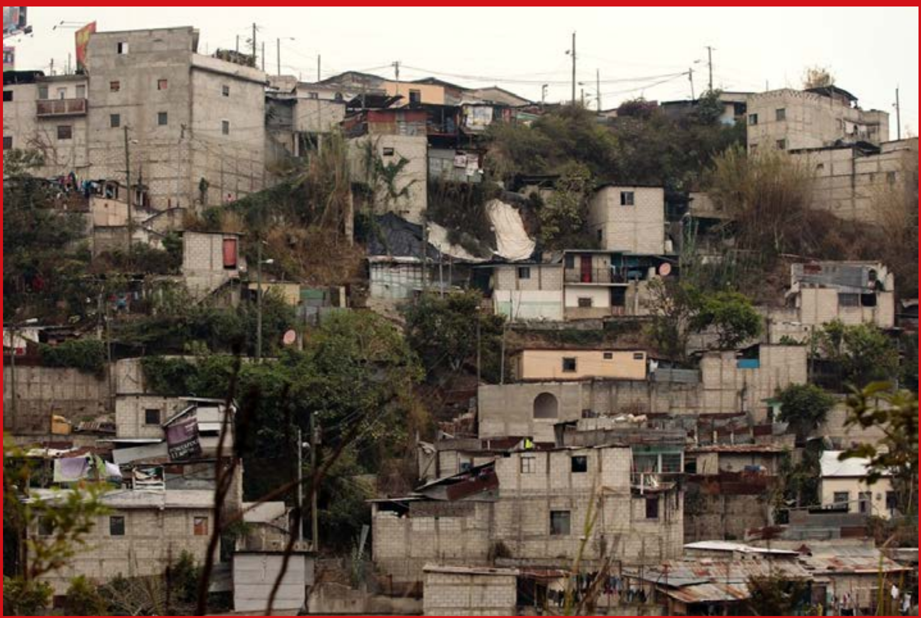
Eventually, some areas of cities will become truly uninhabitable, and the people who live there will become willing to relocate. Consideration of these areas must include informal settlements, while acknowledging that the definition of 'uninhabitable' will likely vary based on local knowledge and preferences (Hino et al. 2017). This can be anticipated in the climate-resilient urban expansion plans, to some degree. The total land made available in the expansion area should be increased by an amount equal to the occupied area that will be lost due to sea level rise, regardless of the legal status of the inhabitants. This will support managed retreat by keeping land available and affordable, while ensuring that informal settlers are included in climate adaptation plans.

BOX 4
GUATEMALA CITY: EVICTION IN THE NAME OF IMPROVING CITY RESILIENCE

Residential land in the metropolitan area of Guatemala City, Guatemala, is clearly divided into two types: relatively flat land on the plateaus, and land in the canyons *(barrancos)* cutting into those plateaus (Figure 6). Formal sector housing generally occupies the flat lands, while the informal sector occupies the slopes of the canyons. In 2000, approximately 40 per cent of the city's population lived on those slopes, some of them for decades (Angel 2000).

Yet the 2010 development plan for the metropolitan area recommended declaring these settlements as areas of high risk and endangerment to their inhabitants and transferring them to dormitory communities outside the metropolitan area (Municipality of Guatemala 1995, 64). In the process, it promised to increase the amount of land in the metropolitan area devoted to green areas, forests, and protected areas to 46.1 per cent of the total: "The canyons within the metropolitan area would be utilized as forested areas that will create the ecological green belt" (Municipality of Guatemala 1995, 9).

FIGURE 6
Barranco housing at risk of landslides in Guatemala City in 2018 (UN Women/Ryan Brown).



These recommendations were a direct policy response to the landslides that devastated the metropolitan area in 1976. Fortunately for the many residents of those areas, the 2010 development plan did not include plans for resettling the population at risk of mudslides or the budget for implementing them, and none have ever materialised. In fact, the actual percentage of the metropolitan population that would be in serious danger of mudslides could be roughly estimated from the preliminary results of a study undertaken in 1997 (ILS 1997) to be around 5 per cent. The rest were in areas where the landslide risk could be mitigated with low levels of drainage infrastructure improvements.

Such city resilience policies – motivated by exaggerated fear of pending climate disasters – are unrealistic, unattainable, and, imposing as they are, postpone the improvement of infrastructure services and homes in these informal communities. They delay the mitigation of environmental risk and the consequent investment of families in consolidating their houses and transforming them into dignified dwellings.

Efforts to use regulations to limit construction on steep slopes have been unsuccessful in many developing countries. Steep terrain is often cited as a key characteristic of informal settlements (Sant'Anna et al. 2021). These settlements evolved due to their proximity to employment centres, giving their residents access to wage-earning opportunities. When steep slopes become the only locations where urban residents can settle in order to access those opportunities, it is highly likely that they will be occupied.

LIMITING EXTREME TEMPERATURES

One of the most dangerous effects of global warming facing informal settlements is extreme temperatures, both extreme cold and extreme heat. A recent global study (Zhao et al. 2021) estimated that during the 2000-2019 period more than five million annual deaths, on average, were associated with non-optimal temperatures, accounting for 9.4 per cent of all deaths (Table 1).[1]

1 Nine out of ten of those deaths were cold-related, and one out of ten was heat-related. Although the share of heat-related deaths is small compared to cold-related ones, the former is now on the increase and the latter on the decrease, with both changes attributed to climate change.

Heat-related public health issues are particularly acute in developing countries, including the rapidly urbanising countries which are the focus of this paper, but the dangers of excessive heat are often neglected by governments. A 2014 report notes that "[e]xcessive heat events do not elicit the same immediate response as floods, fires, earthquakes, and typical disaster scenarios. They destroy less property but have claimed more lives over the past 15 years than all other declared disaster events combined.… The human body functions best at 98.6 degrees F (37 degrees C) …. The body has mechanisms to rid itself of excess heat – most notably sweating. But at a certain point, that fails to work, especially if humidity is high and perspiration cannot evaporate." (State of New Hampshire 2014).

The poorest households often reside and work in the hottest locations (Park et al. 2018; McDonald et al. 2021). In a study of Nairobi, Scott et al. (2017) found that "[d]uring the hottest summer on record in Nairobi, temperatures measured within three informal settlement neighbourhoods – Kibera, Mathare, and Mukuru – regularly exceed temperatures at the central, non-slum monitoring station by several degrees or more. These differences persist throughout the day and night."

Trees can play an important role in reducing daytime temperatures. In a study of Accra, Hosek (2019) found that "the more important services of urban trees include reduced indoor and outdoor temperatures, removal of traffic-derived pollutants and particulate matter, and reduced storm water run-off." Hosek also found that average tree canopy cover in Accra varied from 23.1 per cent in non-poor neighbourhoods to 12.4 per cent in moderately poor neighbourhoods, and to 3.5 per cent in very poor neighbourhoods.

TABLE 1

Annual average excess deaths due to non-optimal temperatures, 2000-2019 (Redrawn from Zhao et al. 2021, Table 1).

Region	Total		Cold-related		Heat-related?	
	Number	Regional Share %	Number	Regional Share %	Number	Regional Share %
Global	5,083,173	100.0	4,594,098	100	489,075	100
Regions with Rapidly Urbanising Countries	4,036,538	79.4	3,748,879	81.6	287,659	58.5
Eastern Asia	1,235,428	24.3	1,155,656	25.16	79,772	16.31
Southeast Asia	189,569	3.73	168,295	3.66	21,274	4.35
South and Central Asia	1,065,510	21.0	951,238	20.7	114,272	23.4
Western Asia and North Africa	252,261	5.0	236,376	5.1	15,885	3.2
Sub-Saharan Africa	1,088,589	21.42	1,070,221	23.30	18,368	3.76
Latin America and the Caribbean	200,055	3.94	163,360	3.56	36,695	7.50
Oceania (without Australia and New Zealand)	5,126	0.10	3,733	0.1	1,393	0.3

THE MORE IMPORTANT SERVICES OF URBAN TREES INCLUDE REDUCED INDOOR AND OUTDOOR TEMPERATURES, REMOVAL OF TRAFFIC-DERIVED POLLUTANTS AND PARTICULATE MATTER, AND REDUCED STORM WATER RUN-OFF

Water is also critical for avoiding dehydration, and municipal water, though often considered undrinkable in developing countries, can be a resource of last resort in extreme circumstances. Electricity can power air conditioners and fans, which, though far from ubiquitous in informal settlements, are becoming increasingly common worldwide as incomes and temperatures continue to rise. During an extreme temperature event, access to water and electricity could save many lives.

