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World's human migration patterns in 2000–2019 unveiled by high-resolution data

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Despite being a topical issue in public debate and on the political agenda for many countries, a global-scale, high-resolution quantification of migration and its major drivers for the recent decades remained missing. We created a global dataset of annual net migration between 2000 and 2019 (~10 km grid, covering the areas of 216 countries or sovereign states), based on reported and downscaled subnational birth (2,555 administrative units) and death (2,067 administrative units) rates. We show that, globally, around 50% of the world's urban population lived in areas where migration accelerated urban population growth, while a third of the global population lived in provinces where rural areas experienced positive net migration. Finally, we show that, globally, socioeconomic factors are more strongly associated with migration patterns than climatic factors. While our method is dependent on census data, incurring notable uncertainties in regions where census data coverage or quality is low, we were able to capture migration patterns not only between but also within countries, as well as by socioeconomic and geophysical zonings. Our results highlight the importance of subnational analysis of migration—a necessity for policy design, international cooperation and shared responsibility for managing internal and international migration.

Since the 1990s, human migration has been one of the top public concerns and political agenda items in Europe and North America[1]. Millions of people have been forced to flee due to conflicts while also millions have voluntarily moved to urban areas seeking better economic prospects. Around the world, diverse environmental factors, such as droughts, floods and other natural hazards also push people to move. Most of this mobility takes place within a short distance, making internal migration the most prevalent form of migration across the globe[2]. Indeed, climate-induced migration is shown to be more common within national borders[3]. Yet, public attention tends to focus on international migration including both voluntary and forced migration. Subnational information about the estimates of the number of migrants (and immobile persons), their origin and destination and the conditions of migration are much needed for planning of urban services and infrastructure as well as rural development[4]. Understanding migration patterns across spatial scales—including its conditions, magnitude and impact—is thus fundamental for policy design.

Whilst subnational (5 arcmin, ~10 km resolution) decadal estimates of net migration for three decades between 1970 and 2000 are available[5], global-scale data on subnational migration for more recent years are sparse. One study[6] provides a more recent estimate of migration at grid cell level for 1975–2015 (5 year interval) but the baseline data

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are derived from national-level birth and death data. Other estimates describe global international migration by using national-level data[7,8] or internal migration at the national level, based on national census data. These studies suffer from a long time interval between census years (typically 10 years)[9]. The coarse spatial and temporal resolutions of these data hinder the ability to conduct gridded migration trend analyses over time.

Our study aims to address these research gaps by developing a detailed annual net migration dataset, by collecting, gap-filling and harmonizing (1) comprehensive national-level birth and death rate datasets for 216 countries or sovereign states; and (2) subnational data for births (covering 163 countries, divided into 2,555 administrative units) and deaths (123 countries, 2,067 administrative units) (Extended Data Fig. 1; Methods). In doing so, we provide a detailed analysis of the spatiotemporal development of (1) the magnitude of net migration and (2) its impact on population growth over the past two decades. Firstly, for magnitude, we collected reported data from various sources to create an annual net migration dataset for 2000–2019, using national and subnational birth and death data, downscaled to 5 arcmin resolution (~10 km at the equator) with selected socioeconomic variables (Fig. 1; Methods). These data enable us to perform analyses on net migration trends and patterns from local to global scales. Our gridded net migration data allow, for instance, comparing the intensity of net migration and its trends at several administrative scales. It is also possible to analyse the types of sending and receiving areas (rural or urban) at multiple scales (regional, national (administrative 0), provincial (administrative 1) and communal (administrative 2)) over the past two decades. Indeed, there is no such systematic global-scale classification on, for instance, which urban areas are net senders and which rural areas are net receivers. Here, we present rigorous analyses of the distribution of the types of origin and destination areas.

Our paper also contributes to analysing the impact of human migration on population change. Using our annual gridded dataset to map migration in parallel with demographic and geophysical data (Extended Data Figs. 2 and 3), we were able to assess the impact of net migration on rural and urban population change at national, subnational and communal levels and across different societal and climatic conditions. Understanding the contribution of migration to population change is crucial because migration affects sending and receiving societies in various ways. In terms of economic consequences, migration influences socioeconomic development of both sending and receiving areas—for example, by increasing productivity in receiving areas and reducing income inequalities across countries through remittances[10,11]. Nevertheless, migration can also cause considerable pressure on the infrastructure and services of the receiving areas[4] and consequently exacerbate the vulnerability of migrants[12,13]. However, few empirical studies have analysed the impact of migration on population change at the global scale over the past decades. Our analysis thus provides a solid quantitative foundation towards understanding the extended societal impacts caused by migration.

Results

We first developed a gridded global net migration dataset at annual timesteps for 2000–2019 (Fig. 1). This here-developed dataset (openly available at https://doi.org/10.5281/zenodo.7997134) was constructed from subnational (administrative 1) birth and death rate data collected across 2,555 and 2,067 administrative units, respectively (Fig. 1a–b; Methods), downscaled to 5 arcmin resolution with rasterized socioeconomic data developed in this study and finally adjusted to match the subnational data collected (Fig. 1c–f; Methods).

Our birth and death rate data revealed considerable intranational heterogeneities, particularly in large countries, such as Russia, the United States, China, Brazil and India (Fig. 1g–h). This highlights the importance of using subnational (particularly downscaled) data instead of national data (as used in ref. 6) for understanding global population dynamics. These downscaled birth and death data then allowed us to estimate natural change in population (deaths subtracted from births) for each year and grid cell (Fig. 1i). When combined with reported annual population change over the same time period (Fig. 1j), we were able to estimate annual net migration in each grid cell (Fig. 1k) using a similar method to that of ref. 5 (Methods). Here, net migration can be either negative (more people out-migrating than in-migrating) or positive (more people in-migrating than out-migrating).

