Title: Rising rural body-mass index is the main driver of the global obesity epidemic

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Body-mass index (BMI) has increased steadily in most countries parallel to the rise in the share of the population who live in cities.[1,2] This has led to a widely reported view that urbanisation is one of the most important drivers of the global rise in obesity.[3-6] Here, we use 2,009 population-based studies, with measurement of height and weight in over 112 million adults, to report national, regional and global trends in BMI by rural and urban place of residence from 1985 to 2017. We show that, contrary to the dominant paradigm, more than 55% of the global rise in mean BMI from 1985 to 2017, and up to 90% in some low- and middle-income regions, was due to increases in BMI in rural areas. This large contribution stems from the fact that, with the exception of women in sub-Saharan Africa, BMI is rising at the same rate or faster in rural areas than in cities. These trends have in turn resulted in a closing, and in some countries reversal, of the urban-rural BMI gap in low- and middle-income countries, especially for women. In high-income and industrialised countries, we noted a persistent rural excess BMI. There is an urgent need for an integrated approach to rural nutrition that enhances financial and physical access to healthy foods, to avoid replacing the rural undernutrition disadvantage in poor countries with a more general malnutrition disadvantage that entails excessive consumption of low-quality calories.

Being underweight as well as overweight can lead to adverse health outcomes. Body-mass index (BMI), a measure of underweight or overweight, is rising in most countries.[2] It is commonly stated that urbanisation is one of the most important drivers of the worldwide rise in BMI because diet and lifestyle in cities lead to adiposity.[3-6] Yet, such statements are typically based on cross-sectional comparisons in one or a small number of countries. Only a few studies have analysed how BMI is changing over time in rural and urban areas. The majority have been in one country, over short durations, and/or in one sex and narrow age groups. The few studies that covered more than one country[7-12] used at most a few dozen data sources and hence could not systematically estimate trends, and focused primarily on women of child-bearing age.

Data on how BMI in rural and urban populations is changing are needed to plan interventions that address underweight and obesity. Here, we report on mean BMI in rural and urban areas of 200 countries and territories from 1985 to 2017. We used 2,009 population-based studies of human anthropometry conducted in 190 countries (Extended Data Fig.1), with measurement of height and weight in over 112 million adults aged 18 years and older. We excluded data based on self-reported height and weight because they are subject to bias. We used a Bayesian hierarchical model to estimate mean BMI by year, country and rural and urban place of residence. As described in Methods, the estimated trends in population BMI represent a combination of (i) change in the health of individuals due to change in their economic status and environment, and (ii) change in the composition of individuals that make up the population (and their economic status and environment).

From 1985 to 2017, the share of the world's population in urban areas increased from 41% to 55%.[1] Over the same period, global age-standardised mean BMI increased from 22.6 kg/m^2 (95% credible interval 22.4-22.9) to 24.7 kg/m^2 (24.5-24.9) in women, and from 22.2 kg/m^2 (22.0-22.4) to 24.4 kg/m^2 (24.2-24.5) in men. The increase in mean BMI was 2.09 kg/m^2 (1.73-2.44) and 2.10 kg/m^2 (1.79-2.41) among rural women and men, respectively, compared to 1.35 kg/m^2 (1.05-1.65) and 1.59 kg/m^2 (1.33-1.84) in urban women and men. Nationally, change in mean BMI ranged from small decreases among women in eleven countries in Europe and Asia Pacific, to a rise of >5 kg/m^2 among women in Egypt and Honduras. The lowest observed sex-specific mean BMI over these 33 years was that of rural women in Bangladesh at 17.7 kg/m^2 (16.3-19.2) and rural men in Ethiopia at 18.4 kg/m^2 (17.0-19.9), both in 1985; the highest were 35.4 kg/m^2 (33.7-37.1) for urban women and 34.6 kg/m^2 (33.1-35.9) for rural men in American Samoa in 2017 (Extended Data Fig. 2 and Extended Data Fig. 3), representing a two-fold difference.

In 1985, urban men and women in every country in east, south and southeast Asia, Oceania, Latin America and the Caribbean, and a region covering central Asia, Middle East and north Africa had higher mean BMI than their rural counterparts (Figs. 1 and 2). The urban-rural gap was as large as 3.25 kg/m^2 (2.57-3.96) in women and 3.05 kg/m^2 (2.44-3.68) in men in India. Over time, the BMI gap between rural and urban women shrank in all these regions at least 40%, as BMI rose faster in rural areas than in cities (Fig. 3). In fourteen countries in these regions, including Armenia, Chile, Jamaica, Jordan, Malaysia, Taiwan and Turkey, the ordering of rural and urban female BMI reversed over time, and rural women had higher BMI than their urban peers in 2017 (Fig. 1 and Extended Data Fig. 4).