Climate-resilient urban expansion planning can address excessive heat by supporting the planting of shade trees and by easing the provision of piped drinking water and electricity. The proposed arterial road network in the urban expansion area of the city consists of 30m-wide roads spaced 1 km apart. These roads can carry trunk infrastructure and are wide enough to allow for large shade trees. Municipalities engaged in urban expansion planning can ensure that all new areas are no more than 500m from one of these roads.

Efforts to extend tree cover, water, and electricity into new urban neighbourhoods may require some interventions to improve the quality of street layouts. Introducing infrastructure services into dense informal communities in Brazil cost three to six times more than introducing them into planned subdivisions (Abiko et al. 2007). Street tree plantings also depend on having enough street space to plant the trees, which is not always the case in new urban neighbourhoods. Improved neighbourhood layouts can also be aligned with inversion flows (breezes) and can include solar-conscious plot design to encourage better building orientations, both of which can reduce nighttime temperatures (Krayenhoff et al. 2018).

Municipalities engaging in urban expansion planning can also take direct action to improve neighbourhood layouts on the urban periphery. For example, in Hawassa, Ethiopia, the city government worked with informal settlers to widen and straighten neighbourhood streets, while also making room for the arterial road network. Participating residents were given formal titles and connected to the municipal water supply (Lamson-Hall et al. 2018).

Municipalities can work with informal developers who subdivide and sell plots on the urban periphery to improve their subdivision practices. Houses in gridded sites-and-services neighbourhoods increase in quality and value faster than houses in informal neighbourhoods with upgraded infrastructure (Michaels et al. 2021), so a strong economic rationale exists for the developers to take these measures.

IMPROVING BUILDING QUALITY

Buildings in informal settlements in the expansion areas of cities will be relatively more vulnerable to adverse climate events. Informal households and migrant households in particular are more vulnerable to climate change, in part beacuse the quality of construction in the informal settlements where they often live is typically lower than in other areas. Indeed, some homes are essentially temporary in nature, and cannot survive extreme events.

Municipalities are often charged with implementing building codes and overseeing construction standards, but in secondary cities in rapidly urbanising countries the resources to do so are limited. Any effort to tighten building standards would no doubt lead to some increase in the share of compliant buildings in the formal sector, but it would also increase building costs, incentivising more households and firms to build in informal settlements where inspections and enforcement are essentially non-existent.

Climate-resilient urban expansion planning can help address the quality of construction in expansion areas by creating conditions for greater investment in buildings. It does this by reducing the cost of land for construction, encouraging formal development over informal development, and by supporting the regularisation of informal settlements.

Urban expansion plans affect the cost of land by increasing the supply of well-connected land for development on the urban periphery. This was described earlier in the context of controlling sprawl. It also helps poor households improve building quality, because the price of land is a major driver of the cost of homes. Buildings in informal settlements are often built incrementally over many years, but land must be acquired up front, either with an informal mortgage or using savings. By reducing the cost of land, household budgets for housing can shift toward higher quality materials and greater investment in the structures.

The same mechanism – lower land prices – also makes formal development relatively more competitive versus informal development. Land prices in formal development areas are typically much higher than in informal areas (Selod and Tobin 2018). Municipalities often create a scarcity of formal sector land by overregulating development or by inaccurately forecasting growth (Goytia 2019). When formal land is more abundant and less costly, more people will settle in formal areas. These people will have formal land titles (though not necessarily building permission), which increases investment in private buildings in informal settlements (Field 2005).

Urban expansion planning has also stimulated some municipalities (such as Hawassa, Ethiopia, mentioned earlier) to experiment with new strategies for regularising informal settlements. This also leads to more households having formal land titles, even in areas where development initially proceeded along informal lines and should be expected to have the same impacts on investment as in the example above.

Climate-resilient urban expansion planning is unlikely to stop the formation of informal settlements, particularly in countries with rapid urban growth. It can, however, lay the groundwork for adaptation and risk reduction strategies that address many of the major vulnerabilities faced at the household and neighbourhood levels. Investments in arterial roads, titling, land supply, basic infrastructure, and improved settlement layouts will improve resilience in the face of climate risks.

CONFRONTING CLIMATE DEMANDS ON URBAN INFRASTRUCTURE IN EXPANSION AREAS

Secondary cities in rapidly urbanising countries are facing enormous spatial expansion, and much of it is occurring without adequate public services or infrastructure. Servicing new and existing areas with infrastructure is a multi-generational task.

Urban expansion planning keeps options open for future leaders and conserves resources by reserving land for future infrastructure. This happens via the arterial road rights-of-way. These rights-of-way are planned to service the next 30 years of anticipated spatial expansion on the urban periphery. This establishes corridors in the urban expansion area that can carry public transportation, pedestrians, cyclists, private vehicles, and trunk infrastructure.

Investing in the arterial road rights-of-way in the short-term is much cheaper than attempting to acquire these corridors gradually over the next three decades. Competition for land will increase as the city develops, and some routes will be occupied before they can be acquired. Acquisition of the corridors does not mean that they have to be developed immediately, however.

The same is true of protected environmentally sensitive areas, which should be acquired and kept free of development when land is cheap. Investing in turning them into attractive public open spaces can come later.

Climate-resilient urban expansion planning applies the same principle: by anticipating future areas of settlement, minimal investments can be made that anticipate future infrastructure needs. Making investments in preparing for climate change now is orders of magnitude cheaper than attempting to make those investments later.

Climate change will make infrastructure provision in expansion areas more difficult by straining drinking water supplies while also increasing the need for flood protection and stormwater management, and major upgrades to roads, power lines, bridges, and other vital connective infrastructure. Competing investment demands will strain municipal requirements and not all areas will be equally protected or serviced.

PLANNING FOR WATER SUPPLY SHORTAGES

Urbanisation will place additional strains on already limited water supplies (e.g., Ayeni 2017) in secondary cities in rapidly urbanising countries. In some places, this can be remedied with additional investments in pumps, distribution lines, and treatment systems. Major savings can also come from investments in conservation. In other places, the challenge is more fundamental and comes down to total water availability, which will need to be remedied by bringing in outside supplies, reducing waste, and increasing storage capacity.

Particularly in secondary cities in rapidly urbanising countries, urban expansion and the increase in population in urban areas are rapidly raising the demand for water. This is partly due to increased water demand resulting from higher per capita incomes and more residents and businesses. The main reason, however, is greater demand for agricultural goods from the urban hinterland as agricultural users consume dramatically more of the available water than urban areas (OECD 2014). Water management systems must consider the total consumption within a hydrological area, both rural and urban.

Climate-resilient urban expansion plans can support this activity by highlighting new areas where growth is likely to occur, and by adding predictability and scope to the long-term urban growth process. The plans concern the existing area of the city and adjacent expansion areas. In some cases, this includes areas of water extraction and storage, and the urban expansion planning exercise can highlight existing water supply areas and consider future water storage and extraction needs.

The plans can also be used to protect surface water supplies as one component of protecting environmentally sensitive areas. For example, Hawassa, Ethiopia, draws its water from an endorheic lake that is closely abutted by urban development. Recognising that the city government is unable to afford sewerage and drainage water treatment, the urban expansion team included a 100m passive protective buffer along the lakeshore in the plan. This buffer is designed to remain heavily vegetated, capture contaminants from the urban area, and slow their infiltration into the lake (Lamson-Hall et al. 2018).

