

- 1 **Title: Diminishing benefits of urban living for growth and development of school-aged**
- 2 **children and adolescents in the 21st century**
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4 **Optimal growth and development in late childhood and adolescence is critical for lifelong**
5 **health and wellbeing. Many health programmes narrowly focus on specific features of**
6 **diet and the environment in cities or rural areas¹⁻⁶, with little consideration of the**
7 **similarities or differences in growth and development outcomes in these settings. We**
8 **used 2,325 population-based studies, with measurement of height and weight in 71**
9 **million participants, to report trends from 1990 to 2020 in height and body-mass index**
10 **(BMI) of children and adolescents aged 5-19 years by rural and urban place of residence**
11 **in 200 countries and territories. In 1990, children and adolescents in cities were taller**
12 **than their rural counterparts in all but a few, mostly high-income, countries. By 2020, the**
13 **urban height advantage became smaller in most countries, and in many high-income**
14 **western countries reversed into a small urban disadvantage. The exception, where the**
15 **urban height advantage increased, was for boys in most countries in sub-Saharan Africa,**
16 **and in some countries in Oceania, South Asia, and the region of central Asia, Middle East**
17 **and north Africa. In many of these countries, successive cohorts of rural boys either did**
18 **not gain height or possibly even became shorter. The difference between age-**
19 **standardised mean BMI of children in urban and rural areas was <1.1 kg/m² in the vast**
20 **majority of countries throughout this period. Within this relatively small range, BMI**
21 **increased slightly more in cities than in rural areas, except in south Asia, sub-Saharan**
22 **Africa, and some countries in central and eastern Europe, where rural BMI increased**
23 **more. In many countries in sub-Saharan Africa, rural BMI surpassed the median of the**
24 **WHO reference population, and in some cases approached the threshold for being**
25 **overweight. Our results show that in much of the world, the growth and developmental**
26 **advantages of living in cities have diminished in the 21st century, whereas in much of**
27 **sub-Saharan Africa they have amplified. These global trends, and the macroeconomic,**
28 **social and health system policies that underlie them, have made rural Africa the**

29 **epicentre of suboptimal growth and development during school ages, with long-term**
30 **adverse consequences for health and wellbeing.**

31
32 Throughout school ages (i.e., ages 5-19 years), children and adolescents' growth and
33 development are influenced by their nutrition and environment at home, in the community and at
34 school⁷. Healthy growth and development at these ages helps consolidate gains and mitigate
35 inadequacies from early childhood, and vice versa,⁸⁻¹¹ with lifelong implications for health and
36 wellbeing. Until recently, growth and development of older children and adolescents received
37 substantially less attention than in early childhood and adulthood^{12,13}. Increasing policy attention
38 to health and nutrition during school years has been accompanied by a presumption that
39 differences in nutrition and environment lead to distinct, and generally less healthy, patterns of
40 growth and development in these ages in cities compared to their rural counterparts^{1,4,14-21}, even
41 though some empirical studies, in particular in the USA, have found that food quality and
42 nutrition are better in cities²²⁻²⁵.

43
44 Data on growth and developmental outcomes in school ages are needed, alongside data on
45 efficacy of specific interventions and policies, to select and prioritise policies and programmes
46 both for the increasing urban population and for children who continue to grow up in rural areas.
47 Consistent and comparable global data also help benchmark across countries and draw lessons
48 on good practice. Yet, globally there are far fewer data on growth trajectories in rural and urban
49 areas in these formative ages than for under-five children²⁶ or for adults²⁷. The available studies
50 have been in one country, at one point in time and/or in one sex and narrow age groups^{24,28-33};
51 the few studies³⁴⁻³⁶ that covered more than one country mostly focused on older girls, and used
52 at most a few dozen data sources and hence could not systematically measure long-term
53 trends. Consequently, many policies and programmes that aim to enhance healthy growth and
54 development in school ages focus narrowly, and somewhat generically, on specific features of

55 nutrition or the environment in either cities or rural areas¹⁻⁶, with little attention to similarities and
56 differences between relevant outcomes in these settings, nor to the heterogeneity of the urban-
57 rural difference across countries.

58

59 Here, we report on mean height and body-mass index (BMI) of school-aged children and
60 adolescents in rural and urban areas of 200 countries and territories from 1990 to 2020. Height
61 and BMI are anthropometric measures of growth and development that are influenced by the
62 quality of nutrition and healthiness of the living environment, and are highly predictive of health
63 and wellbeing throughout life in observational and Mendelian randomization studies³⁷⁻⁴¹. These
64 studies have shown that having low height and excessively low BMI increases the risk of
65 morbidity and mortality, and low height impairs cognitive development, and reduces educational
66 performance and work productivity in later life^{37,38,40}. Having high BMI in these ages increases
67 the lifelong risk of overweight and obesity and several non-communicable diseases, and might
68 contribute to poor educational outcomes^{39,41}.

69

70 We used 2,325 population-based studies that had measured height and weight in 71 million
71 participants in 194 countries (Extended Data Fig.1, Supplementary Table 2). We used these
72 data in a Bayesian hierarchical meta-regression model to estimate mean height and BMI of
73 children and adolescents aged 5-19 years by rural and urban place of residence, year and age
74 for 200 countries and territories. Details of data sources and statistical methods are provided in
75 Methods. Our results represent height and BMI for children and adolescents of the same age
76 over time, i.e., successive cohorts, in each country's rural and urban areas, and the difference
77 between the two. For presentation, we summarise the 15 age-specific estimates, for single
78 years of age from 5 through 19, through age standardisation which puts each country-year's
79 child and adolescent population on the same age distribution, and allows comparisons to be

80 made over time and across countries. We also show results, graphically and numerically, for
81 index ages of 5, 10, 15 and 19 years in Extended Data and Supplementary Materials.

82
83 In 1990, school-aged boys and girls who lived in cities had a height advantage (i.e., were taller)
84 compared to their rural counterparts, except in high-income countries where the urban height
85 advantage was either negligible (<1 cm for age-standardised mean height; posterior probability
86 (PP) for urban children being taller ranging from 0.51 to >0.99) or there was even a small rural
87 advantage (e.g., Belgium, Netherlands, and the UK) (PP for rural children being taller ranging
88 from 0.53 to >0.99 where there was a rural height advantage) (Fig. 1A and Extended Data Fig.
89 2). The largest height differences between cities and rural areas in 1990 occurred in some
90 countries in Latin America (e.g., Mexico, Guatemala, Panama and Peru), east and southeast
91 Asia (China, Indonesia and Vietnam), central and eastern Europe (Bulgaria, Hungary and
92 Romania), and sub-Saharan Africa (DR Congo and Rwanda). The urban height advantage in
93 boys and girls in the named countries ranged 2.5-5.0 cm and the PP of urban children being
94 taller than rural children was >0.99 (see Supplementary Table 3 for country-specific numerical
95 values of height in rural and urban areas, their difference, and the corresponding credible
96 intervals).

97
98 The urban-rural height gap in the late 20th century differed among low- and middle-income
99 countries based on how much children and adolescents in cities and rural areas had
100 approached versus fallen behind their peers in high-income countries, where there was little
101 difference in rural and urban height. In countries such as Bulgaria, Hungary and Romania,
102 urban children and adolescents' height approached that of high-income countries, whereas rural
103 children and adolescents still lagged behind, leading to a relatively large gap. In much of sub-
104 Saharan Africa and south Asia, the height of both urban and rural children and adolescents
105 lagged behind their peers in high-income countries, such that the urban-rural gap was relatively

106 small. In a third group of low- or middle-income countries that included Indonesia, Vietnam,
107 Panama, Peru, DR Congo and Rwanda, urban children were still shorter than in high-income
108 countries, while rural children lagged so far behind that the urban-rural gap became large.