Mean BMI of rural men also increased more than that of urban men in south Asia and Oceania, shrinking the BMI urban-rural gap by more than half. In east and southeast Asia, Latin America and the Caribbean, and central Asia, Middle East and north Africa, rural and urban men experienced a similar BMI increase, and hence the urban excess BMI did not change much over time.

In contrast to emerging economies, excess BMI among urban women became larger in sub-Saharan Africa (Fig. 3): from 2.59 kg/m^2 (2.21-2.98) in 1985 compared to 3.17 kg/m^2 (2.93-3.42) in 2017 (posterior probability of the observed increase being a true increase = 0.99). This occurred because female BMI rose faster in cities than in rural areas in sub-Saharan Africa. Therefore, women in sub-Saharan African countries, especially those in west Africa, had the largest urban excess BMI of any country in 2017, e.g. more than 3.35 kg/m^2 in Niger, Burkina Faso, Togo and Ghana (Fig. 1 and Extended Data Fig. 4). BMI increased at a similar rate in rural and urban men in sub-Saharan Africa, with the difference in 2017 (1.66 kg/m^2; 1.37-1.94) being similar to 1985 (1.60 kg/m^2; 1.13-2.07) (Fig. 2 and Extended Data Fig. 4).

BMI was previously lower in rural areas of low- and middle-income countries than in cities, both because rural residents had higher energy expenditure in their daily work, especially agriculture, and domestic activities such as fuelwood and water collections,[13,14] and because lower incomes in rural areas restricted food consumption.[15] In middle-income countries, agriculture is increasingly mechanised, cars are used for rural transport as income increases and road infrastructure improves, service and administrative jobs have become more common in rural areas, and some household tasks are no longer needed, for example because homes have water connection and use commercial fuels.[16] Further, higher incomes as a result of economic growth allow more spending on food and hence higher caloric intake, disproportionately more in rural areas, where a significant share of income was previously spent on food. Further, the consumption of processed carbohydrates may have increased disproportionately in rural areas where such foods became more readily available through national and transnational companies.[9,17-21] These changes, referred to as "urbanisation of rural life" by some researchers,[6] would contribute to faster-rising rural BMI.[22,23]

Unlike other regions, urbanisation in sub-Saharan Africa preceded significant economic growth.[24] Subsistence farming remains common in Africa, and agriculture remains mostly manual; fuelwood, commonly collected by women, is still the dominant fuel in rural Africa; and the use of cars for transportation is limited by poor infrastructure and poverty. In African cities, many people have service and office jobs and mobility has become less energy-intensive due to shorter travel distances and the use of cars and buses. Further, urban markets where fresh produce is sold are increasingly replaced by commercially prepared and processed foods from transnational and local industries and street vendors.[25-27] These effects are exacerbated by limited time and space for cooking healthy meals and possibly perceptions of large weight as a sign of affluence.[28,29]

In contrast to low- and middle-income regions, urban women in high-income western and Asia Pacific regions, and in central and eastern Europe, had lower mean BMI than their rural counterparts in 2017 (Fig. 3). The rural excess female BMI in these regions changed little from 1985 to 2017. Nationally, rural women's excess BMI was largest in central and eastern European countries (e.g., ~1 kg/m^2 or more in Belarus, Czech Republic and Latvia) (Fig. 1 and Extended Data Fig. 4). Rural men in high-income western countries also had an excess BMI compared to urban men throughout the analysis period. The rural excess BMI in 2017 was largest in Sweden, Czech Republic, Ireland, Australia, Austria and the USA, all >0.35 kg/m^2. In high-income Asia Pacific region and in central and eastern Europe, rural and urban men had virtually identical BMI throughout these three decades (Fig. 2 and Extended Data Fig. 4).

The lower urban BMI in high-income and industrialised countries reflects a growing rural economic and social disadvantage, including lower education and income, lower availability and higher price of healthy and fresh foods,[30,31] less access to and use of public transport and walking than in cities,[32,33] and limited availability of facilities for sports and recreational activity,[34] which account for a significant share of overall physical activity in high-income and industrialised countries.

We also estimated how much of the overall rise in mean BMI since 1985 has been due to increases in BMI of rural and urban populations versus due to urbanisation (defined as an increase in the share of population who live in urban areas), in each region and in the world as a whole. At the global level, 60% (56-64) of the rise in mean BMI from 1985 to 2017 in women and 57% (53-60) in men was due to increases in the BMI of rural populations; 28% (24-31) in women and 30% (27-32) in men due to BMI rise in urban populations; and 13% (11-15) and 14% (12-16) due to urbanisation (Table 1). The contribution of the rise in rural BMI ranged between ~60% and 90% in the mostly rural regions of sub-Saharan Africa, east, south and southeast Asia and Oceania. The contribution of urbanisation was small in all regions, with maximum values of 19% (15-25) among women and 14% (10-21) among men in sub-Saharan Africa.

