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- 1 **Title:** Rising rural body-mass index is the main driver of the global obesity epidemic
- 2 **Authors:** NCD Risk Factor Collaboration (NCD-RisC)

3 **Body-mass index (BMI) has increased steadily in most countries parallel to the rise in the**
4 **share of the population who live in cities.^{1,2} This has led to a widely reported view that**
5 **urbanisation is one of the most important drivers of the global rise in obesity.³⁻⁶ Here, we use**
6 **2,009 population-based studies, with measurement of height and weight in over 112 million**
7 **adults, to report national, regional and global trends in BMI by rural and urban place of**
8 **residence from 1985 to 2017. We show that, contrary to the dominant paradigm, more than**
9 **55% of the global rise in mean BMI from 1985 to 2017, and up to 90% in some low- and**
10 **middle-income regions, was due to increases in BMI in rural areas. This large contribution**
11 **stems from the fact that, with the exception of women in sub-Saharan Africa, BMI is rising**
12 **at the same rate or faster in rural areas than in cities. These trends have in turn resulted in**
13 **a closing, and in some countries reversal, of the urban-rural BMI gap in low- and middle-**
14 **income countries, especially for women. In high-income and industrialised countries, we**
15 **noted a persistent rural excess BMI. There is an urgent need for an integrated approach to**
16 **rural nutrition that enhances financial and physical access to healthy foods, to avoid**
17 **replacing the rural undernutrition disadvantage in poor countries with a more general**
18 **malnutrition disadvantage that entails excessive consumption of low-quality calories.**

19

20 Being underweight as well as overweight can lead to adverse health outcomes. Body-mass index
21 (BMI), a measure of underweight or overweight, is rising in most countries.² It is commonly stated
22 that urbanisation is one of the most important drivers of the worldwide rise in BMI because diet
23 and lifestyle in cities lead to adiposity.³⁻⁶ Yet, such statements are typically based on cross-
24 sectional comparisons in one or a small number of countries. Only a few studies have analysed
25 how BMI is changing over time in rural and urban areas. The majority have been in one country,

26 over short durations, and/or in one sex and narrow age groups. The few studies that covered more
27 than one country⁷⁻¹² used at most a few dozen data sources and hence could not systematically
28 estimate trends, and focused primarily on women of child-bearing age.

29
30 Data on how BMI in rural and urban populations is changing are needed to plan interventions that
31 address underweight and obesity. Here, we report on mean BMI in rural and urban areas of 200
32 countries and territories from 1985 to 2017. We used 2,009 population-based studies of human
33 anthropometry conducted in 190 countries (Extended Data Fig.1), with measurement of height and
34 weight in over 112 million adults aged 18 years and older. We excluded data based on self-reported
35 height and weight because they are subject to bias. We used a Bayesian hierarchical model to
36 estimate mean BMI by year, country and rural and urban place of residence. As described in
37 Methods, the estimated trends in population BMI represent a combination of (i) change in the
38 health of individuals due to change in their economic status and environment, and (ii) change in
39 the composition of individuals that make up the population (and their economic status and
40 environment).

41
42 From 1985 to 2017, the share of the world's population in urban areas increased from 41% to
43 55%.¹ Over the same period, global age-standardised mean BMI increased from 22.6 kg/m² (95%
44 credible interval 22.4-22.9) to 24.7 kg/m² (24.5-24.9) in women, and from 22.2 kg/m² (22.0-22.4)
45 to 24.4 kg/m² (24.2-24.5) in men. The increase in mean BMI was 2.09 kg/m² (1.73-2.44) and 2.10
46 kg/m² (1.79-2.41) among rural women and men, respectively, compared to 1.35 kg/m² (1.05-1.65)
47 and 1.59 kg/m² (1.33-1.84) in urban women and men. Nationally, change in mean BMI ranged
48 from small decreases among women in eleven countries in Europe and Asia Pacific, to a rise of >5

49 kg/m² among women in Egypt and Honduras. The lowest observed sex-specific mean BMI over
50 these 33 years was that of rural women in Bangladesh at 17.7 kg/m² (16.3-19.2) and rural men in
51 Ethiopia at 18.4 kg/m² (17.0-19.9), both in 1985; the highest were 35.4 kg/m² (33.7-37.1) for urban
52 women and 34.6 kg/m² (33.1-35.9) for rural men in American Samoa in 2017 (Extended Data Fig.
53 2 and Extended Data Fig. 3), representing a two-fold difference.