109
110 By 2020, the urban height advantage in school ages became smaller in much of the world, and,
111 in many high-income western countries and some central European countries it disappeared or
112 reversed into a small (typically <1 cm) urban disadvantage (Fig. 1A, Extended Data Fig. 2 and
113 Extended Data Fig. 9). Countries with substantial convergence over these three decades were
114 in central and eastern Europe (e.g., Croatia), Latin America and the Caribbean (e.g., Argentina,
115 Brazil, Chile and Paraguay), east and southeast Asia (e.g., Taiwan), and for girls in central Asia
116 (e.g., Kazakhstan and Uzbekistan). The urban height advantage in the named countries
117 declined by ~1-2 cm from 1990 to 2020; the PP of urban-rural height difference having declined
118 ≥ 0.90 for named countries). In many other middle-income countries (e.g., China, Romania and
119 Vietnam), the urban-rural height gaps declined, but children and adolescents living in cities
120 remained taller than their rural counterparts (by 1.7-2.5 cm in the named countries for boys and
121 girls; PP of urban children being taller than rural children >0.99). The exception to this
122 convergence was for boys in most countries in sub-Saharan Africa and some countries in
123 Oceania, South Asia, and the region of central Asia, Middle East and north Africa, where the
124 urban height advantage slightly increased over these three decades. The largest increase in the
125 urban height advantage occurred in countries in East Africa such as Ethiopia (0.9 cm larger
126 height gap in 2020 than 1990; 95% credible interval (CrI) -0.9 to 2.9 and PP of increase = 0.93),
127 Rwanda (1.0, -0.7 to 3.0 and PP = 0.88), and Uganda (1.1, -0.6 to 3.1 and PP = 0.89). For girls
128 in many countries in sub-Saharan Africa and south Asia, the urban-rural gap remained largely
129 unchanged.

130

131 In middle-income and emerging economies (i.e., newly high-income and industrialised
132 countries) where rural children and adolescents' height converged to those in cities, successive
133 cohorts of rural children and adolescents outpaced their urban counterparts in becoming taller
134 and attained what urban children in the same countries had done decades earlier: growing to
135 heights closer to those seen in high-income countries (Fig. 2). Successive cohorts of rural
136 children and adolescents in sub-Saharan Africa did not experience the accelerated height gain
137 seen in rural areas of middle-income countries; and, in the case of boys, there was no gain, or
138 possibly even a decrease, in height, which in turn led to a persistence or even widening of the
139 urban-rural gap. As a result of these global trends, by 2020, the largest urban-rural height gaps
140 were seen in Andean and central Latin America (e.g., Bolivia, Panama and Peru), by up to 4.7
141 (4.0-5.5) cm for boys and 3.81 (3.3-4.3) cm for girls, and, especially for boys, in sub-Saharan
142 Africa (e.g., DR Congo, Ethiopia, Mozambique and Rwanda) by up to 4.2 (2.7-5.7) cm.

143
144 The urban-rural BMI difference was relatively small throughout these three decades: $<1.4 \text{ kg/m}^2$
145 in all countries and years, and $<1.1 \text{ kg/m}^2$ in all but nine countries, for age-standardised mean
146 BMI (Fig. 1B, Extended Data Fig. 3 and Extended Data Fig. 10). In 1990, the urban-rural BMI
147 gap was largest in sub-Saharan Africa (e.g., Ethiopia, Kenya and Malawi, South Africa and
148 Zimbabwe) and south Asia (e.g., Bangladesh and India), followed by parts of Latin America
149 (e.g., Mexico and Peru); the urban-rural BMI gap in the two sexes in the named countries
150 ranged from $0.4\text{-}1.2 \text{ kg/m}^2$ and the PP of urban children having higher BMI than rural children
151 ≥ 0.89 . At that time, girls and/or boys in rural areas of some of these countries had mean BMI
152 levels that were close to, and in some ages even below, the thresholds of being underweight
153 (i.e., $>1\text{SD}$ below the median of the WHO reference population^{42,43}).

154
155 From 1990 to 2020, the BMI of successive cohorts of both urban and rural children and
156 adolescents increased in all but a few high-income countries (e.g., Denmark, Italy and Spain)

157 (Fig. 3). There was heterogeneity in low- and middle-income countries in how much BMI
158 increased in cities versus rural areas. In the great majority of countries in sub-Saharan Africa
159 and south Asia, BMI of successive cohorts of children and adolescents increased more in rural
160 areas than in cities leading to a closing of the urban-rural difference; the reductions in the urban-
161 rural BMI gap ranged from 0.1 to 0.65 kg/m² for both girls and boys, and the PP of urban-rural
162 BMI difference declining from 1990 to 2020 ranged from 0.52 to 0.95. In both sub-Saharan
163 Africa and south Asia, these changes shifted the mean BMI of rural boys and girls out of the
164 range for being underweight; in many countries in sub-Saharan Africa this shift continued
165 beyond the median of the WHO reference population, and in some cases approached the
166 threshold for being overweight (i.e., >1SD above the median of the WHO reference population).
167 The opposite, i.e., a larger rise in urban BMI happened in most other low-and middle-income
168 countries, leading to a slightly larger urban BMI excess in 2020 than in 1990. High-income
169 countries and those in central and eastern Europe experienced a mix of increasing and
170 decreasing urban BMI excess but remained within a relatively small range (-0.3 to 0.6 kg/m² for
171 almost all countries) over the entire period of analysis; at the regional level the urban-rural BMI
172 difference changed by <0.25 kg/m² in these regions.

173
174 The urban height advantage was larger in boys than girls in most countries (Extended Data Fig.
175 7). Urban excess BMI was higher in boys in only about one half of countries; in the other half,
176 mostly in high-income western countries and those in sub-Saharan Africa, urban excess BMI
177 was higher in girls. The urban height advantage was slightly larger at five years of age than at
178 19 years of age in most low- and middle-income countries, especially for girls, but there was
179 little difference across ages in high-income regions and in central and eastern Europe
180 (Extended Data Fig. 4).

181

182 Since the introduction of modern sanitation in 19th century, cities provided substantial nutritional
183 and health advantages in high-income and subsequently low- and middle-income
184 countries^{25,44,45}. Our results show that, in the 21st century, during school ages these advantages
185 have disappeared in high-income countries and diminished in middle-income countries and
186 emerging economies in Asia, Latin America and the Caribbean, and parts of Middle East and
187 north Africa. Specifically, in countries of these regions, successive cohorts of school-aged
188 children and adolescents living in cities were outpaced by those in rural areas in terms of height
189 gain but gained slightly more weight, typically in the unhealthy range. This contrasted with the
190 world's poorest region, sub-Saharan Africa, where the urban height advantage persisted or
191 even expanded while rural mean BMI went beyond remedying underweight and surpassed the
192 median of the WHO reference population in 2020, hence consolidating the urban advantage.
193 South Asia had a mixed pattern of urban versus rural trends from 1990 to 2020, with children
194 and adolescents in rural areas gaining both more height and more weight for their height than
195 those in cities in. Importantly, our results also show that differences in height and BMI between
196 urban and rural populations within most countries are smaller than the differences across
197 countries, even those in the same region.

198
199 Long-term follow up studies have shown that children and adolescents do not achieve their
200 height potential without sufficient and diverse nutritious foods, or if they are exposed to repeated
201 or persistent infections which result in loss of nutrients^{37,46-48}. Studies with data on household
202 socioeconomic and environmental variables have indicated that these physiological
203 determinants of height are themselves affected by income, quality of the living environment, and
204 access to healthcare in rural as well as urban areas^{49,50}. This evidence indicates that, underlying
205 our finding on small urban-rural height differential in high-income countries may be a greater
206 abundance of nutritious foods, including some fortified foods, better healthcare, and greater
207 ability to finance programmes that promote healthy growth in countries with greater per-capita

208 income and better infrastructure. Variations across these countries in the urban-rural height gap
209 within this small range may be due to socioeconomic inequalities, poverty differentials and
210 differences in availability and cost of different foods between cities and rural areas, and whether
211 there are specific programmes that improve nutrition of disadvantaged rural and urban groups⁵¹⁻
212 ⁵³. The more striking changes in height in urban versus rural areas took place in middle-income
213 countries and emerging economies. Case studies in some countries where the of heights of
214 rural and urban children and adolescents converged show that the convergence was partly due
215 to using the growth in national income towards programmes and services that helped close
216 gaps in nutrition, sanitation and healthcare between different areas and social groups⁵⁴⁻⁵⁹. In
217 countries in central and eastern Europe, transition to a market economy and increases in trade
218 may have reduced disparity in access to, and seasonality of, healthy foods between urban and
219 rural areas⁶⁰, and partly underlie the convergence of height seen in our results. In contrast,
220 country case studies show that where economic growth was accompanied by large inequalities
221 in income, nutrition and/or services, the urban advantage persisted⁶¹⁻⁶⁷.