Our results show that, contrary to the prevailing view,[3-6] BMI is rising at the same rate or faster in rural areas compared to cities, except among women in sub-Saharan Africa. These trends have resulted in a rural-urban convergence in BMI in most low- and middle-income countries, especially for women. The rising rural BMI is the largest contributor to the BMI rise in low- and middle-income regions and in the world as a whole over the last 33 years, which challenges the current paradigm of urban living and urbanisation as the key driver of the global epidemic of obesity.

In poor societies, urban areas historically had lower levels of undernutrition,[35,36] possibly because infrastructure such as roads and electricity facilitate food trade, transport and storage in cities, which can in turn reduce the impacts of agricultural shocks and seasonality. As economic growth and rural nutrition programmes reduce rural caloric deficiency, the rural undernutrition disadvantage may be replaced with a more general and complex malnutrition that entails excessive consumption of low-quality calories. To avoid such an unhealthy transition, the fragmented national and international responses to undernutrition and obesity should be integrated, and the narrow focus of international aid on undernutrition should be broadened, to enhance access to healthier foods in poor rural and urban communities.

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Methods

Our aim was to estimate trends in mean BMI from 1985 to 2017 by rural and urban place of residence for 200 countries and territories (Supplementary Table 2). To achieve this aim, we pooled cross-sectional population-based data on height and weight in adults aged 18 years and older. Therefore, by design, our results measure total change in BMI in each country's rural and urban populations, which consists of (i) change in the health of individuals due to change in their economic status and environment, and (ii) change in the composition of individuals that make up the population (and their economic status and environment). Change in population composition occurs naturally due to fertility and mortality, as well as due to migration. Therefore, our results should not be interpreted as solely a change in the BMI of individuals. Both components of change are relevant for policy formulation because policies should address the environment and nutrition of the contemporary population.

We used mean BMI as the primary outcome, rather than prevalence of overweight or obesity, because the relationship between BMI and disease risk is continuous with each unit lower BMI being associated with a constant proportional reduction in disease risk from a BMI of around 21-23 kg/m^2 which is below the cut-offs used to define overweight and obesity.[37-39] Therefore, the largest health benefits of weight management are achieved by lowering the population distribution of BMI. Mean BMI is the simplest summary statistic of the population distribution. Nonetheless, mean BMI and prevalence of overweight and obesity are closely associated (Extended Data Fig. 5).

Data sources

We used a database on cardiometabolic risk factors collated by the Non-Communicable Disease Risk Factor Collaboration (NCD-RisC). NCD-RisC is a worldwide network of health researchers and practitioners whose aim is to document systematically the worldwide trends and variations in NCD risk factors. The database was collated through multiple routes for identifying and accessing data. We accessed publicly available population-based measurement surveys (e.g., Demographic and Health Surveys (DHS), Global School-based Student Health Surveys (GSHS), the European Health Interview and Health Examination Surveys (EHIS and EHES) and those available via the Inter-university Consortium for Political and Social Research (ICPSR). We requested, via the World Health Organization (WHO) and its regional and country offices, help with identification and access to population-based surveys from ministries of health and other national health and statistical agencies. Requests were also sent via the World Heart Federation to its national partners. We made similar requests to the co-authors of an earlier pooled analysis of cardiometabolic risk factors,[40-43] and invited them to reanalyse data from their studies and join NCD-RisC. Finally, to identify major sources not accessed through the above routes, we searched and reviewed published studies as detailed previously,[44] and invited all eligible studies to join NCD-RisC.

Anonymised individual record data from sources included in NCD-RisC were reanalysed by the Pooled Analysis and Writing Group or by data holders according to a common protocol. Within each survey, we included participants aged 18 years and older who were not pregnant. We dropped participants with implausible BMI levels (defined as BMI <10 kg/m^2 or BMI >80 kg/m^2) or with implausible height or weight values (defined as height <100 cm, height >250 cm, weight <12 kg or weight >300 kg) (<0.2% of all subjects). We also dropped participants whose urban-rural status was unknown in surveys that had recorded place of residence (0.05% of all participants). We calculated mean BMI and the associated standard error by sex, age group (18 years, 19 years, 10-year age groups from 20-29 years to 70-79 years and 80+ years) and place of residence (rural and urban). All analyses incorporated appropriate sample weights and complex survey design, when applicable, in calculating summary statistics. Countries typically use the rural and urban classification of communities by their statistical offices at any given time both for survey design and for reporting of population to the United Nations Population Division. The classification can change, for example as previously-rural areas grow and industrialise and hence become, and are (re)designated as, de novo cities. To the extent that the re-classifications keep up with changes in the real status of each community, survey and population data reflect the status of each community at the time of measurement. For surveys without information on place or residence, we calculated age- and sex-stratified summary statistics for the entire sample, which represented the population-weighted sum of rural and urban means.