54
55 In 1985, urban men and women in every country in east, south and southeast Asia, Oceania, Latin
56 America and the Caribbean, and a region covering central Asia, Middle East and north Africa had
57 higher mean BMI than their rural counterparts (Figs. 1 and 2). The urban-rural gap was as large as
58 3.25 kg/m² (2.57-3.96) in women and 3.05 kg/m² (2.44-3.68) in men in India. Over time, the BMI
59 gap between rural and urban women shrank in all these regions at least 40%, as BMI rose faster in
60 rural areas than in cities (Fig. 3). In fourteen countries in these regions, including Armenia, Chile,
61 Jamaica, Jordan, Malaysia, Taiwan and Turkey, the ordering of rural and urban female BMI
62 reversed over time, and rural women had higher BMI than their urban peers in 2017 (Fig. 1 and
63 Extended Data Fig. 4).

64
65 Mean BMI of rural men also increased more than that of urban men in south Asia and Oceania,
66 shrinking the BMI urban-rural gap by more than half. In east and southeast Asia, Latin America
67 and the Caribbean, and central Asia, Middle East and north Africa, rural and urban men
68 experienced a similar BMI increase, and hence the urban excess BMI did not change much over
69 time.

70

71 In contrast to emerging economies, excess BMI among urban women became larger in sub-
72 Saharan Africa (Fig. 3): from 2.59 kg/m² (2.21-2.98) in 1985 compared to 3.17 kg/m² (2.93-3.42)
73 in 2017 (posterior probability of the observed increase being a true increase = 0.99). This occurred
74 because female BMI rose faster in cities than in rural areas in sub-Saharan Africa. Therefore,
75 women in sub-Saharan African countries, especially those in west Africa, had the largest urban
76 excess BMI of any country in 2017, e.g. more than 3.35 kg/m² in Niger, Burkina Faso, Togo and
77 Ghana (Fig. 1 and Extended Data Fig. 4). BMI increased at a similar rate in rural and urban men
78 in sub-Saharan Africa, with the difference in 2017 (1.66 kg/m²; 1.37-1.94) being similar to 1985
79 (1.60 kg/m²; 1.13-2.07) (Fig. 2 and Extended Data Fig. 4).

80

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

94

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

104

105 In contrast to low- and middle-income regions, urban women in high-income western and Asia
106 Pacific regions, and in central and eastern Europe, had lower mean BMI than their rural
107 counterparts in 2017 (Fig. 3). The rural excess female BMI in these regions changed little from
108 1985 to 2017. Nationally, rural women's excess BMI was largest in central and eastern European
109 countries (e.g., ~1 kg/m² or more in Belarus, Czech Republic and Latvia) (Fig. 1 and Extended
110 Data Fig. 4). Rural men in high-income western countries also had an excess BMI compared to
111 urban men throughout the analysis period. The rural excess BMI in 2017 was largest in Sweden,
112 Czech Republic, Ireland, Australia, Austria and the USA, all >0.35 kg/m². In high-income Asia
113 Pacific region and in central and eastern Europe, rural and urban men had virtually identical BMI
114 throughout these three decades (Fig. 2 and Extended Data Fig. 4).

115

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

122
123 We also estimated how much of the overall rise in mean BMI since 1985 has been due to increases
124 in BMI of rural and urban populations versus due to urbanisation (defined as an increase in the
125 share of population who live in urban areas), in each region and in the world as a whole. At the
126 global level, 60% (56-64) of the rise in mean BMI from 1985 to 2017 in women and 57% (53-60)
127 in men was due to increases in the BMI of rural populations; 28% (24-31) in women and 30% (27-
128 32) in men due to BMI rise in urban populations; and 13% (11-15) and 14% (12-16) due to
129 urbanisation (Table 1). The contribution of the rise in rural BMI ranged between ~60% and 90%
130 in the mostly rural regions of sub-Saharan Africa, east, south and southeast Asia and Oceania. The
131 contribution of urbanisation was small in all regions, with maximum values of 19% (15-25) among
132 women and 14% (10-21) among men in sub-Saharan Africa.

133
134 Our results show that, contrary to the prevailing view,³⁻⁶ BMI is rising at the same rate or faster in
135 rural areas compared to cities, except among women in sub-Saharan Africa. These trends have
136 resulted in a rural-urban convergence in BMI in most low- and middle-income countries,
137 especially for women. The rising rural BMI is the largest contributor to the BMI rise in low- and
138 middle-income regions and in the world as a whole over the last 33 years, which challenges the

139 current paradigm of urban living and urbanisation as the key driver of the global epidemic of
140 obesity.

