NICKLAS NORDFORS

DEVELOPMENT DISSERTATION BRIEF

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CLIMATE, WEATHER SHOCKS AND CITIES

EBA

Climate, Weather Shocks and Cities

Nicklas Nordfors

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The Expert Group for Aid Studies (EBA)

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Sammanfattning

Andelen av jordens befolkning som bor i städer har ökat det senaste decenniet. Samtidigt som urbaniseringen planat ut i många höginkomstländer väntas städer i låginkomstländer fortsätta växa kraftigt de kommande decennierna. En vanlig hypotes är att alltmer ogynnsamma klimatförhållanden och extremväder kommer att leda till en ökad urbanisering genom ökad migration från landsbygd till städer. I kapitlet *Droughts and the growth of cities* i min avhandling, undersöker jag denna hypotes genom att estimera det långsiktiga förhållandet mellan torka och stadstillväxt – vilket mäts med hjälp av städers ”fotavtryck” – och konstaterar att torka leder till en långsammare urban tillväxttakt. Dessa resultat tyder på att negativa väderchocker inte nödvändigtvis leder till en förflyttning av människor till städer.

I kapitlet *Rapid population growth and city shape* undersöker jag sambandet mellan befolkningstillväxt och *sättet* en stad växer på. Med hjälp av högupplösta data, om den fysiska miljön i städer, visar jag att när städer upplever perioder med högre befolkningstillväxt växer de annorlunda jämfört med perioder med lägre befolkningstillväxt. Närmare bestämt expanderar städerna mer i områden som utsätts för risk för översvämning, tenderar att vara lägre byggda och är mer informella.

Resultaten tyder på att det kan finns utrymme att förbättra förutsättningarna för de växande befolkningarna i urbana miljöer att hantera naturkatastrofer, klimatförändringar och väderchocker, till exempel genom förebyggande stadsplanering.

Abstract

The share of the world population living in cities has increased over the last decade. While urbanization has plateaued in many higher-income countries, cities in lower-income countries are on track to keep growing substantially in the coming decades. A common hypothesis is that increasingly adverse climate conditions and weather shocks will induce urbanization through increased rural-to-urban migration. In my thesis chapter *Droughts and the growth of cities*, I study this hypothesis by empirically estimating the long-run relationship between droughts and city growth – measured using the footprint of cities – and find that local droughts lead to slower city growth. This suggests that on average, adverse weather shocks may not induce a reallocation of people towards cities.

In the chapter *Rapid population growth and city shape*, I explore the association between population growth and *how* a city grows. Using high-resolution data on the built environment within cities, I show that when cities experience periods of higher population growth, they grow in a different way compared to periods with lower population growth. Specifically, cities expand more in areas exposed to flood risk, tend to be lower built and are more informal.

These results suggest that there may be some scope to improve conditions for the growing urban populations to cope with environmental hazards, climate change and weather shocks, for example by preventative urban planning.

Introduction

The world is urbanizing rapidly, with more people than ever before living in towns and cities. This rapid urbanization is particularly striking in some of the lowest-income areas of the world, for example Sub-Saharan Africa (United Nations, 2018).

Cities are commonly lauded as engines of economic growth and innovation (Rossi-Hansberg and Wright, 2007). Some fear that cities expand in a manner which is less conducive to economic growth (Lall et al., 2021). Climate scientists predict that the frequency, intensity, and severity of droughts will increase with climate change (IPCC, 2022). Many believe this will lead to an increase in rural-to-urban migration and increased city growth. However, empirical evidence on these relationships remains limited. Empirical research on cities in the developing world has long been constrained by the absence of disaggregated or high-frequency data on city growth or how cities are shaped.

This Development Dissertation Brief summarizes the first two chapters in my thesis, *Essays on Development and the Environment* (Nordfors, 2024), which both study cities located in low-income countries. In these chapters, I employ novel data, primarily derived from satellite imagery, that has provided the opportunity to study cities at a micro level.