To ensure summaries were prepared according to the study protocol, the Pooled Analysis and Writing Group provided computer code to NCD-RisC members who requested assistance. All submitted data were checked by at least two independent members of the Pooled Analysis and Writing Group. Questions and clarifications were discussed with NCD-RisC members and resolved before data were incorporated in the database.

Finally, we incorporated all nationally representative data from sources that were identified but not accessed via the above routes, by extracting summary statistics from published reports. Data were also extracted for nine STEPS surveys, one Countrywide Integrated Non-communicable Diseases Intervention (CINDI) survey, and five sites of the WHO Multinational MONItoring of trends and determinants in CArdiovascular disease (MONICA) project that were not deposited in the MONICA Data Centre. Data were extracted from published reports only when reported by sex and in age groups no wider than 20 years. We also used data from a previous global-data pooling study[43] when such data had not been accessed through the routes described.

All NCD-RisC members are asked periodically to review the list of sources from their country, to suggest additional sources not in the database, and to verify that the included data meet the inclusion criteria listed below and are not duplicates. The NCD-RisC database is continuously updated through this contact with NCD-RisC members and all the above routes. For this paper, we used data from the NCD-RisC database for years 1985 to 2017 and ages 18 years and above. A list of the data sources we used in this analysis and their characteristics is provided in Supplementary Table 1.

Data inclusion and exclusion

Data sources were included in NCD-RisC database if:

- measured data on height, weight, waist circumference, or hip circumference were available;
- study participants were five years of age and older;
- data were collected using a probabilistic sampling method with a defined sampling frame;
- data were from population samples at the national, sub-national (i.e., covering one or more sub-national regions, more than three urban communities or more than five rural communities), or community level;
- data were from the countries and territories listed in Supplementary Table 2.

We excluded all data sources that were solely based on self-reported weight and height without a measurement component because these data are subject to biases that vary by geography, time, age, sex and socioeconomic characteristics.[45-47] Due to these variations, approaches to correcting self-reported data leave residual bias. We also excluded data sources on population subgroups whose anthropometric status may differ systematically from the general population, including:

- studies that had included or excluded people based on their health status or cardiovascular risk;
- studies whose participants were only ethnic minorities;
- specific educational, occupational, or socioeconomic subgroups, with the exception noted below;
- those recruited through health facilities, with the exception noted below; and
- women aged 15-19 years in surveys which sampled only ever-married women or measured height and weight only among mothers.

We used school-based data in countries, and in age-sex groups, with school enrolment of 70% or higher. We used data whose sampling frame was health insurance schemes in countries where at least 80% of the population were insured. Finally, we used data collected through general practice and primary care systems in high-income and central European countries with universal insurance, because contact with the primary care systems tends to be as good as or better than response rates for population-based surveys.

Conversion of BMI prevalence metrics to mean BMI

In 2% of our data points, mostly extracted from published reports or from the a previous pooling analysis,[43] mean BMI was not reported, but data were available for the prevalence of one or more BMI categories, e.g., BMI $\geq$30 kg/m^2. In order to use these data, we used previously-validated conversion regressions[2] to estimate the missing primary outcome from the available BMI prevalence metric(s). All sources of uncertainty in the conversion – including the sampling uncertainty of the original data, the uncertainty of the regression coefficients and random effects, and the regression residuals – were carried forward by using repeated draws from their joint posterior distribution, accounting for the correlations among the uncertainties of regression coefficients and random effects.

Statistical analysis of BMI trends by rural and urban place of residence

We used a Bayesian hierarchical model to estimate mean BMI by country, year, sex, age and place of residence. The statistical model is described in detail in a statistical paper and related substantive papers,[2,35,40-44,48-51] and in Supplementary Information. In summary, we organised countries into 21 regions (Supplementary Table 2), mostly based on geography and national income. The exception was high-income English-speaking countries (Australia, Canada, Ireland, New Zealand, the UK, and the USA), grouped together in one region because BMI and other cardiometabolic risk factors have similar trends in these countries, which can be distinct from other countries in their geographical regions.[2,49,50,52] Regions were in turn organised into nine super-regions.