It should be noted that our data are prone to uncertainties that originate from collected subnational data but propagate to all derived data products—including birth and death rates, natural change in population, as well as net migration estimates. Subject to data availability, we performed a partial validation for our data products by comparing gridded data with subnational (mostly administrative 2 level) data (Methods; Supplementary Table 2 and Supplementary Figs. 1–6). However, this validation cannot capture areas where uncertainties may be the highest—that is, areas in which the collected census data are not available or of poor quality, for example, those suffering from sporadic census years or changing subnational administrative units. To ensure global spatial and temporal coverage, we applied a series of adjustments and corrections to the data (Methods). Nevertheless, higher uncertainties remain in some countries (such as those in Africa, the Middle East and parts of Asia) than in others (such as those in Europe and much the Americas). As proxies of original data quality, we provide the description, resolution, timespan and sources of each collected dataset in the Supplementary Data.

Magnitude of global net migration

Temporal dynamics of net migration depend on scale. To assess global migration dynamics, we aggregated net migration at three spatial levels: communal (administrative level 2), provincial (administrative level 1) and national (administrative level 0) (Fig. 2). This approach allowed us to compare the magnitude of migration that occurs at different spatial levels. Our results show that migration patterns vary remarkably across nations. On a national scale over the entire 20 year study period, net migration was positive (that is, in-migration was greater than out-migration) in Australia, North America, as well as parts of Europe and the Middle East—all being areas that have attracted either asylum or job seekers or both (Fig. 2 and Extended Data Fig. 4). Net migration was negative in countries like Syria, Lithuania, Zimbabwe, Venezuela and Guyana (Fig. 2e)—in line with previous assessments from Venezuela and Syria, where millions of people have fled a humanitarian crisis and conflict[14–16] and also from Lithuania and Zimbabwe where numerous people have out-migrated in search of better economic prospects[17,18].

At a provincial level, the migration patterns reflect the prevalence of internal migration in many countries, as can be observed from both net-positive and net-negative provinces. For example, in China, the coastal areas show positive net migration while negative net migration (out-migration is greater than in-migration) was observed in many inland provinces (Fig. 2c). This is consistent with the well-founded internal migration patterns in China where labour migration is concentrated towards urban, coastal areas[19]. The same applies to many other countries, such as the United States, where urban centres are attracting people from other states and abroad[20,21]. When assessing net migration at even finer spatial detail (communal level), interesting patterns start to arise. For example, in the United States, many states with positive net migration (Fig. 2c) are characterized by mainly negative county-level net migration (Fig. 2a). See our online net migration explorer tool for more detail: https://wdrg.aalto.fi/global-net-migration-explorer/

Our dataset also allowed us to explore the temporal dynamics of net migration over the study period (2000–2019) across three administrative levels. We assessed the trend of net migration at each level over the study period (2000–2019) by using linear regression. The results follow a similar pattern as cumulative net migration where

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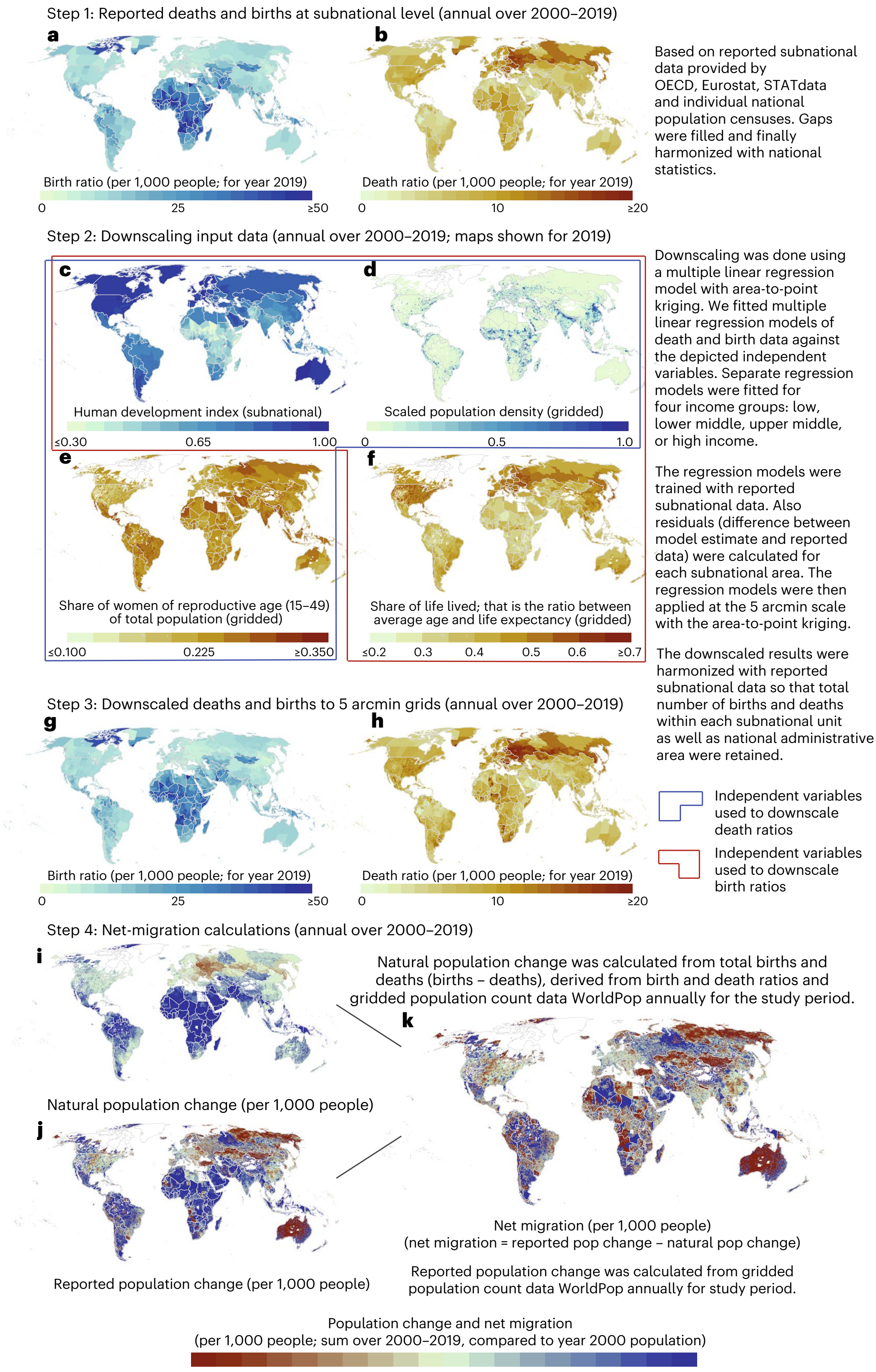

