5 The shape of cities and sustainable development

Using the new global definitions of cities and metropolitan areas, this chapter analyses the changing shape of cities around the world. It examines how densification and expansion of cities affect sustainable development. It sheds light on the extent to which metropolitan areas decentralise, i.e. grow faster in commuting zones than in the city itself. In discussing and analysing these developments, the chapter assesses their impact on urban mobility and people's exposure to pollution, flooding, storms and sea level rise.

Key messages

- The population living in cities has more than doubled between 1975 and 2015. This increase led to a doubling of the number of cities, an expansion of existing cities and the densification of the original cities. Because cities expanded less quickly in area than in population, city densities went up, especially in large cities (1 million inhabitants or more). Small cities (less than 250 000 inhabitants) were the exception where densities dropped over time.
- In virtually all growing metropolitan areas, the population in the commuting zone grows faster. Even in shrinking metropolitan areas, commuting zones either still grow or shrink less quickly than the city, leading to a smaller and more dispersed metropolitan population.
- Rapidly growing cities, especially in low-income countries, have struggled to keep up construction with population growth. As a result, one in four low-income cities has a low and shrinking level of capital stock per person; in other words, they became more crowded and underdeveloped. At the other extreme, two out of five cities in high-income countries had a high and growing capital stock per person, which is expensive. This indicates that many cities in poor countries are faced with underinvestment, while certain cities in rich countries may face heavy investments largely to compensate for a more dispersed population structure.
- Access to public transport differs widely between cities. Many European cities provide access to frequent public transport to a large share of their population. Other cities provide mostly access to low-frequency departures, for example in North America. Some low-income cities do provide high-frequency access but only to a small share of the population, as is the case in some African cities.
- Low-density cities need to spend more on road infrastructure and public transport to offer the same level of service. Especially the shift from moderate to low density leads to a big increase in costs, while shifts between high and moderate levels of density have less of an impact.
- Cities are more polluted than less densely populated areas. Large and low-income cities tend to have particularly high levels of air pollution, such as fine particulate matter (PM 2.5). Unsurprisingly, people living in cities are less satisfied with air quality than those living in towns and semi-dense areas or rural areas. This also the case in high-income countries, where pollution levels tend to be lower.
- Cities are exposed to floods, storms and sea level rise. One in five city residents is exposed to a 100-year flood. Over 600 cities risk being fully inundated by a 100-year flood. City population in low elevation coastal zones has been growing faster than the city population in other zones. As a result, 14% of the city population lives in zones that are vulnerable to storm surges and rising sea levels. Of the population in towns and semi-dense areas, 10% is exposed and 6% of the rural population.

Introduction

The shape of cities and their impact on sustainable development is heavily scrutinised and debated (see for example OECD (2018[1])). Cities have a somewhat paradoxical relationship with environmental sustainability. On the one hand, cities allow people to lead lives which pollute relatively little, for example, by facilitating walking, cycling and efficient public transport. In cities, people also tend to live in smaller dwellings, which require less energy to heat and cool (see for example Owen (2009[2])). On the other hand, city dwellers are often exposed to high levels of pollution through fine particle matter (PM 2.5) or nitrogen dioxide (NO2).[1]

Concerns that a lower-density and thus more spread-out city would lead to worse environmental outcomes have led to many national and local policies trying to limit the spatial expansion of cities and maintaining or even increasing population density, even in countries where densities were already high. In the past, the lack of a global definition of a city made it difficult to reliably compare cities. The population density was notoriously difficult to compare because it is so sensitive to where the boundary of a city is drawn. This may explain why a lot of literature focused more on the changes over time than density levels.

This report uses that new definition to compare population density levels, before assessing how it has changed over time. It does the same with the amount of land dedicated to buildings and infrastructure. Instead of recommending densification and limiting all costs, this report identifies different priorities from building more – to accommodate a rapidly growing population – to building less and promoting the more efficient use of what has already been built. City and neighbourhood density have a big impact on the cost of public transport provision and how many residents can easily access it. Thus, the report makes recommendations ranging from expanding public transport networks to encouraging high densities close to public transport.

This chapter explores city densities and how they have changed over time. Subsequently, it takes a metropolitan view to look at population changes in the commuting zones and the city. Next, it describes how the shape of a city influences its need for investments in buildings, roads and public transport networks. It concludes by highlighting cities' exposure to pollution, flooding and storms.

City densification and expansion

Cities densities differ by income level and world region

In general, the higher the income of a country, the lower the densities of its cities. As seen in Chapter 1, cities in low-income countries have the highest densities, close to 10 000 inhabitants per km^2, compared to 7 200 in lower-middle-income countries, 5 300 in upper-middle-income and only 2 800 in high-income countries. As a result, cities in low-income countries are almost four times denser than the cities in high-income countries. These averages hide many exceptions, for example, Santiago in Chile, Seoul and Singapore have densities of at least 7 500 inhabitants per km^2 but they are also in high-income countries.

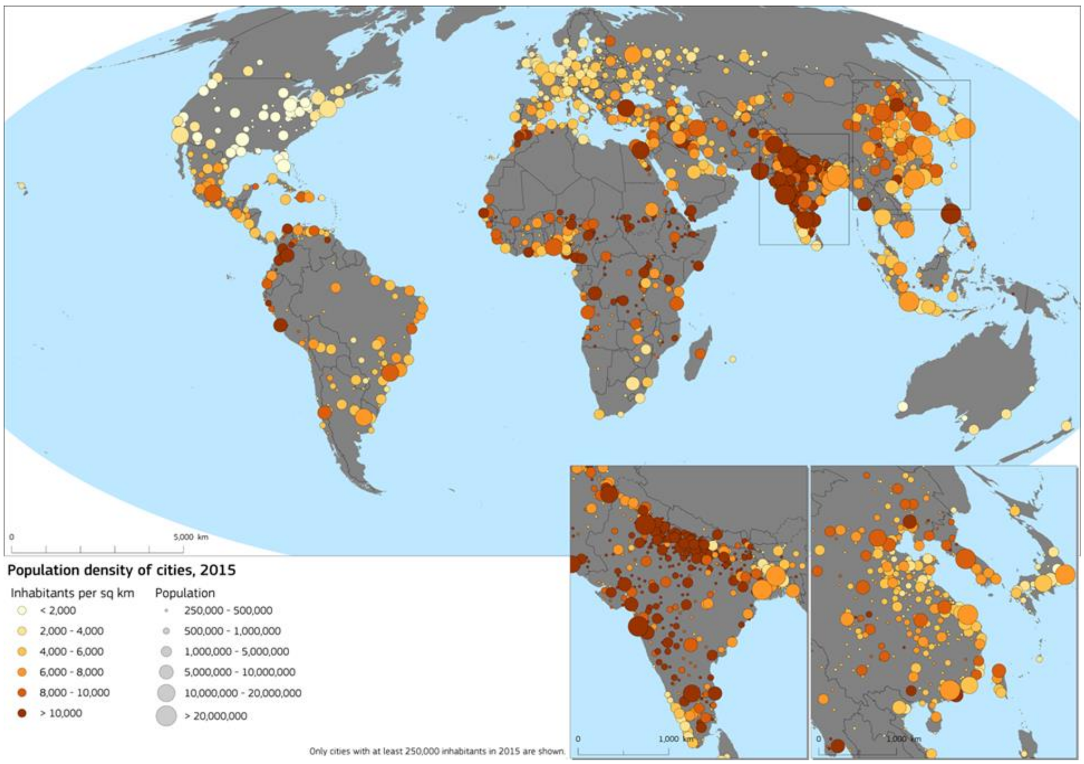
City density does not only vary by income but also by region (Figure 5.1). In North America, cities have a density of 1 700 inhabitants per km^2, compared to close to 4 000 in Central Asia and Europe, 5 000 in East Asia and the Pacific, 6 000 in North Africa, Latin America and the Caribbean, and the Middle East and 8 000 in Sub-Saharan Africa and South Asia. As a consequence, for a given population size, a city in North America will be four times bigger in area than in Sub-Saharan Africa or South Asia and twice as big as a city in Europe and Central Asia.

On average, the larger the city, the denser it is (Figure 5.2). This density gradient is clearly visible in high- and upper-middle-income countries and to a lesser degree in lower-middle-income countries. In low-income countries, however, this gradient is absent: cities in the four size groups are all very dense. The high density of cities in low-income countries may be due to a combination of small dwellings and a high share of trips done on foot, as well as to public policies limiting the expansion of cities. The differences in density between the income groups are so big that it offsets the effect of city size. For example, a small city in a low-income country is more than twice as dense as a very large city in a high-income country.

Cities are becoming denser, except for the small ones

The comparison of city density and income for one point in time suggests that as income goes up, city density should drop and the density in small cities should drop faster. Globally, however, city densities have increased not dropped. This is mainly driven by the increasing density of the large and very large cities, which increased in all four income groups (Figure 5.2). Densities in large cities increased more in low- and middle-income countries than in high-income countries. In contrast, small cities did see a reduction in density and this reduction was much bigger in low- and middle-income countries than in high-income countries. This means that over time the difference in densities of (very) large cities between different income groups has been growing, while it has been shrinking for small cities.

Figure 5.1. Population density of cities, 2015

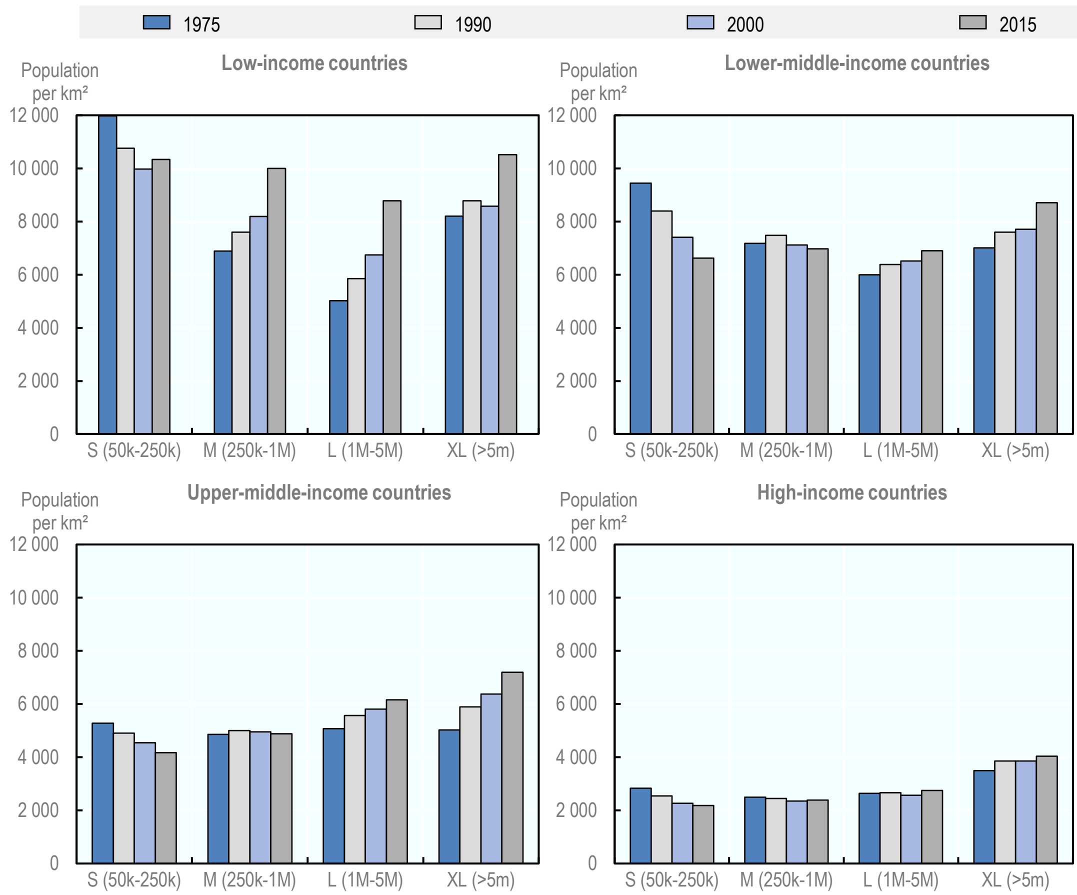


Source: Florczyk, A. et al. (2019[3]), *GHS Urban Centre Database 2015, Multitemporal and Multidimensional Attributes, R2019A (dataset)*, https://data.jrc.ec.europa.eu/dataset/53473144-b88c-44bc-b4a3-4583ed1f547e.

Cities in high-income countries had a low density back in 1975 (Figure 5.2). Historically, these cities did have higher densities but to observe those, one would have to go back further into time. The introduction of large tram, train and metro systems in the late 19th century and early 20th century allowed the population to live further away from the city (Gonzalez-Navarro and Turner, 2019[4]). From the 1950s onwards, the increasing car ownership and the creation of a dense network of roads and highways has further reduced city densities (LeRoy and Sonstelie, 1983[5]). The United States (US) was at the forefront of this trend and today has the lowest city density in the world: 1 640 inhabitants per km^2.

City densities have changed rapidly in the last four decades. For example, in 1975, Australia, New Zealand and the US had city densities around 1 500 inhabitants per km^2. By 2015, Australia and New Zealand increased densities to around 2 000. City densities in the US also increased but only slightly to 1 640 inhabitants per km^2. Cities in Canada were denser than American cities in 1975 (1 900 inhabitants per km^2) and their densities increased to 2 500 by 2015, with most of that increase happening in the last 15 years. Other countries saw significant reductions in their city densities because they grew more in area than in population or in a few cases because population shrank. For example, cities in South Korea reduced their density from 8 000 in 1975 to 7 000 in 2015, while the population of these cities grew. In contrast, Romanian cities saw their densities drop from 6 000 to 5 000, in part because their population shrank.