The first chapter studies how droughts in cities' hinterlands impact the growth of cities. In the second chapter, I explore whether city population growth is associated with *how* cities grow in Sub-Saharan Africa, for example, whether they expand more in flood prone areas. The research questions in these chapters touch on issues related to safe and sustainable urbanization, as highlighted in the sustainable development goals.

Droughts and the growth of cities

Researchers and policymakers alike believe that extreme weather events will lead to an increase in migration, projecting the number of internal climate migrants in low-income countries to reach 200 million by 2050 (Clement et al., 2021), many of whom are likely to move to cities (Cattaneo and Peri, 2016) which would increase city growth and urbanization.

However, the empirical evidence on the weather–city growth relationship shows mixed results, and the theoretical prediction of the impact of adverse weather shocks on urbanization is ambiguous. While rural-to-urban migration could be used as a coping mechanism for affected households (Morten, 2019; Kleemans and Magruder, 2018), adverse weather events could also decrease migration. Especially for the poorest and agricultural households who are liquidity constrained, because it wipes out the funds needed to migrate (Bryan et al., 2014; Kleemans, 2023). Our understanding of this relationship has been constrained by the absence of disaggregated or high-frequency data on city growth, necessary to trace out the effects of specific weather events over time at lower spatial scales.[1]

I address these challenges by first assembling data on the annual growth of cities – as measured by city footprint, the horizontal built-up area – for nearly 7,000 cities in 108 low- to middle-income countries, where the effects of droughts are likely to be most salient. I then combine these data with historical weather data to measure the effect of drought exposure on the growth of cities over the course of 23 years.

[1] Disaggregated data is helpful to discern variation within countries. Without it, we cannot draw conclusions about effects at the city level. High-frequency data, i.e. data which are observed more often, allows for the estimation of impacts over multiple years.

Findings

This section presents the estimated impact of local drought exposure on a city's growth rate, in terms of horizontal urban area growth, over multiple years. A detailed description on how I arrive at these estimates is provided in the Methods section below.

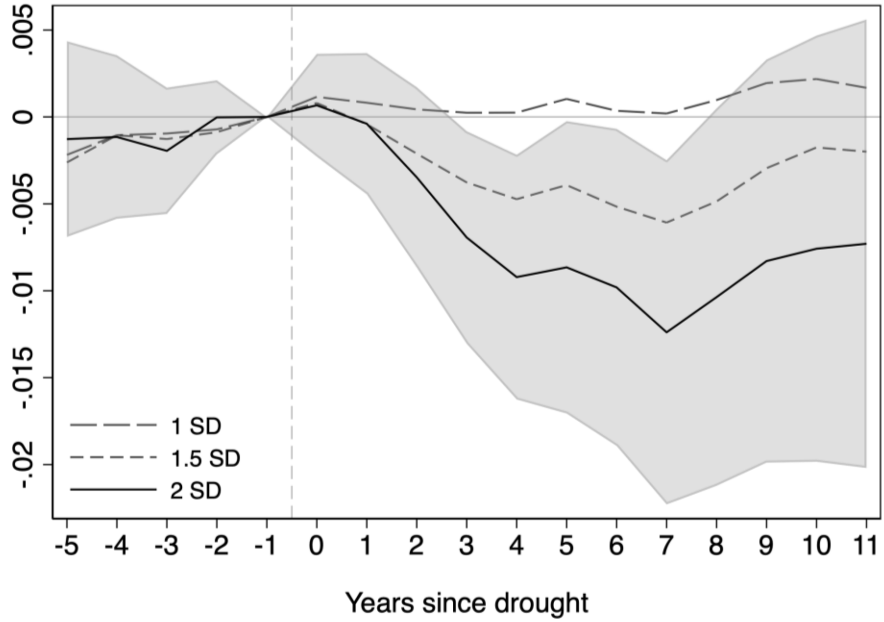
Main results

Following exposure to a drought, cities remain smaller for up to 11 years after exposure, compared to a scenario with no drought exposure, for medium and or high intensity droughts (1.5 or 2 SD). However, the magnitude of the effect varies depending on drought intensity. The estimated effects of exposure to the least intense droughts (1 SD[2]) are not statistically or economically significant over the course of 11 years.