222
223 We also found that the urban-rural BMI gap, although dynamic, changed much less than the
224 BMI of either subgroup of the population, and less than commonly assumed when discussing
225 the role of cities in the obesity epidemic^{1,4,14,17,19,20}. Urban-rural BMI differences were especially
226 small in high-income countries, consistent with the evidence from a few countries that diets and
227 behaviours are affected more by household socioeconomic status than whether children and
228 adolescents live in cities or rural areas^{23,53,68-70}. Urban BMI excess increased slightly more in
229 middle-income countries in east and southeast Asia, Latin America and the Caribbean, and
230 Middle East and north Africa, a trend that was the opposite of the convergence in BMI of adults
231 in these same regions²⁷. Additional analysis of NCD-RisC data for young adults (20-29 and 30-
232 39 years) showed that the shift from a small divergent trend to convergence of BMI between
233 urban and rural areas happens in young adulthood (Extended Data Fig. 8), a period during

234 which there is substantial, but variable, weight gain among population subgroups⁷¹⁻⁷³. These
235 shifts in trends from adolescence to young adulthood might be a result of changes in diet and
236 energy expenditure that accompany changes in household structure, social and economic roles
237 and the living environment⁷⁴⁻⁸⁰.

238

239 The notable exception in the global trends was sub-Saharan Africa, where a stagnation or
240 reversal of height gain in rural areas led to persistence or widening of urban-rural height
241 differences, while the opposite happened for BMI. Case studies of specific countries have
242 indicated that unfavourable trends in nutrition in rural Africa, where the majority of the world's
243 poorest people live⁸¹, started from macroeconomic shocks in the late 20th century, and the
244 subsequent agriculture, trade and development policies that limited improvements in income
245 and services in rural Africa, which increased urban-rural income inequality, and emphasised
246 agricultural exports over local food security and diversity⁸²⁻⁸⁷. These macroeconomic factors in
247 turn led to less diverse diets, with higher caloric intake rather than shifting to protein- and
248 nutrient-rich foods (e.g., animal products, seafood, fruits and vegetables)⁸⁶⁻⁹⁴, while the slow
249 expansion of infrastructure and services in rural areas restricted improvements in other
250 determinants of healthy growth such as clean water and sanitation and health care^{94,95}.
251 Secondary factors underlying the observed trends in height and BMI in rural sub-Saharan Africa
252 may be changes in the age of puberty onset, which is influenced by weight gain during
253 childhood, and might affect height gain during the adolescent growth spurt and in late
254 adolescence^{96,97}, differential trends in survival beyond five years of age in rural and urban areas,
255 and possibly rural to urban migration.

256

257 Some researchers and international development organisations have argued that the
258 simultaneous rise, as a result of the COVID-19 pandemic and of the invasion of Ukraine, in
259 poverty and the cost of agricultural supplies like fertilisers and food, especially of nutrient-rich

260 foods, can hinder and set back the gains in growth and development throughout the world⁹⁸⁻¹⁰².
261 These setbacks may be particularly large in poor countries and population subgroups, both
262 those in rural areas who rely on food production and those in cities who purchase foods. These
263 groups, especially those in rural Africa, already face food insecurity^{91,103} and emerged in our
264 results as the most pronounced loci of suboptimal growth and development during school ages,
265 with potential long-term adverse consequences for health and wellbeing. As attention in global
266 health turns to older children and adolescents¹⁰⁴, there is a need for policies and programmes
267 that take into account patterns of growth and development in population subgroups. Our results
268 on growth and development outcomes in rural and urban areas of different countries, together
269 with the extant evidence on the role of poverty and poor infrastructure and services⁵⁰, indicate
270 that there is a need for social, economic and development policies that reduce poverty and
271 infrastructure inadequacies and inequalities across and within rural and urban areas^{105,106}.
272 Second, as these macro policies are implemented and with deteriorating global poverty and
273 food crises, based on the evidence from specific countries on the benefits of targeted nutrition
274 programmes and health and social services^{58,107-115}, there is an urgent need for programmes
275 that equalise nutrition, and health and social services for children and adolescents at home,
276 school and in the community.

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586

587 **Methods**

588 We estimated trends in mean height and BMI for children aged 5-19 years from 1990 to 2020 by
589 rural and urban place of residence for 200 countries and territories listed in Supplementary
590 Table 1. We pooled, in a Bayesian meta-regression, repeated cross-sectional population-based
591 data on height and BMI. Our results represent estimates of height and BMI for children and
592 adolescents of the same age over time, i.e., for successive cohorts, in each country's rural and
593 urban settings.

594

595 **Data sources**

596 We used a database on cardiometabolic risk factors collated by the Non-Communicable
597 Disease Risk Factor Collaboration (NCD-RisC). Data were obtained from publicly available
598 multi-country and national measurement surveys (e.g., Demographic and Health Surveys
599 (DHS), WHO-STEPwise approach to Surveillance (STEPS) surveys, and those identified via the
600 Inter-University Consortium for Political and Social Research, UK Data Service, and European
601 Health Interview & Health Examination Surveys Database). With the help of World Health
602 Organization (WHO) and its regional and country offices as well as World Heart Federation, we
603 identified and accessed population-based survey data from national health and statistical
604 agencies. We searched and reviewed published studies as detailed previously¹¹⁶ and invited
605 eligible studies to join NCD-RisC, as did we with data holders from earlier pooled analyses of
606 cardiometabolic risk factors¹¹⁷⁻¹²⁰. The NCD-RisC database is continuously updated through all
607 the above routes and periodic requests to NCD-RisC members to suggest additional sources in
608 their countries.

609

610 We carefully checked that each data source met our inclusion criteria, as listed below. Potential
611 duplicate data sources were first identified by comparing studies from the same country and
612 year, followed by checking with NCD-RisC members that had provided data about whether the

613 sources from the same country and year were the same or distinct. If two sources were
614 confirmed as duplicates, one was discarded. All NCD-RisC members were also periodically
615 asked to review the list of sources from their country, to verify that the included data meet the
616 inclusion criteria and are not duplicates.

617
618 For each data source, we recorded the study population, sampling approach, years of
619 measurement, and measurement methods. Only data that were representative of the population
620 were included. All data sources were assessed in terms of whether they covered the whole
621 country, multiple subnational regions (i.e., one or more subnational regions/provinces/states,
622 more than three cities or more than five rural communities), or one or a small number of
623 communities (limited geographical scope not meeting above national or subnational criteria),
624 and whether participants in rural, urban or both areas were included. As stated in the sections
625 on statistical model, these study-level attributes were used in the Bayesian hierarchical model to
626 estimate mean height and BMI by country, year, sex, age and place of residence using all
627 available data while taking into account differences in the populations from which different
628 studies had sampled. All submitted data were checked by at least two independent persons.
629 Questions and clarifications were discussed with NCD-RisC members and resolved before data
630 were incorporated in the database.