In addition, the plans support access to piped drinking water supplies. The arterial road grids are designed to carry trunk infrastructure, including water mains, which can make it both cheaper and easier to provide basic services in adjacent neighbourhoods, whether formal or informal.

BASIC ACTIONS CAN ADDRESS WATER ACCESS AND WATER QUALITY. HOWEVER, THEY DO LITTLE TO ADDRESS THE QUESTION OF TOTAL WATER SUPPLY WITHIN A HYDROLOGICAL AREA. THE CONDITIONS THAT CREATE URBAN DROUGHT ALSO EXACERBATE THE CHALLENGES FACING RURAL RESIDENTS, BUT THEY MAY NOT BE BEST ADDRESSED AT THE CITY LEVEL.

Water scarcity and drought have a variable scale depending on the water resources available. In some cases, water is managed within a hydrological basin that is similar to that of the urban area itself. In that case, water management is also an urban spatial management issue, with the protection of the watershed a key priority for municipal officials (Box 5). In other cases, water is drawn from large underground aquifers or surface water sources that are managed over a much larger area than that which is controlled by city officials. In these cases, the possible impact of spatial planning decisions taken by city officials will be more limited.

BOX 5
ENCROACHMENT ON THE RESERVOIR: JIGJIGA, ETHIOPIA

In the rural hinterland of Jigjiga, Ethiopia, a multi-year drought has led to a partial collapse of the pastoralist economy in the surrounding area. Surface water sources have dried up, and traditional storage sources such as birkas and hand-dug wells have also gone dry. Displaced pastoralists have migrated to the city and live in informal settlements on the urban edge (Kerins and Burke 2019; Zewdie and Tesfaye 2000).

Jigjiga itself is dependent on a small man-made reservoir. Water from this reservoir is pumped to tanker trucks, delivered door-to-door by donkey carts, and flows through a network of water supply pipes. It is supplemented by 24 boreholes. As with rural water sources, the water supply in Jigjiga is dependent on rain for direct recharge of the reservoir and replenishment of groundwater sources that supplement it (ibid).

The current water system was designed in 1975 for a population of 20,000 (Asfaw et al. 2016), however, and will require significant expansion to fully satisfy demand.

In 2003, the distance from the city of Jigjiga to the reservoir was 5 km. Because of urban growth, itself partly driven by drought, the reservoir in Jigjiga is now only 2 km from the edge of the city (Figure 7). When Jigjiga was preparing its urban expansion plan, it became clear that the city's reservoir and water supply infrastructure would soon be surrounded by the rapidly growing city, increasing the risk of contamination of the water supply, particularly considering the lack of any sewage treatment in the city. Planners are now working to guide growth away from that area by providing land for expansion to the west of the city.

FIGURE 7

Encroachment on the drinking water reservoir in Jigjiga, Ethiopia from 2003 (left) to 2021 (right) (Google, n.d.).

By 2050, 1.9 billion urban dwellers will be exposed to seasonal water shortages. This represents 82.6 per cent of the total urban population growth that will take place in the next 30 years (World Bank 2018.) Frameworks for water resources management can help address this challenge by considering the total water availability within a hydrological region and helping to explore tradeoffs among different uses, such as agriculture versus urban development. This can help highlight the role of cities in rural water management practices, for example, and lead to more investments in water supply and conservation (Gober 2010).

Historically, these investments have been forthcoming, and water supply in cities has expanded in line with population growth. Developing countries, however, have struggled to keep pace with rapid urban growth. Water supply projects are capital-intensive, multi-year undertakings. Failure to expand water supply sources in response to a growing population can result from many factors, but it is often linked to insufficient revenue capture mechanisms, organisational shortfalls, and a lack of access to capital (Wilson Center 1999).

Reforming water supply through privatisation or franchising of water systems has been successfully implemented in many countries, improving service delivery and reducing losses from poor maintenance and operation, which in some cases can exceed 50 per cent of total supply (Noll et al. 2000). This is mainly due to increases in rates and expansion of rate payers, which enables the utility to fully cover costs and borrow to finance expansions and upgrades of equipment (OECD 2014).

WATER SUPPLY PROJECTS, BY THEIR NATURE, ANTICIPATE DEMAND. THE URBAN EXPANSION PLAN DOES NOT CONTAIN INFORMATION ABOUT PER CAPITA CONSUMPTION AND IS NOT ABLE TO ANTICIPATE HOW CONSUMPTION PATTERNS WILL CHANGE OVER TIME. HOWEVER, IT CAN HIGHLIGHT THE TOTAL NUMBER OF PEOPLE AND THE TOTAL URBAN AREA THAT URBAN WATER SYSTEMS WILL NEED TO SERVICE.

Providing this information to water authorities through appropriate institutional channels can support an examination of total water demand. Basic precipitation information developed in the course of assessing urban risks can also provide an important input for anticipating future supply challenges and storage needs. City leaders are an important stakeholder in this process and should support the delivery and consideration of this information at the local, regional, and national level.

When urban expansion plans have been implemented – with land on the ground reserved for arterial roads – city leaders should turn their attention to advocating for urban water management systems that are able to support their anticipated population growth. These systems must be robust enough to make necessary investments and manage regional water resources within a hydrological area. Actions to improve water management will necessarily include management of extreme precipitation and flooding, which are expected to occur alongside water scarcity in the coming decades.

MANAGING FLOODING

Climate change is altering precipitation patterns, leading to more frequent extreme rainfall. Rainfall results in flooding for three reasons:

1) the ground becomes saturated with water and can no longer absorb falling rain;

2) impervious surfaces prevent infiltration of water from occurring; and

3) drainage channels and networks become overwhelmed by unexpectedly high volumes of water (Tabari 2020).

Cities may also be exposed to compound flooding when high tides or storm surge correspond with extreme rainfall, blocking drainage channels (Revi et al. 2014b, 555).

Cities can reduce or avoid flooding by using drainage infrastructure to remove excess stormwater and by protecting open spaces that allow water to infiltrate into the soil. Assessing drainage at the city level can lead to better flood control than a neighbourhood-based approach (Mailhot and Duchesne 2010).

Climate-resilient urban expansion plans cover the future area of the city for the next 30 years, and arterial road grids in expansion areas can carry major drainage lines that ferry water away from neighbourhoods. Road rights-of-way and environmentally sensitive zones in the expansion area can be aligned to accommodate existing drainage patterns on the land and promote infiltration of stormwater to help recharge groundwater sources, in line with the Rio Declaration call for sustainable drainage systems (Zhou 2014).

Arterial road rights-of-way near water bodies can eventually be developed as levees, embankments, or other water management infrastructure. Topographic maps, already used in the expansion planning process, can be incorporated to align the expansion plans with the contour of the land, supporting the construction of gravity-fed drainage lines.

Urban expansion plans currently provide buffers alongside water bodies with the idea of avoiding settlement in floodplains and minimising water pollution from human settlements. Climate-resilient urban expansion plans should calibrate the buffers along waterways with an assessment of flood risk and include expanded buffers where water bodies discharge into the sea.

These buffer zones must be adequately protected, and it may not be possible to discourage settlement in all the designated areas. City leaders pursuing climate-resilient urban expansion planning should work with residents of flood prone areas to ensure that they are fully informed about the risks they face and identify supportive infrastructure investments (Marfai, Sekaranom and Ward 2015), particularly those that can facilitate temporary evacuation during peak flood events.

In light of the clear and important role of drainage in urban expansion areas, climate-resilient urban expansion planning teams should be expanded to include a drainage expert or hydrologist who can guide the arterial grid alignment and the placement of open spaces. This expertise will help ensure that urban expansion areas can take maximum advantage of the opportunity to create resilient water management infrastructure for the next 30 years of growth.