Figure 5.2. Population density by city size and income, 1975-2015



Note: The spatial extent of the city was classified for each reference year. Densities are calculated based on the total city area and city population of the reference year in each size class. Cities have been classified by their population size in 2015, to avoid changes in density caused by cities switching size classes. New cities were included in the year that they emerged.

Source: Florczyk, A. et al. (2019[3]), *GHS Urban Centre Database 2015, Multitemporal and Multidimensional Attributes, R2019A (dataset)*, https://data.jrc.ec.europa.eu/dataset/53473144-b88c-44bc-b4a3-4583ed1f547e.

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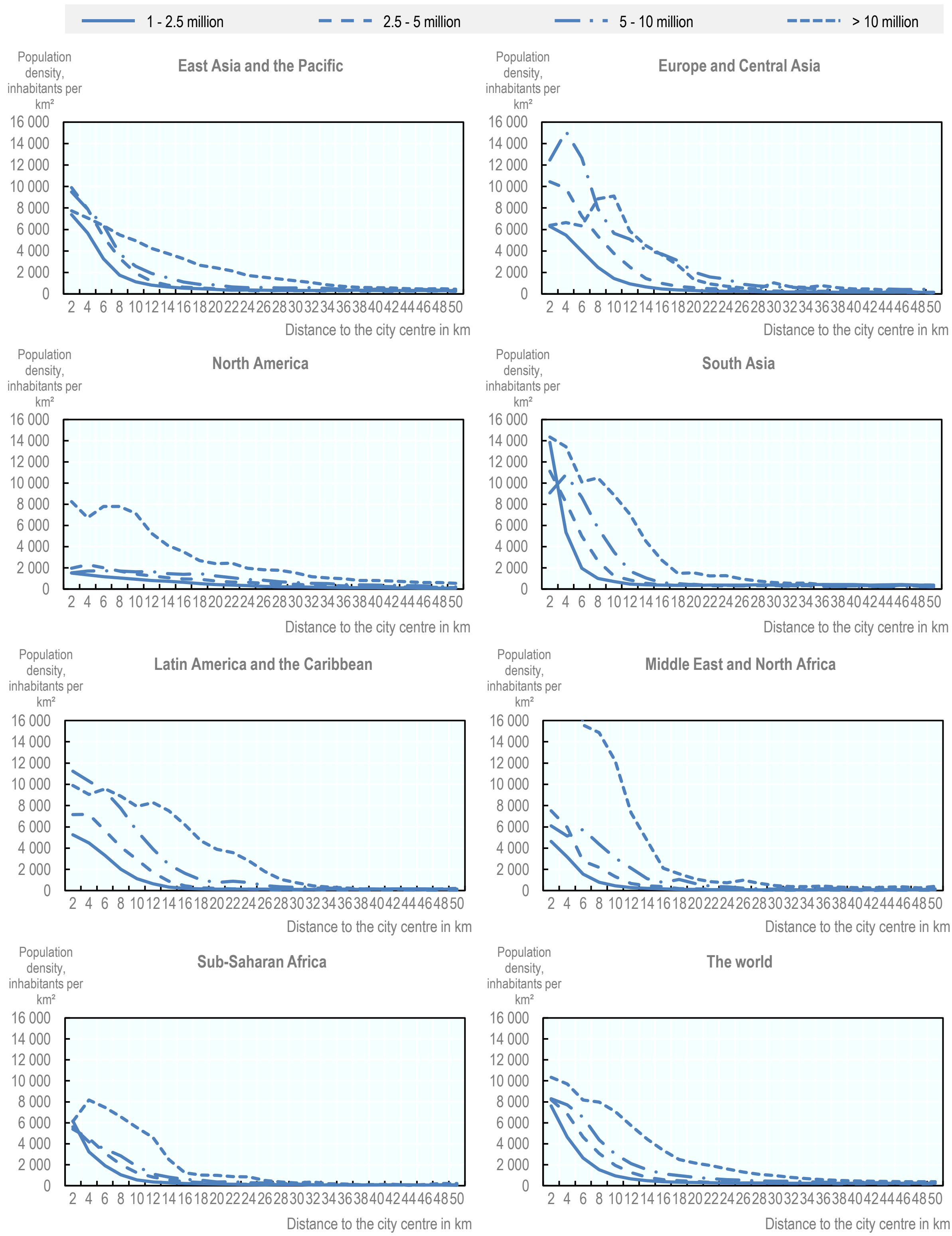
City expansion in most countries did not reduce overall city densities. In four out of five countries, city densities increased between 1975 and 2015. The overall increase in city densities implies that the density increases within the initial city boundary are not offset by the lower densities of the areas added to the city.

Densities drop further from the centre

Comparing how densities drop by distance to the city centre shows a few universal patterns and few differences. There are two well-known universal patterns, which our data confirm. The further away from the city centre, the lower the densities are. The larger the city, the more distance is needed for densities to drop (Figure 5.3).

Two differences stand out. Depending on the country, the density close to the centre varies from less than 2 000 inhabitants per km^2 for cities under 10 million inhabitants in North America to around 6 000 in Sub-Saharan Africa, 8 000 in East Asia and the Pacific and even higher in South Asia. The other aspect that varies is how quickly density declines. In Africa and Asia, most densities tend to decline very rapidly. In Latin America and Europe, densities decline more slowly, while in North America the density declines very slowly.

Figure 5.3. Density by distance to the city centre by city size and by world region, 2015



Source: Calculations using the population-weighted centroids of cities in Florczyk, A. et al. (2019[3]), *GHS Urban Centre Database 2015, Multitemporal and Multidimensional Attributes, R2019A (dataset)*, https://data.jrc.ec.europa.eu/dataset/53473144-b88c-44bc-b4a3-4583ed1f547e and Florczyk, A. et al. (2019[6]), *GHSL Data Package 2019 (database)*, http://dx.doi.org/10.2760/062975.

Cities are growing and expanding

Three factors contribute to the rapid growth of the population living in cities and this section will deal with them in turn: i) towns growing into cities; ii) city expansion; and iii) city densification. The main source of growth is densification, which captures between 50% and 60% of the additional city population (Table 5.1). City expansion is the second most important source which covers around 25% of the additional city population. Increases in city population from towns growing into cities have become less important over time. In 1990, towns becoming cities was responsible for 24% of the growth in city population, dropping to only 16% in 2015. Because city densification – by definition – does not require the city to acquire any additional land, the main source of area change is city expansion.

Table 5.1. Sources of city population growth, 1975-2015

Time period	Towns growing into cities	City expansion	City densification	Total
Population change (%)				
1975-90	23.9	26.4	49.7	100
1990-2000	18.3	29.3	52.4	100
2000-15	15.5	24.8	59.7	100
Area change (%)				
1975-90	30.5	69.5	0	100
1990-2000	22.8	77.2	0	100
2000-15	22.6	77.4	0	100

Source: Florczyk, A. et al. (2019[3]), *GHS Urban Centre Database 2015, Multitemporal and Multidimensional Attributes, R2019A (dataset)*, https://data.jrc.ec.europa.eu/dataset/53473144-b88c-44bc-b4a3-4583ed1f547e.

As the population of a town grows past 50 000, the town becomes a city. Between 1975 and 2015, the number of cities in the world doubled from around 5 000 to 10 000 (Table 5.2). This growth in the number of cities is linked to the income of countries. Low-income countries saw their number of cities triple from 1975 to 2015, compared to a doubling in middle-income countries and an increase of 50% in high-income countries. Virtually all these cities were first a town. The number of new cities has been slowing down over time. Between 1975 and 1990, the number of cities increased by 41%, while between 2000 and 2015, it only increased by 19%. This reduction in the number of new cities also meant that their share of all land that became part of a city dropped (Table 5.1).

Table 5.2 Number of cities by income group, 1975-2015

	1975	1990	2000	2015	2015/1975
Low income	326	518	703	942	2.9
Lower middle	2 025	2 981	3 577	4 266	2.1
Upper middle	1 908	2 740	3 201	3 704	1.9
High income	911	1 050	1 184	1 391	1.5
World	**5 170**	**7 289**	**8 665**	**10 303**	**2.0**

Source: Florczyk, A. et al. (2019[3]), *GHS Urban Centre Database 2015, Multitemporal and Multidimensional Attributes, R2019A (dataset)*, https://data.jrc.ec.europa.eu/dataset/53473144-b88c-44bc-b4a3-4583ed1f547e.

Cities expand by building new dense neighbourhoods at the edge of the city or densifying existing suburbs. Expansion means a city's population grows by incorporating the population already living in these areas and by adding more people to this new part of the city. In low-income countries, the initial population of these expansion areas is very low. In contrast, in high-income countries more than half of the population added to the city was already living there in the previous period.

City expansion is most pronounced in low-income and lower-middle-income countries with annual area growth rates of 2% to 3% (Figure 5.4). This means that the areas double or treble within 40 years. The small cities tend to expand faster, but this also includes towns growing into cities. In upper-middle- and high-income countries, on the other hand, city expansion is much lower and has been slowing down. Cities in upper-middle-income countries expanded by only 1% a year between 2000 and 2015 (except the small cities). In high-income countries, cities expanded approximately 0.8% and 0.5% a year (except the small cities, which grew between 2% and 3%, see Figure 5.4). With a growth rate of 0.5% a year, it takes almost 150 years to double in size.

City expansion also means a wider area that requires infrastructure and public services. The high speed of city expansion in low-income countries is especially challenging as they need to invest large amounts quickly, merely to keep providing the same level of service to the population in their growing area.

Densification means that the population grows within the initial boundary of the city. This densification comes in different forms: crowding, infilling and scaling up. Crowding means more people have to fit in the same number of houses. This may occur when a city receives a big inflow of people due to a natural disaster or armed conflict. Infilling means building on land that was not yet developed within the city. This could be land that was initially in a less desirable location or more expensive to develop. Scaling up means that low-rise buildings are replaced by mid- or high-rise buildings. Both infilling and scaling up have the benefit that they do not reduce the amount of floor space per household. The data used in this report, unfortunately, does not capture building height. As a result, it cannot distinguish scaling up from crowding. By analysing the changes in built-up area, however, the report can identify to what extent infilling is occurring, which is the focus of the section on crowded and sprawling cities below.

Decentralisation

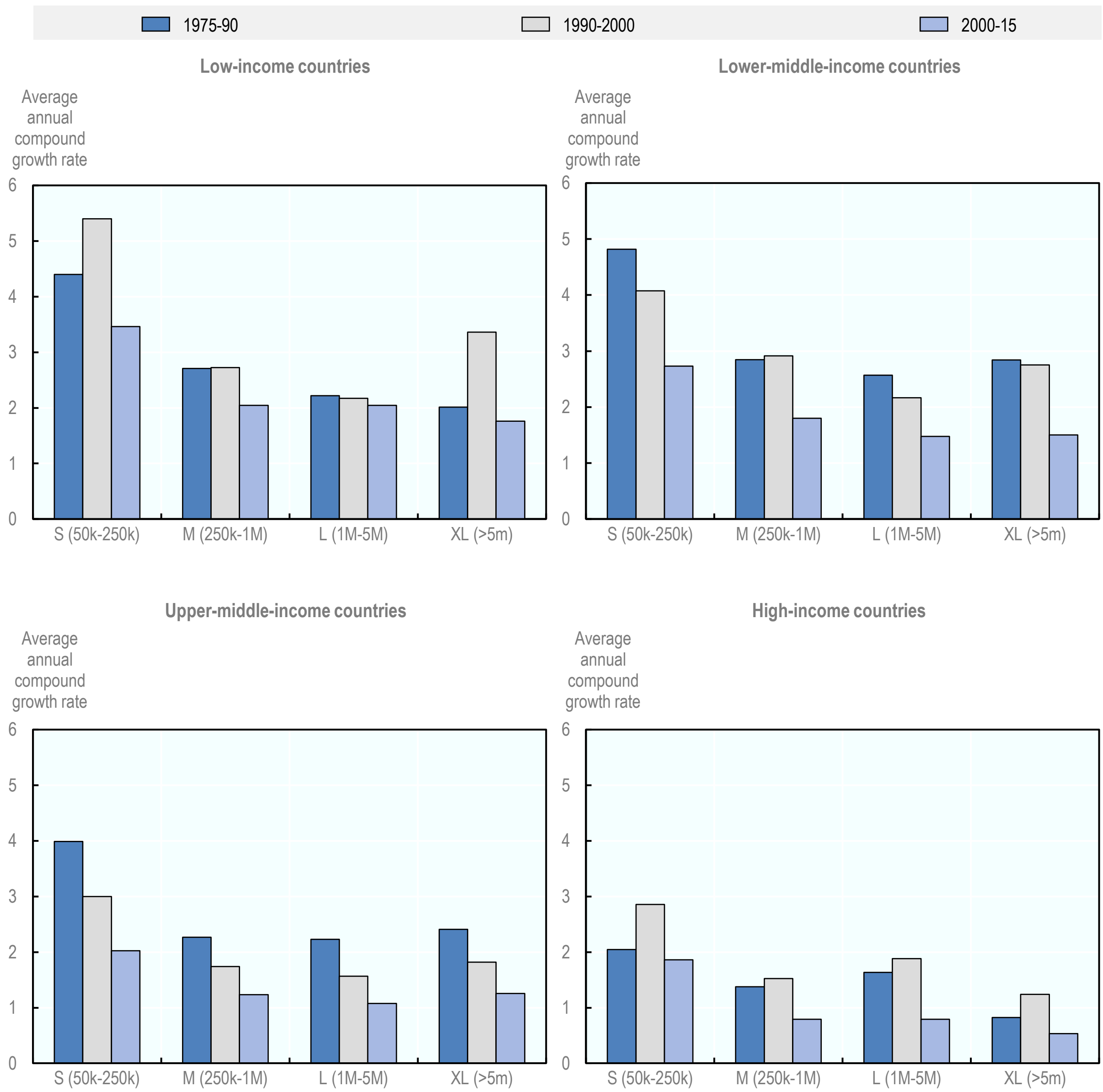
Whereas the previous section looked at the changes within a city, this section zooms out to include the changes in the commuting zones. Population growth in commuting zones implies that cities need to extend their road and public transport networks to reach these areas. If this development is relatively concentrated, for example in satellite towns, it requires less investment to provide good access for the people living there. If this development, however, is more dispersed, it requires more roads and it becomes difficult to provide good public transport access.