631
632 Anonymised individual data from the studies in the NCD-RisC database were reanalysed
633 according to a common protocol. We calculated mean height and mean BMI, and the
634 associated standard errors, by sex, single year of age from five to 19 years, and rural or urban
635 place of residence. Additionally, for analysis of height, participants aged 20-30 years were
636 included, assigned to their corresponding birth cohort, because mean height in these ages
637 would be at least that when they were aged 19 years, given that the decline of height with age
638 begins in the third and fourth decades of life¹²¹. All analyses incorporated sample weights and

639 complex survey design, when applicable, in calculating summary statistics. For studies that had
640 used simple random sampling, we calculated mean as average of all individuals within the
641 group and their associated standard errors (standard deviation divided by the square root of
642 sample size); for studies that had used multistage (stratified) sampling, we accounted for survey
643 design features including clusters, strata and sample weights, to weight each observation by the
644 inverse sampling probability and estimate standard error via Taylor series linearisation, as
645 implemented in the R ‘survey’ package¹²². Computer code was provided to NCD-RisC members
646 who requested assistance. For surveys without information on place of residence, we calculated
647 age- and sex-stratified summary statistics for the entire sample, which represented the
648 population-weighted sum of rural and urban means; data on the share of population in urban
649 versus rural areas were from the United Nations Population Division¹²³.

650
651 Additionally, summary statistics for nationally representative data from sources that were
652 identified but not accessed via the above routes were extracted from published reports. Data
653 were also extracted for two STEPS surveys that were not publicly available. We also included
654 data from a previous global-data pooling study¹²⁰, when not accessed through the above routes.

655

656 **Data inclusion and exclusion**

657 Data sources were included in the NCD-RisC height and weight database if:

- 658 • measured data on height and weight were available;
- 659 • study participants were five years of age and older;
- 660 • data were collected using a probabilistic sampling method with a defined sampling frame;
- 661 • data were from population samples at the national, subnational, or community level as
662 defined above; and
- 663 • data were from the countries and territories listed in Supplementary Table 1.

664

665 We excluded all data sources that were solely based on self-reported weight and height without
666 a measurement component because these data are subject to biases that vary by geography,
667 time, age, sex and socioeconomic characteristics¹²⁴⁻¹²⁶. Due to these variations, approaches to
668 correcting self-reported data may leave residual bias. We also excluded data sources on
669 population subgroups whose anthropometric status may differ systematically from the general
670 population, including:

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

679

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

686

687 We excluded <0.01% of all participants whose age was <18 years and whose data not reported
688 by single year of age because height and weight may have non-linear age associations in these

689 ages, especially during growth spurts. We excluded BMI data for females who were pregnant at
690 the time of measurement (<0.01% of all participants). We excluded <0.2% of all participants
691 who had recorded height outside the range <60 cm or >180 cm for ages <10 years; <80 cm or
692 >200 cm for ages 10-14 years; <100 cm or >250 cm for ages ≥ 15 years, recorded weight
693 outside the range <5 kg or >90 kg for age <10 years; <8 kg or >150 kg for ages 10-14 years;
694 <12 kg or >300 kg for ages ≥ 15 years, or recorded BMI outside the range <6 kg/m² or >40 kg/m²
695 for ages < 10 years; <8 kg/m² or >60 kg/m² for ages 10-14 years; <10 kg/m² or >80 kg/m² for
696 ages ≥ 15 years.

697

698 **Conversion of BMI prevalence metrics to mean BMI**

699 In 0.5% of our data points mostly extracted from published reports or from a previous pooling
700 analysis¹²⁰, mean BMI was not reported, but data were available for the prevalence of one or
701 more BMI categories, for example, BMI ≥ 30 kg/m². In order to use these data, we used
702 previously validated conversion regressions⁴³ to estimate the missing primary outcome from the
703 available BMI prevalence metric(s). Additional details on regression model specifications along
704 with the regression coefficients are reported on <https://github.com/NCD-RisC/ncdrisc-methods/>.

705

706 **Statistical model overview**

707 We used a Bayesian hierarchical meta-regression model to estimate mean height and BMI by
708 country, year, sex, age and place of residence using the aforementioned data. For presentation,
709 we summarised the 15 age-specific estimates, for single years of age from 5 through 19,
710 through age standardisation which puts each country-year's child and adolescent population on
711 the same age distribution, and hence allows comparisons to be made over time and across
712 countries. We generated age-standardised estimates by taking weighted means of age-specific
713 estimates, using age weights from the WHO standard population¹²⁷. We also show results,

714 graphically and numerically, for index ages of 5, 10, 15 and 19 years in Extended Data and
715 Supplementary Materials.

716
717 The statistical model is described in detail in statistical papers^{128,129}, related substantive
718 papers^{13,26,27,43,117-120,130} and in the section below on model specification. In summary, the model
719 had a hierarchical structure in which estimates for each country and year were informed by its
720 own data, if available, and by data from other years in the same country and from other
721 countries, especially those in the same region and super-region, with data for similar time
722 periods. The extent to which estimates for each country-year were influenced by data from other
723 years and other countries depended on whether the country had data, the sample size of the
724 data, whether they were national, and the within-country and within-region variability of the
725 available data. For the purpose of hierarchical analysis, countries were organised into 21
726 regions, mostly based on geography and national income (Supplementary Table 1). Regions
727 were in turn organised into nine super-regions.

728
729 We used observation year, i.e., the year in which data were collected, as the time-scale for the
730 analysis of BMI and birth year as the time scale for the analysis of height, consistent with
731 previous
732 analyses^{13,43,131}. Time trends were modelled through a combination of a linear term, to capture
733 gradual long-term change, and a second-order random walk, which allows for non-linear
734 trends¹³², both modelled hierarchically. The age associations of height and BMI were modelled,
735 using cubic splines, to allow non-linear changes over age, including periods of rapid as well as
736 slow rise.. Periods of rapid rise represent adolescent growth spurts, which occur earlier in girls
737 than boys^{42,133,134}, was reflected in placement of spline knots for boys and girls, respectively, as
738 detailed in the section on model specification. Spline coefficients were allowed to vary across

739 countries, based on their own data as well as in a hierarchical structure, as previously
740 described¹³⁰.

741
742 The model also accounted for the possibility that height or BMI in subnational and community
743 samples might differ systematically from nationally representative samples and have larger
744 variation than in national studies. These features were accounted for through the inclusion of
745 fixed-effect and random-effect terms for subnational and community data as detailed in the
746 model specification section below. The fixed effects accounted for systematic differences
747 between subnational or community studies and national studies. The inclusion of random effects
748 allowed national data to have greater influence on the estimates than subnational or community
749 data with similar sample sizes, because the subnational and community data have additional
750 variance from the random effect terms. Both were estimated empirically as a part of model
751 fitting.

752
753 Following the approach of previous papers^{26,27,128}, the model included parameters representing
754 the urban-rural height or BMI difference, which is empirically estimated and allowed to vary by
755 country, year, and age. We further expanded the model to allow urban-rural difference in height
756 or BMI to vary by age, as height or weight with age may vary between rural versus urban
757 children. If data for a country-year-age group contained mixed urban and rural children, but
758 were not stratified by place of residence (21% of all data sources), the estimated BMI difference
759 was informed by stratified data from other age groups, years and countries, especially those in
760 the same region with data from similar time periods and/or ages.