IMPROVING INFRASTRUCTURE RESILIENCE

Climate risks can overwhelm and damage urban infrastructure networks, including water, electricity, sewerage, streets, roads, public transportation, rail lines, and bridges. Extreme events can sever these systems, cutting off parts of the city from necessary services and connective infrastructure.

Urban infrastructure systems are vital for maintaining livable conditions in cities. Without the services these systems provide, highly populated areas would quickly lose the ability to sustain productive activities. In the face of climate risks, the resilience of this critical infrastructure is vital to the sustainability of the urban system.

Municipalities have a role to play in making these systems more resilient, especially those under their direct control. Other systems may be operated, owned, or maintained by private vendors, parastatals, or other levels of government. It may not be within the scope of the municipality to prevent failures, but the consequences of such failures will demand an emergency response from the municipality. and planning efforts should include infrastructure considerations.

THE VULNERABILITY OF WATER SUPPLY HAS ALREADY BEEN EXAMINED IN SOME DETAIL. WATER DISTRIBUTION NETWORKS, PARTICULARLY IN COUNTRIES WITH SUBSIDISED WATER PROVISION, ARE OFTEN EXTREMELY UNRELIABLE ALREADY (MAJURU ET AL. 2016), AND SUPPLY CHALLENGES WILL ONLY EXACERBATE THIS.

Urban expansion planning has been shown to help with the expansion of distribution networks. Climate-resilient urban expansion planning should consider the robustness of those networks. The urban climate risk assessment, shared with water authorities, can help with safe placement of water infrastructure that may be damaged by extreme events. Hidden elements of the distribution network, such as informal water vendors, can be reconsidered in light of climate risks, which should provide an added impetus for extension of the formal distribution network.

Electrical provision is endangered by numerous risk factors:

extreme storms that can bring down power lines and power poles,

storm surge and floods which can swamp power generation and distribution facilities,

landslides that can bring down long-distance high-tension lines,

extreme heat which reduces transmission efficiency and increases line sagging,

and lightning strikes that destroy distribution equipment.

80 PER CENT OF BLACKOUT EVENTS IN THE UNITED STATES FROM 2003 TO 2012 WERE RELATED TO EXTREME WEATHER

The impacts of these risks are increasing, and 80 per cent of blackout events in the United States from 2003 to 2012 were related to extreme weather (Kenward and Raja 2014). Aged components are more vulnerable to these risks than newer equipment (Panteli and Mancarella 2015).

Municipal governments rarely maintain or own electrical supply infrastructure. However, local distribution infrastructure is typically located on city streets and roads. The placement of light and power poles within the road right-of-way can affect their vulnerability to storms. Maintenance of street trees in proximity to power lines is also an important activity. Provision of wide arterial roads in the urban expansion plan can provide more space for safe placement of electrical infrastructure.

Sewage systems and the disposal of municipal waste can be compromised by flooding and extreme rainfall. In wealthy countries, this can overwhelm wastewater treatment plants, sending untreated waste into water bodies (Olds et al. 2018). In most rapidly urbanising countries, wastewater treatment is nonexistent, and sewage is already co-mingled with stormwater in drainage systems. Diseases resulting from exposure to sewage pathogens drive mortality rates, particularly in informal settlements. Building on earlier arguments around flood control, reduction in pathogen exposure is another powerful reason for climate-resilient urban expansion planning to carefully consider the drainage network in the expansion area of the city, ensuring that it has adequate capacity and channels excess stormwater to safe locations for discharge or infiltration.

The impact to roads, bridges, rail lines and tunnels is similarly severe, as vulnerable transportation links may lose serviceability after an extreme event. In rapidly urbanising countries, the destruction of these links may impact national development trajectories by isolating communities or neighbourhoods and will demand increased expenditure on maintenance (Espinet 2016).

Planning for climate-resilient urban expansion should include a planned and progressive strategy for locating infrastructure corridors to minimise the vulnerability of these vital links. This should not be done in a way that compromises the usefulness of the infrastructure, but it should be sensitive to climate risks as presented in the proposed urban climate risk assessment. Scenario modeling shows that the benefits of adaptation investments are still considerable, even in a context of forecasting uncertainty (Abadie et al. 2020).

Urban infrastructure of all types is highly vulnerable to climate change. Municipal governments can use urban planning to reduce that vulnerability as part of preparing for expansion on the urban periphery. This includes using forecasting and climate risk data to improve assessments of future needs and risks, and directly controlling the locations of infrastructure corridors through the deployment of the arterial grid. If done in consultation with local experts, this can help protect water supplies, improve drainage, and safeguard other vital links, reducing flooding and maintaining connectivity and basic services during extreme events.

COMPETITION FOR ADAPTATION INVESTMENTS

Adaptation to climate risks in cities will require additional investments in drainage and flood control infrastructure to ensure the survival of urban infrastructure and prevent loss of life (Revi et al. 2014b). Many decision-making tools for adaptation investments assume that the area of the city is static and offer little insight in how to prepare new lands that will someday become urban (for example, Gargiulo et al. 2020).

Secondary cities in rapidly urbanising countries will be impacted to an outsized degree due to the geography of climate risk (Collier et al. 2008; Dasgupta et al. 2007), but they generally lack the resources to comprehensively invest in the sea walls, storm surge barriers, flood control dams, drainage channels, levees, dikes, and pumps that comprise much of the hard infrastructure of adaptation. Nonetheless, there are actions cities can take to prepare their expansion areas for future adaptation investments.

Climate-resilient urban expansion planning acknowledges that cities are growing and plans for that growth. This helps municipalities anticipate where urban growth is likely to occur, based on the simple idea that development follows roads. Urban expansion planning initially only provides road rights-of-way, but growth will follow the construction of the arterial roads over time. This has been observed in Ethiopian cities, for example (Lamson-Hall et al. 2022). Thus, it becomes possible for municipalities to consider the urban periphery in conversations about adaptation and to develop a pipeline of investments to service new areas.

Pressure for adaptation investments will be greatest in core areas of cities, where cost-benefit ratios can easily be calculated and where, all else being equal, the greatest concentrations of population and capital can be found. Cities facing rapid urban growth should also consider how to make new and peripheral areas competitive for adaptation investments on a technical basis.

The main criteria used by funding agencies for evaluating adaptation investments are their long-term sustainability and the number of beneficiaries or amount of property protected for a given investment. New urban areas that grow at a higher density – whether of property or of people – will be better positioned to secure funds for these investments. Compact growth patterns on the urban periphery will also help stretch resources by reducing the area that must be protected.

It is not generally possible for cities to prescribe minimum densities, but many actions that cities take can inadvertently result in lower densities (Bertaud and Malpezzi 2003). Plot size minimums, restrictions on building height, plot coverage maximums, minimum unit sizes, and other well-intentioned efforts to improve housing quality can also have the side effect of reducing the density of population and capital in cities (Angel et al. 2021). In wealthier countries, this can result in urban sprawl (Box 6).

Climate-resilient urban expansion planning can promote higher densities on the urban periphery by providing a grid of arterial roads (previously considered in the section on low-density sprawl), which should reduce total urban growth and promote compact development. To proponents of green belts and urban growth boundaries, this may seem ridiculous. How can supporting urban expansion promote compact and high-density development?

THE THREE MOST IMPORTANT FACTORS THAT DETERMINE THE AMOUNT OF URBAN EXPANSION IN A CITY ARE URBAN POPULATION GROWTH, TRANSPORT COSTS, AND AGRICULTURAL LAND PRICES. PROPERLY MANAGED URBAN EXPANSION CAN LEAD TO SMALLER URBAN FOOTPRINTS

1) Urban population growth is driven by natural increase in the urban population and the migration of people from rural areas to cities. The trend of urbanisation is exclusively driven by rural-to-urban migration, as rural areas have higher birthrates than urban areas. Implementation of an arterial road grid in one city will make that city more attractive for business and residential development, all else being equal. Increased economic growth and improved access to serviced urban land will also make the city more attractive, potentially increasing the share of national urban population growth that the city is able to attract. If arterial road grids are put in place in all the primary, secondary, and tertiary cities in the country, no individual city will have an advantage, and the net effect on the share of migration to each city should be nil.