Metropolitan areas have larger commuting zones in high-income countries

Population in commuting zones represent 17% of the overall metropolitan population and 9% of the total world population. This share is linked to a country's income level (Figure 5.5). The share of the metropolitan population in commuting zones is biggest (31%) in high-income countries, while it decreases to 18% and 10% in upper-middle- and lower-middle-income countries respectively. In low-income countries, commuting zones represent less than 4% of the metropolitan population.

In high-income countries, the population has tended to shift from the city to the commuting zone in most metropolitan areas. As suggested by the literature, this outward shift of population and employment from the city to the surrounding towns & semi-dense and rural areas took place due to a variety of factors, including lower costs of land, lower taxes, preferences for single-family dwellings and greener surroundings. As car ownership grew, more roads were constructed and public transport improved, people were able to live further out (Gordon and Richardson, 1996[7]; Gonzalez-Navarro and Turner, 2019[4]).

Figure 5.4 Growth in city area by city size and income group, 1975-2015



Source: Florczyk, A. et al. (2019[3]), *GHS Urban Centre Database 2015, Multitemporal and Multidimensional Attributes, R2019A (dataset)*, https://data.jrc.ec.europa.eu/dataset/53473144-b88c-44bc-b4a3-4583ed1f547e.

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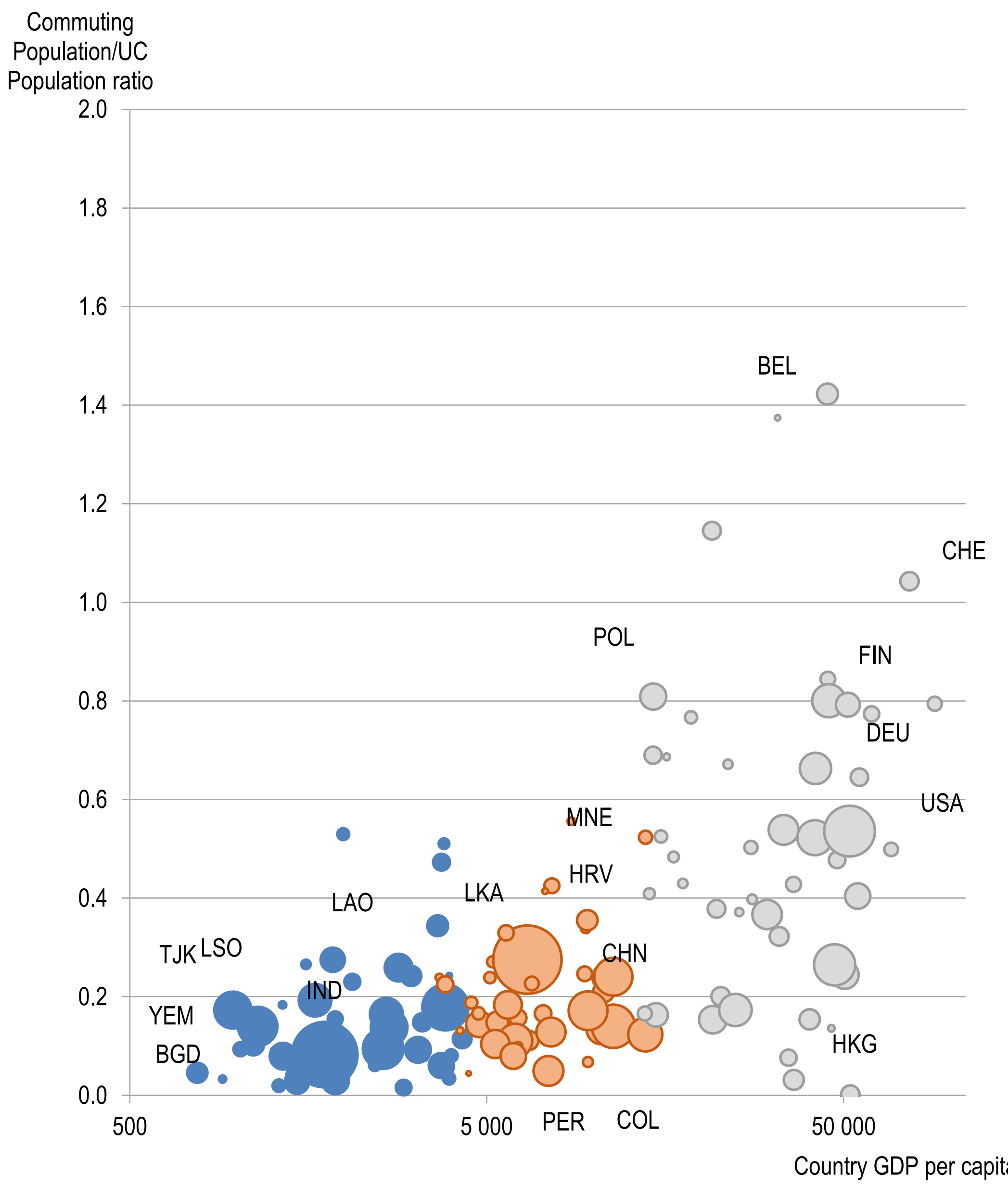
Figure 5.5 Country income and importance of commuting zone, 2015

Bubbles are proportional to the population size of the metropolitan area



Source: Adapted from Moreno-Monroy, A., M. Schiavina and P. Veneri (2020[8]), "Metropolitan areas in the world. Delineation and population trends", *Journal of Urban Economics*, https://doi.org/10.1016/j.jue.2020.103242.

Commuting zones grow faster than their city

Of all metropolitan areas in 2000, 78% experienced population growth between 2000 and 2015. Of these growing metropolitan areas, 85% experienced growth in both their city and commuting zone (Table 5.3). In 7% of these metropolitan areas, the city lost population but the growth in the commuting zone offset this reduction. In contrast, 8% of growing metropolitan areas experienced growth in the city but a decline in its commuting zone.

Among the growing metropolitan areas, 89% had faster population growth in the commuting zone than in the city between 2000 and 2015, confirming previous evidence from OECD countries (Veneri, 2018[9]). The observed patterns suggest a slow but widespread pattern of decentralisation of the metropolitan population towards the commuting zones. In rapidly growing cities, it may be that people have to move to the commuting zone because not enough housing is being built in the city itself.

Table 5.3. Metropolitan areas by growth or decline in the city and commuting zone, 2000-15

		Both city and commuting zone grow	City shrinks and commuting zone grows	City grows and commuting zone shrinks	Both city and commuting zone shrink	Total
Growing metropolitan areas	Number	5 252	398	500		6 150
	Share (%)	85.4	6.5	8.1		100
Declining metropolitan areas	Number		859	15	819	1 693
	Share (%)		50.7	0.9	48.4	100

Note: Only metropolitan areas with a city in 2000 were included.
Source: EC calculations based on Florczyk, A. et al. (2019[6]), *GHSL Data Package 2019 (database)*, http://dx.doi.org/10.2760/062975 and the boundaries of Moreno-Monroy, A., M. Schiavina and P. Veneri (2020[8]), "Metropolitan areas in the world. Delineation and population trends", *Journal of Urban Economics*, https://doi.org/10.1016/j.jue.2020.103242.

Population growth in a commuting zone can pose serious planning challenges, especially if the growth is highly dispersed. Providing sufficient infrastructure and services to the population outside the city requires significant investments. In Africa, however, some fast-growing cities are caught in a low development trap and are unable to attract investment. To overcome low investor expectations and encourage economic growth, governments can implement policies towards formalising land markets, clarifying property rights and investing in effective urban planning. Further, in the absence of regulated markets, governments should make early and co-ordinated infrastructure investments to link workers with businesses and services and signal to investors that it will make these investments. While these solutions will prove particularly challenging in countries with extremely limited financial resources and public capacity, the success of cities in other regions provides evidence on the value of co-ordinated and sustained action (Lall, Henderson and Venables, 2017[10]).

Some commuting zones lose population

Of the metropolitan areas in 2000, 22% lost population between 2000 and 2015. In half of these shrinking metropolitan areas, both the city and the commuting zone lost population. In the other half of shrinking metropolitan areas, the city lost population while the commuting zone still grew, but the population growth in the commuting zone was insufficient to avoid an overall decline (Table 5.3). Population growth in the city was extremely rare among shrinking metropolitan areas: only 1% or 15 metropolitan areas experienced this. This meant that virtually all shrinking metropolitan areas saw densities drop in their city.

Among the shrinking metropolitan areas, 85% had a faster population growth (or slower decline) in its commuting zone as compared to its city. This mirrors the trend in growing metropolitan areas but here, this is not because the city cannot accommodate more population. On the contrary, the universal drop in city population means that even when the pressure on the housing market of a city drops, people still prefer to live outside the city. It may be that the shrinking population reduces travel time to the city and thus reduces people's incentive to move.

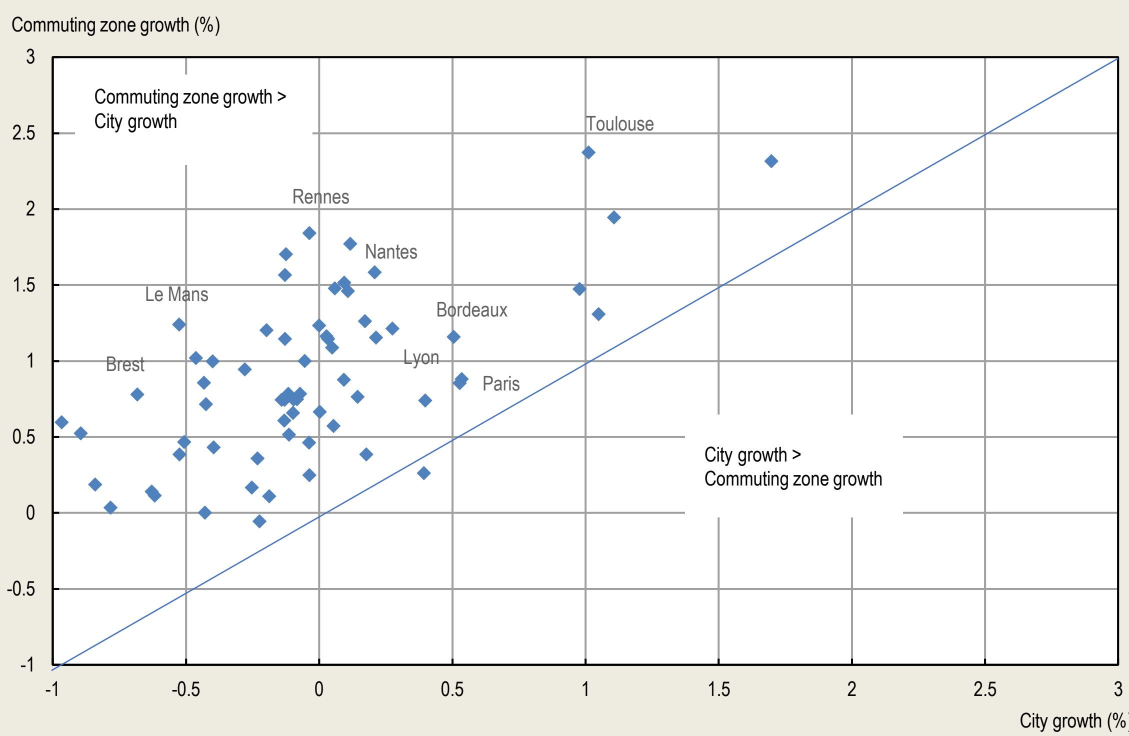
Box 5.1. Commuting zones grow faster than cities in France

Measuring population changes within metropolitan areas makes it possible to identify when the city is shrinking but the commuting zone is growing fast enough to offset the population loss in the city. In such a case, rather than describing this as population decline, it would be more appropriate to talk about population decentralisation. In many metropolitan areas in the developed world, it is common to observe a stable or growing metropolitan population characterised by decentralisation from the dense city.

France's overall annual population growth rate of 0.54% is equal to the OECD average and its fertility rate (around 2) is one of the highest in the OECD. Nevertheless, the country is experiencing shrinking cities. Out of 64 French metropolitan areas, 38 had a shrinking population within its city (Figure 5.6). The figure shows a striking relationship in which over half of French cities are declining, while growth in the surrounding commuting zones is positive and, in two-thirds of the cases, offsetting the city decline. Such a pattern of population growth in the commuting zone offsetting the decline in the city occurs primarily in smaller cities, although examples of cities with over a half a million inhabitants include Grenoble, Lille, Rennes and Rouen. In the 26 French metropolitan areas with a growing city population, the population in the commuting zones grew faster in all but one. Also, in other OECD countries including Poland, the Slovak Republic, Slovenia and South Korea, the population in the commuting zone tends to grow faster than in the city.

Only, 13 metropolitan areas experience population decline. They are primarily located in former mining and industrial regions in the north and northeast of France. This spatial pattern confirms a tendency towards urban shrinkage in regions with declining economic sectors.

Figure 5.6 Population growth in cities and commuting zones in France, 2000-15



Source: OECD calculations based on Florczyk, A. et al. (2019[3]), *GHS Urban Centre Database 2015, Multitemporal and Multidimensional Attributes, R2019A (dataset)*, https://data.jrc.ec.europa.eu/dataset/53473144-b88c-44bc-b4a3-4583ed1f547e.