These results can be found in Figure 1 below, which shows the cumulative effects of drought exposure on city growth relative to a drought-free city counterfactual from five years before (labeled year−5) up to 11 years after (year 11) drought exposure. Each line shows the results of using the three different intensities of drought exposure in separate analyses, where 1 SD represents the least intense drought measure, and 2 SD the most intense drought.

[2] I classify drought intensity following the classifications in Wang et al. (2014).

Figure 1: The impact of local droughts on city growth rates



Note: The x-axis indicates the number of years before and after drought exposure. The y-axis is the cumulative impact at a specific year, in percentage points. The lines show the point estimates, and the shaded area around them are 95% confidence intervals. Graph based on data described in Nordfors (2024).

Higher intensity droughts have larger effects on city growth, and the effects are more persistent compared to less intense droughts. While 1.5 SD droughts are estimated to decrease city size by 0.5 percent 7 years after exposure, this effect gradually disappears over time. The pattern is similar for 2 SD droughts. However, the estimated effects are almost twice as large compared to 1.5 SD droughts. After 7 years, the cumulative effect is 1.2 percent. The effect is also more persistent over time. While the estimated effect decreases slightly, it does not vanish, although confidence intervals become wider.

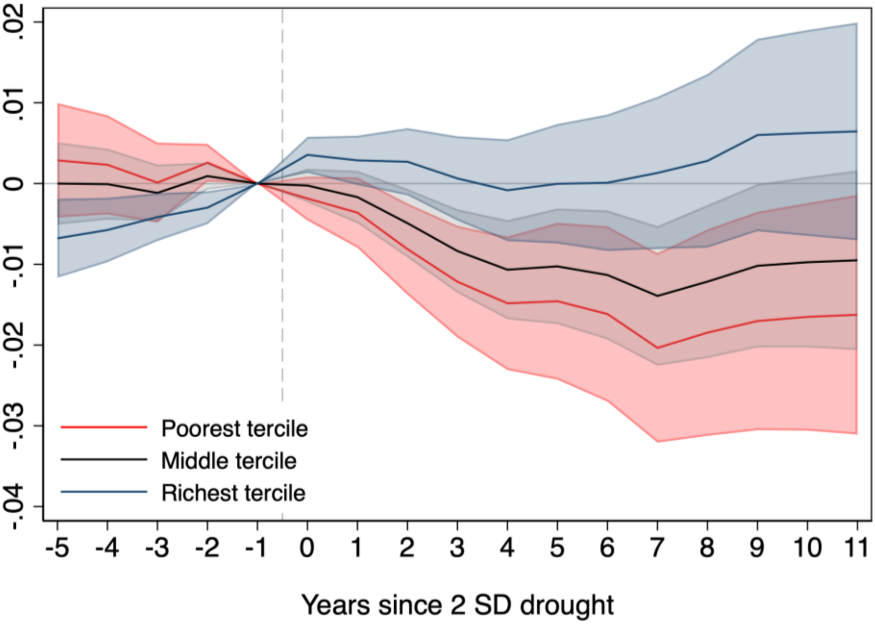
The pattern of the estimated effects across drought intensities also suggests that the effect may be non-linear. The likelihood of a drought happening decreases with intensity – the least intense droughts occur as often as every 5–6 years, while higher intensity droughts happen once every 15–50 years. As such, more intense droughts are both more damaging and more unexpected.