The model had a hierarchical structure in which estimates for each country and year were informed by its own data, if available, and by data from other years in the same country and from other countries, especially those in the same region with data for similar time periods. The extent to which estimates for each country-year were influenced by data from other years and other countries depended on whether the country had data, the sample size of the data, whether they were national, and the within-country and within-region variability of the available data. The model incorporated non-linear time trends comprising linear terms and a second-order random walk, all modelled hierarchically. The age association of BMI was modelled using a cubic spline to allow non-linear age patterns, which could vary across countries. The model accounted for the possibility that BMI in sub-national and community samples might differ systematically from nationally representative ones and have larger variation than in national studies. These features were implemented by including data-driven fixed-effect and random-effect terms for sub-national and community data. The fixed effects adjusted for systematic differences between sub-national or community studies and national studies. The random effects allowed national data to have larger influence on the estimates than sub-national or community data with similar sample sizes. All analyses were done separately by sex because geographical and temporal patterns of BMI differ between men and women.[2]

Here, we extended the model to make estimates for rural and urban populations following the approach of Paciorek et al.[35,51] This model includes a parameter representing the urban-rural BMI difference, which is empirically estimated and allowed to vary by country and year. The model uses all the data – those stratified by rural and urban place of residence as well as those reported for the entire population. If data for a country-year were not stratified by place of residence, the estimated BMI difference was informed by stratified data from other years and countries, especially those in the same region with data from similar time periods.

We fitted the statistical model with the Markov chain Monte Carlo (MCMC) algorithm and obtained 5,000 post-burn in samples (or draws) from the posterior distribution of model parameters, which were in turn used to obtain the posterior distributions of our primary outcomes – mean urban BMI, mean rural BMI and mean urban-rural BMI difference. Posterior estimates were made in 1-year age groups for ages 18 and 19 and 5-year age groups for those aged 20 years and older. We generated age-standardised estimates by taking weighted means of age-specific estimates, using age weights from the WHO standard population. Regional and global rural and urban mean BMI estimates were calculated as population-weighted averages of rural and urban mean for the constituent country estimates by age-group and sex. National mean BMI was calculated as population-weighted averages of the rural and urban means.

The reported credible intervals represent the 2.5th and the 97.5th percentiles of the posterior distributions. We also report the posterior probability that the estimated urban-rural BMI difference is a true difference in the same direction as the point estimate. We also report the posterior probability that the estimated change in the rural-urban BMI difference over time represents a true increase or decrease.

Validation of statistical model

We calculated the difference between the posterior estimates from the model and data from national studies. Median errors were very close to zero (0.03 kg/m^2 for women and -0.02 kg/m^2 men) and median absolute errors were 0.32 kg/m^2 for women and 0.26 kg/m^2 for men, indicating that the estimates were unbiased and had small deviations relative to national studies. The differences were indistinguishable from zero at 5% statistical significance level.

We also tested how well our statistical model predicts missing data, known as external predictive validity, in two different tests. In Test 1, we held out all data from 10% of countries with data (i.e., created the appearance of countries with no data where we actually had data). The countries whose data were withheld were randomly selected from the following three groups: data-rich (8 or more data sources for women, and 7 or more data sources for men), data-poor (1-3 data sources for women, and 1-2 for men), and average data availability (4-7 data sources for women, and 3-6 for men). All data-rich countries had at least one data source after 2000 and at least one source with data stratified on rural and urban place of residence. We fitted the model to the data from the remaining 90% of countries and made estimates of the held-out observations. In Test 2, we assessed other patterns of missing data by holding out 10% of our data sources, again from a mix of data-rich, data-poor, and average-data countries, as defined above. For a given country, we either held out a random one third of the country's data or all of the country's 2000-2017 data to determine, respectively, how well we filled in the gaps for countries with intermittent data and how well we estimated in countries without recent data. We fitted the model to the remaining 90% of the dataset and made estimates of the held-out observations. We repeated each test five times, holding out a different subset of data in each repetition. In both tests, we calculated the differences between the held-out data and the estimates. We also calculated the 95% credible intervals of the estimates; in a model with good external predictive validity, 95% of held-out values would be included in the 95% credible intervals.