761
762 **Statistical model specification**

763 As stated earlier, for each data source, we calculated mean height and BMI, together with
764 corresponding standard errors, stratified by sex, age and rural or urban place of residence. For

765 sources that did not stratify the sample on the place of residence, we obtained age-and-sex-
766 stratified data. Each study contributed up to 30 mean BMI data points or 32 mean height data
767 points for each sex with the exact number depending how many age groups were represented
768 in the study, and whether or not the study provided data stratified on urban and rural place of
769 residence. The likelihood for an observation at urbanicity level s (urban-only, rural-only or
770 mixed; referred to as stratum hereinafter) and age group h , with age z , from study i , carried out
771 in country j at time t is:

$$y_{s,h,i} \sim N(a_{j[t]} + b_{j[t]}t_i + u_{j[t],t_i} + \gamma_i(z_h) + \mathbf{X}_i\boldsymbol{\beta} + e_i + I_{s,i}[p_{j[t]} + q_{j[t]}t_i + r_{j[t]}z_h + d_i], SD_{s,h,i}^2/n_{s,h,i} + \tau_i^2)$$

772
773 where the country-specific intercept and linear time slope from the j^{th} country ($j = 1 \dots J$, where J
774 = 200 which is the total number of countries in our analysis) are denoted a_j and b_j , respectively.
775 We describe the hierarchical model used for the a 's and b 's in *Linear components of country*
776 *time trends* section. Letting $T = 31$ be the total number of years from 1990 to 2020, the T -vector
777 u_j captures smooth non-linear change over time in country j , as described in *Non-linear change*
778 section. The age effects of the h^{th} age group (with age z) in study i are denoted by γ_i ; we
779 describe the age model in *Age model* section. The matrix \mathbf{X} contains terms describing whether
780 studies were representative at the national, sub-national or community level. In addition, a
781 random effect, e_i , is estimated for each study, described in *Study-level term and study-specific*
782 *random effects* section.

783

784 *Linear components of country time trends*

785 The model had a hierarchical structure: studies were nested in countries, which were nested in
786 regions (indexed by k), which were nested in super-regions (indexed by l), which were, of
787 course, all nested in the globe (see Supplementary Table 1 for list of countries in each region,
788 and regions in each super-region). This structure allowed the model to share information across

789 units to a greater degree when data were non-existent or weakly informative (e.g., have a small
 790 sample size or were not nationally representative), and to a lesser extent in data-rich countries
 791 and regions¹³⁵.

792

793 The a and b terms are country-specific linear intercepts and time slopes with terms at each level
 794 of the hierarchy, denoted by the superscripts c, r, s , and g , respectively:

$$a_j = a_j^c + a_{k[j]}^r + a_{l[k]}^s + a^g$$

$$b_j = b_j^c + b_{k[j]}^r + b_{l[k]}^s + b^g$$

$$a_j^x \sim N(0, \kappa_a^x)$$

$$795 \quad b_j^x \sim N(0, \kappa_b^x) \text{ (where } x = \{c, r, s\})$$

796

797 The κ terms are each assigned a flat prior on the standard deviation scale¹³⁶. We also assigned
 798 flat priors to a^g and b^g .

799

800 *Non-linear change*

801 Mean BMI or height may change non-linearly over time^{13,43,116,120,131}. We captured smooth non-
 802 linear change in time in urban and rural strata of country j using the vector u_j . Just as a_j and b_j
 803 are each defined as the sum of country, region, super-region, and global components, we
 804 defined:

$$u_j = u_j^c + u_{k[j]}^r + u_{l[k]}^s + u^g$$

805

806 In order to allow the model to differentiate between the degrees of non-linearity that exist at the
 807 country, region, super-region, and global levels, we assigned each of the u 's four components a
 808 Gaussian autoregressive prior as in Breslow and Clayton¹³⁷ and Rue and Held¹³². In particular,
 809 the T -vectors u_j^c ($j = 1 \dots J$), u_k^r ($k = 1 \dots K$), u_l^s ($l = 1 \dots L$), and u^g each have a normal prior

810 with mean zero and precision $\lambda_c P$, $\lambda_r P$, $\lambda_s P$, and $\lambda_g P$ respectively, where the scaled precision
 811 matrix P in the Gaussian autoregressive prior penalizes first and second differences:

$$\begin{aligned}
 P &= \begin{bmatrix} 1 & 0 & 0 & \dots & 0 \\ -2 & 1 & 0 & \dots & 0 \\ 1 & -2 & 1 & \dots & 0 \\ 0 & 1 & -2 & \dots & 0 \\ 0 & 0 & 1 & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \dots & 1 \end{bmatrix} \begin{bmatrix} 1 & -2 & 1 & 0 & 0 & \dots & 0 \\ 0 & 1 & -2 & 1 & 0 & \dots & 0 \\ 0 & 0 & 1 & -2 & 1 & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & 0 & 0 & \dots & 1 \end{bmatrix} \\
 &= \begin{bmatrix} 1 & -2 & 1 & 0 & 0 & \dots & 0 \\ -2 & 5 & -4 & 1 & 0 & \dots & 0 \\ 1 & -4 & 6 & -4 & 1 & \dots & 0 \\ 0 & 1 & -4 & 6 & -4 & \dots & 0 \\ 0 & 0 & 1 & -4 & 6 & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & 0 & 0 & \dots & 1 \end{bmatrix}.
 \end{aligned}$$

812
 813 P is multiplied by the estimated precision parameters λ_c , λ_r , λ_s , and λ_g , thus up-weighting or
 814 down-weighting the strength of its penalties and ultimately determining the degree of smoothing
 815 at each level. For each of the four precision parameters, we used a truncated flat prior on the
 816 standard deviation scale ($1/\sqrt{\lambda}$) as recommended by Gelman¹³⁶. We truncated these priors such
 817 that $\log \lambda \leq 20$ for each of the four λ 's. This upper bound is enforced as a computational
 818 convenience: models with $\log \lambda > 20$ are treated as equivalent to a model with $\log \lambda = 20$ as they
 819 essentially have no extra-linear variability in time. In practice, this upper bound had little effect
 820 on the parameter estimates. Furthermore, we order the λ 's a priori: $\lambda_c < \lambda_r < \lambda_s < \lambda_g$. This prior
 821 constraint conveys the natural expectation that, for example, the global BMI trend has less
 822 extra-linear variability than the trend of any given region.

823

824 The matrix P has rank $T - 2$, corresponding to a flat, improper prior on the mean and the slope
 825 of the u_j^c 's, the u_k^r 's, the u_l^s 's and of u^g , and is not invertible¹³⁸ Thus, we have a proper prior in a
 826 reduced-dimension space as discussed in Rue and Held¹³², with the prior expressed as:

$$P(u_j^c | \lambda_c) \propto \lambda_c^{\frac{T-2}{2}} \exp\left\{-\frac{\lambda_c}{2} u_j^{c'} P u_j^c\right\}$$

827
 828 Note that if u_j^c had a non-zero mean, this would introduce non-identifiability with respect to a_j^c .
 829 By the same token, b_j^c would not be identified if u_j had a non-zero time slope, and similarly for
 830 the other means and slopes. Thus, in order to achieve identifiability of the a 's, b 's, and u 's, we
 831 constrained the mean and slope of u^g and of each u^s , u^r , and u^c to be zero. Enforcing
 832 orthogonality between the linear and non-linear portions of the time trends means that each can
 833 be interpreted independently.

834
 835 In cases where we have observations for at least two different time points, this improper prior
 836 will not lead to an improper posterior since the data will provide information about the mean and
 837 slope. However, to enforce the desired orthogonality between the linear and non-linear portions
 838 of the model, we constrained the mean and slope of the u_j^c 's, u_k^r 's, u_l^s 's, and of u^g to be zero,
 839 using the approach described by Rue and Held¹³².

840
 841 For the six countries with no height data, and seven countries with no BMI data, we took the
 842 Moore-Penrose pseudoinverse of P ¹³⁹, setting to infinity those eigenvalues that correspond to
 843 the non-identifiability. This effectively constrains the non-identified portions of the model to zero,
 844 as the corresponding variances are set to zero¹³⁷; in this case the Rue and Held correction¹³² is
 845 not needed. An intermediate case occurs when data are observed for only one time point in a
 846 country. In this case, the full conditional precision has rank $T - 1$ because the mean but not the

847 linear trend of u_j^c is identified by the data. We thus constrained the linear trend of u_j^c to zero by
 848 taking the generalised inverse of the full conditional precision. We then constrained the mean of
 849 u_j^c to zero using the one-dimensional version of the correction described in Rue and Held¹³².

