International Journal of Epidemiology, 2017, 1–11
doi: 10.1093/ije/dyx263
Original article

Original article

Rapidly increasing body mass index among children, adolescents and young adults in a transitioning population, South Africa, 2008–15

B Sartorius,[1]* K Sartorius,[1,2] M Taylor,[1] J Aagaard-Hansen,[3] N Dukhi,[1] C Day,[4] N Ndlovu,[4] R Slotow[5,6] and K Hofman[7]

[1]Public Health Medicine, University of KwaZulu-Natal, Durban, South Africa, [2]Faculty of Commerce, University of the Witwatersrand, Johannesburg, South Africa, [3]Steno Diabetes Center Copenhagen, Gentofte, Denmark, and MRC Developmental Pathways for Health Research Unit, University of the Witwatersrand, Johannesburg, South Africa, [4]Health Systems Trust, Westville, South Africa, [5]School of Life Sciences, University of KwaZulu-Natal, Durban, South Africa, [6]Department of Genetics, Evolution and Environment, University College London, London, UK and [7]School of Public Health, University of the Witwatersrand, Johannesburg, South Africa

*Corresponding author. Public Health Medicine, 236 George Campbell Building, Howard College Campus, University of KwaZulu-Natal, King George V Avenue, Durban, 4041, South Africa. E-mail: sartorius@ukzn.ac.za

Editorial decision 21 November 2017; Accepted 4 December 2017

Abstract

Background: There is a global epidemic of overweight and obesity; however, this rate of increase is even greater in some low- and middle-income countries (LMIC). South Africa (SA) is undergoing rapid socioeconomic and demographic changes that have triggered a rapid nutrition transition. The paper focuses on the recent rate of change of body mass index (BMI) among children, adolescents and young adults, further stratified by key sociodemographic factors.

Methods: We analysed mean BMI of 28 247 individuals (including children) from 7301 households by age and year, from anthropometric data from four national cross-sectional (repeated panel) surveys using non-linear fitted curves and associated 95% confidence intervals.

Results: From 2008 to 2015, there was rapid rise in mean BMI in the 6–25 age band, with the highest risk (3–4+ BMI unit increase) among children aged 8–10 years. The increase was largely among females in urban areas and of middle-high socioeconomic standing. Prominent gains were also observed in certain rural areas, with extensive geographical heterogeneity across the country.

Conclusions: We have demonstrated a major deviation from the current understanding of patterns of BMI increase, with a rate of increase substantially greater in the developing world context compared with the global pattern. This population-wide effect will have major consequences for national development as the epidemic of related non-communicable disease unfolds, and will overtax the national health care budget. Our refined understanding highlights that risks are further compounded for certain groups/

places, and emphasizes that urgent geographical and population-targeted interventions are necessary. These interventions could include a sugar tax, clearer food labelling, revised school feeding programmes and mandatory bans on unhealthy food marketing to children.The scenario unfolding in South Africa will likely be followed in other LMICs.

Key words: Body mass index, rapid gain, nutritional transition, children, adolescents, young adults, South Africa

Key Messages

- South Africa is experiencing exponential increases in population mean BMI within a relatively short time period , particularly among female school-aged children, adolescents and young adults.
- The increase in mean BMI in the 8–10 year age group over a short period (7 years) is 6–7-fold higher than global BMI increases reported between 1980 and 2008.
- The largest mean increases in BMI over the period show strong geographical heterogeneity, with the increase greatest in urban settlements (both informal and formal) and in middle/high socioeconomic groups.
- Our results highlight the need for close investigation in other LMIC, where similar patterns may exist, and where there may also be unexpected increases of BMI and subsequently future explosions in non-communicable diseases, with concomitant negative outcomes for life expectancy, and health care costs.
- Our results demonstrate a rapid BMI change in specific age groups, thus providing a basis for public health interventions specifically targeting geographical areas and/or population segments, as well as potentially some more general innovative policy measures.