Our statistical model also performed very well in the external validation tests, i.e. in estimating mean BMI when data were missing. The estimates of mean BMI were unbiased, as evidenced with median errors that were zero or close to zero globally (0.03 and -0.03 kg/m^2 for women and -0.15 and 0.00 kg/m^2 for men in the Tests 1 and 2, respectively), and less than ±0.20 kg/m^2 in every subset of withheld data except 1985-1999 data in Test 1 for men where median error was -0.24 kg/m^2 (Extended Data Table 2). Most of the median errors were indistinguishable from zero at 5% statistical significance level. The 95% credible intervals of estimated mean BMI covered 94-98% of true data globally; coverage was >93% in all but one subset of withheld data. Median absolute errors ranged from 0.52 to 1.09 kg/m^2 globally, and were at most 1.29 kg/m^2 in all subsets of withheld data. Median absolute errors were smaller in Test 2, where a subset of data sources from some countries are withheld, than in Test 1, where all data from some countries are withheld. Given that we had data for 190 out of 200 countries for women and 183 out of 200 countries for men, Test 2 is a better reflection of data availability in our analysis. For comparison, median absolute differences for mean BMI between pairs of nationally representative surveys done in the same country and in the same year was 0.46 kg/m^2, indicating that our estimates perform almost as well as running two parallel surveys in the same country and year.

Contributions of urbanisation and rural and urban BMI change to changes in population mean BMI

We calculated the contributions of the following components to change in population mean BMI from 1985 to 2017: the contribution of change in BMI in rural areas, the contribution of change in BMI in urban areas, and the contribution of urbanisation (i.e. increase in the proportion of people living in urban areas). The first two parts were calculated by fixing the proportion of people living in rural and urban areas to 1985 levels and allowing BMI to change as it did in the respective population. The contribution of urbanisation was calculated by fixing BMI in rural and urban areas to 2017 levels and allowing the proportion of people living in cities to change as it did. Percentage contributions were calculated using posterior draws, with reported credible intervals representing the 2.5th and the 97.5th percentiles of their posterior distributions.

$$Change\ in\ mean\ BMI\ from\ 1985\ to\ 2017$$
$$= contribution\ of\ change\ in\ rural\ BMI + contribution\ of\ change\ in\ urban\ BMI$$
$$+ contribution\ of\ change\ in\ the\ proportion\ of\ the\ population\ living\ in\ urban\ areas$$
$$= (Change\ in\ BMI_{rural\ 1985-2017})(percent\ living\ in\ rural\ areas_{1985})$$
$$+ (Change\ in\ BMI_{urban\ 1985-2017})(percent\ living\ in\ urban\ areas_{1985})$$
$$+ (Change\ in\ percent\ living\ in\ urban\ areas_{1985-2017})(BMI_{urban\ 2017} - BMI_{rural\ 2017})$$

Strengths and limitations

Urbanisation is regarded as one of the most important contributors to global obesity epidemic, but this perspective is based on limited data. We have presented the first comparable estimates of mean BMI for rural and urban populations worldwide over three decades using, to our knowledge, the largest and most comprehensive global database of human anthropometry with information on urban or rural place of residence. We used population-based measurement data from almost all countries, with information on participants' urban or rural place of residence for the majority of data sources. We maintained a high level of data quality through repeated checks of study characteristics against our inclusion and exclusion criteria, which were verified by NCD-RisC members, and did not use any self-reported data to avoid bias in height and weight. Data were analysed according to a common protocol to obtain mean BMI by age, sex and place of residence. We used a statistical model that used all available data, while giving more weight to national data than sub-national and community studies and took into account the epidemiological features of

BMI by using non-linear time trends and age associations. The model used information on the urban-rural difference in BMI where available and estimated this difference hierarchically and temporally in the absence of stratified data.

Despite our large-scale data collation effort, some countries and regions had fewer data, particularly the Caribbean and Polynesia and Micronesia. There were also fewer data sources before 2000. This temporal and geographical sparsity of data led to wider uncertainty intervals for these countries, regions and years. Although health surveys commonly use the rural and urban classification of national statistical offices, cities and rural areas in different countries vary in their demographic characteristics (e.g., population size or density), economic activity, administrative structures, infrastructure, and environment. These differences appropriately exist because countries themselves differ in terms of their demography, geography and economy. For example, a country with a smaller population may use a lower threshold to urban designation than one with a larger population, because its cities are naturally smaller even if they serve the same functions. Official rural and urban classifications are used for resource allocation and planning for nutrition and health,[53-58] which makes them the appropriate unit for tracking outcomes. Nonetheless, understanding the causes of change in rural and urban areas can be enriched with use of more complex and multi-dimensional measures of urbanicity involving size, density, economic and commercial activities and infrastructures.[59,60] Finally, urbanisation could arise from a variety of mechanisms: (1) natural increase due to excess births over deaths in cities compared to rural areas, (2) rural to urban migration (often related to opportunities for work and education) and (3) reclassification of previously-rural areas as they grow and industrialise and hence become, and are (re)designated as, de novo cities. The contributions of these mechanisms to urbanisation vary across countries. The use of time-varying rural versus urban classification of communities ensures that in any year, the rural and urban strata represent the actual status of each community. However, each of these mechanisms may have different implications for change in nutrition and physical activity, and hence BMI.