850

851 *Age Model*

852 To capture sex-specific patterns of growth, especially adolescent growth spurts, we modelled
 853 age using cubic splines. The number and position of splines' knots were selected based on a
 854 combination of physiological and statistical considerations, as described in a national level
 855 analysis¹³. For age group h with age z , in study i , the age effect for height and BMI is given,
 856 respectively, by:

857
$$\gamma_i(z_h) = \gamma_{1i}z_h + \gamma_{2i}z_h^2 + \gamma_{3i}z_h^3 + \gamma_{4i}(z_h - k_1)_+^3 + \gamma_{5i}(z_h - k_2)_+^3 + \gamma_{6i}(z_h - k_3)_+^3 + \gamma_{7i}(z_h - k_4)_+^3 \quad (\text{height})$$

858
$$\gamma_i(z_h) = \gamma_{1i}z_h + \gamma_{2i}z_h^2 + \gamma_{3i}z_h^3 + \gamma_{4i}(z_h - k_1)_+^3 + \gamma_{5i}(z_h - k_2)_+^3 \quad (\text{BMI})$$

859

860 For height, four spline knots were placed at ages $\{k_1, k_2, k_3, k_4\} = \{8, 10, 12, 14\}$ for girls and at
 861 ages $\{k_1, k_2, k_3, k_4\} = \{10, 12, 14, 16\}$ for boys. For BMI, we used two spline knots (at ages 10
 862 and 15 years) because, at the population level, changes in BMI with age are smoother than
 863 those in height^{13,42,133}. Each of the spline coefficients was allowed to vary across countries, with
 864 a hierarchical structure as described in a previous paper¹³⁰, using the equation below, where ψ
 865 is the global intercept and c, r, s are the country, region and super-region random intercepts,
 866 respectively, The age effect coefficients ($\gamma_{k,i}$) for each age group h , with age z , are given by:

867
$$\gamma_{k,i} = \psi_k + c_{k,j[i]} + r_{k,l[i]} + s_{k,m[i]}$$

$$c_{k,j} \sim N(0, \sigma_{k,c}^2)$$

$$r_{k,l} \sim N(0, \sigma_{k,r}^2)$$

$$s_{k,l} \sim N(0, \sigma_{k,s}^2)$$

868 A flat improper prior was placed of each of the σ_k 's.

869

870 *Study-level term and study-specific random effects*

871 Mean height or BMI from individual studies may deviate from the true country-year mean due to
872 factors associated with sampling, response or measurement. We used a study-level term to
873 help account for potential systematic differences associated with data sources that are
874 representative of sub-national and community populations. Our model thus included time-
875 varying offsets (referred to as fixed effects above) for sub-national and community data in the
876 term $X_i\beta$:

$$X_i\beta = \beta_1 I \{X_{j[i],t[i]}^{cvrg} = \text{subnational}\} + \beta_2 I \{X_{j[i],t[i]}^{cvrg} = \text{subnational}\} t_i + \\ \beta_3 I \{X_{j[i],t[i]}^{cvrg} = \text{community}\} + \beta_4 I \{X_{j[i],t[i]}^{cvrg} = \text{community}\} t_i$$

877

878 where $X_{j[i],t[i]}^{cvrg}$ is the indicator for whether the coverage of study i , in country j and year t , is sub-
879 national or community.

880

881 Even after accounting for sampling variability, national studies may still not reflect the country's
882 true mean BMI level with perfect accuracy, and sub-national and community studies have even
883 larger variability. In study i , the study-specific random effect e_i allows all age groups from the
884 same study to have an unusually high or an unusually low mean after conditioning on the other
885 terms in the model. Each e_i is assigned a normal prior with variance depending on whether
886 study i is representative at the national, sub-national or community level. Random effects from
887 national studies were constrained to have smaller variance (v_n) than random effects of sub-
888 national studies (v_s), which were in turn constrained to have smaller variance than community
889 studies (v_c). To make country-level predictions, we set $e_i = 0$, thus not including random effects
890 due to imperfections in study design and to within-country variability of BMI means.

891

892 *Urban and rural strata*

893 To model mean height and BMI by urban and rural places of residence, the model included
894 offsets for the two strata. The offsets were captured by country-specific intercept, linear time
895 and age effects, using a centred indicator term ($I_{s,i}$):

$$896 \quad I_{s,i} [p_{j[i]} + q_{j[i]}t_i + r_{j[i]}z_h + d_i] \quad (\text{where, } I_{s,i} = -1 + 2X_{s,i}^{urb})$$

897 with

$$X_{s,i}^{urb} = \begin{cases} 1, & \text{if stratum } s \text{ contains only urban individuals} \\ 0, & \text{if stratum } s \text{ contains only rural individuals} \\ X_{j[i],t[i]}^{urb} & \text{if stratum } s \text{ contains a mixture of urban and rural individuals} \end{cases}$$

898 In other words, for data not stratified by place of residence, the model treats the unstratified
899 mean height or BMI as equivalent to the weighted sum of the (unobserved) urban sample mean
900 BMI and rural sample mean BMI, with the weights based on the proportion of the study
901 country's population living in urban areas in the year of the survey ($X_{j[i],t[i]}^{urb}$).

902

903 The intercept (p) and slope (q) terms capture the country-to-country variation in the magnitude
904 of the height or BMI difference between urban and rural populations and how the difference
905 changes over time. The slope (r) captures the country-to-country variation in the BMI or height
906 difference between urban and rural populations across age groups. These were specified with
907 the same geographical hierarchy as the country-specific intercepts (a) and slopes (b):

$$908 \quad p_j = p_j^c + p_{k[j]}^r + p_{l[k]}^s + p^g,$$

$$909 \quad q_j = q_j^c + q_{k[j]}^r + q_{l[k]}^s + q^g,$$

$$910 \quad r = r_j^c + r_{k[j]}^r + r_{l[k]}^s + r^g,$$

$$911 \quad p_j^x \sim N(0, \kappa_p^x),$$

$$912 \quad q_j^x \sim N(0, \kappa_q^x),$$

$$913 \quad r_j^x \sim N(0, \kappa_r^x) \quad (\text{where, } x = \{c, r, s\})$$

914 The study random effect term d_i incorporates deviations from the country-level urban-rural
915 difference in each study and is analogous to e_i .

916

917 *Residual age-by-study variability*

918 The age patterns across communities within a given country may differ from their country's
919 overall age pattern. This within-study variability cannot be captured by the e 's, which are equal
920 across age-specific observations in each study, so we include an additional variance component
921 for each study, τ_i^2 . We again assume that there is less residual variability in national studies
922 than in sub-national and community-level studies, with $\tau_n^2 < \tau_s^2 < \tau_c^2$.

923

924 **Model implementation**

925 All analyses were done separately by sex because age, geographical and temporal patterns of
926 height and BMI differ between girls and boys^{13,43}. We fitted the statistical model using Markov
927 chain Monte Carlo (MCMC). We started 35 parallel MCMC from randomly-generated over-
928 dispersed starting values. For computational efficiency, each chain was run for a total of 75,000
929 iterations. All chains converged to the same target distribution within this number, but with the
930 over-dispersed initial values, the length of burn-in required to converge to the target distribution
931 varied. After the runs were completed, we used trace plots to monitor convergence and select
932 chains that had completed burn-in within 35,000 iterations. This resulted in 16 chains for boys
933 and 17 for girls for BMI; 14 chains for boys and 16 for girls for height. Within each chain, post-
934 burn-in iterations were thinned by keeping every 10th iteration, which were then combined for all
935 chains and further thinned to a final set of 5,000 draws of the model parameter estimates. We
936 used the posterior distribution of the model parameters to obtain the posterior distributions of
937 our outcomes: mean urban and rural height and BMI, and the urban-rural difference in mean
938 height and BMI. Posterior estimates were made for by one-year age groups from five to 19

939 years, as well as for age-standardised outcomes, by year. The reported credible intervals
940 represent the 2.5th and the 97.5th percentiles of the posterior distributions. We also report the
941 posterior standard deviation of estimates, and posterior probability that the estimated change in
942 height or BMI in rural or urban areas, and in the estimated urban-rural height or BMI difference
943 over time, represents a true increase or decrease.