Crowded metropolitan areas and sprawling metropolitan areas

Cities with a rapidly growing population often struggle to build the infrastructure to accommodate such a surge. Consequently, some cities are extremely crowded and lack sufficient infrastructure. Public transport and roads struggle to accommodate high levels of demand. People live in small houses with many persons to a room. They work and shop in cramped conditions. These high levels of crowding and congestion can reduce the quality of life and the economic performance of that city.

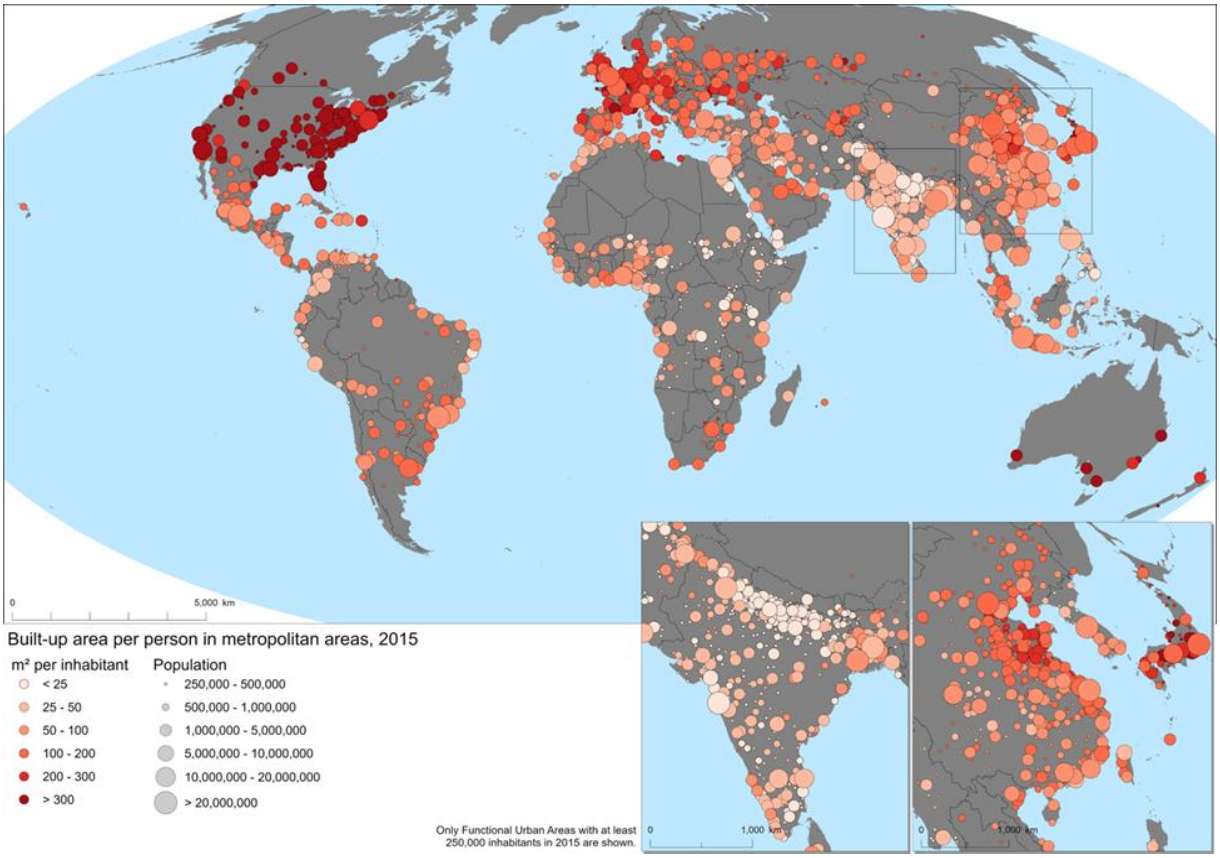
In contrast, some rich cities have very high levels of infrastructure provision with an extensive road network, spacious houses, large shopping malls and big office parks. This high level of infrastructure provision, however, has a number of drawbacks. It is costly to build and maintain an extensive road network and its accompanying water, electricity and information and communication technology (ICT) networks. It also tends to lead to a very spread-out population, which makes it more expensive to provide public transport and reduces the number of destinations that can easily be reached on foot or by bicycle. This type of urban development is often referred to as urban sprawl.

Although there is no consensus on the optimal level of infrastructure provision for a city or metropolitan area, the amount of land dedicated to buildings and infrastructure varies massively. Many metropolitan areas have less than 25 m^2 of land per person dedicated to buildings and infrastructure (Figure 5.7) compared to a global average of 100, while others have more than 300 using built-up area as detected by GHS-BUILT (see Box 5.2). Nevertheless, there are clear cases of under-provision. Several fast-growing metropolitan areas in developing countries struggle with high levels of congestion and a growing share of the population without access to piped drinking water. Overprovision is less clear cut. A metropolitan area with a dispersed population will generate more and longer car trips than one with a more concentrated population. As a result, despite the considerably longer road network per person in a dispersed metropolitan area, it may still encounter some congestion. Furthermore, metropolitan areas with a shrinking population will see their local revenues drop exactly when they need to downsize their infrastructure. As a result, such metropolitan areas may end up with too many buildings and too much infrastructure for their population size that they can ill afford to maintain.

The goal of preventing urban sprawl is a prominent part of the United Nation's New Urban Agenda[2] and its Sustainable Development Goal 11. Goal 11 includes an indicator that compares changes in land use and changes in population. The interpretation of this indicator, however, depends on the starting position of a city. If a city lacks enough buildings and infrastructure for the people living and working there, it should aim to build these faster than the population grows to ease crowding and congestion. In a city with sufficient buildings and infrastructure, a similar growth rate of buildings and infrastructure would be ideal. In a metropolitan area with an overprovision, ideally, the population would increase faster than buildings and infrastructure to ensure a higher and thus efficient use of this infrastructure and make its maintenance more affordable.

In a way, the amount of buildings and infrastructure per person in a metropolitan area is similar to the body mass index or BMI. As a result, the amount of built-up area per person indicator could be seen as a "City Mass Index" where cities with low levels should seek to build more and cities with high levels should seek to build less. One crucial limitation of this approach, however, is that it does not consider building heights. Replacing low-rise with high-rise buildings can reduce crowding without increasing the amount of built-up land. Globally consistent data on building heights is, unfortunately, not yet available. Improvements in remote-sensing or more detailed digital building cadastres may in the future be able to fill this gap.

Figure 5.7. Built-up area per person in metropolitan areas, 2015



Source: EC calculations based on Florczyk, A. et al. (2019[6]), *GHSL Data Package 2019 (database)*, http://dx.doi.org/10.2760/062975 and the boundaries of Moreno-Monroy, A., M. Schiavina and P. Veneri (2020[8]), "Metropolitan areas in the world. Delineation and population trends", *Journal of Urban Economics*, https://doi.org/10.1016/j.jue.2020.103242.

To demonstrate this City Mass Index approach, metropolitan areas were classified as having a low amount of buildings and infrastructure if they had less than 100 m^2 of built-up area per person, medium if they had between 100 and 200 and high if they had more than 200 in 2000. Changes in built-up area per person between 2000 and 2015 were classified as shrinking if it dropped by more than 5 m^2 per person, growing if it increased by more than 5 m^2 per person. The metropolitan areas where it changed by less than 5 m^2 per person were classified as stable. This classification shows that virtually all metropolitan areas in low-income and lower-middle-income countries have a low level of built-up area per person (Table 5.4) while two-thirds of the metropolitan areas in high-income countries have a high level. Half the metropolitan areas in upper-middle- and high-income countries have a growing built-up area per person, while this is rare in the other countries.

The combination of the two classifications shows that in high-income countries, two out of five metropolitan areas have a high and growing level of built-up areas per person (Table 5.5). In other countries, however, this is virtually absent. In other words, urban sprawl seems to be a problem only in high-income countries. Fortunately, one in five metropolitan areas in a high-income county had a high level of built-up area per person in 2000 but reduced it between 2000 and 2015 (Figure 5.8). In other words, these metropolitan areas were reducing the City Mass Index and are becoming less sprawled.

Table 5.4 Share of metropolitan areas by income group, built-up area per person and built-up area per person change

	Built-up area per person, 2000 (%)				Change in built-up area per person, 2000-15			
	Low	Medium	High	Total	Shrinking	Stable	Growing	Total
Low income	95.2	4.5	0.3	100	29.7	66.9	3.4	100
Lower-middle income	92.4	5.9	1.7	100	16.7	68.6	14.7	100
Upper-middle income	55.4	39.4	5.2	100	26.6	20.2	53.2	100
High income	9.7	23.0	67.3	100	27.8	17.2	55.0	100
World	68.4	20.2	11.4	100	22.9	44.1	33.0	100

Note: Only metropolitan areas with a city in 2000 were included in this table.
Source: EC calculations based on Florczyk, A. et al. (2019[6]), *GHSL Data Package 2019 (database)*, http://dx.doi.org/10.2760/062975 and the boundaries of Moreno-Monroy, A., M. Schiavina and P. Veneri (2020[8]), "Metropolitan areas in the world. Delineation and population trends", *Journal of Urban Economics*, https://doi.org/10.1016/j.jue.2020.103242.

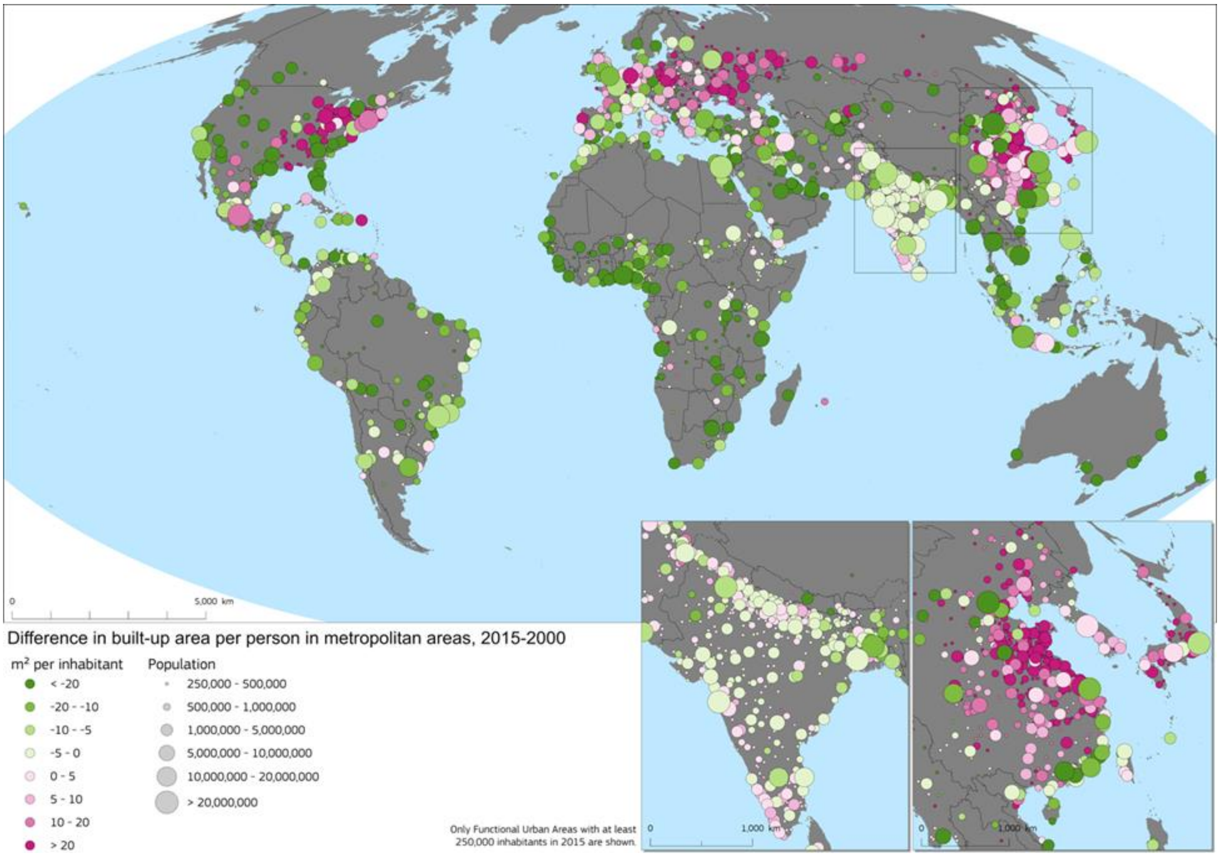
In contrast, metropolitan areas with a low and shrinking level of built-up area per person are most prevalent in low-income and middle-income, and almost absent in high-income countries. In other words, crowded cities where investments in buildings and infrastructure fail to keep up with population growth are most common in low-income countries. Fortunately, some metropolitan areas are increasing investments faster than population growth, especially in upper-middle-income countries, where 30% of the metropolitan areas have a low but growing built-up area per person.

Table 5.5 Share of metropolitan areas by built-up area per person levels, 2000, and change, 2000-15, by income group

	Low and growing (%)	High and shrinking (%)	Medium and/or stable (%)	Low and shrinking (%)	High and growing (%)
Low income	3.4	0.3	71.4	24.9	0.0
Lower-middle income	12.1	0.7	73.8	12.4	1.0
Upper-middle income	30.2	2.3	54.4	10.5	2.6
High income	3.0	19.0	35.7	3.1	39.2
World	16.8	3.6	61.5	11.7	6.4

Note: Only metropolitan areas with a city in 2000 were included in this table.
Source: EC calculations based on Florczyk, A. et al. (2019[6]), *GHSL Data Package 2019 (database)*, http://dx.doi.org/10.2760/062975 and the boundaries of Moreno-Monroy, A., M. Schiavina and P. Veneri (2020[8]), "Metropolitan areas in the world. Delineation and population trends", *Journal of Urban Economics*, https://doi.org/10.1016/j.jue.2020.103242.