Data availability

Estimates of mean BMI by country, year, sex and place of residence (urban and rural) will be available from www.ncdrisc.org upon publication of the paper. Input data from publicly available sources can also be downloaded from www.ncdrisc.org upon publication of the paper. For other data sources, contact information for data providers can be obtained from www.ncdrisc.org.

Code availability

The computer code for the Bayesian hierarchical model used in this work will be available at www.ncdrisc.org upon publication of the paper.

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Supplementary information

This file contains details of the statistical model used to estimate BMI trends by rural and urban place of residence, Supplementary Table 1, Supplementary Table 2 and Supplementary Table 3.

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Author contributions

ME designed the study and oversaw research. HB led the data collection, statistical analysis and prepared results. Pooled Analysis and Writing Group contributed to study design, collated data, checked all data sources in consultation with the Country and Regional Data Group, analysed pooled data, and prepared results. Country and Regional Data Group collected and reanalysed data and checked pooled data. ME and HB wrote the first draft of the report. Other authors commented on the draft report.

Author information

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Table 1. Contributions of rise in mean BMI in rural and urban populations and of urbanisation (defined as an increase in the share of population who live in urban areas) to rise in mean BMI from 1985 to 2017, by region.

		Rural component		Urban component		Urbanisation component	
		Absolute contribution (kg/m^2)	Percentage contribution	Absolute contribution (kg/m^2)	Percentage contribution	Absolute contribution (kg/m^2)	Percentage contribution
Emerging economies							
Central Asia, Middle East and north Africa	Men	1.30 (0.96–1.64)	48 (41–54)	1.33 (1.02–1.65)	49 (44–54)	0.09 (0.06–0.12)	3 (2–5)
	Women	1.96 (1.57–2.33)	59 (54–64)	1.31 (0.95–1.69)	39 (34–44)	0.06 (0.03– 0.09)	2 (1–3)
East and southeast Asia	Men	1.99 (1.62–2.37)	67 (63–71)	0.66 (0.53–0.80)	22 (20–24)	0.33 (0.26–0.39)	11 (9–14)
	Women	1.81 (1.36–2.26)	73 (67–80)	0.47 (0.32–0.64)	19 (16–22)	0.18 (0.10– 0.26)	7 (4–11)
Latin America and the Caribbean	Men	0.86 (0.63–1.09)	31 (26–37)	1.73 (1.31–2.16)	63 (58–67)	0.17 (0.13–0.20)	6 (5–8)
	Women	1.29 (1.07–1.51)	38 (34–43)	2.01 (1.56–2.49)	60 (55–63)	0.06 (0.03– 0.10)	2 (1–3)
Oceania	Men	2.24 (1.12–3.37)	90 (80–102)	0.24 (-0.03–0.51)	10 (-2–20)	0.00 (0.00–0.00)	0 (0–0)
	Women	2.41 (0.89–3.98)	81 (69–90)	0.53 (0.18–0.89)	19 (10–31)	0.00 (0.00– 0.00)	0 (0–0)
South Asia	Men	1.99 (1.42–2.54)	86 (79–94)	0.20 (0.00–0.40)	8 (0–15)	0.12 (0.09–0.15)	5 (3–8)
	Women	2.18 (1.46–2.87)	80 (73–87)	0.36 (0.13–0.60)	13 (6–19)	0.19 (0.16– 0.23)	7 (5–11)
Sub-Saharan Africa							
Sub-Saharan Africa	Men	1.14 (0.64–1.63)	64 (53–73)	0.39 (0.22–0.55)	22 (15–28)	0.23 (0.19–0.27)	14 (10–21)
	Women	1.37 (0.90–1.83)	57 (49–63)	0.58 (0.42–0.74)	24 (21–28)	0.45 (0.42– 0.49)	19 (15–25)
High-income and other industrialised regions							
Central and eastern Europe	Men	0.59 (0.35–0.82)	35 (26–44)	1.10 (0.70–1.50)	65 (57–73)	0.00 (-0.01–0.01)	0 (-1–1)
	Women	0.14 (-0.19–0.45)	*	0.13 (-0.45–0.69)	*	-0.02 (-0.03– 0.00)	*
High-income Asia Pacific	Men	0.48 (0.37–0.59)	31 (25–37)	1.15 (0.84–1.46)	72 (68–75)	-0.04 (-0.08–0.00)	-2 (-6–0)
	Women	0.12 (-0.01–0.27)	*	-0.02 (-0.38–0.36)	*	-0.10 (-0.15–-0.06)	*
High-income western countries	Men	0.58 (0.47–0.69)	24 (22–27)	1.80 (1.53–2.07)	76 (74–78)	-0.01 (-0.02–0.00)	0 (-1–0)
	Women	0.39 (0.24–0.54)	21 (15–26)	1.44 (1.09–1.79)	79 (74–84)	0.00 (-0.02– 0.01)	0 (-1–1)
World							
World	Men	1.24 (1.06–1.43)	57 (53–60)	0.65 (0.54–0.75)	30 (27–32)	0.30 (0.28–0.32)	14 (12–16)
	Women	1.22 (1.01–1.43)	60 (56–64)	0.56 (0.44–0.69)	28 (24–31)	0.25 (0.23– 0.27)	13 (11–15)