2) The deployment of arterial road grids in urban areas should reduce their transportation costs, which is associated with increased urban growth. This should occur through lower levels of traffic congestion due to a greater share of land in streets and roads and through the availability of more direct routes, reducing travel distances. However, in studies that considered the role of transport cost in urban growth, the main considerations were the cost of commuting as a share of a normal income and the cost of fuel, which accounts for much of the impact. Thus, only a portion of effect on transportation costs will be due to route choice and congestion, and the balance will be due to fuel.

3) Most importantly, the establishment of the arterial road grid in rural areas adjacent to cities should have a major impact on both urban and rural land prices, lowering the former and increasing the latter. This is because the grid increases the supply of urban land, depressing the price of urban land. The grid also improves the accessibility of rural land, expanding its access to market and the profitability of goods produced there, increasing the price of rural land. If the grid is deployed throughout the urban periphery and simple dirt roads are constructed to improve access to rural lands, the net effect of these price shifts should be to reduce the amount of land that is converted from rural to urban use, providing a market incentive for higher density of both people and capital and improving the prospects for adaptation investments on the urban periphery.

BOX 6
WHAT IS URBAN SPRAWL?

'Urban sprawl' refers to a pattern of urban growth that includes low-density, single-use residential areas; fragmented development with limited pedestrian infrastructure; car-dependent development; and monotonous streetscapes (Figure 8) (Peiser 1989).

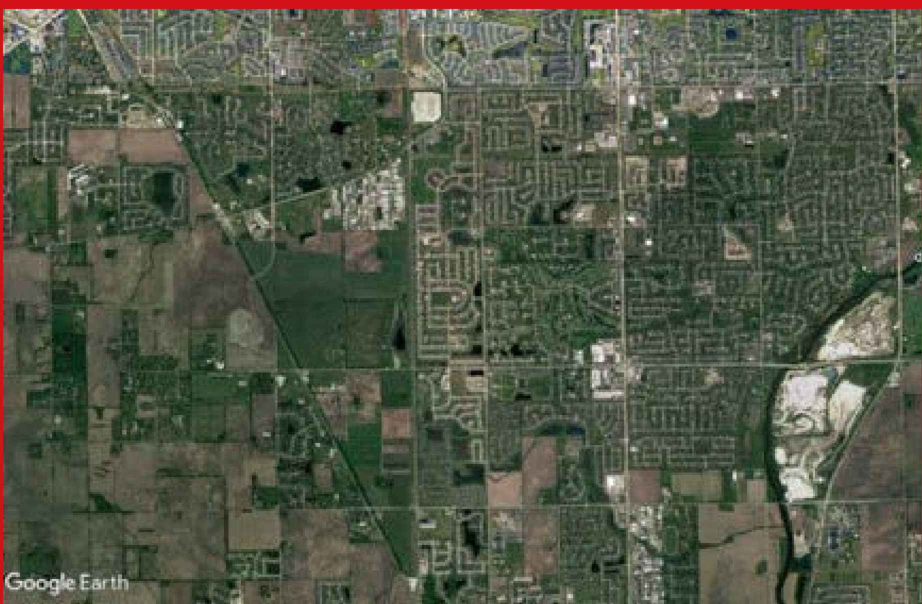
This type of growth has been associated with heightened obesity (Ewing et al. 2003), less walking (ibid), fewer and weaker interpersonal relationships (Leyden 2003), and higher infrastructure expenditures (Carruthers and Ulfarsson 2003), among other social and economic consequences.

The modern pattern originated in land-rich developed countries (LRDCs), such as the United States and Australia, and is driven by increased incomes, low agricultural land prices, transportation system choices, and zoning and land use regulations (Brueckner et al. 2001), which lead to higher consumption of land. When seeking to label urban sprawl, it is important to distinguish between necessary consumption of urban land due to population and economic growth and unnecessary consumption of urban land that results from wasteful policies such as these (Adaku 2014).

Efforts to control the growth of cities raise land prices by limiting land supply. This is inherently anti-poor, because poor people are much more sensitive to land prices than wealthier people. It often leads to lower housing quality and reduced floorspace consumption among low-income residents (Bertaud 2018). In rapidly growing cities, policies to limit land supply can also increase informality (Kaganova and Zenebe 2014).

Cities in rapidly urbanising countries develop at higher densities than those seen in the LRDCs and most likely should not worry about urban sprawl. A bigger problem in rapidly urbanising countries is fragmented development, which can undermine walking, cycling, and public transportation. Cities can make meaningful investments in supporting these modes by planning compact and functional road layouts and avoiding zoning and building codes that mandate lower densities (Lamson-Hall et al. 2020).

FIGURE 8
Low-density urban sprawl on the outskirts of Chicago, Illinois (Google Earth, n.d.).



Adaptation decisions are technical but also political. As cities in developing countries expand, including an equity component in decisions about adaptation investments can help make urban climate adaptation an inclusive and socially sustainable process (Shi, 2021). Urban expansion planning is already a pro-poor and inclusive process focused on meeting the needs of rural-urban migrants and urban natives with flexible, accommodating growth plans. Expanding this rationale to include climate resilience means considering the adaptation needs of expansion areas when preparing investment plans and helping make new areas competitive for those investments.

The compact growth and higher density enabled by urban expansion planning can also have a real impact on mitigation, discussed in the next section.

MITIGATION ON THE URBAN PERIPHERY

Cities in rapidly urbanizing countries have a role to play in mitigating greenhouse gas (GHG) emissions. The contribution of secondary cities in rapidly urbanizing countries to global emissions is marginal, butthis will likely change over time as their populations and economies grow.

This paper primarily focuses on the use of climate-resilient urban expansion plans to help secondary cities in those countries adapt to several broad categories of risk that will impact urban expasnion areas in the near term. Those countries presently generate lower GHG emissions per capita than countries that are more urbanized (Figure 9), and their cities are built at higher densities (Figure 10).

By 2050, the most rapidly urbanising regions – South and Central Asia and Sub-Saharan Africa – will have the first and third largest urban populations, respectively. Even at current levels of emissions, the 2.2-fold increase in population will make those regions major emitters. This will be especially true in relative terms if nations meet their commitments to reduce GHG emissions.

With economic growth, per capita emissions from rapidly urbanising regions will increase considerably. Exacerbating this is the importation of older vehicles and older air conditioning equipment that are less efficient than new machines. Ongoing investments in coal-fired power generation will also contribute to higher per capita GHG emissions from those regions, particularly as electricity consumption increases.

Mitigation measures in developed countries often centre on near-term mitigation of GHG emissions through 'compact city' densification and urban containment policies, reduction of building emissions, and electrification of vehicle fleets. Secondary cities in developing countries must focus on adaptation to climate change in the near term, while still preparing for longer-term, low-carbon development.

Climate-resilient urban expansion planning can help secondary cities in rapidly urbanising countries make structural preparations for low-carbon development. This mainly comes down to the benefits of a gridded street network to reduce vehicle kilometres traveled and the complementary effect of encouraging compact, contiguous development. Cities can also attend to building construction standards in expansion areas, improving the efficiency of building operation.

FIGURE 9

Rapidly urbanising countries generate lower per capita GHG emissions.