Introduction

Globally, there is a rapidly rising trend in body mass index (BMI) and overweight and obesity in adults,[1–3] and childhood obesity has emerged as one of the most serious public health issues of the 21st century.[4] Epidemiological studies have shown a substantial increase in the risk of disease with elevated BMI (i.e. severe or morbid obesity).[5] The current and future risks of overweight/obesity include a range of obesity-related non-communicable disorders, including cardiovascular and kidney diseases, diabetes, early onset metabolic syndrome, hypertension, many cancers and musculoskeletal disorders.[6–10] The Global BMI Mortality Collaboration has examined the relationship between body mass index (BMI) and all-cause mortality, using individual participant data meta-analyses of 189 prospective studies, involving a total of 3 951 455 participants. The association between both overweight and obesity with higher all-cause mortality was consistently demonstrated across all settings.[11] In recent years, increasing efforts have been made to assess BMI trends both within and across nations.[1,12] A systematic review and meta-analysis of epidemiological studies, carried out in 199 countries over three decades, indicated that in all but a few countries, the average BMI of the adult population increased between 1980 and 2008. The average rate of increase was 0.4 kg/m^2 per decade for men and 0.5 kg/m^2 per decade for women.[2] The cost of obesity in national health budgets has risen markedly, and it has been estimated that the cost of obesity/overweight has increased from 6.5% to 9.1% of annual medical spending in national health budgets.[13] A combination of these concerns regarding the potential health and economic burden of increasing BMI, has led to adiposity being included among the global non-communicable disease (NCD) targets, namely to halt the rise in obesity prevalence by 2025 compared with 2010 levels.[14,15] Significant health benefits and cost savings, therefore, could be achieved by reducing overweight/obesity in children and adolescents as part of a programme to reduce the population distribution of BMI.[16] Thus, information on whether countries are on track to achieve this target is needed to support accountability towards the global NCD commitments.[17]

Southern Africa, and particularly South Africa (middle-income), is undergoing rapid socioeconomic, epidemiological and lifestyle transitions that have precipitated a rapid nutritional transition. These transitions underpin the aetiology of a rapidly rising trend in BMI and waist circumference (WC), as evidenced by previous overweight/obesity studies and their associated determinants.[18,19] Evidence from 19 other South African studies suggests a far higher increase in childhood/adolescent obesity than the global averages of 0.4 kg/m^2/decade for men and 0.5 kg/m^2/decade for women.[20] The rapid changes in obesity in South Africa indicate that in only 6 years (between 2002 and 2008) adolescent obesity rates doubled, whereas in the USA this took twice as long (13 years).[21] It can be hypothesized that this increase is progressing at a far greater rate than that observed globally both in LMIC and high-income countries (HIC), and there is a need to quantify this rate of increase in specific populations longitudinally.

Furthermore, previous studies have focused on adults and dichotomized obesity classification (rather than underlying BMI and WC distribution), thus neglecting the key child and adolescent groups[22] which are often more susceptible to rapid transitions. The aim of this study was to use longitudinal national survey data of anthropometric measurements to quantify the rapidly changing BMI distribution by age for the 6- to 25-year-old population group in South Africa. We also show the rate of change of BMI from 2008 to 2015 across a range of demographic factors that include gender, population group, socioeconomic status, rural-urban divide and geographical districts in South Africa.

Methods

Data

Data were taken from the four panel (cross-sectional) waves of the South African National Income Dynamics Study (SA-NIDS),[23] the first national panel study in South Africa. SA-NIDS was undertaken by the South African Labour and Development Research Unit based at the School of Economics at the University of Cape Town. The surveys took place in 2008, 2010–11, 2012 and 2014–15. These are named waves 1–4, respectively. A stratified, two-stage random cluster sample design was employed to sample households for inclusion at baseline, and proportionally allocated stratification was based on the 52 district councils (DCs) in South Africa. Within each DC [primary sampling unit (PSU)], clusters of dwelling units were systematically drawn. A detailed report on the methodology employed in this study is provided elsewhere.[24] The household-level response rate was 69% and the individual response rate within households was 93%. The baseline SA-NIDS survey provides data for 28 247 individuals (including children) from 7301 households. Weight and height measurements were taken for all individuals, as well as waist circumference measurements for all adults (aged 18+) in the household.