Fig. 1 | Schematic outline of our study. a,**b**, Reported annual subnational birth (**a**) and death rates (**b**) for 2000–2019 are based on various global and national datasets with some of the intermediate results (Methods). **c**–**f**, For downscaling to 5 arcmin grid level, we used four annual gridded or subnational datasets of (**c**) human development index, (**d**) scaled population density, (**e**) share of reproductive women and (**f**) share of life lived in each grid cell, as detailed in the panels. **g**–**i**, The annual downscaled birth (**g**) and death (**h**) rates allowed us to estimate the natural population change for each year (**i**). **j**,**k**, When combining this with reported population change based on WorldPop[55] (**j**), we were able to calculate annual net migration for 2000–2019 (**k**). See Methods for more details.

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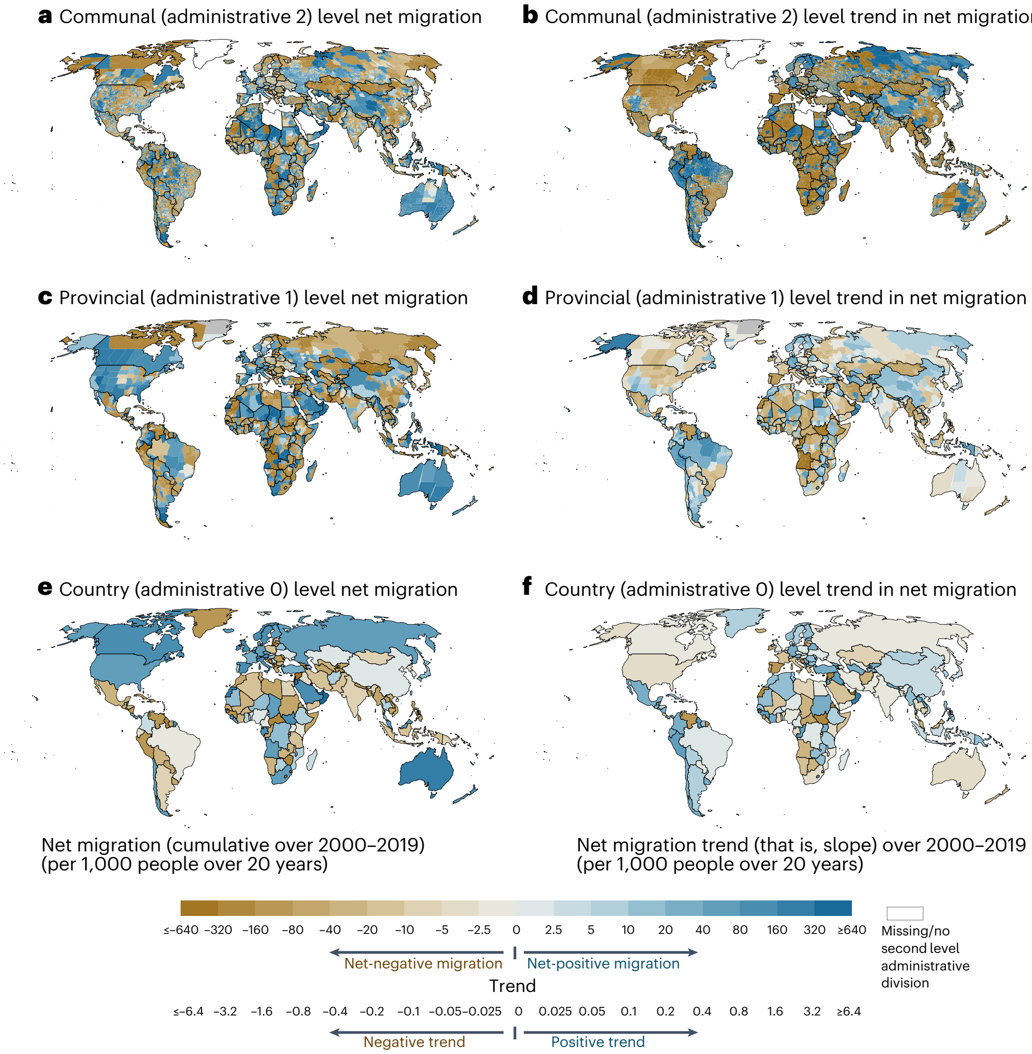