141
142 In poor societies, urban areas historically had lower levels of undernutrition,^{35,36} possibly because
143 infrastructure such as roads and electricity facilitate food trade, transport and storage in cities,
144 which can in turn reduce the impacts of agricultural shocks and seasonality. As economic growth
145 and rural nutrition programmes reduce rural caloric deficiency, the rural undernutrition
146 disadvantage may be replaced with a more general and complex malnutrition that entails excessive
147 consumption of low-quality calories. To avoid such an unhealthy transition, the fragmented
148 national and international responses to undernutrition and obesity should be integrated, and the
149 narrow focus of international aid on undernutrition should be broadened, to enhance access to
150 healthier foods in poor rural and urban communities.

151

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240

241 **Methods**

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

253

254 We used mean BMI as the primary outcome, rather than prevalence of overweight or obesity,
255 because the relationship between BMI and disease risk is continuous with each unit lower BMI
256 being associated with a constant proportional reduction in disease risk from a BMI of around 21-
257 23 kg/m² which is below the cut-offs used to define overweight and obesity.³⁷⁻³⁹ Therefore, the
258 largest health benefits of weight management are achieved by lowering the population distribution
259 of BMI. Mean BMI is the simplest summary statistic of the population distribution. Nonetheless,
260 mean BMI and prevalence of overweight and obesity are closely associated (Extended Data Fig.
261 5).

262

263 **Data sources**

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

279
280 Anonymised individual record data from sources included in NCD-RisC were reanalysed by the
281 Pooled Analysis and Writing Group or by data holders according to a common protocol. Within
282 each survey, we included participants aged 18 years and older who were not pregnant. We dropped
283 participants with implausible BMI levels (defined as BMI <10 kg/m² or BMI >80 kg/m²) or with
284 implausible height or weight values (defined as height <100 cm, height >250 cm, weight <12 kg
285 or weight >300 kg) (<0.2% of all subjects). We also dropped participants whose urban-rural status
286 was unknown in surveys that had recorded place of residence (0.05% of all participants). We

287 calculated mean BMI and the associated standard error by sex, age group (18 years, 19 years, 10-
288 year age groups from 20-29 years to 70-79 years and 80+ years) and place of residence (rural and
289 urban). All analyses incorporated appropriate sample weights and complex survey design, when
290 applicable, in calculating summary statistics. Countries typically use the rural and urban
291 classification of communities by their statistical offices at any given time both for survey design
292 and for reporting of population to the United Nations Population Division. The classification can
293 change, for example as previously-rural areas grow and industrialise and hence become, and are
294 (re)designated as, de novo cities. To the extent that the re-classifications keep up with changes in
295 the real status of each community, survey and population data reflect the status of each community
296 at the time of measurement. For surveys without information on place or residence, we calculated
297 age- and sex-stratified summary statistics for the entire sample, which represented the population-
298 weighted sum of rural and urban means.

299

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

305

306 Finally, we incorporated all nationally representative data from sources that were identified but
307 not accessed via the above routes, by extracting summary statistics from published reports. Data
308 were also extracted for nine STEPS surveys, one Countrywide Integrated Non-communicable
309 Diseases Intervention (CINDI) survey, and five sites of the WHO Multinational MONItoring of

310 trends and determinants in Cardiovascular disease (MONICA) project that were not deposited in
311 the MONICA Data Centre. Data were extracted from published reports only when reported by sex
312 and in age groups no wider than 20 years. We also used data from a previous global-data pooling
313 study⁴³ when such data had not been accessed through the routes described.

314

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

322

323 **Data inclusion and exclusion**

324 Data sources were included in NCD-RisC database if:

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

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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

356 In 2% of our data points, mostly extracted from published reports or from the a previous pooling
357 analysis,⁴³ mean BMI was not reported, but data were available for the prevalence of one or more
358 BMI categories, e.g., BMI \geq 30 kg/m². In order to use these data, we used previously-validated
359 conversion regressions² to estimate the missing primary outcome from the available BMI
360 prevalence metric(s). All sources of uncertainty in the conversion – including the sampling
361 uncertainty of the original data, the uncertainty of the regression coefficients and random effects,
362 and the regression residuals – were carried forward by using repeated draws from their joint
363 posterior distribution, accounting for the correlations among the uncertainties of regression
364 coefficients and random effects.