Study population

We restricted our analysis to individuals aged 5 to 79 years. Pregnant women were excluded from the analysis given the confounding impact of pregnancy on weight and waist circumference.

Outcome

BMI for adults and BMI-for-age z-scores [or equivalent BMI-for-age percentile] for children using the latest World Health Organization (WHO) growth reference standards.[25] Overweight and obese cut-offs for BMI among adults were set at 25–29.9 and 30+ kg/m^2, based on international cut-offs. We also included additional analysis of waist circumference (WC), which is presented as supplementary material (available as Supplementary data at *IJE* online).

Sociodemographic variables

Sociodemographic variables include:

- panel year (four survey waves);
- age (2–64 years);
- gender;
- ethnicity, classified as Black/African and non-African (Coloured, Indian/Asian, Caucasian);
- provincial districts of South Africa;
- geotype;
- socioeconomic status (household income) classified into low [mean South African rand (ZAR) of 681 per month, range of 1 to 1000], medium (mean ZAR of 1516 per month, range ZAR > 1000 to 2000) and high tertiale (mean ZAR of 7017 per month, range > 2000 to 300,000) categories.

There are four major geotypes in South Africa, two rural, namely rural formal and tribal authority areas (TAAs), and two urban, namely urban formal and urban informal:

rural: 'farms';
TAAs: 'communally-owned land under the jurisdiction of traditional leaders. Settlements within these areas are villages';
urban: 'a continuously built-up area that is established through township establishment such as cities, towns, 'townships', small towns and hamlets';
formal residential: 'single houses, town houses, high-rise flats, scheme housing, estates';
informal residential: 'illegal informal structures'.

Data analysis

Analyses were performed using Stata software version 13 (StataCorp. 2013; Stata Statistical Software, Release 13, College Station, TX]. Clustering, as well as survey design effects, were accounted for using sample weights to correctly estimate standard error, and hence 95% confidence intervals (CIs) around BMI point estimates.

Mean BMI (and standard deviation) or median (and interquartile range) by age and survey round were further stratified by other sociodemographic variables such ethnicity and gender, socioeconomic status and geotype; 95% confidence intervals were also calculated around point estimates.

As the distribution of mean BMI by age was non-linear, we fitted non-linear smoothed curves using a mathematical growth curve proposed by Preece and Baines.[26] Fitted BMI curves by age and survey round were also stratified by the aforementioned sociodemographic characteristics, to visually highlight changes in specific age bands by period and demographic characteristics.

BMI-for-age z-scores and abnormal levels among children aged 2–18 years

We calculated BMI-for-age z-scores and BMI categories for children ages 2 to 18, using the WHO 2007 reference standards based on height, weight, gender and age in months.[27] BMI-for-age z-scores were generated using the 'zanthro' and 'zbmicat' commands in Stata. A z-score of + 1 to 1.99 is classified as overweight, and a score of 2+ is classified as obese. Additional supplementary analyses of waist circumference among adults were conducted and included in Figure A1 and Table A3, available as Supplementary data at *IJE* online. A waist circumference greater than 94 cm among men, and greater than 80 cm among women, was classified as overweight/obese.[28,29]

Mapping/Geographic Information Score

Maps depicting change in BMI-for-age z-score and BMI by district among children (aged 2–18 years) and adults (19–64 years), respectively, from 2008 to 2014/15 were developed using Map Info Professional.

Results

The baseline sample for all age groups in South Africa (2008) comprised 21 024 subjects (out of a total of 28 247) with anthropometric data. The baseline sample comprised: 3254 (11.5%) children under 5; 4355 (15.4%) children between the ages of 5 and 11 years; 4487 (15.9%) adolescents between the ages of 12 and 18 years; 5172 (18.3%) young adults aged 19–29 years; 4470 (16.9%) middle-aged adults (30–44 years); 4333 (15.4%) adults aged 45–64 years; and 1779 (6.3%) elderly adults (65+ years of age) (Table 1); 76 subjects had a missing age. The majority of subjects were African ($n = 17\ 309$, 82.3%).