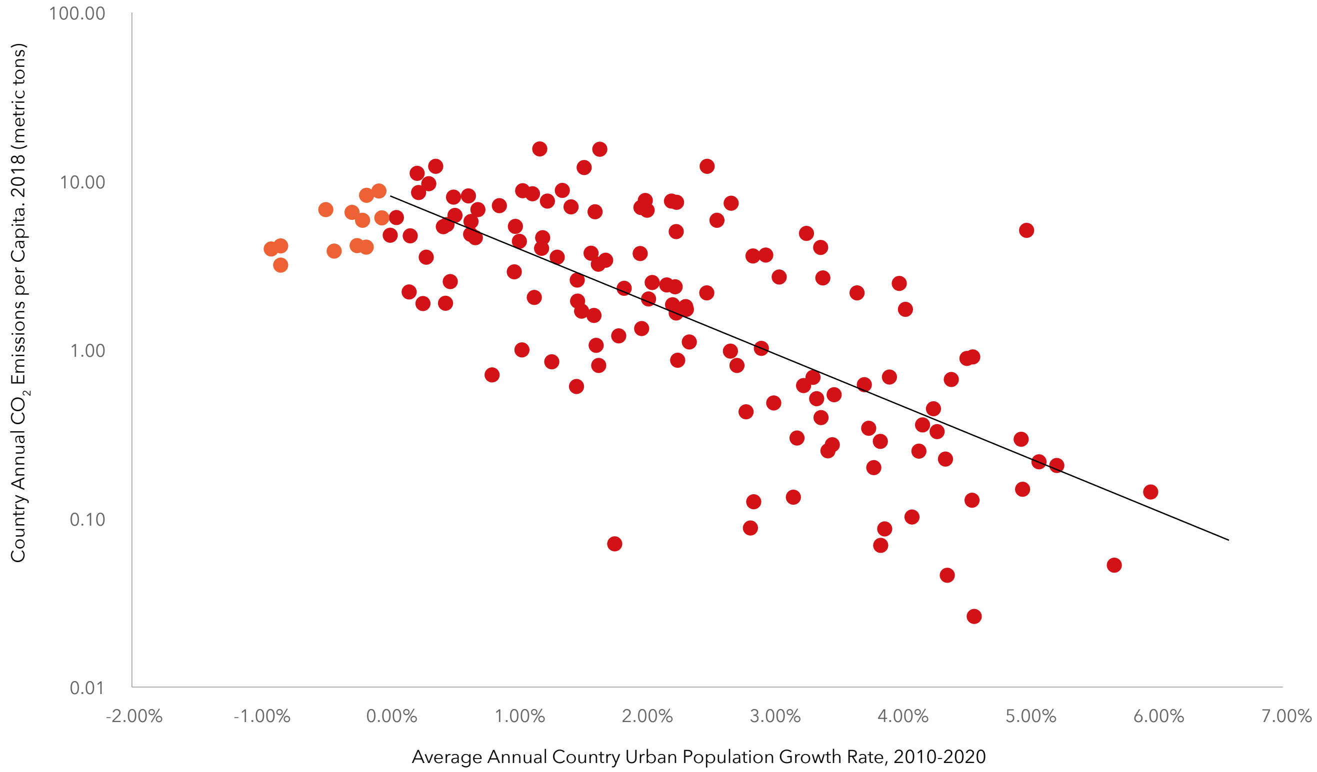
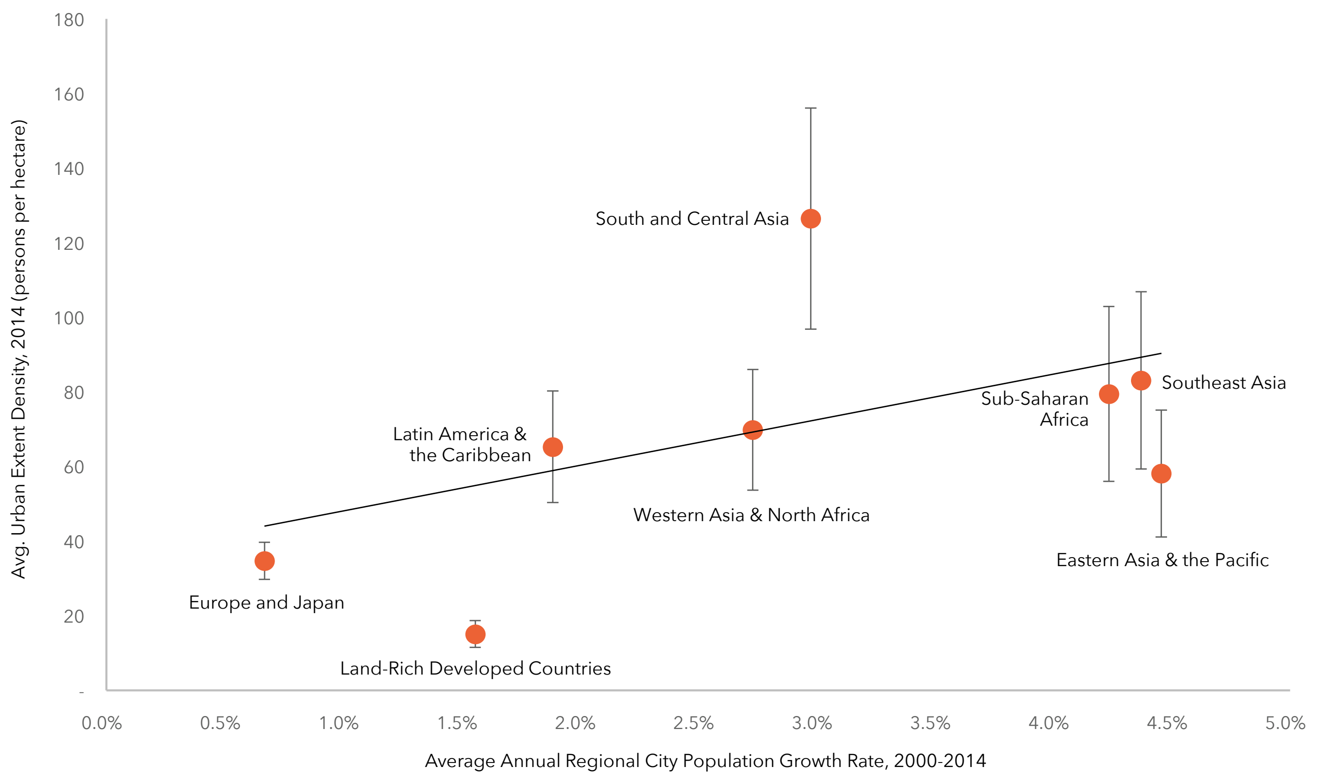


FIGURE 10

Cities in regions with more rapid urban population growth rates have higher average densities in their urban extents.



BUILDING EFFICIENCY

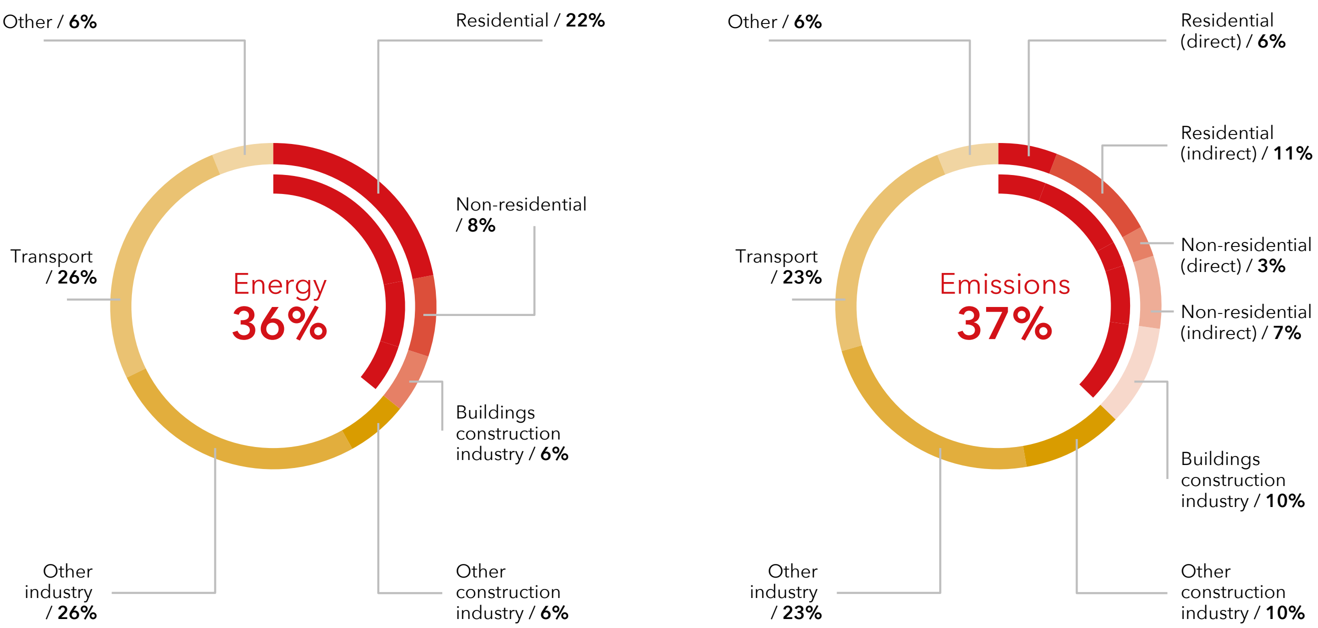
The building sector in 2020 was responsible for 36 per cent of global energy use, generating 37 per cent of total GHG emissions (Figure 11). Eight per cent of emissions in the sector were due to the production of concrete and eight per cent to the production of steel. The rest were attributed to the transport and manufacturing of building materials, construction processes, and the operation of building systems, including lighting, cooking, heating, and cooling.