944
945 Convergence was confirmed for the country-sex specific posterior outcomes – namely mean
946 urban height and BMI, mean rural height and BMI and the urban-rural difference in mean height
947 and BMI – for reporting ages (5, 10, 15, 19 years and age-standardised) and years (1990 and
948 2020) using the R-hat diagnostic^{140,141}. For height, the 2.5th to 97.5th percentiles of the R-hats for
949 the reporting ages and years were 0.999-1.010 for girls and 0.999-1.004 for boys. For BMI, the
950 2.5th to 97.5th percentiles of the R-hats were 0.999-1.004 for girls and 0.999-1.005 for boys.

951
952 We applied the pool-adjacent-violators algorithm, a monotonic regression that uses an iterative
953 algorithm based on least squares to fit a free-form line to a sequence of observations such that
954 the fitted line is non-decreasing^{142,143}, on the posterior height estimates to ensure that each birth
955 cohort's height increased monotonically with age. In practice, this had little effect on the results,
956 with height at age 19 years adjusted by an average 0.26 cm or less for both boys and girls.

957
958 **Strengths and limitations**

959 An important strength of our study is its novel scope of presenting consistent and comparable
960 estimates of urban and rural height and BMI among school-aged children and adolescents,
961 which is essential to formulate and evaluate policies that aim to improve health in these
962 formative ages. We used an unprecedented amount of population-based data from 194
963 countries and territories covering ~99% of the world's population. We maintained a high level of
964 data quality and representativeness through repeated checks of study characteristics against

965 our inclusion and exclusion criteria, and did not use any self-reported data to avoid bias in
966 height and weight. Data were analysed according to a consistent protocol, and the
967 characteristics and quality of data from each country were rigorously verified through repeated
968 checks by NCD-RisC members. We used a statistical model that used all available data and
969 took into account the epidemiological features of height and BMI by using non-linear time trends
970 and age associations. The model used the available information on the urban-rural difference in
971 height and BMI and estimated the age- and time-varying urban-rural difference for all countries
972 hierarchically.

973

974 Despite our extensive efforts to identify and access data, some countries and regions had fewer
975 data, especially those in the Caribbean and Polynesia, Micronesia, and sub-Saharan Africa. Of
976 the studies used, fewer than half had data for children aged 5-9 years compared with nearly
977 90% with data for children and adolescents aged 10-19 years, which increases the uncertainty
978 of findings. The scarcity of data is reflected in the larger uncertainty of our estimates for these
979 countries and regions, and younger age groups. This reflects the need to systematically include
980 school-aged children in both health and nutrition surveys, and especially in countries where
981 school enrolment is high, to use schools as a platform for monitoring growth and developmental
982 outcomes for entire national populations and key subgroups such as those in rural and urban
983 areas. Though urban and rural classifications are commonly based on national statistical offices
984 definitions, classification of cities and rural areas may, appropriately, vary by country due to their
985 demographic characteristics (e.g., population size or density), economic activity, administrative
986 structures, infrastructure and environment. Similarly, urbanisation takes place through a variety
987 of mechanisms such as changes in fertility in rural and urban areas, migration, and
988 reclassification of previously rural areas to urban as they grow and industrialise. Each of these
989 mechanisms may have different implications for nutrition and physical activity, and hence height
990 and/or BMI, and should be a subject of studies that follow individual participants and changes in

991 their place of residence. Finally, there is variation in growth and development of children within
992 rural or urban areas, based on household socioeconomic status and community characteristics
993 that affect access to and the quality of nutrition, the living environment and healthcare^{29,50,144}.
994 Among these, in some cities, a large number of families live in slums^{25,145}. School-aged children
995 and adolescents in slums have nutrition, environment and healthcare access that is typically
996 worse than other residents of the city, although often better than those in rural areas^{25,145-148}.

997

998 **Data availability**

999 Estimates of mean BMI and height by country, year, sex, single year of age as well as age-
1000 standardised, and place of residence (urban and rural) will be available from www.ncdrisc.org in
1001 machine-readable numerical format and as visualisations upon publication of the paper. Input
1002 data from publicly available sources can also be downloaded from www.ncdrisc.org upon
1003 publication of the paper. For other data sources, contact information for data providers can be
1004 obtained from www.ncdrisc.org.

1005

1006 **Code availability**

1007 The computer code for the Bayesian hierarchical model as well as code to generate tables and
1008 figures used in this work will be available at www.ncdrisc.org upon publication of the paper.

1009

1010

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1096 **Supplementary information**

1097 This file contains Supplementary Tables 1-4, Supplementary Figures 1-6 and Supplementary
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1099

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2457

2458 **Fig. 1. Change in the urban-rural height and body-mass index (BMI) difference from 1990**
2459 **to 2020.**

2460

2461 (A) Change in urban-rural difference in age-standardised mean height in relation to change in
2462 age-standardised mean rural height. (B) Change in urban-rural difference in age-standardised
2463 mean BMI in relation to change in age-standardised mean rural BMI. (C) Change in urban-rural
2464 difference in age-standardised mean height and urban-rural difference in age-standardised
2465 mean BMI.

2466

2467 Each solid arrow in lighter shade shows one country, beginning in 1990 and ending in 2020.
2468 The dashed arrows in darker shade show the regional averages, calculated as the unweighted
2469 arithmetic mean of the values for all countries in each region along the horizontal and vertical
2470 axes. For urban-rural difference, a positive number shows higher urban mean height and BMI
2471 and a negative number shows higher rural mean height and BMI.

2472

2473 See Extended Data Fig. 2 and Extended Data Fig. 3 for urban-rural differences in age-
2474 standardised mean height and BMI, and their change over time shown as maps, together with
2475 uncertainties in the estimates. See Extended Data Fig. 4 for results at ages 5, 10, 15 and 19
2476 years.

2477

2478 We did not estimate the difference between rural and urban height for areas classified as
2479 entirely urban (Bermuda, Kuwait, Nauru and Singapore) or entirely rural (Tokelau).

2480 **Fig. 2. Urban and rural height in 2020 and change from 1990 to 2020.**

2481

2482 The maps show age-standardised mean height in 2020 and change from 1990 to 2020, by
2483 urban and rural place of residence for girls and boys. The density plot below each map shows
2484 the distribution of estimates across countries. The top right graph in each panel shows the age-
2485 standardised mean height in 2020 for all countries, together with their 95% credible intervals.
2486 Countries are ordered by region and super-region. The bottom right graph in each panel shows
2487 the change from 1990 to 2020 in mean height in relation to the uncertainty of the change
2488 measured by posterior standard deviation. Each point shows one country. Shaded areas show
2489 the posterior probability (PP) of an estimated change being a true increase or decrease. The PP
2490 of a decrease is one minus that of an increase. If an increase in mean height is
2491 statistically indistinguishable from a decrease, the PP of an increase and a decrease is 0.50.
2492 PPs closer to 0.50 indicate more uncertainty, those towards 1 indicate more certainty of change.

2493

2494 See Extended Data Fig. 5 for a map of PPs of the estimated change. See Supplementary
2495 Figure 3 for results at ages 5, 10, 15 and 19 years. See Supplementary Table 3 for numerical
2496 results, including credible intervals, as age-standardised and at ages 5, 10, 15 and 19 years.

2497

2498 We did not estimate mean rural height in areas classified as entirely urban (Bermuda, Kuwait,
2499 Nauru and Singapore), mean urban height in areas classified as entirely rural (Tokelau), or their
2500 change over time in these areas, as indicated by grey colour.

2501 **Fig. 3. Urban and rural body-mass index (BMI) in 2020 and change from 1990 to 2020.**

2502

2503 The maps show age-standardised mean BMI in 2020 and change from 1990 to 2020, by urban
2504 and rural place of residence for girls and boys. See Fig. 2 caption for descriptions of other
2505 sections of the figure and for definitions.