Fig. 2 | Net migration for three administrative levels and cumulative net migration trends within communal, provincial and national administrative areas. a,**c**,**e**, Sum of annual net migration over 2000–2019 is shown for communal (administrative 2) (**a**), provincial (administrative 1) (**c**) and national (administrative 0) (**e**) levels. **b**,**d**,**f**, Net migration trend (slope) over 2000–2019 is shown for communes (**b**), provinces (**d**) and countries (**f**). The trend was determined by calculating the slope of linear regression line. Negative net migration refers to a situation in which more people out-migrate than in-migrate and positive net migration refers to a situation in which more people in-migrate than out-migrate. With our online net migration explorer tool, it is possible to explore these patterns for each year and subnational unit: https://wdrg.aalto.fi/global-net-migration-explorer/.

the trend changes according to the administrative level. Further, the results show interesting patterns of where net migration has a negative trend and where it has a positive trend over the past two decades. In North America, for instance, net migration shows a declining trend in almost all regions, excluding small pockets in the southwest (Fig. 2b,d). The same applies to South America, especially Brazil and Chile, where net migration has been on a growing trend in the northern parts of these countries, while in the south the trend has been declining; and Australia, where the trend of net migration has been positive in the middle parts, while being negative in the coastal regions of the continent (Fig. 2b,d).

Rural and urban migration show high global variation. We further assessed the development of net migration by studying how net migration differs in rural and urban areas (Extended Data Fig. 5). Urban areas often receive migrants from rural areas— the so-called 'urban pull–rural push' situation[22]. We assessed if this holds true across 12 world regions (Extended Data Fig. 4) and for each country at three administrative levels by using the GADM delineation (national, administrative level 0; provincial, administrative level 1; and communal, administrative level 2). Here, we combined our net migration dataset with an urban extent dataset for 2000–2019 that was created for this study. The urban extent dataset maps urban areas on the basis of scaled population density and share of urban population at national level, annually for 2000–2019 (Methods; Extended Data Fig. 3).

Our data show that when aggregated globally, urban net migration was positive (more in-migrants than out-migrants) throughout the study period (2000–2019), while rural net migration remained negative (except for years 2010 and 2012) (Fig. 3m). The magnitude of global net migration ranged annually from near-zero to around three net migrants per 1,000 people (Fig. 3m). Notable spatiotemporal variation between rural and urban net migration was evident at the regional level (Fig. 3a–l) as well as at national, provincial and communal levels (Extended Data Fig. 6). However, no considerable change in net migration rates towards urban or rural areas was observed in any region between 2000 and 2019. Both rural and urban net migration were negative (down to approximately −10 net migrants per 1,000 people) nearly throughout the study period in Central America (Fig. 3a), whereas in North America (Fig. 3g) and Oceania (Fig. 3h), total net migration was steadily positive (with a constant magnitude of at least +5 net

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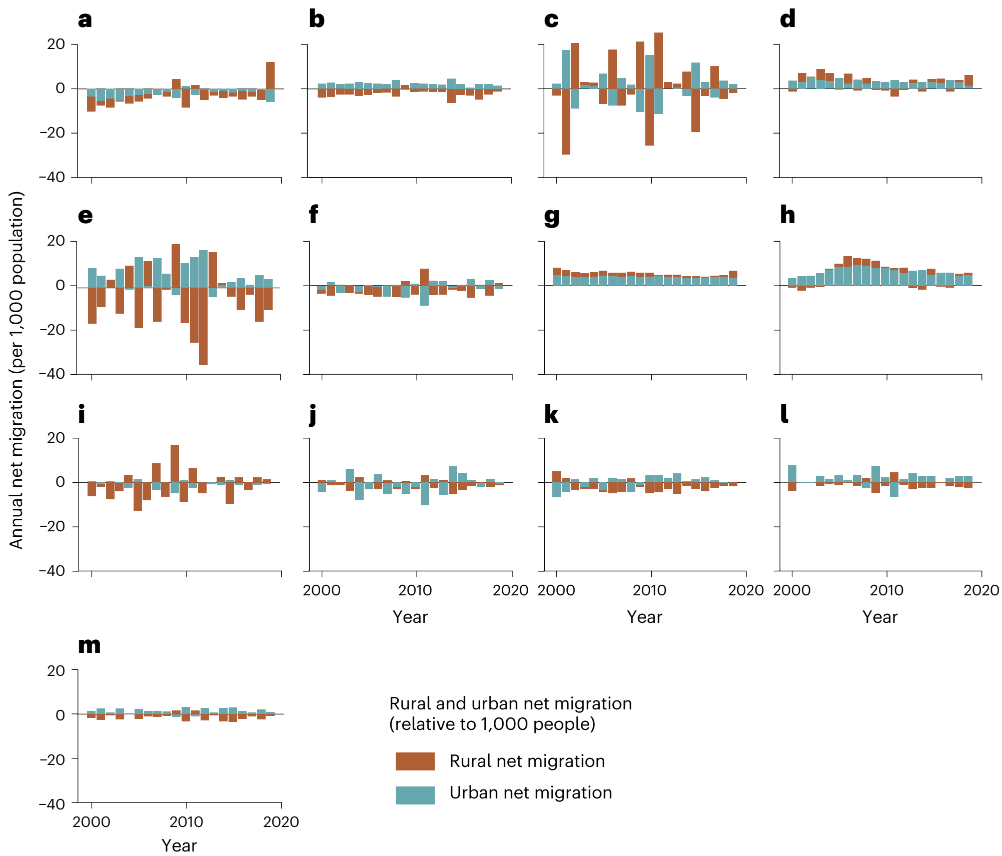