Figure 5.8. Difference in built-up area per person in metropolitan areas, 2000-15



Source: EC calculations based on Florczyk, A. et al. (2019[6]), *GHSL Data Package 2019 (database)*, http://dx.doi.org/10.2760/062975 and the boundaries of Moreno-Monroy, A., M. Schiavina and P. Veneri (2020[8]), “Metropolitan areas in the world. Delineation and population trends”, *Journal of Urban Economics*, https://doi.org/10.1016/j.jue.2020.103242.

Box 5.2. The GHS-BUILT multi-temporal classification of built-up areas

The Global Human Settlement Built-Up Grid (GHS-BU) measures the presence of built-up areas (at 30 m spatial resolution) for 1975, 1990, 2000 and 2015. The data was processed by fully automatic and reproducible methods (Corbane et al., 2017[11]) based on statistical learning (Symbolic Machine Learning) (Pesaresi, Syrris and Julea, 2016[12]). No manual or ad-hoc rule-based editing of the results was applied in the post-processing.

It is based on the processing of individual Landsat data collections (Landsat8, collection 2000, collection 1990, collection 1975), previously tiled and mosaicked. The built-up areas of the most recent year (2015) are considered as the most reliable (Corbane et al., 2019[13]). Earlier years are created by removing built-up from 2015 when Landsat imagery shows no evidence of any built-up area for that year. This means that built-up areas can only grow over time and not decline. This assumption makes the data more robust and is valid in the vast majority of cases.

Built-up areas are the spatial generalisation of a building defined as: “areas (spatial units) where buildings can be found”. The “built-up area” as defined in the GHSL framework is “the union of all the satellite data samples that corresponds to a roofed construction above ground which is intended or used for the shelter of humans, animals, things, the production of economic goods or the delivery of services" (Pesaresi et al., 2013[14]).

The classification of the 30 m by 30 m cells is dichotomous: built up or not built up. Evidence of (a small part of) a building will lead to classifying the entire cells as built-up. As a result, more areas will be classified as built-up as compared to higher resolution data on building footprints. Imperviousness or sealed surfaces includes buildings as well as areas that are covered by asphalt, concrete, brick or stone, such as roads, sidewalks, driveways and parking lots (European Environment Agency, 2015[15]). GHS-BUILT does not include roads infrastructure in areas with an only limited amount of buildings. In areas with a high density of buildings, road infrastructure will typically be included as part of the built-up. As a result, within a city, GHS-BUILT should be seen as the area that is (partially) covered by buildings or road infrastructure.

Source: Corbane, C. et al. (2017[11]), "Big earth data analytics on Sentinel-1 and Landsat imagery in support to global human settlements mapping", http://dx.doi.org/10.1080/20964471.2017.1397899; Pesaresi, M., V. Syrris and A. Julea (2016[12]), "A new method for earth observation data analytics based on symbolic machine learning", http://dx.doi.org/10.3390/rs8050399; Corbane, C. et al. (2019[13]), "Automated global delineation of human settlements from 40 years of Landsat satellite data archives", *Big Earth Data*, Vol. 3/2, pp. 140-169; Pesaresi, M. et al. (2013[14]), "A global human settlement layer from optical HR/VHR RS data: Concept and first results", *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, Vol. 6/5, pp. 2102-2131; European Environment Agency (2015[15]), "Imperviousness and imperviousness change", https://www.eea.europa.eu/data-and-maps/indicators/imperviousness-change-1/assessment (accessed on 21 March 2020).

Urban mobility and accessibility

Cities and metropolitan areas present a unique mix of challenges and opportunities for mobility. The globally consistent definition of a city and its commuting zone used in this report allows for a more meaningful comparison of transport options. The high population density of cities can facilitate walking but some trips may be too long to walk, especially in large metropolitan areas, and road infrastructure may not be designed for pedestrians. Many (large) metropolitan areas have a highly developed public transport network with most residents close to high-frequency stops. In many cities, however, most people drive to reach their destinations but the high number of drivers can overwhelm the road infrastructure capacity leading to high levels of congestion, delays and pollution.

This section focuses primarily on the provision of public transport, as good information on walking and cycling conditions is still difficult to obtain. Increasingly the road network in cities has been mapped but good information on its capacity and use is often not available. As a result, this section only briefly touches on driving.

The section starts by analysing public transport in cities using two SDG indicators and the new EC-ITF-OECD urban accessibility framework. It focuses on cities first because they have the density and the critical mass of potential users that should support a dense and frequent public transport service. Finally, it considers the impact of the shape of the metropolitan area, i.e. a city plus its commuting zone, on the costs of public transport provision.

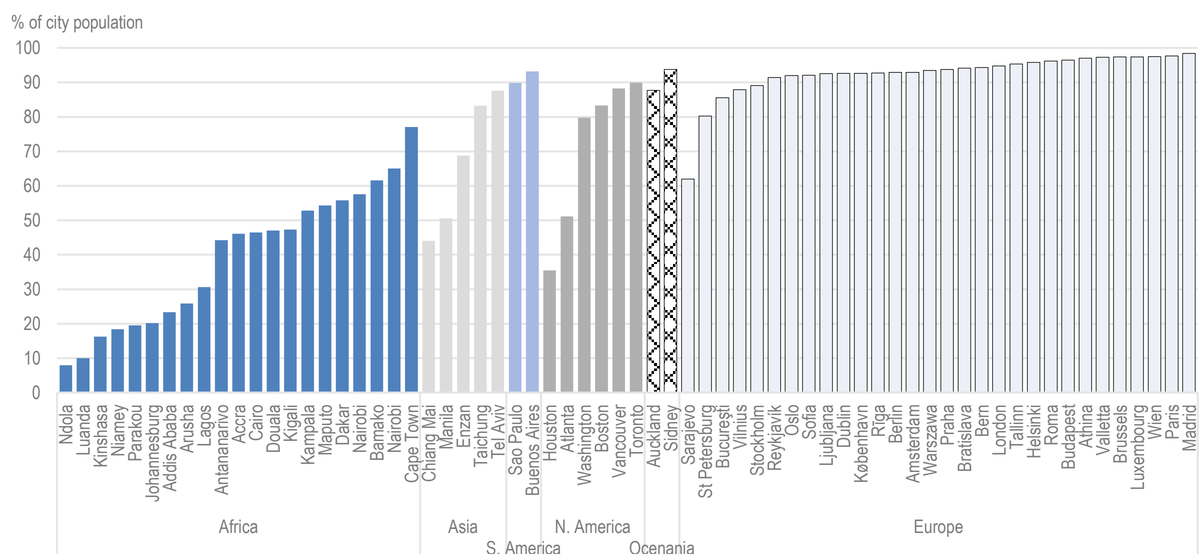
Cities can provide easy access to public transport

Large cities need public transport to ensure people can get where they need to go as distances become too big to easily walk or cycle to their destinations. Many city residents are too young or too old to drive. Some simply prefer to use public transport, while others cannot afford a car. Furthermore, a high share of car trips is likely to lead to high levels of congestion. Good public transport is critical to reducing congestion, air pollution and greenhouse gas emissions from transportation as well as providing better accessibility for all, including the young, the old and the poor.

The United Nations (UN) Sustainable Development Goal 11 includes an indicator that measures the proportion of the population that has convenient access to public transport. In its simplest formulation, it measures what share of the city population lives within a 500-metre walk of a public transport stop. The benefit of this indicator is that it takes into account the spatial distribution of the stops and the population and does not require a large amount of data: just the location of the stops and the population per block or grid cell. Nevertheless, data on the location of public transport stops, including informal transit, is often unavailable.

Comparing 68 cities across the globe with available data shows that in most of European cities, more than 90% of the population lives within a 500-metre walk of a public transport stop (Figure 5.9). By contrast, in most African cities included in this analysis, this share is below 50%, despite including informal transit. The shares for the cities included from North America and Asia vary from less than 50% to over 90%. The 4 cities included from South America and Oceania (Buenos Aires and São Paolo, Auckland and Sydney), all have more than 80% of their population close to a public transport stop.

Figure 5.9 Population within a 500 m walk to a public transport stop in selected cities in the world



Source: ITF, UN-Habitat and EC calculations using the boundaries of the GHS Urban Centre Database, Florczyk, A. et al. (2019[3]), *GHS Urban Centre Database 2015, Multitemporal and Multidimensional Attributes, R2019A (dataset)*, https://data.jrc.ec.europa.eu/dataset/53473144-b88c-44bc-b4a3-4583ed1f547e.

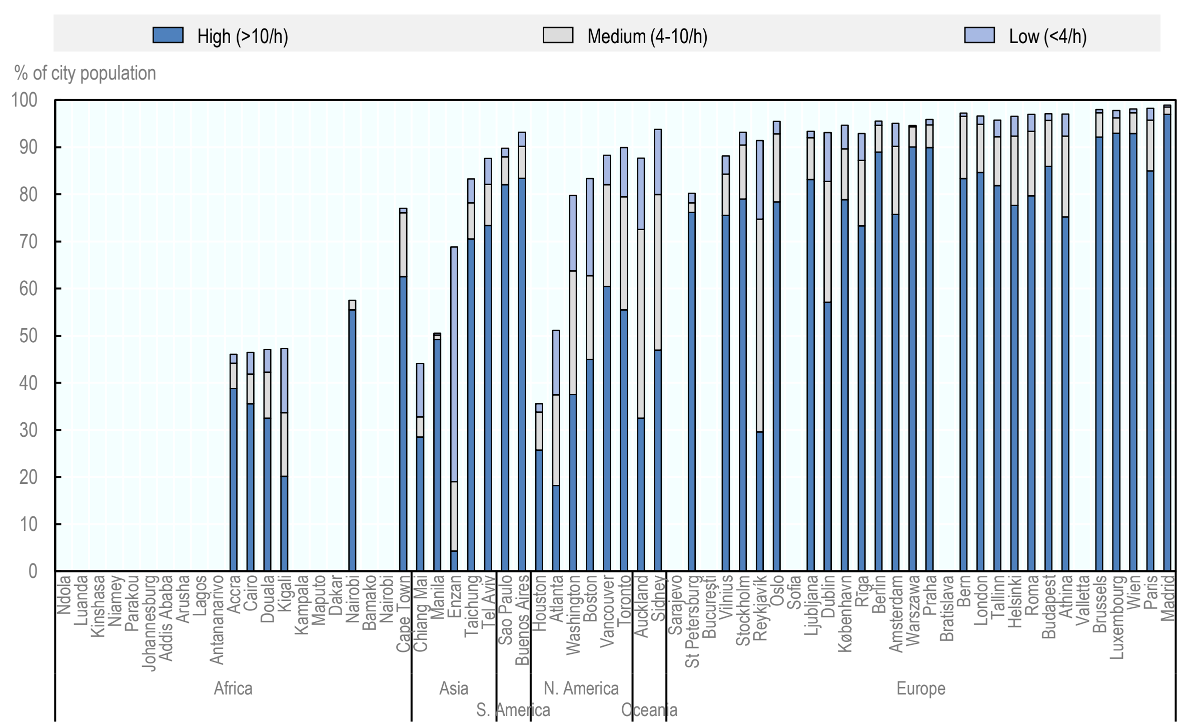
A city can improve access to public transport by adding transport stops in neighbourhoods without access and/or increasing population densities around public transport stops, often referred to as transit-oriented development. Cities with low access to public transport and high densities should focus more on expanding the public transport network to neighbourhoods without access. For example, only 16% of the population of Kinshasa lives close to a public transport stop but it has a neighbourhood density of 30 000 inhabitants per km^2. Cities with low access and low densities should focus more on boosting densities and transit-oriented development; especially as public transport in low-density neighbourhoods tend to attract a low number of riders. In Atlanta, for example, 50% of the population lives close to public transport but neighbourhood density is only 1 100 inhabitants per km^2. A low population share with access to public transport together with high neighbourhood densities suggest an underdeveloped public transport network, while low access combined with low neighbourhood densities implies a lack of density around public transport stops.

Access to high-frequency public transport varies strongly across cities

A more demanding but also more informative indicator differentiates by frequency and by public transport mode. It distinguishes access to a stop with more than ten departures an hour (high access), between four and ten in an hour (medium access), less than four (low access) or without convenient access (no access). For slower modes such as buses and trams, it uses the same 500-metre walk, while for higher speed and capacity modes such as metro, train, bus rapid transit (BRT) and ferry, it uses a 1000-metre walk. This approach is mentioned as a complementary indicator in the metadata of SDG Indicator 11.2.1, as defined by the United Nations.[3]

This indicator shows a far more differentiated picture. Comparing Figure 5.9 to Figure 5.10 shows more variation with Europe. For example, Dublin and Reykjavik have high overall access but access to a stop with a high frequency of departures is relatively rare. On the other hand, the South American cities of Buenos Aires and São Paulo offer a high level of access to more than 80% of their residents. The cities in North America and Oceania in this figure stand out with relatively low population shares with access to high-frequency departures.

Figure 5.10 Population by frequency of public transport departures in selected cities in the world



Source: ITF and DG REGIO calculations based on GTFS data from a variety of sources using the boundaries of Florczyk, A. et al. (2019[3]), *GHS Urban Centre Database 2015, Multitemporal and Multidimensional Attributes, R2019A (dataset)*, https://data.jrc.ec.europa.eu/dataset/53473144-b88c-44bc-b4a3-4583ed1f547e.