2506

2507 See Extended Data Fig. 6 for a map of posterior probabilities of the estimated change. See
2508 Supplementary Figure 4 for results at ages 5, 10, 15 and 19 years. See Supplementary Table 4
2509 for numerical results, including credible intervals, as age-standardised and at ages 5, 10, 15 and
2510 19 years.

2511

2512 We did not estimate mean rural BMI in areas classified as entirely urban (Singapore, Bermuda
2513 and Nauru), mean urban BMI in areas classified as entirely rural (Tokelau), or their change over
2514 time, as indicated by grey colour.

2515 **Extended Data Fig. 1. Number of data sources used in the analysis, by country.**

2516 **Extended Data Fig. 2. Urban-rural height difference in 2020 and change from 1990 to**
2517 **2020.**

2518
2519 The top map in each panel shows the urban-rural difference in age-standardised mean height in
2520 2020 for girls and boys. A positive number shows higher urban mean height and a negative
2521 number shows higher rural mean height. The bottom map in each panel shows the change from
2522 1990 to 2020. The density plot below each map shows the distribution of estimates across
2523 countries. The top right graph in each panel shows the urban-rural difference in age-
2524 standardised mean height in relation to the uncertainty of the change measured by posterior
2525 standard deviation. The bottom right graph in each panel shows the change from 1990 to 2020
2526 in urban-rural difference in mean height in relation to the uncertainty of the change measured by
2527 posterior standard deviation. Each point shows one country. Shaded areas show the posterior
2528 probability (PP) of a true difference (top right panel) and of a true increase or decrease in
2529 difference (bottom right panel).

2530
2531 See Extended Data Fig. 9 for PPs of the urban-rural difference in age-standardised mean height
2532 and its change. See Supplementary Figure 5 for results at ages 5, 10, 15 and 19 years.

2533
2534 We did not estimate the difference between rural and urban height for areas classified as
2535 entirely urban (Bermuda, Kuwait, Nauru and Singapore) or entirely rural (Tokelau), as indicated
2536 by grey colour.

2537 **Extended Data Fig. 3. Urban-rural body-mass index (BMI) difference in 2020 and change**
2538 **from 1990 to 2020.**

2539

2540 The maps show the urban-rural difference in age-standardised mean BMI in 2020, and its
2541 change from 1990 to 2020 for girls and boys. A positive number shows higher urban mean BMI
2542 and a negative number show higher rural mean BMI. See Extended Data Fig. 2 caption for
2543 descriptions of other sections of the figure.

2544

2545 See Extended Data Fig. 10 for posterior probabilities of the urban-rural difference in age-
2546 standardised mean BMI and its change. See Supplementary Figure 6 for results at ages 5, 10,
2547 15 and 19 years.

2548

2549 We did not estimate the difference between rural and urban BMI for areas classified as entirely
2550 urban (Bermuda, Kuwait, Nauru and Singapore) or entirely rural (Tokelau), as indicated by grey
2551 colour.

2552 **Extended Data Fig. 4. Change in the urban-rural height and body-mass index (BMI)**
2553 **difference from 1990 to 2020, by age.**

2554

2555 (A) Change in urban-rural difference in mean height in relation to change in mean rural height at
2556 ages 5, 10, 15 and 19 years. (B) Change in urban-rural difference in mean BMI in relation to
2557 change in mean BMI in at ages 5, 10, 15 and 19 years. (C) Change in urban-rural difference in
2558 mean height and urban-rural difference in mean BMI at ages 5, 10, 15 and 19 years.

2559

2560 Each solid arrow in lighter shading shows one country, beginning in 1990 and ending in 2020.
2561 The dashed arrows in darker shade show the regional averages, calculated as the unweighted
2562 arithmetic mean of the values for all countries in each region along the horizontal and vertical
2563 axes. For urban-rural difference, a positive number shows higher urban mean height and BMI
2564 and a negative number shows higher rural mean height and BMI. The dark vertical dashed lines
2565 indicate the median of the WHO reference population. For BMI, the lighter vertical dashed lines
2566 are placed one standard deviation below and above the median of the WHO reference
2567 population.

2568

2569 We did not estimate the difference between rural and urban height for areas classified as
2570 entirely urban (Bermuda, Kuwait, Nauru and Singapore) or entirely rural (Tokelau).

2571

2572 **Extended Data Fig. 5. Posterior probability of increase in mean height in urban and rural**
2573 **areas from 1990 to 2020.**

2574

2575 The maps show the posterior probability (PP) that the age-standardised mean height increased
2576 from 1990 to 2020. The PP of a decrease is one minus that of an increase. If an increase in
2577 mean height is statistically indistinguishable from a decrease, the PP is 0.50. PPs closer to 0.50
2578 indicate more uncertainty, those towards 1 indicate more certainty of an increase, and those
2579 towards 0 indicate more certainty of a decrease.

2580

2581

2582 We did not estimate PP for change in mean height in rural areas in countries classified as
2583 entirely urban (Bermuda, Kuwait, Nauru and Singapore) or change in mean height in urban
2584 areas in countries classified as entirely rural (Tokelau).

2585 **Extended Data Fig. 6. Posterior probability of increase in mean body-mass index (BMI) in**
2586 **urban and rural areas from 1990 to 2020.**

2587

2588 The maps show the posterior probability (PP) that the age-standardised mean BMI increased
2589 from 1990 to 2020. The PP of a decrease is one minus that of an increase.

2590

2591 We did not estimate PP for change in mean rural BMI in areas classified as entirely urban
2592 (Bermuda, Kuwait, Nauru and Singapore) or change in mean urban BMI in areas classified as
2593 entirely rural (Tokelau).

2594 **Extended Data Fig. 7. Comparison of urban-rural difference in height and body-mass**
2595 **index (BMI) by sex in 2020.**

2596

2597 We did not estimate the difference between rural and urban BMI or height for areas classified as
2598 entirely urban (Bermuda, Kuwait, Nauru and Singapore) or entirely rural (Tokelau).

2599 **Extended Data Fig. 8. Trends in body-mass index (BMI) by place of residence for**
2600 **children, adolescents and young adults.**

2601

2602 The figure shows trends in mean BMI at ages five and 19 years, and in age-standardised mean
2603 BMI for young adults (20-29 years and 30-39 years). Shaded areas show the 95% credible
2604 intervals. Trend for young adults were estimated using a model similar to the one described in
2605 Methods, where BMI-age patterns were allowed to vary flexibly via a cubic spline function
2606 without knots.

2607 **Extended Data Fig. 9. Posterior probability of urban-rural height difference and its**
2608 **increase from 1990 to 2020.**

2609

2610 The maps show the posterior probability (PP) that age-standardised mean height in 2020 in
2611 urban areas was higher than in rural areas (left-hand panels), and the PP that the urban-rural
2612 difference in age-standardised mean height increased from 1990 to 2020 (right-hand panels).
2613 For 2020, if estimated age-standardised mean urban height is statistically indistinguishable from
2614 rural height, the PP is 0.50. PPs closer to 0.50 indicate more uncertainty, those towards 1
2615 indicate more certainty of urban children being taller, and those towards 0 indicate more
2616 certainty of rural being taller.

2617

2618 We did not estimate the PP for differences between rural and urban height for areas classified
2619 as entirely urban (Bermuda, Kuwait, Nauru and Singapore) or entirely rural (Tokelau), as
2620 indicated by grey colour.

2621 **Extended Data Fig. 10. Posterior probability of urban-rural body-mass index (BMI)**
2622 **difference and its increase from 1990 to 2020.**

2623

2624 The maps show the posterior probability (PP) that age-standardised mean BMI in 2020 in urban
2625 areas was higher than in rural areas (left-hand panels), and the PP that the urban-rural
2626 difference in mean BMI increased from 1990 to 2020 (right-hand panels).