Building technologies can work both to mitigate and adapt to climate change (adaptation is discussed in a previous section.) Mitigation is helped by better insulation, use of clean energy for cooking, heating, cooling, energy efficient appliances, and generating electricity from roof solar panels. Mitigation is also helped by using more renewable building materials, such as wood, and less steel and cement, which require enormous amounts of energy to produce.

Many new buildings will be constructed in the coming decades in the expansion areas of secondary cities in rapidly urbanising countries. In developed countries, improvements in building efficiency can be implemented through legislative action, subsidies, tax credits, and other tools. In developing countries, the mechanisms to influence building efficiency are less developed, in part because of the prevalence of informality as discussed in previous sections.

MUNICIPALITIES IN RAPIDLY URBANIZING COUNTRIES CAN ACT TO IMPROVE THE EFFICIENCY OF BUILDINGS IN BOTH FORMAL AND INFORMAL SETTLEMENTS BY PROVIDING USEFUL INFORMATION ON APPROPRIATE, AFFORDABLE, AND RESILIENT BUILDING TECHNOLOGIES AND DEMONSTRATING THEM WITH REAL EXAMPLES WHENEVER POSSIBLE.

FIGURE 11
The share of building and construction in global final energy and energy-related CO_2 emissions, 2020. Source: Global ABC, 2021.



Municipalities can also help create markets for local and energy efficient building materials by adopting such materials in municipal infrastructure projects and civic buildings, both in existing and expansion areas. Using municipal investment in this way may violate least-cost procurement rules, which should be modified to consider lifecycle costs of building operation as well as other co-benefits to local economies.

Supporting a market for vernacular materials is difficult and requires municipalities to work with suppliers to ensure reliable supplies of building materials. It will also require real efforts to reduce costs if those markets are to be competitive. Financial incentives can help encourage exploration of cheap, easily used local materials for construction. This can help preserve important local knowledge and may be especially useful in self-built housing.

Municipalities can go beyond information campaigns, demonstration projects, and support for markets. They can encourage additional spending on buildings in informal settlements and expansion areas by providing residents with assurances that they will not be evicted, accelerating the provision of secure tenure through proper recognition and documentation and providing municipal infrastructure to lend credence to their claims. There is ample evidence that secure tenure accelerates people's investments in improving their homes, using higher quality and more resilient building materials and construction methods.

GREENHOUSE GAS EMISSIONS FROM TRANSPORT

Car-dependent patterns of urban growth in cities in developed countries have resulted in a situation in which 30 per cent or more of total GHG emissions are from transportation (Wei et al. 2021). Globally, transportation is responsible for one-fifth of global CO_2 emissions (Ritchie 2020). Because of this outsized share, much of the focus on reducing GHG emissions in cities is on reducing emissions from transportation.

Access to good data on emissions from cities in developing countries is limited, both in terms of total emissions and the breakdown of sources. In developing countries overall, measurements indicate that emissions from on-road vehicles are about one-half that of developed countries, despite the larger share of the world's population living in developing countries (Wei et al. 2021). For cities in developing countries, including those with which this paper is concerned, emissions from transportation are believed to be comparatively modest, and this is supported by data on private vehicle ownership and transportation mode share by individuals (though it omits freight emissions and emissions from public transportation in cities).

Good data is hard to come by, but meta-studies indicate that in sub-Saharan Africa – one of two rapidly urbanising regions – between 42 per cent and 74 per cent of daily trips are made through walking. Secondary cities in rapidly urbanising countries can focus on electrification of private and public vehicles, but the net impact of this action on GHG emissions will depend on the greenness of the grid and, in some limited cases, can result in higher GHG emissions than simply burning gasoline (Smith 2021).

THOUGH GHG EMISSIONS FROM TRANSPORTATION IN RAPIDLY URBANISING COUNTRIES MAY COMPRISE A RELATIVELY SMALL SHARE OF TOTAL EMISSIONS AND AN EVEN SMALLER SHARE OF GLOBAL EMISSIONS, IT IS STILL IMPORTANT TO CONSIDER ACTIONS THAT THESE CITIES CAN UNDERTAKE TO REDUCE EMISSIONS FROM TRANSPORT.

This is the case for two reasons. First, as emissions from cities in developed countries are reduced in the coming decades, the remaining emissions from developing countries will become proportionately more important. Second, urbanisation and rising incomes are already leading to increased ownership and use of private vehicles in many developing countries (Olvera et al. 2013). Many of these cars are older imports from countries in Europe and Asia and are more polluting than newer vehicles (Kablan 2010).

Urban labour markets are most efficient when all workers have access to all jobs, and all firms have access to all workers. This requires that workers be able to commute across the city efficiently, preferably taking less than 30 minutes to get to work. In the case of rapidly growing cities that are expanding spatially, the only realistic way to maintain access to the entire metropolitan labour market (and therefore retain the key benefit of urbanisation) is through the use of vehicles, either public transit or privately owned, electric, two-wheeler, pedal, or powered by gasoline.

With regard to transportation and GHG emissions, the key question facing secondary cities as they grow is whether or not they will follow the car-dependent growth trajectories of cities in developed countries. Motorisation is the path of least resistance. If these cities are to follow low-carbon development pathways, alternative modes will have to remain competitive with private vehicles, which are swift, comfortable, and convenient.

Cities that are rapidly growing should take actions that will help keep walking, cycling, e-mobility, and public transportation competitive with private vehicles by creating infrastructure to support green transportation. An arterial road grid on the urban periphery, coupled with properly laid out subdivisions, will provide the road network for a public transport system that generates lower GHG emissions. Arterial roads may also have bike lanes. Alternatively, expansion areas can have green networks with green paths for walking and biking. Such a network, in combination with other policies, may reduce emissions by addressing the modal shift in the city.

A green network can also work to reduce emissions from private vehicles. A citywide gridded arterial road network developed through urban expansion planning can reduce GHG emissions when compared to unplanned networks. This is due primarily to two complementary effects: shorter travel distances and reduced vehicle congestion. These effects allow vehicles to run at peak efficiency, reduce vehicle kilometres traveled, and promote the use of public transportation, walking, and cycling.

Traffic congestion occurs when demand for road space exceeds capacity, resulting in a shortage of space per vehicle and lower-than-optimal vehicle speeds. At peak periods, stop-and-go driving conditions can make vehicles highly inefficient.