Public transport performance is higher in European and South American cities

The two indicators described above are based on the supply of public transport services at a stop but this does not take into account where a person can travel to. This section relies on the new urban accessibility framework developed by the European Commission, International Transport Forum and OECD[4] to measure how well public transport allows people to get to their destination. It uses two overlapping concepts to measure the performance of a mode of transport. The first component is the accessibility, which is the total number of destinations that can be reached by public transport within a fixed period of time. Destinations are identified in terms of population because comprehensive data on other destinations is not available. Accessible population, i.e. how many people can be reached in 45-minutes of travel by public transport, was calculated for each inhabited grid cell of 500 m by 500 m in a city. The second component is called proximity and corresponds to the number of nearby destinations. Proximity or the nearby population, i.e. the number of people within a radius of 12 km, was calculated for each grid cell. Finally, transport performance is the ratio between the accessible population and the nearby population (multiplied by 100). It shows how well public transport provides access to nearby destinations for each grid cell in a city. The city-level indicator is the population-weighted average of all the grid cells in the city.

Figure 5.11 shows these three indicators for 31 cities across the globe. For example, in London, the average accessible population is more than 4 million people. Cities with only a million inhabitants can never reach such a high level of accessibility because it simply lacks a large enough population. This underlines that the accessible population is heavily influenced by the population size of the city and should not be used to assess public transport. The nearby population is high in several cities. For example, it is between 3 and 4 million in Manilla, Paris and St Petersburg. The nearby population will be high in large, dense cities and lower in smaller or less dense cities.

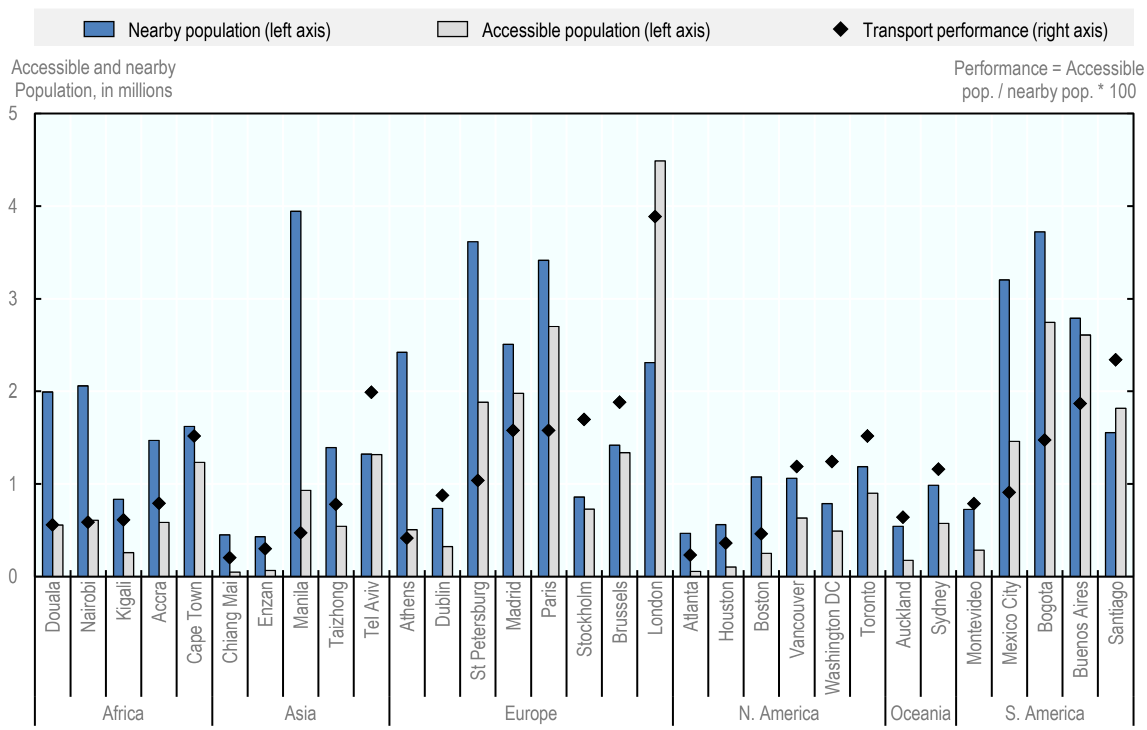
Comparing the accessible population to the nearby population makes it possible to eliminate the effect of city size and to assess the performance of public transport more comparably. While only large cities can have a high level of accessible population, smaller cities can score well in terms of public transport performance. For example, Brussels or Tel Aviv score better than Paris in terms of transport performance.

Transport performance depends on how many people live close to a stop, the frequency and the speed of public transport vehicles and the design of the network. Cities with a high share of their population living close to a stop with frequent, high-speed transport will perform better. Cities with a metro network will perform better all other things being equal (see section on metro systems). Providing dedicated rights of way to buses and trams will also improve performance. Bus rapid transit systems, such as the one in Bogota, will also improve performance as it allows for higher speeds and frequencies for the buses in that system.

If neighbourhood densities are low, a longer network is needed to provide access to public transport to a large share of the population. Longer networks, however, are more expensive to build and operate and the distances between origin and destinations are higher too. As a result, cities with a low neighbourhood density tend to offer a lower level of access, lower frequencies and a lower performance. To improve both accessibility and performance, cities with a low neighbourhood density may wish to increase these densities, in particular close to public transport nodes. Cities with a high neighbourhood density, but a low public transport performance, should focus more on increasing the network, speed and frequencies of public transport to improve accessibility.

Good public transport is key to the quality of life and the economy of a large city. Access to public transport shows how many people can walk to a stop and which cities do lack a large enough network. Access by frequency shows how many departures an hour people can choose from. Low frequencies of departures tend to make public transport less attractive as it will take people longer to get to their destination. Neither of these indicators, however, show what destinations one can reach with public transport. The urban accessibility framework provides a new approach to comparing the performance of public transport in cities. It compares the accessible population to the nearby population to assess the performance of public transport. It shows which cities should focus on increasing the network, departures and speed to improve accessibility and which ones should (also) focus on reducing the distance between people and more generally between origins and destinations.

Figure 5.11. Accessible population, nearby population and public transport performance in selected cities in the world, 2019



Source: ITF calculations using the boundaries of Florczyk, A. et al. (2019[3]), *GHS Urban Centre Database 2015, Multitemporal and Multidimensional Attributes, R2019A (dataset)*, https://data.jrc.ec.europa.eu/dataset/53473144-b88c-44bc-b4a3-4583ed1f547e.

Metro systems are mostly present in large cities in high-income countries

Metro systems offer a relatively high-speed and high-capacity form of public transport. The cost of constructing a metro system, however, is also high. Metro systems are typically constructed in large cities and do not extend into the suburbs (as defined by the degree of urbanisation). In high-income countries, 60% of the cities over 1 million inhabitants have a metro system, compared to only 7% in lower-middle-income countries (Table 5.6).

The metro systems in high-income countries started much earlier than in middle-income countries. Several metro lines were opened in the 19th century: Boston, Budapest, Chicago, London, Paris and Tokyo. Since the 2000s, the number of metro systems opened each decade has increased. Between 1970 and 2010, about 20 systems were opened each decade. Between 2010 and 2018 even 37 were opened, primarily in China which opened 20 of them and India which opened 7.

The metros in high-income countries have four times the stations per inhabitants and three times the network length per inhabitants as compared to those in lower-middle-income countries. They have more than twice the number of trips per capita compared to lower-middle-income countries but its stations are less busy.

Table 5.6. Cities with metro systems and their characteristics, 2018

	Share of cities with 1 million inhabitants with a metro system (%)	In cities with a metro system and 1 million inhabitants				
		Stations per 100 000 inhab.	Metro length in km per 100 000 inhab.	Annual trips per inhab.	Million annual trips per station	Average year metro opened
Low income	3	0.8	1.2	13	2.3	1973
Lower middle	7	0.6	0.8	31	5.2	1996
Upper middle	40	1.1	1.5	40	4.5	1999
High income	60	2.5	2.8	72	3.8	1965

Note: In low-income countries, only one city has a metro: Pyongyang, North Korea.
Source: EC calculations based on UITP (2018[16]), *World Metro Figures 2018*, Union Internationale des Transports Publics/International Association of Public Transport, Brussels, using the boundaries of Florczyk, A. et al. (2019[3]), *GHS Urban Centre Database 2015, Multitemporal and Multidimensional Attributes, R2019A (dataset)*, https://data.jrc.ec.europa.eu/dataset/53473144-b88c-44bc-b4a3-4583ed1f547e.

Looking at 12 selected cities shows the strong correlation between the share of the population within 1 km of a metro station and the trips per inhabitant (Table 5.7). This share explains 63% of the variation in the trips per inhabitant. In Chicago, São Paulo and Toronto, only 15% or less of the inhabitants are within 1 km of a metro station and the number of metro trips a year per inhabitant is only between 35 and 70. In cities where at least 30% lives within 1 km, the number of trips per inhabitant is up to four times higher: between 108 and 173 trips per inhabitant.

Table 5.7 Metro system, ridership and access to a metro station in 12 selected cities, 2015

City name	Country name	Population (millions)	Length in km per 100 000 inhab.	Stations per 100 000 inhab.	Annual trips per inhabitant	Share of inhabitants within 1km walk of a station (%)
Sao Paulo	Brazil	19.1	0.4	0.4	70	8
Toronto	Canada	6.0	1.4	1.2	48	12
Chicago	United States	6.8	2.4	2.1	34	15
Mexico City	Mexico	19.6	1.2	0.8	86	16
Milan	Italy	2.9	3.1	3.8	164	25
St. Petersburg	Russia	4.2	2.7	1.6	173	30
London	United Kingdom	9.6	4.5	3.2	156	30
Berlin	Germany	3.3	4.5	5.3	172	34
Paris	France	9.7	2.1	3.1	154	35
Brussels	Belgium	1.4	3.2	4.3	108	36
New York	United States	16.0	2.7	3.2	119	38
Madrid	Spain	4.7	6.2	5.0	132	49

Source: EC calculations based on UITP (2018[16]), *World Metro Figures 2018*, Union Internationale des Transports Publics/International Association of Public Transport, Brussels, using the boundaries of Florczyk, A. et al. (2019[3]), *GHS Urban Centre Database 2015, Multitemporal and Multidimensional Attributes, R2019A (dataset)*, https://data.jrc.ec.europa.eu/dataset/53473144-b88c-44bc-b4a3-4583ed1f547e.

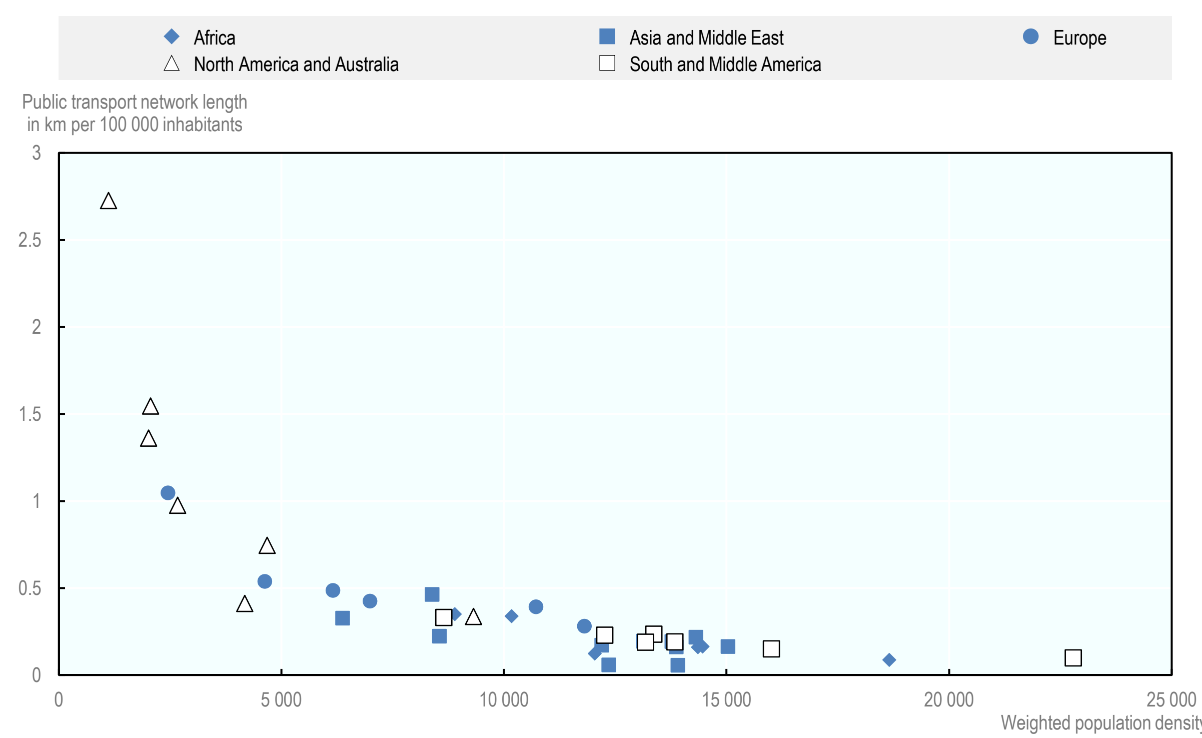
The shape of a metropolitan area changes the cost of providing public transport

The spatial distribution of the population within a metropolitan area can have a big impact on the cost of providing public transport. The literature on sprawl typically relies on the assumption that low density and discontinuous urban development increase these costs. This report takes a different approach and tries to assess the costs of public transport by measuring and modelling the length of the public transport network in 37 large metropolitan areas in all continents (see Annex 5.A). The results reveal big differences. Hong Kong and Mumbai can provide public transport to 80% of its residents with a network of only 6 km per 100 000 inhabitants. Houston needs 26 times more (155 km) and Atlanta needs 45 times more (273 km). This would substantially raise the cost of constructing and operating such a network if it were ever constructed. In practice, it usually means that a much lower share of the population has access to public transport in cities like Houston and Atlanta.