Fig. 3 | Annual rural and urban net migration aggregated over geographical regions. a–m, The regional sums for each year (Central America (**a**), East Asia (**b**), Eastern Europe (**c**), Europe (**d**), Middle East (**e**), North Africa (**f**), North America (**g**), Oceania (**h**), South American (**i**), South Asia (**j**), Southeast Asia (**k**) and Sub-Saharan Africa (**l**)) and the annual global sum (**m**) of urban and rural net migration. Urban and rural net migration are reported per 1,000 urban or rural inhabitants in each region. The regional division follows the UN country grouping (Extended Data Fig. 4). See gridded net migration in rural and urban areas in Extended Data Fig. 5.

migrants per 1,000 people). In East Asia (Fig. 3b), net migration was negative in rural areas and positive in urban areas (with magnitudes <5 net migrants per 1,000 people) while in other regions, the pattern was more complex (Fig. 3).

In Eastern Europe and the Middle East, rural and urban net migration rates fluctuated annually, especially during the years preceding the Arab Spring, followed by massive rural out-migration and urban in-migration between 2011 and 2013—with magnitudes up to almost +40 net migrants per 1,000 people and down to −20 net migrants per 1,000 people (Fig. 3e). Out-migration from Syria was among the largest in the world between 2010 and 2015, during when more than 2 million people left to neighbouring countries Turkey and Lebanon[2,14,23]. This explains a sharp influx of migrants to rural and urban areas in Eastern Europe group that includes Turkey (Fig. 3c). Although our results align with previous estimates of migration in the Middle East, these regions are prone to high uncertainties in the data.

Net-receiving provinces contain a third of global population. When focusing on national and subnational scales, the global urban pull–rural push pattern (Fig. 3m) becomes patchier (Fig. 4). At the national scale, 36% of global population (in 2019) lived in countries where this pattern was evident. These countries include the Nordics and several countries in Africa, Southeast and East Asia (Fig. 4c). However, at the subnational scale, many more people lived in provinces and communes which were either net receivers or net senders, as presented by negative or positive net migration in both urban and rural areas. Such provinces were located in the United States, Canada and Australia, while Russia, the northeast of the United States, Mexico and the Balkans, for example, accommodated multiple net-sending provinces (Fig. 4b).

A situation where urban net migration was negative and rural net migration positive (rural pull–urban push) was observed in few locations, such as certain provinces of Indonesia, Congo, Venezuela and Pakistan (Fig. 4b), covering in total 22% of the world's population. Notably, 37% of the global population lived in the urban and rural areas of net-receiving communes. Extensive rural in-migration is probably explained by interprovincial and intercommunal migration between rural areas and immigration from other countries. Studies show that a trend of rural–urban migration is shifting towards more complex mobility patterns, of which rural–rural mobility is one of the most prevalent types of internal migration. Especially in Sub-Saharan Africa, people tend to move between rural areas as seasonal circular migration and for economic diversification, given better access to land or job prospects than in cities[24,25]. In Europe, a similar pattern appears in rural areas attracting workers in the agricultural sector within the same country or from abroad[26]. Large urban agglomerates may also push people to move to rural areas in search of more affordable housing (counter-urbanization; see ref. 27 for counter-urbanization in Australia and ref. 28 for the United States). It should be noted that the results are strongly influenced by the delineation of urban areas (Methods).

Impact of migration on population change

Migration often accelerates urban population growth. Net migration taking place in densely populated areas can be relatively large compared to natural population change (Figs. 1i,k and 2a). In such

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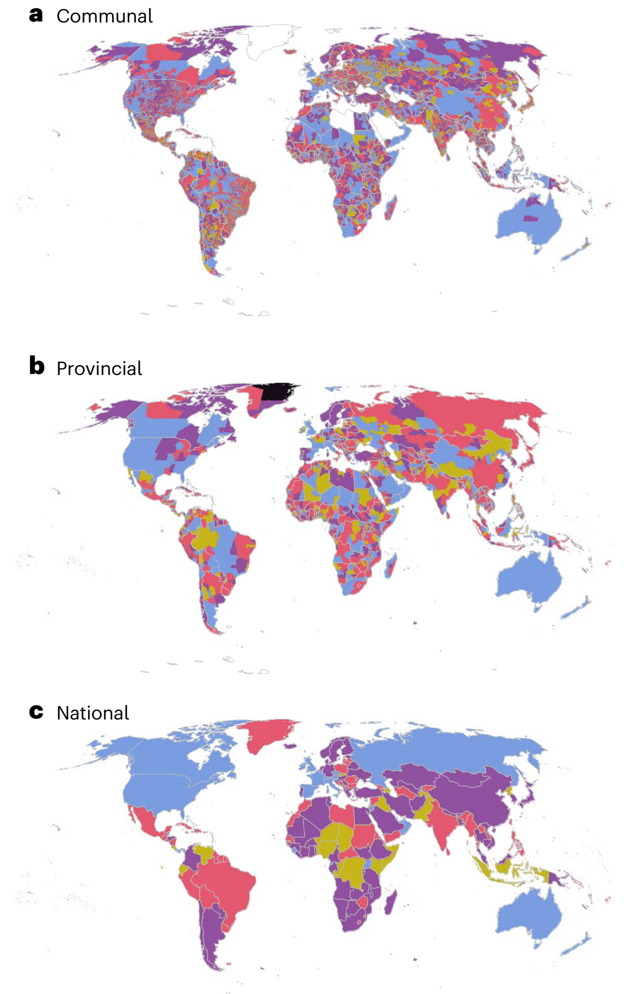