Results by income and agricultural employment

The analysis establishes that the average effect of local droughts on city growth is negative. Macroeconomic models of climate impacts often emphasize the importance of agriculture and income (Dell et al., 2012). This has been corroborated by multiple empirical studies on the relationship between temperature and GDP, for example, Burke et al. (2015), Nath et al. (2023), and Zappalà (2023), whose results show that weather shocks have a larger impact on agricultural GDP and the agricultural sector. I investigate whether dependency on agriculture and income levels could be channels that could explain the differences in the impact between cities in different countries.

The results of estimating the relationship between droughts and city growth while interacting with country level income, as measured by the average GDP between 1992 and 2015, are shown in Figure 1. The largest effects are found for the cities in the poorest tercile, and the effect is similar for the middle tercile. Cities in the relatively richest countries are least affected, with statistically insignificant estimates close to zero. Altogether, these results suggest that the cities which are most impacted by local droughts are cities in relatively low-income countries.

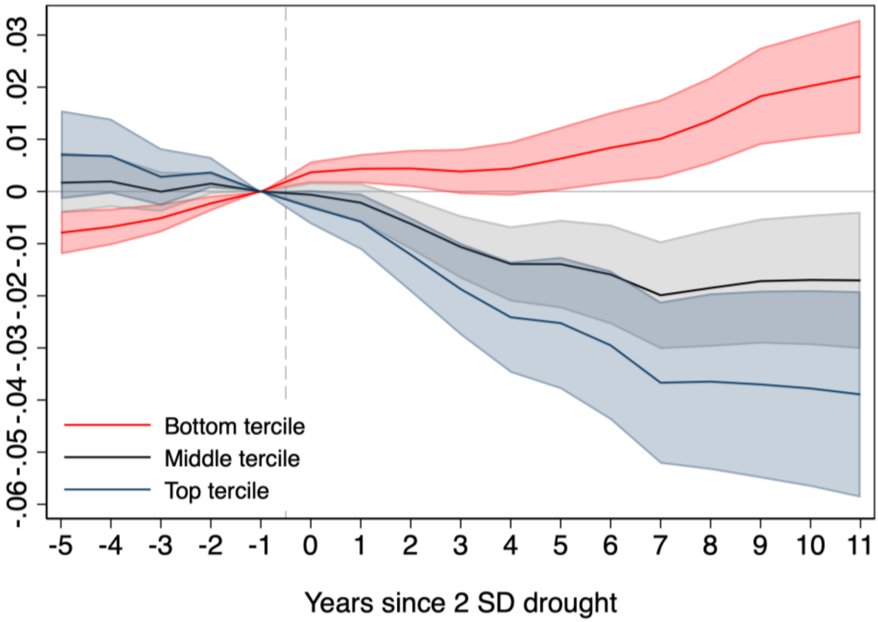
Figure 2: The impact of local droughts on city growth rates by country level GDP, divided by terciles of the GDP distribution. The poorest tercile refers to the countries with the lowest GDP, the richest tercile refers to the countries with the highest GDP.



Note: The x-axis indicates the number of years before and after drought exposure. The y-axis is the cumulative impact at a specific year, in percentage points. The lines show the point estimates, and the shaded area around them are 95% confidence intervals. Graph based on data described in Nordfors (2024).

I also examine whether cities in countries which have a large agricultural sector are more impacted compared to cities in countries with a smaller agricultural sector. An indirect measure of agricultural dependence is used in the form of the agricultural share of employment in 1992; the results are found in Figure 3. The largest effect is seen in cities in countries with the highest share of employment in agriculture (the top, third tercile). There is only a small and statistically insignificant effect in the countries with the relatively low shares of agricultural employment. The results suggest that the agricultural share of the economic sector are important channels in understanding the magnitude of the impact of drought on city growth. This makes sense, as farming is greatly affected by climate change.

Figure 3: The impact of local droughts on city growth rates by country level agricultural employment in 1992, by terciles of the distribution. The bottom tercile refers to the countries with the lowest rate of employment in agriculture, the top tercile refers to the countries with the highest employment.