* Percentage contribution not reported because regional change in mean BMI, which appears in the denominator of percentage contribution, was small (<0.5 kg/m^2), leading to unstable estimates. Urbanisation is defined as an increase in the share of population who live in urban areas. Percentage contributions were calculated as detailed in Methods. The reported values are the

means and 95% credible intervals. The three percentages sum to 100%. When one component causes an increase in BMI in a region and another does the opposite, the components can be negative or greater than 100%.

Urban and rural mean body-mass index (BMI) and percentage of the population living in urban areas in 1985 and 2017, by region are provided in Extended Data Table 1.

Fig. 1. The difference between rural and urban age-standardised mean body-mass index (BMI) in women in 1985 and in 2017, by country. A positive number shows a higher urban mean BMI and a negative number a higher rural mean BMI. We did not estimate the difference between rural and urban areas for countries and territories where the entire population live in areas classified as urban (Singapore, Hong Kong, Bermuda and Nauru) or rural (Tokelau). See Extended Fig. 2 for mean BMI in national, rural and urban populations in 1985 and 2017. See Extended Fig. 6 for comparison of results between women and men.

Fig. 2. The difference between rural and urban age-standardised mean body-mass index (BMI) in men in 1985 and in 2017, by country. A positive number shows a higher urban mean BMI and a negative number a higher rural mean BMI. We did not estimate the difference between rural and urban areas for countries and territories where the entire population live in areas classified as urban (Singapore, Hong Kong, Bermuda and Nauru) or rural (Tokelau). See Extended Fig. 3 for mean BMI in national, rural and urban populations in 1985 and 2017. See Extended Fig. 6 for comparison of results between women and men.

Fig. 3 Trends in age-standardised mean body-mass index (BMI) of rural and urban place of residence, by region. The lines show the posterior mean estimates and the shaded areas show the 95% credible intervals.

Extended Data Table 1. Age-standardised urban and rural mean body-mass index (BMI) and percentage of the population living in urban areas in 1985 and 2017, by region.

Extended Data Table 2. Results of model validation.

Extended Data Fig. 1. Number of data sources by country.

Extended Data Fig. 2. Age-standardised national, rural and urban mean body-mass index (BMI) in women aged 18 years and older in 1985 and 2017, by country. The numerical values are provided in Supplementary Table 3.

Extended Data Fig. 3. Age-standardised national, rural and urban mean body-mass index (BMI) in men aged 18 years and older in 1985 and 2017, by country. The numerical values are provided in Supplementary Table 3.

Extended Data Fig. 4. The difference between rural and urban mean age-standardised body-mass index (BMI) in 1985 versus in 2017. Each point shows one country. A positive number shows a higher urban mean BMI and a negative number a higher rural mean BMI. (A) countries with an urban excess BMI that increased from 1985 to 2017. (B) countries with an urban excess BMI that declined from 1985 to 2017. (C) countries with an urban excess BMI in 1985 that reversed to an excess rural BMI in 2017. (D) countries with a rural excess BMI that increased from 1985 to 2017. (E) countries with a rural excess BMI that declined from 1985 to 2017. (F) countries with a rural excess BMI in 1985 that reversed to an urban excess BMI in 2017.

Extended Data Fig. 5 The relationship between mean BMI and prevalence of overweight (BMI $\geq$25 kg/m^2). Prevalence is plotted on a probit scale because which changes in an approximately linear manner as mean changes. Each point represents an age-group-and-sex-specific mean, stratified by place of residence as described in Methods and with more than 25 participants, from data sources in the NCD-RisC database.

Extended Data Fig. 6. Comparison of the difference between rural and urban age-standardised mean body-mass index (BMI) in women and men aged 18 years and older in 1985 and 2017. Each point shows one country.