365

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

367 We used a Bayesian hierarchical model to estimate mean BMI by country, year, sex, age and place
368 of residence. The statistical model is described in detail in a statistical paper and related substantive
369 papers,^{2,35,40-44,48-51} and in Supplementary Information. In summary, we organised countries into
370 21 regions (Supplementary Table 2), mostly based on geography and national income. The
371 exception was high-income English-speaking countries (Australia, Canada, Ireland, New Zealand,
372 the UK, and the USA), grouped together in one region because BMI and other cardiometabolic
373 risk factors have similar trends in these countries, which can be distinct from other countries in
374 their geographical regions.^{2,49,50,52} Regions were in turn organised into nine super-regions.

375

376 The model had a hierarchical structure in which estimates for each country and year were informed
377 by its own data, if available, and by data from other years in the same country and from other
378 countries, especially those in the same region with data for similar time periods. The extent to

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

393
394 Here, we extended the model to make estimates for rural and urban populations following the
395 approach of Paciorek *et al.*^{35,51} This model includes a parameter representing the urban-rural BMI
396 difference, which is empirically estimated and allowed to vary by country and year. The model
397 uses all the data – those stratified by rural and urban place of residence as well as those reported
398 for the entire population. If data for a country-year were not stratified by place of residence, the
399 estimated BMI difference was informed by stratified data from other years and countries,
400 especially those in the same region with data from similar time periods.

401

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

412

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

418

419 **Validation of statistical model**

420 We calculated the difference between the posterior estimates from the model and data from
421 national studies. Median errors were very close to zero (0.03 kg/m² for women and -0.02 kg/m²
422 men) and median absolute errors were 0.32 kg/m² for women and 0.26 kg/m² for men, indicating
423 that the estimates were unbiased and had small deviations relative to national studies. The
424 differences were indistinguishable from zero at 5% statistical significance level.

425

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

445

446 Our statistical model also performed very well in the external validation tests, i.e. in estimating
447 mean BMI when data were missing. The estimates of mean BMI were unbiased, as evidenced with

448 median errors that were zero or close to zero globally (0.03 and -0.03 kg/m² for women and -0.15
449 and 0.00 kg/m² for men in the Tests 1 and 2, respectively), and less than ±0.20 kg/m² in every
450 subset of withheld data except 1985-1999 data in Test 1 for men where median error was -0.24
451 kg/m² (Extended Data Table 2). Most of the median errors were indistinguishable from zero at 5%
452 statistical significance level. The 95% credible intervals of estimated mean BMI covered 94-98%
453 of true data globally; coverage was >93% in all but one subset of withheld data. Median absolute
454 errors ranged from 0.52 to 1.09 kg/m² globally, and were at most 1.29 kg/m² in all subsets of
455 withheld data. Median absolute errors were smaller in Test 2, where a subset of data sources from
456 some countries are withheld, than in Test 1, where all data from some countries are withheld.
457 Given that we had data for 190 out of 200 countries for women and 183 out of 200 countries for
458 men, Test 2 is a better reflection of data availability in our analysis. For comparison, median
459 absolute differences for mean BMI between pairs of nationally representative surveys done in the
460 same country and in the same year was 0.46 kg/m², indicating that our estimates perform almost
461 as well as running two parallel surveys in the same country and year.

462

463 **Contributions of urbanisation and rural and urban BMI change to changes in population** 464 **mean BMI**

465 We calculated the contributions of the following components to change in population mean BMI
466 from 1985 to 2017: the contribution of change in BMI in rural areas, the contribution of change in
467 BMI in urban areas, and the contribution of urbanisation (i.e. increase in the proportion of people
468 living in urban areas). The first two parts were calculated by fixing the proportion of people living
469 in rural and urban areas to 1985 levels and allowing BMI to change as it did in the respective
470 population. The contribution of urbanisation was calculated by fixing BMI in rural and urban areas

471 to 2017 levels and allowing the proportion of people living in cities to change as it did. Percentage
472 contributions were calculated using posterior draws, with reported credible intervals representing
473 the 2.5th and the 97.5th percentiles of their posterior distributions.

474

475 *Change in mean BMI from 1985 to 2017*

476 *= contribution of change in rural BMI + contribution of change in urban BMI*

477 *+ contribution of change in the proportion of the population living in urban areas*

478 *= (Change in BMI_{rural 1985–2017})(percent living in rural areas₁₉₈₅)*

479 *+ (Change in BMI_{urban 1985–2017})(percent living in urban areas₁₉₈₅)*

480 *+ (Change in percent living in urban areas_{1985–2017})(BMI_{urban 2017} – BMI_{rural 2017})*