Note: The x-axis indicates the number of years before and after drought exposure. The y-axis is the cumulative impact at a specific year, in percentage points. The lines show the point estimates, and the shaded area around them are 95% confidence intervals. Graph based on data described in Nordfors (2024).

Data and variables

I create a panel data set tracking city growth and drought exposure over time by combining high resolution data of urban area expansion with drought conditions. An overview of the sample and data used in this chapter is provided in Figure 4. The data measuring urban area expansion are provided by Marconcini et al. (2022) and derived from satellite imagery. It shows whether a pixel consists primarily of urban area in each year between 1985 and 2015.[3] Because data are missing for many cities in the earlier period, I only include data between 1992 and 2015.

Drought conditions are captured using the standardized precipitation-evapotranspiration index (SPEI). SPEI is a drought index based on climatic data. It can be used for determining the onset, duration and magnitude of drought conditions with respect to normal conditions and is available globally. Calculating the SPEI involves a model-based approach where both temperature and precipitation are incorporated. This is a method which has shown high accuracy in comparison with other measures of drought, which often include only precipitation (Vicente-Serrano et al., 2010). The data itself is provided by Vicente-Serrano et al. (2022), in a disaggregated format.

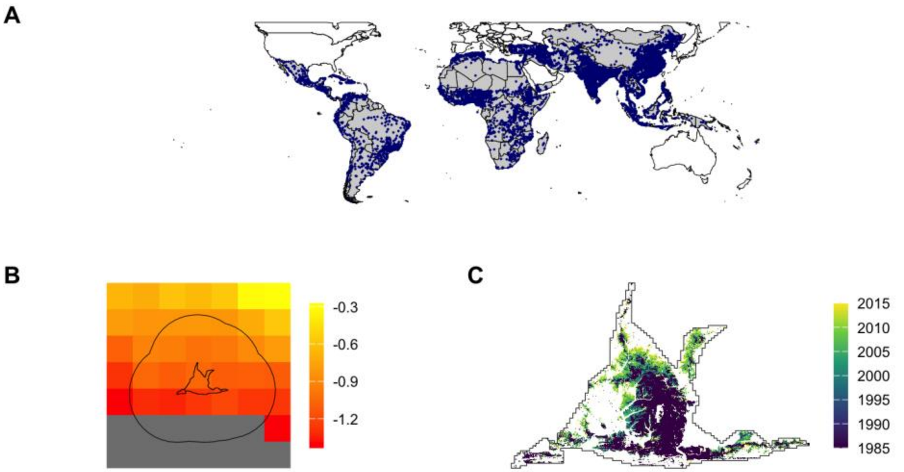
I limit my analysis to cities in the low-to middle-income world, excluding countries in Europe, as well as dependencies of higher-income countries.[4] This yields a total sample of 6,999 cities in 108 countries around the world, representing all continents (except Europe).

[3] The format of the data is analogous to an image, wherein each pixel (or grid cell) in the data set contains a value.

[4] For example, I exclude overseas territories of France, and the United States of America. The definition of low- and middle-income countries is taken from the World Bank. In addition, since drought data for many smaller island nations are missing, they are also effectively excluded from the sample.

Figure 4: An illustration of the panel data set

A: The countries included in the sample. Blue points indicate cities.
B: The extent and 100-kilometer buffer around Lagos, Nigeria. The shaded grid cells are SPEI values.
C: The evolution of the city footprint in Lagos, Nigeria.



Note: Figure based on data described in Nordfors (2024).

Methods

I use the SPEI data (described in the previous section) to define drought exposure in my sample. To estimate the causal effects of local droughts on city growth, I use an event-study regression model framework. Using this model, I estimate the cumulative effects of drought exposure across 11 years. The regression model accounts for multiple factors, including time-invariant city characteristics and time trends, such as common economic shocks. The methodology is described in detail in Nordfors (2024).