Division of net migration between urban and rural areas	Urban	Rural		Share of population in 2019 (%) living in each category: Communal	Provincial	National
(blue)	+	+	'net receivers'	37	29	17
(red)	−	−	'net senders'	31	35	30
(yellow)	−	+	'rural pull–urban push'	19	22	17
(purple)	+	−	'urban pull–rural push'	13	14	36
(black)	Zero migration			0	0	0
(white)	No data					

+ Net-positive migration − Net-negative migration

Fig. 4 | Division of net migration between urban and rural areas. a–c, The communal (**a**), provincial (**b**) and national (**c**) levels. Each administrative unit was categorized into one of the four classes on the basis of the 'direction' of migration in rural and urban areas. For example, if net migration in an administrative unit was positive in both urban and rural areas, then that unit would be categorized as a net receiver, whereas a unit in which urban net migration was positive and rural net migration negative would be categorized as urban pull–rural push. The share of population living in each category was calculated for each administrative level. For instance, 36% of global population lived in communes where both urban and rural net migration were positive (net-receiving communes). See net migration in rural and urban areas by different administrative levels in Extended Data Fig. 6.

cases, large-scale migration can strain natural and human resources, as well as infrastructure, which are insufficient to serve a steep surge in population, particularly in urban areas[4,29]. On the other hand, migration can potentially help ageing societies like those in Europe to maintain their work force[30,31]. To empirically examine the role of migration in population change globally, we compared natural population change (deaths subtracted from births) with reported population change in rural and urban areas at the three administrative levels.

We found that about half of the global urban population lived in areas that were affected by positive net migration in a way that positive net migration added to a naturally growing urban population. Notably, in some urban areas—especially in the Nordics, Germany, Austria and Spain—positive net migration even shifted a naturally decreasing population towards growth (Fig. 5c,e). In very few countries, positive net migration slowed down natural decline in urban population but this affected urban areas accounting only for ~1% of global urban population. About 39–44% of the urban population lived in areas affected by negative net migration that slowed down urban population growth (Fig. 5). There were fewer cases (0–6% of urban population) where naturally growing urban population declined due to intensive out-migration. Such areas could be detected mainly at communal level in countries such as France, Italy, the United States and India.

Negative net migration impacted rural areas more often than urban areas: 10% of global rural population lived in communes where out-migration turned rural population growth to a total population decline (Fig. 5b). Approximately half of the global rural population lived in countries where rural population growth was slowed down by negative net migration, whereas one-fifth of rural population lived in countries where negative net migration accelerated the prevailing decline in population (Fig. 5f). Yet, positive net migration propelled rural population growth in multiple provinces and communes accounting for around a third of global rural population. In Russian provinces and communes bordering Kazakhstan, for instance, in-migration of skilled workers from Kazakhstan potentially explains the accelerated rural population growth or slowed rural population decline[32].

Human development is associated with migration more than aridity. Global migration is known to be driven by both socioeconomic and environmental factors[3,13]. Here, we analyse how total, urban and rural net migration co-occur with different socioclimatic conditions, dividing the globe into 100 socioclimatic bins (Extended Data Fig. 7) on the basis of the level of aridity, human development (measured by human development index (HDI); Extended Data Fig. 8) and population. Each bin accommodates ~1% of the global population (Methods).

Our results show that, over the past 20 years, high net migration often co-occurs with high HDI and high aridity, which is evident especially in urban areas (Fig. 6a). For instance, urban areas in the Arabian Peninsula, arid parts of North America, Australia, Argentina and the Mediterranean region had high (mostly above +60 net migrants per 1,000 people over the study period) positive net migration rates (Fig. 6a). High positive net-migration rates in many Middle Eastern countries, such as Qatar, Oman and Saudi Arabia (Fig. 2e), are explained by large labour migration particularly from Asian and African countries[33]. On the other hand, in Australia and North America, the 'preference of low-density living'[34] can explain positive net migration in rural areas. Notably, high HDI is common for these regions whereas the range of aridity is wider.

In terms of negative net migration, global out-migration hotspots (areas with substantial negative net migration) are located in socioclimatic conditions with middle-level aridity and human development. This was especially the case in rural areas (Fig. 6c). High negative net migration rates could be observed in regions like Central America, northeastern Brazil, Central Africa and Southeast Asia (mostly below −60 net migrants per 1,000 people over the study period). This aligns with recent studies showing that most migration is originating from areas where people have sufficient capacity to move and use migration as a form of adaptation to unfavourable environmental conditions[3].