In China (Chen et al. 2011, August), India, and elsewhere (Barth and Boriboonsomsin 2009), heightened traffic congestion leads to higher GHG emissions – as much as 70 per cent greater emissions rates per kilometre during congested periods in some real-world studies (Rosca et al. 2014).

Arterial road grids reduce traffic congestion by assigning a higher share of urban land to arterial roads, offering greater road capacity than is typically found in unplanned networks. The gridded layout also increases network connectivity, providing alternative route options that allow users to avoid accidents and bottlenecks (Choi and Ewing 2021). In addition, laying out the grid on the urban periphery encourages the city to grow in all directions rather than along linear corridors, promoting compact development. This is another major determinant of road network efficiency (Tsekeris and Geroliminis 2013).

Routes that are more direct maximise the efficiency of travel and lower travel distances within urban areas, reducing overall vehicle-kilometres traveled (VKT). A gridded network offers the most efficient circulation of any urban form (Institute of Transportation Engineers 2010). At any given road density, road networks offer more connections that will shorten trip distance, and the impact on GHG emissions will be lessened (Barrington-Leigh and Millard-Ball 2017; Kelbaugh 2013).

Arterial grid layouts can promote the efficient design and operation of public transportation systems, particularly when cities are less geographically dispersed (Badia 2016). Arterial grids developed through urban expansion planning also offer sufficient width (typically 30 metres) to carry high-capacity bus rapid transit (APTA 2010 ; Wankhade and Pawade 2014). The recommended road spacing in the urban expansion arterial grid network of about one kilometre, in gridded configuration, means that no point in the arterial network is more than 500m from an arterial road, putting most areas within walking distance of a prospective mass transit route.

Arterial grid layouts improve connectivity and reduce travel distances for cyclists and pedestrians as well. A growing body of evidence shows that gridded neighbourhoods with more connectivity and parallel streets are associated with a higher share of public transportation use (Cervero and Gotham 1995), reduced barriers to walking (Anciaes and Jones 2016) and can slow down the transition from walking and cycling to motor vehicles, even in motorising economies (Pan et al. 2009). This is particularly important in developing countries where the transition to private vehicles is at an early stage.

FOR THESE REASONS – REDUCED TRAVEL DISTANCES, LOWER VEHICLE CONGESTION, AND DIFFERENTIAL MODAL SHIFTS – ORDERLY ARTERIAL ROAD GRIDS FROM URBAN EXPANSION PLANNING ARE A CORE INVESTMENT IN SUSTAINABLE MOBILITY THAT CAN RESULT IN LOWER GHG EMISSIONS FROM TRANSPORT COMPARED TO THE DISORDERLY OR UNPLANNED GROWTH PATTERNS THAT PROLIFERATE ON THE FRINGES OF MANY CITIES TODAY.

CONCLUSION – A PROVEN TOOL TO BUILD URBAN RESILIENCE

Secondary cities in rapidly urbanising countries that seek to address climate adaptation and mitigation can take meaningful action by adopting climate-resilient urban expansion planning. At a minimum, this will allow adaptation programmes to consider future areas of expansion. Although it may seem desirable to simply stop cities from expanding, efforts to resist or prevent urban land from increasing have been basically unsuccessful (Box 3).

Rather than proposing a new action agenda to address urban resilience, this paper argues that limited modifications to the basic urban expansion planning methodology deployed in Ethiopia, Somalia, and Uganda (Box 1) can allow cities to make meaningful initial steps to address sea level rise, storm surge, flooding, drought, and a host of other challenges that affect land use planning on their urban peripheries, using essentially the same methodology that they use to prepare for peripheral growth. This is more efficient and more feasible than introducing new frameworks or programmes. The major modifications to the planning approach are in the types of data that are needed and the factors that are considered when laying out the arterial grid and environmentally sensitive public open spaces.

Climate change does introduce considerable uncertainty into the land forecasting stage of the planning process. Some cities will experience significant, unexpected increases in population or declines in density following extreme events. Planners should err on the side of preparing more, rather than less, land for urban expansion than that estimated from population and density projections in order to accommodate this increased variability (Box 2). City leaders can use the data that emerges from climate-resilient urban expansion planning to advocate for their priorities, including improvements to water supply and infrastructure.

As cities grow, people will continue to seek to build in the most accessible locations to jobs, markets, and schools. This typically translates into expanding the city in a compact manner along its periphery, or in close proximity to roads extending out of its built-up area.

IN LIGHT OF CLIMATE RISKS, THE ONLY REALISTIC REACTION TO THIS EVIDENCE IS TO PROVIDE NEWLY BUILT AREAS WITH NECESSARY INFRASTRUCTURE AS QUICKLY AS POSSIBLE.

Urban expansion planning can facilitate the provision of necessary infrastructure to accommodate urbanisation by reserving in advance the corridors of land that will carry trunk infrastructure, such as water, drainage, and electricity. This lowers the cost of deploying those services and allows for some limited protection of environmentally sensitive areas. Municipalities can build on this work by engaging with informal settlements to improve the quality of neighbourhood layouts,

THE APPROACHES OUTLINED IN THIS PAPER DIFFER FROM MOST ADAPTATION PROPOSALS IN THAT THEY EXPLICITLY TARGET THE AREAS OF CITIES WHICH HAVE NOT YET BEEN BUILT AND DO NOT REQUIRE THE CREATION OF ANY NEW PROGRAMMES. THIS ADDRESSES A REAL AND, TO OUR KNOWLEDGE, UNMET NEED IN RAPIDLY GROWING SECONDARY CITIES. IF SUCCESSFULLY IMPLEMENTED, CLIMATE-RESILIENT URBAN EXPANSION PLANNING CAN LAY THE GROUNDWORK FOR LONG-TERM RESILIENCE, SUSTAINABILITY, PRODUCTIVITY, AND INCLUSIVENESS IN THE FUTURE CITY.

which is beneficial for infrastructure provision and addressing extreme heat by allowing for the planting of trees along public roads.

When planning environmentally sensitive areas, governments must be pragmatic about how much land they can protect from settlement and focus on defending land that provides needed services. Areas in which settlement is difficult and potentially dangerous, but unlikely to halt, should be included in urban expansion plans and serviced with infrastructure regardless of their formality or informality. Embracing formal development processes in those areas can also encourage businesses and homeowners to mobilise the necessary capital to invest in household-level resilience, which is key to managing risks such as landslides (Box 4). Calls to evict residents of informal settlements in high-risk areas should be rejected.

ENVIRONMENTALLY SENSITIVE AREAS SHOULD ALSO BE ALIGNED TO HELP WITH FLOODING AND WATER MANAGEMENT. THE INCLUSION OF A NEW DRAINAGE EXPERT ON MUNICIPAL URBAN EXPANSION PLANNING TEAMS CAN AID WITH THIS AND ADVISE ON ALIGNING THE ARTERIAL GRID TO PROMOTE DRAINAGE AFTER EXTREME PRECIPITATION EVENTS.

Cities can also prepare for new investments in adaptation by using urban expansion planning to promote compact development. This development style will encourage density and make future areas of cities easier to service with protective infrastructure, such as seawalls and storm barriers. An additional advantage of this approach is that it can lead to reductions in GHG emissions from transport and may also contribute to slower urban expansion overall, despite claims to the contrary.

Climate-resilient urban expansion planning is not a new and untested methodology. It builds on a successful existing approach that has produced results on the ground in rapidly growing secondary cities in rapidly urbanising countries. Climate-resilient urban expansion planning is designed to be quickly implemented by local officials on the ground in cities with limited resources, with technical support from international partners and the engagement of regional and national government bureaus.

The approaches outlined in this paper differ from most adaptation proposals in that they explicitly target the areas of cities which have not yet been built and do not require the creation of any new programmes. This addresses a real and, to our knowledge, unmet need in rapidly growing secondary cities. If successfully implemented, climate-resilient urban expansion planning can lay the groundwork for long-term resilience, sustainability, productivity, and inclusiveness in the future city.

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