Conclusions and policy implications

In this study, I find that droughts have a negative impact on city growth. The effect is most pronounced for the most severe droughts, for which the effect is large and persistent over time. The impact of the medium-severe droughts is roughly half of the most severe droughts, and estimates suggest that these effects are more transitory, suggesting that city growth recovers after sufficient time has passed (around ten years). These effects cannot be easily categorized as positive or negative. While city growth is connected to both income growth and structural transformation, this is not always the case, particularly in lower-income settings (Jedwab and Vollrath, 2015). Hence, we cannot with confidence draw the conclusion that slower city growth also implies slower economic growth. What may be problematic is if structural transformation is hindered while agricultural productivity decreases. I cannot answer this directly, but other research suggests this may be the case (Nath, 2024). This would by extension suggest that people may become trapped in low-productivity agriculture, and consequently, poverty.

Droughts primarily affect the largely agricultural hinterland of cities, and I suggest that the effects may be the result of decreasing rural-to-urban migration. However, there are other potential explanations that I cannot directly rule out in this study. These could include a direct economic effect on cities themselves (rather than an impact on hinterlands), which could lead to less construction of new urban areas and as a consequence, lower city growth.

In the broader discussion of the effects of climate change, a prominent view argues that climate change will lead to inevitable urbanization, putting pressure on already constrained cities. My results suggest that this is less of a concern for a large share of cities, which are hindered rather than induced to grow because of adverse climate shocks. However, I emphasize that these results do not speak directly to other climate hazards that many people in developing countries face, for example, cyclones and floods. These events could have a different effect compared to that of droughts.

My findings have some policy implications. As climate change is expected to increase the number and intensity of droughts, efforts to aid the rural and agricultural sector to cope with droughts could increase. This might include introducing or subsidizing technologies such as irrigation. However, such technologies may also contribute to an increased demand and ultimately depletion of groundwater (Carleton et al., 2024; Taylor, 2024). Another potentially important adaptation measure could be a shift to crop types which are more drought resistant.

Population growth and city shape

The world is urbanizing rapidly, with more people than ever before living in towns and cities. Urban infrastructure and services, which are already limited in many African cities, may suffer additional pressure as a result of surging populations (Brueckner and Lall, 2015). Importantly, when populations increase at a pace where local governments struggle to keep up, urban planning risks being neglected, especially in countries with weak institutions. This could result in the growth of informal settlements (Hammam, 2014), fragmented city forms (Lall et al., 2021), and increased exposure to environmental risk (Winsemius et al., 2018).

I examine the relationship between city population growth and how cities grow using new high-resolution data, primarily derived from satellite imagery, that map features of the urban environment with unprecedented levels of detail and precision. The spatially refined data enables analyses down to the neighborhood or pixel level within cities, which has previously been impossible in developing countries.

I use these data to evaluate whether, for example, building height and flood exposure, is linked to rapid population growth in Sub-Saharan Africa. I do so by comparing areas within cities, that were built up during periods of rapid population growth to those that were built up during periods of slower population growth.[5]

Results

My findings show that when cities experience periods of higher population growth, they grow differently compared to periods with lower population growth. Specifically, cities expand more in areas exposed to flood risk, tend to be lower built and are more informal.

The results from estimating the association between population growth and multiple characteristics of the built environment in cities are presented in Table 1. I also investigate the association between population growth and five other aspects of city form. As Table 1 shows, the estimates suggest that in areas built during periods of higher population growth, buildings are on average lower, smaller, more informal and less intensely built-up (columns 2, 4–6). There is no statistically significant estimate for building density (column 3).

In Table 1, the number of observations is the number of pixels in the data. The data are primarily derived from satellite images and provided in a raster format.[6] Each column states the estimated coefficient of pixel level weighted population growth on the outcome variables, weighted by the built-up area in 2020 in a

[5] My empirical approach accounts for time-invariant differences across cities, and differences between areas that were built up at different time periods.