The main determinant of the length of the public transport network in this model is the neighbourhood density (the weighted population density using 1 km² cells), while the overall population density of the metropolitan area becomes insignificant once neighbourhood density is factored in. The only other indicator that has some significance is the share of the population in the commuting zone, with higher shares leading to longer networks. The relationship between neighbourhood density and the public transport network lengths is not linear, but exponential. A change in neighbourhood density can have a bigger or smaller impact on total costs depending on the initial density. For example, reducing the density from 15 000 to 12 000 inhabitants per km² increases costs by 30%, while reducing it from 6 000 to 3 000 increases costs by 120%. The same reduction in density has a four times bigger impact.

The average neighbourhood density in metropolitan areas with at least 1 million inhabitants globally is 14 000 inhabitants per km². In South America, densities are 11 000, which would imply costs that are 30% higher as compared to the global average. In Europe and Central Asia, the density is around 8 000 which would imply costs that are 90% higher. In North America, however, densities are only 3 300, which would imply costs that are 400% higher than the global average. Densities in metropolitan areas of 1 million or more in North Africa, Sub-Saharan Africa and the Middle East (15 000) are slightly above the global average and densities in East Asia and the Pacific (13 000) slightly below it.

Figure 5.12. Simulated public transport network length in 37 metropolitan areas, 2015



Source: See Jacobs-Crisioni, C., L. Dijkstra and A. Kucas (forthcoming[17]), "Does density foster efficient public transport? A network expansion simulation approach" (manuscript submitted for publication). Work is based on the boundaries of Moreno-Monroy, A., M. Schiavina and P. Veneri (2020[8]), "Metropolitan areas in the world. Delineation and population trends", https://doi.org/10.1016/j.jue.2020.103242.

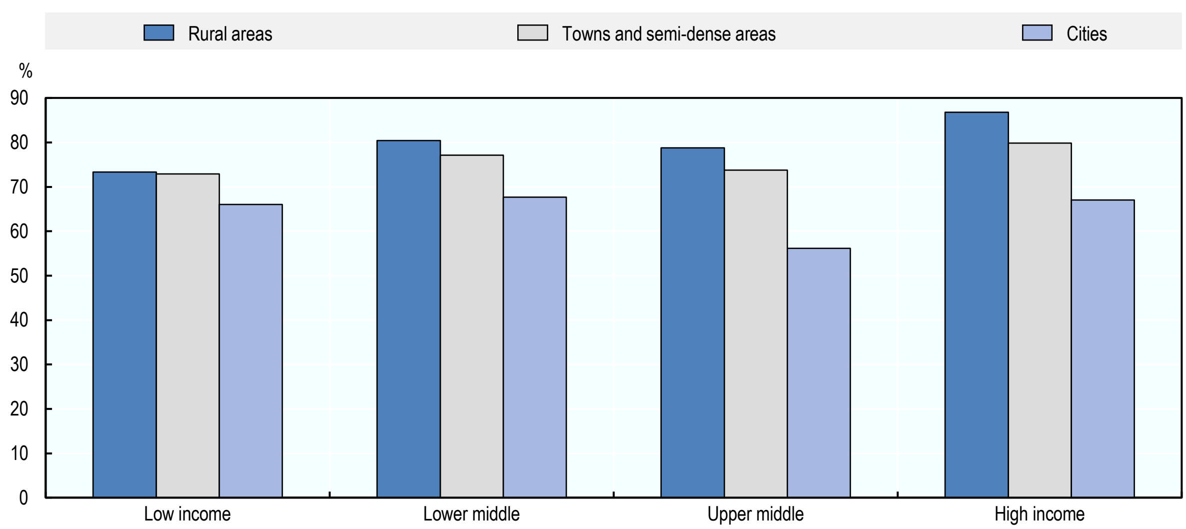
Pollution, natural hazards and climate change

Cities concentrate people and wealth. This high concentration has costs as well as benefits. People living in cities suffer from air pollution, floods and are more exposed to storms and sea level rise.

People living in cities are exposed to higher levels of air pollution

City residents are least satisfied with their air quality. In all four country income groups, people living in cities are less satisfied with air quality than those living in towns and semi-dense areas, which in turn are less satisfied than those in rural areas (Figure 5.13). With higher income levels, satisfaction improves in rural areas, but less in towns and semi-dense areas and not in cities. In part, this reflects the fact that higher income levels do not automatically lead to better air quality in cities, for example, as the use of individual cars typically rises with income. It also reflects that as incomes grow, more people may become concerned about air pollution, even at relatively low pollution levels.

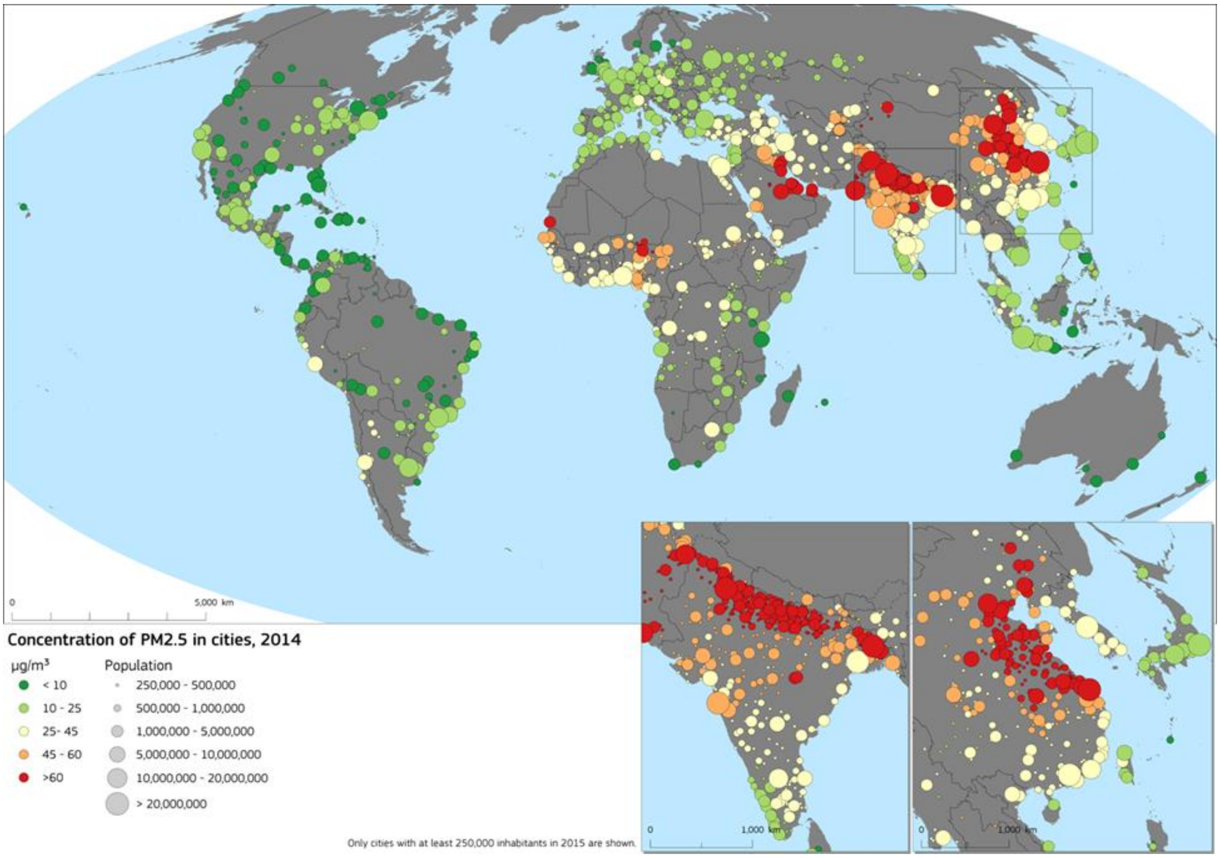
Figure 5.13. Satisfaction (in percentage) with air quality by the degree of urbanisation



Source: Based on Gallup (2017[18]), *Gallup World Poll, 2016-17*, https://www.gallup.com/analytics/232838/world-poll.aspx, elaborated by OECD, 2019.

Air pollution in cities depends on local emissions, geography, wind and emissions nearby. The concentration of PM 2.5 is particularly high in cities in parts of India and the industrial coastal cities in China (Figure 5.14). Although most cities in North America, South America, and Europe record lower levels of air pollution, these levels remain above the 10 μg/m^3 guideline value proposed by WHO.[5] Improving air quality requires a co-ordinated approach covering emissions from different sectors, including industry, transport, agriculture and households, and covering both local and nearby emissions. For example, a significant share of air pollution in cities in the European Union comes from emissions in neighbouring regions, from agriculture or from freight ships at coastal locations.

Figure 5.14. Concentration of PM2.5 in cities, 2014



Source: Florczyk, A. et al. (2019[3]), *GHS Urban Centre Database 2015, Multitemporal and Multidimensional Attributes, R2019A (dataset)*, https://data.jrc.ec.europa.eu/dataset/53473144-b88c-44bc-b4a3-4583ed1f547e.

Flood risks threaten cities on all continents

One in five people living in cities, or 613 million people, are exposed to a 100-year flood (Dottori et al., 2016[19]).[6] This exposure is heavily concentrated in a few cities (Figure 5.15). Of all cities, 70% are not exposed while 6% (630 cities) risk being entirely flooded. The cities with the biggest number of people exposed to a 100-year flood are mostly located in Asia, in part because a high number of the largest cities are located in Asia (Table 5.8). Climate change is likely to increase this risk of 100-year floods due to more extreme weather. Reducing flood risks requires changes both within and beyond the city. Cities can take action to minimise the impact on the people and infrastructure when water rises through flood barriers and considering flood risk when building new housing and infrastructure. Changes along the river can help to manage the speed of the flow and create places where flood water can be channelled with minimal consequences.

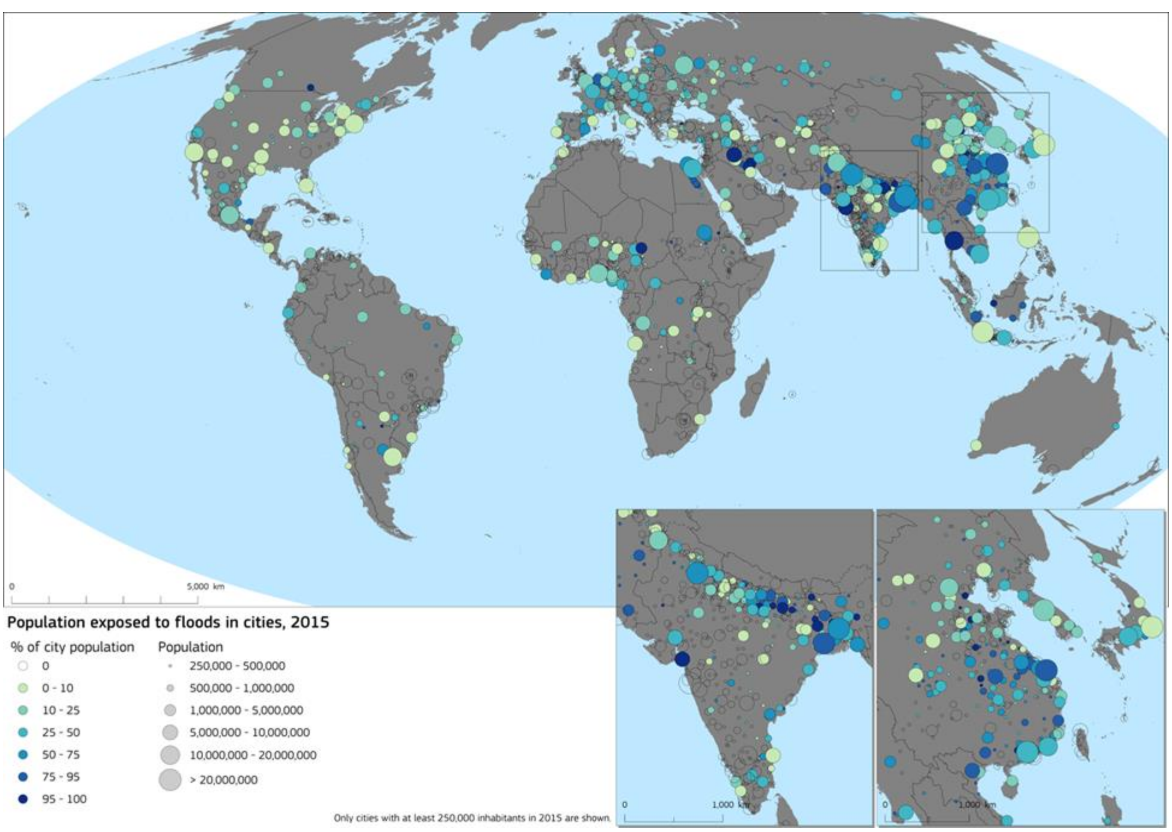
Table 5.8. The 20 cities with the highest population exposed to a 100-year flood, 2015

City	Country	Exposed population, 2015	Percentage of population exposed, 2015
Shanghai	China	21 503 000	88
Guangzhou	China	17 640 000	43
Kolkata	India	17 164 000	79
Dhaka	Bangladesh	15 269 000	64

City	Country	Exposed population, 2015	Percentage of population exposed, 2015
Bangkok	Thailand	14 647 000	99
Delhi	India	14 151 000	53
Cairo	Egypt	9 251 000	47
Tianjin	China	6 642 000	100
Wuhan	China	6 338 000	86
Suzhou	China	5 418 000	63
Surat	India	5 330 000	97
Seoul	South Korea	5 268 000	24
Baghdad	Iraq	5 140 000	96
Ho Chi Minh City	Viet Nam	4 958 000	43
Osaka-Kyoto	Japan	4 827 000	31
Hanoi	Viet Nam	4 533 000	85
Jieyang	China	4 425 000	42
Mexico City	Mexico	4 398 000	22
Chattogram	Bangladesh	3 418 000	65
Khartoum	Sudan	3 270 000	56

Source: Florczyk, A. et al. (2019[3]), *GHS Urban Centre Database 2015, Multitemporal and Multidimensional Attributes, R2019A (dataset)*, https://data.jrc.ec.europa.eu/dataset/53473144-b88c-44bc-b4a3-4583ed1f547e.