Positive net migration often co-occurs with high HDI. When comparing natural population growth with net migration across different socioclimatic conditions, we found that the contribution of migration

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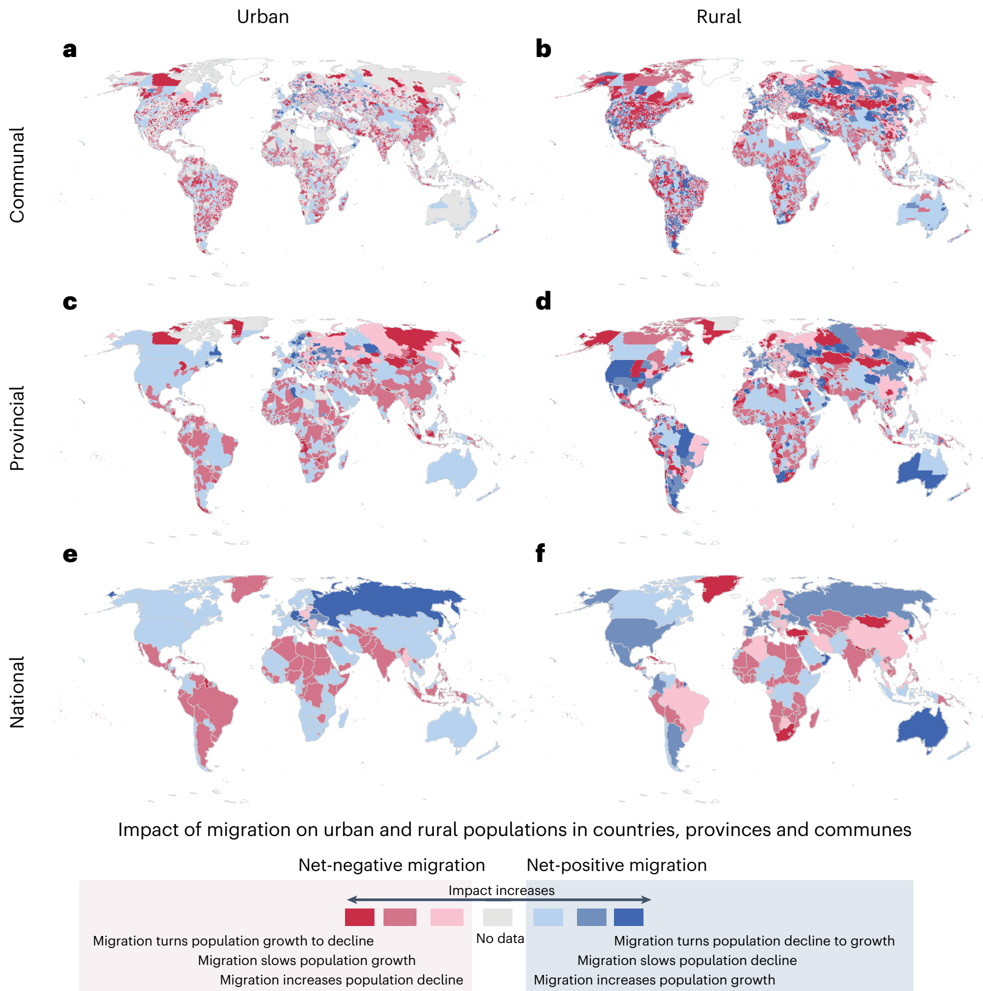

Share of urban and rural population (in 2019) living in each category (%)

Urban							
Communal	6	40	3	0	48	1	3
Provincial	2	44	2	0	48	1	2
National	0	39	1	0	54	1	5
Rural							
Communal	10	33	13	0	31	9	5
Provincial	6	35	15	0	28	12	4
National	3	48	22	0	20	7	0

Fig. 5 | Impact of net migration on population change in urban and rural areas. a–**f**, The communal (**a**,**b**), provincial (**c**,**d**) and national (**e**,**f**) levels for urban (**a**,**c**,**e**) and rural (**b**,**d**,**f**) areas. Impact is divided into seven categories by comparing total population change, net migration and natural population change (growth or decline). Total population change includes both net migration and natural change. Natural change is measured with births and deaths, that is population change without migration. For example, net migration slows down urban population decline when urban net migration is positive but total urban population change is negative (Methods). Share of global urban and rural population living in each category shows the share of global urban or rural inhabitants living in areas under each type of impact.

to population change (Methods) was more strongly associated with the level of human development than with aridity (Fig. 6b,d). Positive net migration often contributed to increasing population growth, slowing population decline or shifting declining population to growth in areas with relatively high human development. Our results show that the climatic factor, as measured by the level of aridity, has a weaker association with the impact of migration on population growth. Therefore, migration can accelerate or slow down population growth in a wide range of climatic conditions.

For instance, most of Europe, North America and Australia, which are regions with high human development, experienced increasing urban population due to positive net migration (Fig. 6b). Notably, the capacity to cope with the pressure on physical and social infrastructure from population growth is high in these regions. On the other hand, many urban regions in West, East and South Africa, Arabia, as well as India, Bangladesh, China and Southeast Asia had positive net migration accelerating their natural population growth, while they also have more limited capacity (HDI) to cope with a growing population (Fig. 6b). Urban regions with the lowest human development level experienced negative net migration and consequently a slowing down of natural population growth. While this may indicate that out-migration from those areas is alleviating the pressure caused by natural population growth, it can also reflect urban out-migration pushed by urban poverty.