[6] Analogous to images, this means that each pixel in the raster data contains a value.

pixel. The outcomes have all been estimated using log values, which gives the effect in percentages.[7]

The estimated coefficients in Table 1 show the effect in percent (except flood risk) of a 1 percentage point population growth. I scale these effects since population growth rates are calculated over 10-year intervals.[8]

Table 1: The effect of population growth on city form outcomes at the pixel level

	Flood exposure	**Building height**	**Building density**	**Avg. building size**	**In-formality**	**Built up area**
Pop. change	0.02	-0.05	0.03	-0.08	0.03	-0.22
	(0.01)	(0.03)	(0.03)	(0.04)	(0.01)	(0.05)
N (obs.)	10,729,488	10,729,488	10,278,233	10,278,233	10,692,371	10,729,488
N (cities)	1,339	1,339	1,310	1,310	1,336	1,339

Note: Standard errors (in parentheses) are clustered at the city level. City fixed effects are included in all regressions. All estimates are weighted using the share built-up area within a pixel in 2020. All outcomes are in log values, except flood risk (which is a binary variable). The mean is the log value mean, except for flood risk. Number of observations is the number of pixels.
Table based on data described in Nordfors (2024).

The scaled effect, using the interquartile range (i.e. the difference between the 75th and 25th percentiles) of population growth estimates, of flood risk is 0.7 percentage points (95% CI: 0.10, 1.29). The effect can be interpreted as follows. The pixels that were built up during periods where the population growth increased from the 25th to the 75th percentile were more likely to be

[7] The one exception is the variable measuring flood risk, which is a binary variable. Each pixel is defined as either being exposed to medium- to high risk of flooding or not. Hence, the estimated coefficient can be interpreted as the likelihood of a pixel being located in areas exposed to flood risk after becoming built up following periods of population growth.
[8] The estimates are scaled using the interquartile range of population growth, using the pooled changes between 1980 and 1990, 1990 and 2000, and 2000 and 2010. The interquartile range of population growth is 32 percent.

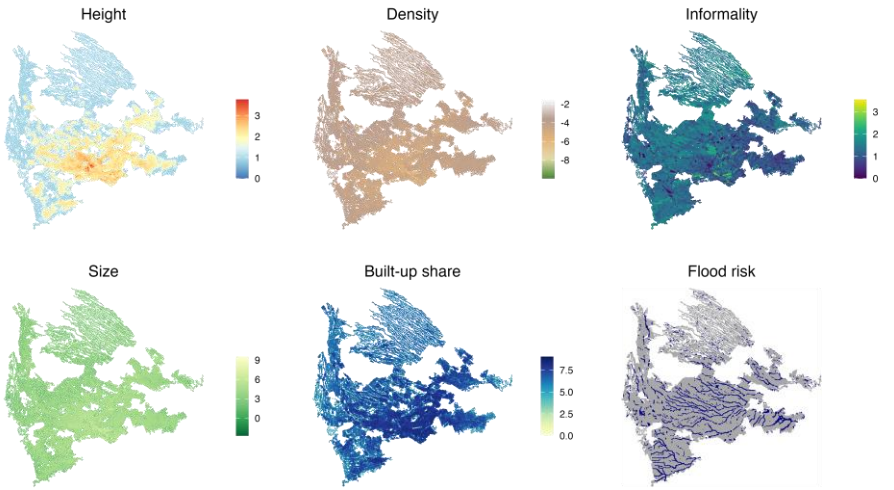
located in areas within cities where the risk of flood exposure is elevated. This risk is around 0.7 percentage points higher. The baseline ”probability” of a pixel being exposed to flood risk is 15 percent, which implies that the probability increases by around 4.7 percent. Hence, areas in cities that were built up during rapid population growth are also more likely to be exposed to floods.