Figure 5.15. Population exposed to floods in cities, 2015

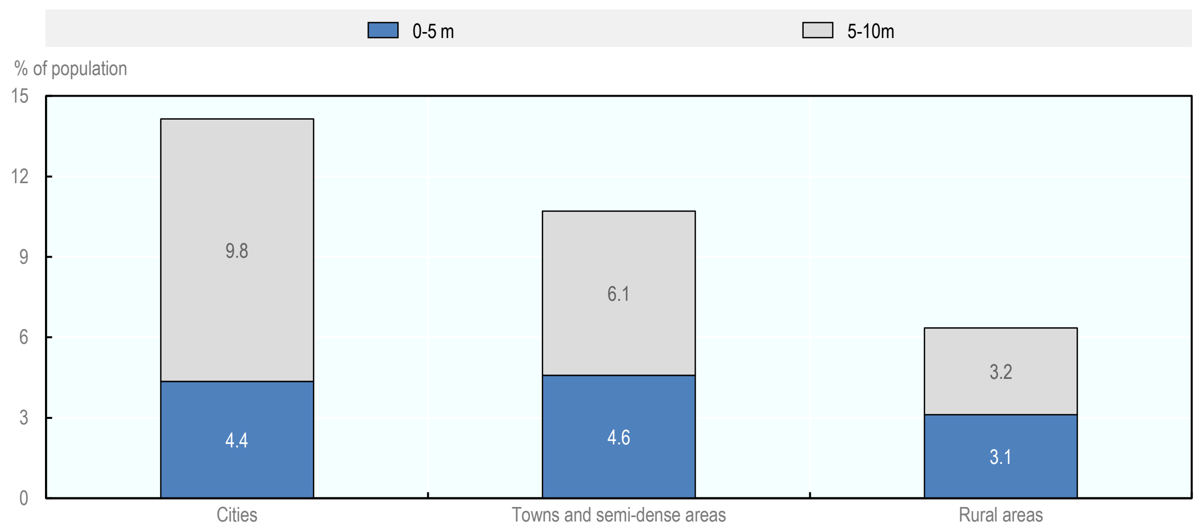


Source: Florczyk, A. et al. (2019[3]), *GHS Urban Centre Database 2015, Multitemporal and Multidimensional Attributes, R2019A (dataset)*, https://data.jrc.ec.europa.eu/dataset/53473144-b88c-44bc-b4a3-4583ed1f547e.

Cities are more exposed sea level rise and storm surges

In 2015, 14% of city dwellers were living in a low elevation coastal zone compared to 11% of the population in towns and semi-dense areas and 6% of the rural population (Figure 5.16). Low elevation coastal zones (LECZs) are areas below 10-metre elevation and contiguous with the seacoast (see (MacManus et al., 2019[20]), based on Yamazaki et al. (2017[21])). Of the city population in these zones, one in three city dwellers was living in the zone most exposed to storms and sea level rise (below 5m, Figure 5.16).

Figure 5.16. Population in low elevation coastal zones by degree of urbanisation, 2015



Source: (MacManus et al., 2019[20]) based on Florczyk, A. et al. (2019[3]), *GHS Urban Centre Database 2015, Multitemporal and Multidimensional Attributes, R2019A (dataset)*, https://data.jrc.ec.europa.eu/dataset/53473144-b88c-44bc-b4a3-4583ed1f547e.

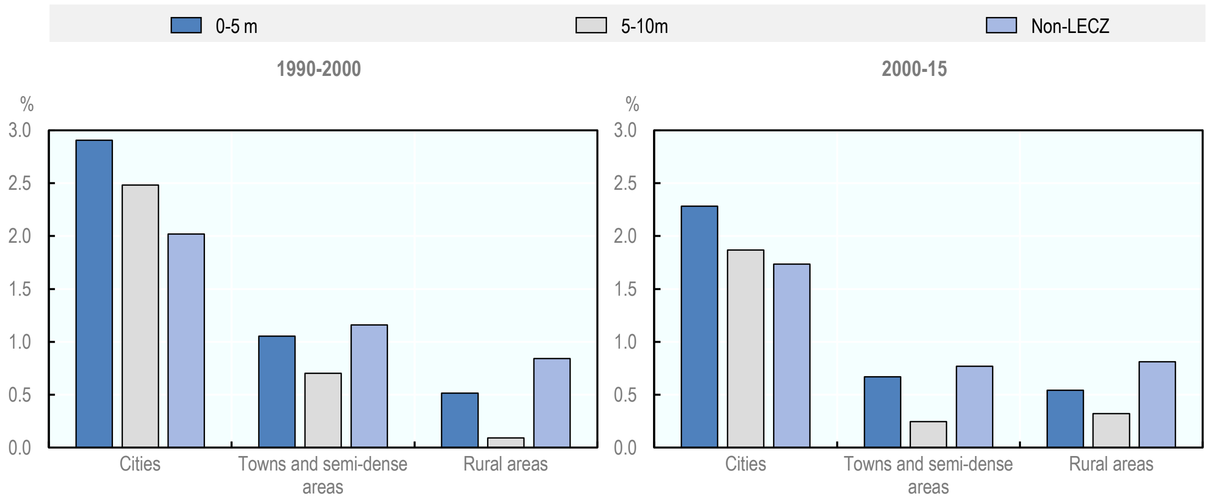
StatLink https://doi.org/10.1787/888934130455

In cities, the population living in low elevation coastal zones has also been growing faster as in towns and semi-dense areas and in rural areas, especially in the highest risk zone (Figure 5.17). Population growth in towns & semi-dense areas and in rural areas has been faster outside the low coastal elevation zones. This means that over time the exposure to this risk has been shrinking outside cities while it has been growing within cities.

Chinese cities have 128 million people living in a low elevation coastal zone, the highest city population exposed (Table 5.9), followed by India with 54 million people. More than one in five city dwellers in Bangladesh, China, Indonesia, Japan and the Philippines live in a LECZ. Thailand and Viet Nam, have 82% and 63% respectively of their city population within a low elevation coastal zone. While total numbers of city dwellers are much smaller, several Latin American and Caribbean nations have their entire (or nearly) city population within the LECZ: Belize, Guyana, Suriname (at 100%) and the Bahamas (80%). In addition, several small developing island states, including the Cayman Islands, the Maldives, the Marshall Islands and Tuvalu have the three-quarters of their population in a low elevation coastal zone.

Current protection against storms varies widely between these cities. Dutch cities benefit from a strong centrally funded infrastructure. Many others, including some in high-income countries like New Orleans, are highly exposed to storms and rising sea levels. The high level of exposure highlights the need for national adaptation plans. Given that 60% of the 815 million people in a low elevation coastal zone live in a city and that this population is growing quickly, developing city adaptation plans should be a priority.

Figure 5.17. Population change in low elevation coastal zones by degree of urbanisation, 1990-2000 and 2000-15



Source: (MacManus et al., 2019[20]) based on Florczyk, A. et al. (2019[3]), *GHS Urban Centre Database 2015, Multitemporal and Multidimensional Attributes, R2019A (dataset)*, https://data.jrc.ec.europa.eu/dataset/53473144-b88c-44bc-b4a3-4583ed1f547e.

Table 5.9. Top ten countries ranked by city population and city population share in the low elevation coastal zones, 2015

	Panel A. Ranked by **total** population living in cities in low elevation coastal zones			Panel B. Ranked by share of population living in cities in low elevation coastal zones		
Rank	Country	Population in the LECZ (thousands)	%	Country	Population in the LECZ (thousands)	%
1	China	127 792	23	Suriname	200	100
2	India	54 456	8	Belize	69	100
3	Bangladesh	40 286	48	Guyana	224	100
4	Indonesia	34 209	24	Thailand	16 747	82
5	Japan	26 467	32	Bahamas	164	80
6	Viet Nam	23 767	63	Mauritania	1 170	80
7	Thailand	16 747	82	Netherlands	5 979	77
8	United States	15 912	10	Djibouti	421	70
9	Egypt	14 038	24	Liberia	1 055	65
10	Philippines	12 763	33	Viet Nam	23 767	63

Note: Countries with a total population of under 100 000 people or smaller than 1 000 square kilometres were excluded from this list.
Source: (MacManus et al., 2019[20]) based on Florczyk, A. et al. (2019[3]), *GHS Urban Centre Database 2015, Multitemporal and Multidimensional Attributes, R2019A (dataset)*, https://data.jrc.ec.europa.eu/dataset/53473144-b88c-44bc-b4a3-4583ed1f547e.

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Notes

[1] https://www.who.int/airpollution/data/cities/en/.

[2] http://habitat3.org/wp-content/uploads/NUA-English.pdf.

[3] https://unstats.un.org/sdgs/metadata/files/Metadata-11-02-01.pdf.

[4] ITF/OECD (2019). *Benchmarking Accessibility in Cities. Measuring the Impact of Proximity and Transport Performance,* https://www.itf-oecd.org/sites/default/files/docs/accessibility-proximity-transport-performance.pdf .

[5] According to the Clean Air Outlook for Europe (https://ec.europa.eu/environment/air/clean_air/outlook.htm), “for fine particulate matter (PM2.5), up to 8 % of the urban population was exposed to concentrations above the EU limit value of 25 µg/m3, and more than 82% to levels above the much stricter WHO guideline value of 10 µg/m3.”

[6] A 100-year flood or a flood with a 100-year return period is a flood that is likely to happen once every 100 years. Climate change is already leading to more extreme weather patterns which may increase the frequency of floods, including those with a 100-year return period.

Annex 5.A. Technical annex

Neighbourhood density or population-weighted population density

Neighbourhood density or population-weighted population density (weighted density) captures the experience of an average resident. It establishes the neighbourhood density for each resident and averages those densities. In this report, we use 1 km² cells to measure neighbourhood density and we report it at both the city and functional urban area level.

The formula is: $\sum_{i=0}^{n}(density_i * \ population_i) / \sum_{i=0}^{n} population_i$

In simpler terms, for all the neighbourhoods in a city, sum up its density multiplied by its population and divide it by the total population of the city.

Taking a random sample of residents from a city and calculating the average of the density of the neighbourhood they live in produces the same result.

The neighbourhood density is always equal or higher than the city density. If every neighbourhood had the same density, it would be the same as the city density. When neighbourhood densities vary, the population weighting ensures that the neighbourhood density is higher than the city density.

The benefit of the neighbourhood density is that it ignores areas without population (because they get a weight of zero). This ensures that the indicator does not reduce density because a large park or undeveloped area is included within the city boundary. As a result, it also makes it less sensitive to where the boundary of a city or metropolitan area is drawn.

Modelling public transport networks

Through shape and density, the urban form has a profound impact on the efficiency and mobility potential of urban transport. A comparison of existing public transport network lengths, however, cannot reveal whether the shape and density of a particular city are efficient because political preferences, income levels and physical geography will play an important role in the extent of those networks (Jacobs-Crisioni, 2016[22]).

Simulated optimal public transport networks can show which cities can provide public transport at a lower cost. The approach ensures that 80% of every functional urban area population has access to public transport. The simulation starts by creating a base network meant to describe all possible network links in the city. Each inhabited grid cells of 1 km² is connected to all other inhabited grid cells within 2 km. All lines are attributed to a relatively low speed of 4 km/h, which is considered a realistic walking speed. Grid cells that do not have any neighbours within the 2 km are given single lines to the closest neighbour(s).

Step 1: Origin-destination matrix-based selection

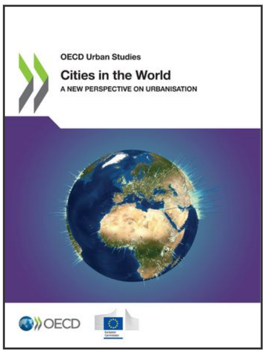
Travel time between all grids is calculated using the shortest path algorithm through the created base network. With grid cell population and travel times, passenger flows on the network are estimated. For each origin-destination pair, costs and benefits of a public transport network connection are estimated. Public transport is assumed to operate at an average speed of 30 km/h. Costs are a combination of fixed costs and a variable cost element based on the length of the connection. Benefits are estimated based on expected gains in passenger-kilometres. Finally, the pair with the highest benefit-cost rate is selected as a connection to upgrade.

Step 2: Find the most attractive path

For the selected connection, the most attractive path is selected using a corridor allocation solving approach (see (Goodchild, 1977[23])). This allows, within set limits, a connection to take a longer path if that yields more passenger-kilometres, thus identifying the most plausible path between origin and destination. The path with the highest total passenger-kilometres is selected.

Step 3: Add a path to the network and evaluate the percentage of the population that is connected

The selected path is added to the network with a speed of 30 km/h, instead of the base 4 km/h travel speeds on walking links. The simulation continues by returning to Step 1, searching another connection to upgrade, until at least 80% of the population lives in a grid cell with a public transport stop.



From:

Cities in the World

A New Perspective on Urbanisation

Access the complete publication at:

https://doi.org/10.1787/d0efcbda-en

Please cite this chapter as:

OECD/European Commission (2020), “The shape of cities and sustainable development”, in *Cities in the World: A New Perspective on Urbanisation*, OECD Publishing, Paris.

DOI: https://doi.org/10.1787/165ea317-en

OECD