481

482 **Strengths and limitations**

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

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

498

499 Despite our large-scale data collation effort, some countries and regions had fewer data,
500 particularly the Caribbean and Polynesia and Micronesia. There were also fewer data sources
501 before 2000. This temporal and geographical sparsity of data led to wider uncertainty intervals for
502 these countries, regions and years. Although health surveys commonly use the rural and urban
503 classification of national statistical offices, cities and rural areas in different countries vary in their
504 demographic characteristics (e.g., population size or density), economic activity, administrative
505 structures, infrastructure, and environment. These differences appropriately exist because
506 countries themselves differ in terms of their demography, geography and economy. For example,
507 a country with a smaller population may use a lower threshold to urban designation than one with
508 a larger population, because its cities are naturally smaller even if they serve the same functions.
509 Official rural and urban classifications are used for resource allocation and planning for nutrition
510 and health,⁵³⁻⁵⁸ which makes them the appropriate unit for tracking outcomes. Nonetheless,
511 understanding the causes of change in rural and urban areas can be enriched with use of more
512 complex and multi-dimensional measures of urbanicity involving size, density, economic and
513 commercial activities and infrastructures.^{59,60} Finally, urbanisation could arise from a variety of
514 mechanisms: (1) natural increase due to excess births over deaths in cities compared to rural areas,
515 (2) rural to urban migration (often related to opportunities for work and education) and (3)
516 reclassification of previously-rural areas as they grow and industrialise and hence become, and are
517 (re)designated as, de novo cities. The contributions of these mechanisms to urbanisation vary

518 across countries. The use of time-varying rural versus urban classification of communities ensures
519 that in any year, the rural and urban strata represent the actual status of each community. However,
520 each of these mechanisms may have different implications for change in nutrition and physical
521 activity, and hence BMI.

522

523 **Data availability**

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

528

529 **Code availability**

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

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600

601 **Supplementary information**

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

604

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611

612 **Author contributions**

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

619

620 **Author information**

621 NCD Risk Factor Collaboration (NCD-RisC) members are listed at the end of the paper. ME
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627

628 **Corresponding author**

629 Correspondence to Majid Ezzati (majid.ezzati@imperial.ac.uk)

630 **Table 1. Contributions of rise in mean BMI in rural and urban populations and of**
631 **urbanisation (defined as an increase in the share of population who live in urban areas) to**
632 **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)

633 * Percentage contribution not reported because regional change in mean BMI, which appears in
634 the denominator of percentage contribution, was small (<0.5 kg/m²), leading to unstable estimates.
635 Urbanisation is defined as an increase in the share of population who live in urban areas.
636 Percentage contributions were calculated as detailed in Methods. The reported values are the

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

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

642

643 **Fig. 1. The difference between rural and urban age-standardised mean body-mass index**
644 **(BMI) in women in 1985 and in 2017, by country.** A positive number shows a higher urban
645 mean BMI and a negative number a higher rural mean BMI. We did not estimate the difference
646 between rural and urban areas for countries and territories where the entire population live in areas
647 classified as urban (Singapore, Hong Kong, Bermuda and Nauru) or rural (Tokelau). See Extended
648 Fig. 2 for mean BMI in national, rural and urban populations in 1985 and 2017. See Extended Fig.
649 6 for comparison of results between women and men.

650

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

658 **Fig. 3 Trends in age-standardised mean body-mass index (BMI) of rural and urban place of**
659 **residence, by region.** The lines show the posterior mean estimates and the shaded areas show the
660 95% credible intervals.

661

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

664 **Extended Data Table 2.** Results of model validation.

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

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

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

672 **Extended Data Fig. 4. The difference between rural and urban mean age-standardised body-**
673 **mass index (BMI) in 1985 versus in 2017.** Each point shows one country. A positive number
674 shows a higher urban mean BMI and a negative number a higher rural mean BMI. (A) countries
675 with an urban excess BMI that increased from 1985 to 2017. (B) countries with an urban excess
676 BMI that declined from 1985 to 2017. (C) countries with an urban excess BMI in 1985 that
677 reversed to an excess rural BMI in 2017. (D) countries with a rural excess BMI that increased from
678 1985 to 2017. (E) countries with a rural excess BMI that declined from 1985 to 2017. (F) countries
679 with a rural excess BMI in 1985 that reversed to an urban excess BMI in 2017.

680 **Extended Data Fig. 5** The relationship between mean BMI and prevalence of overweight (BMI
681 ≥ 25 kg/m²). Prevalence is plotted on a probit scale because which changes in an approximately
682 linear manner as mean changes. Each point represents an age-group-and-sex-specific mean,
683 stratified by place of residence as described in Methods and with more than 25 participants, from
684 data sources in the NCD-RisC database.

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