Data and variables

I combine multiple sources of data measuring city form with data on population growth between 1980 and 2010 from Africapolis (OECD and SWC, 2020) and construct a data set covering up to 1,339 cities, where I measure outcomes at a resolution of 100-meter pixels.

Built up area data, which measures the share of a pixel which has been classified as containing man-made structures, are from the Global Human Settlements (GHS) (Pesaresi and Politis, 2022). Data on building heights are provided by Pesaresi and Politis (2023), which is available at a global scale for the year 2018. I utilize flood risk data from Rentschler et al. (2022) to construct a binary measure of flood risk at the pixel level. The variables measuring average building size and building density are constructed using building footprints data (Sirko et al., 2021). I use data from the Million Neighborhoods research project, which provide block level estimates of informality across Sub-Saharan Africa (Brelsford et al., 2019; Brelsford et al., 2018; Soman et al., 2020). All data is either provided at an approximately 100-meter grid cell resolution. If they are not, I resample them to match the other data. An example of the data for the city of Nairobi, Kenya, is shown in Figure 5 below.

Figure 5. The spatial distribution of the variables measuring city shape, in log-values, for Nairobi, Kenya



Note: Figure based on data described in Nordfors (2024).

Method

To document the link between population growth and city form, I use data on city form outcomes at the pixel level. This allows me to compare areas within cities, rather than relying on making comparisons between different cities. I compare the parts of cities that were built up during periods of higher population growth with the parts that were built up during periods of less population growth. My analysis accounts for cross-sectional differences across cities, and differences between cities built up at different points in time. The methodology is described in detail in Nordfors (2024).

Conclusions and policy implications

I revisit the hypothesis that population growth may shape city growth in undesirable ways using new fine-scaled data at the pixel level. My findings are consistent with there being a relationship between population growth and *how* cities in Sub-Saharan Africa have grown. I find that areas built up during periods of higher population growth are more informal, have lower building heights, have smaller average buildings, are more likely to be exposed to flood risk, and are less intensively built up. An important caveat to these results is that they are correlations, and I cannot fully account for other possible explanations, for example, reverse causality.

As climate change may lead to an increase in extreme precipitation (while average precipitation decreases), floods may also increase. Floods are arguably the most damaging and common environmental hazard facing cities and their residents. Floods cause adverse health outcomes (Rosales-Rueda, 2018), and substantial economic damage (Willner et al., 2018), even when flood events are relatively minor (Patel, 2024).

My findings suggest that cities built up during periods of high population growth tend to grow in more marginal areas, such as flood-exposed areas. Adapting and mitigating flood risk individually may be difficult, if not impossible, for many urban residents. Hence, there may be scope for improvements in dealing with increasing urban populations and their exposure to environmental risk, for example through increased investment in preventative urban planning to manage risk. How optimal urban policy should be designed, and whether it could vary across contexts or even individual cities, is still an open question. To slow down urban expansion in areas exposed to environmental hazards, an unintrusive policy could be to provide detailed hazard exposure maps at the neighborhood level. In addition, recent research has highlighted that the shape of a city may impact economic growth. Compact city shapes (e.g. less sprawl, and higher population densities) are conducive to economic growth through agglomeration benefits and reduced costs of transportation infrastructure (Lall et al., 2021).

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While urbanization has plateaued in many higher-income countries, cities in lower-income countries are on track to keep growing substantially in the coming decades. This study shows that when cities grow, they expand more in more informal areas exposed to flood risk. The study also shows that local droughts lead to slower city growth.

Samtidigt som urbaniseringen planat ut i många höginkomstländer väntas städer i låginkomstländer fortsätta växa kraftigt de kommande decennierna. Denna studie visar att när städer växer, sker det i större utsträckning i mer informella områden med större risk för översvämning. Studien visar också att torka leder till en långsammare urban tillväxttakt.

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