Finally, the role of migration in rural population change follows a general pattern in which regions with higher human development

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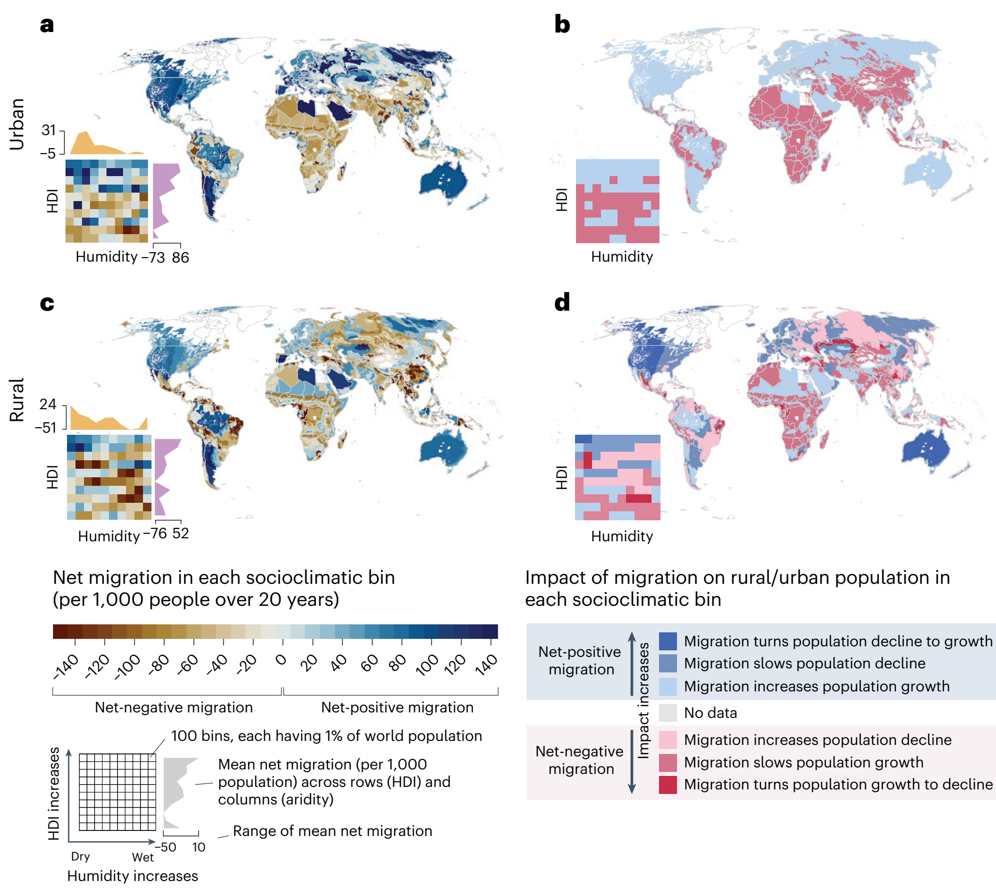

Fig. 6 | Net migration and its impact on population change in socioclimatic bins. a–**d**, For each socioclimatic bin, urban net migration per 1,000 urban population summed over the study period (**a**), the impact of urban net migration on urban population change in each socioclimatic bin (**b**), rural net migration per 1,000 rural population summed over the study period (**c**) and the impact of rural net migration on rural population change (**d**). Here, net migration per urban or rural population was calculated as a zonal sum of net migration in urban (**a**) and rural (**c**) areas in each bin and then divided with the respective urban or rural population count in the respective bin. The maps are spatial representations of the heatmaps. Socioclimatic bins are based on socioeconomic and climatic conditions represented by human development and aridity indices (Methods; Extended Data Figs. 7 and 8).

level are impacted by positive net migration. Declining rural populations turned to growth due to positive net migration in North America and Australia (Fig. 6d), whereas rural population decline was slowed down by positive net migration in most of Europe, parts of Russia and South America.

Discussion and concluding remarks

Despite recent progress in estimating global international[7,8,35,36] and internal migration[9,37], global migration datasets often suffer from poor spatial and/or temporal resolutions. Our annual gridded net migration data cover the entire globe, allowing the analysis of both local and regional net migration patterns at various geospatial scales. Using these data, we have quantified the magnitude and impact of net migration over the past 20 years in three administrative levels and in socioclimatic zones. Our analysis highlights the importance of considering the spatial scale when analysing migration patterns. We showed that global net migration patterns depend strongly on the scale of analysis, both for the magnitude of migration and also for the trend (Fig. 2). Within the study period of 2000–2019, net global urban migration has been predominantly positive while net rural migration has been negative (Fig. 3m), aligning with previous urbanization literature[38]. Further, we showed that the volume and impact of migration are positively associated with the level of human development (positive net migration often co-occurs with high HDI) and this association is stronger than that of climate and migration (Fig. 6).

Previous studies argue that migration often originates from areas where people have sufficient capacity to move and to use migration as one form of adaptation to unfavourable environmental conditions, often by migrating to urban areas[29,39–41]. Our analysis provides a global quantification of this argument and shows that rural out-migration hotspots were located in socioclimatic conditions with a middle level of aridity and human development (Fig. 6c,d). This corresponds to about 50% of the global urban population who experienced accelerated population growth in the past two decades (Fig. 5). Notably, a relatively large volume of positive urban net migration took place in locations with medium-to-high levels of human development, indicating higher capacity to cope with additional pressures (Fig. 6a,b).

Despite accelerating urbanization over the past 20 years, positive net migration has increased population growth and helped to slow down population decline in many rural areas (Figs. 5 and 6c,d). Rural–rural migration, especially over short distances, is common particularly in smaller countries with few provincial and communal urban centres that attract migrants from other parts of the country[7]. Our results show that areas where migration slowed rural population decline were located in high-income countries (Fig. 6d), and some countries may have reached a point where urbanization has turned to counter-urbanization[34]. On the other hand, the share of people living in urban areas is expected to grow, especially in lower income regions, such as Africa[42]. With the global average temperatures continuing to rise, impoverished urban areas are particularly vulnerable to the impact