Table 1. Baseline characteristics of the study population

Characteristic	*n* ($N = 21024$)	%
Gender:		
Male	9174	43.6
Female	11849	56.4
Unknown	1	0.0
Age group (years):		
Unknown	21	0.1
< 5	2074	9.9
5–9	2482	11.8
10–14	2664	12.7
15–24	4357	20.7
25–34	2613	12.4
35–44	2290	10.9
45–54	1903	9.1
55–64	1329	6.3
65+	1291	6.1
Ethnicity:		
Black/African	17309	82.3
Coloured	2678	12.7
Asian/Indian	244	1.2
Caucasian	793	3.8
Geotype:		
Rural	2069	9.8
Tribal authority areas	9966	47.4
Urban (formal)	7744	36.8
Urban (informal)	1245	5.9

The following cut-offs for central overweight/obesity based on waist circumference were used for males (> 94 cm) and females (> 80cm), as currently specified in international guidelines.

Four waves of data from 2008 to 2015 are used to show the distribution of mean BMI by age (5–79 years) in Figure 1 (also see Table A1). A rapid rise in mean BMI was observed from young childhood, with a plateau around 40–50 years of age, and thereafter a decline towards elderly age. An increase was observed among adults aged 26–57, with a linear decrease in the gain in this group with increasing age. Overall, the mean gain in BMI among males from waves 1 to 4 was +0.5 units (95% CI: −0.1 to + 1.1) and +1.7 units (95% CI: +1.1 to + 2.3) among females.

From 2008 to 2015 there was a mean +2 BMI increase among young children (especially aged 8–10) to young adulthood. This increase (comparing wave 4 with wave 1 in Figure 1) in the 6–25 years age band (captured between the orange lines) was statistically significant (Figure 2). The largest gains in this age group were among the 8–10-year-olds, with a 3 to 4 mean BMI gain over the 7-year period.

We further unpacked the change in the proportion of subjects that were overweight and/or obese by age and survey wave (Figure 3). A pronounced rise ('hump') in the proportion of children aged 5–12 who were overweight or

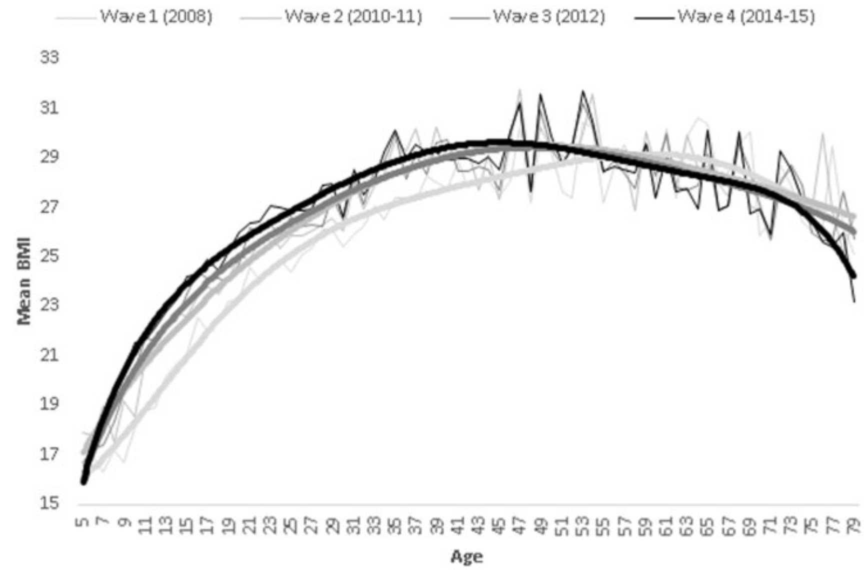

Figure 1. Distribution of BMI by age and survey round. (Note: thicker lines represent the fitted non-linear curves for each wave of the same colour).

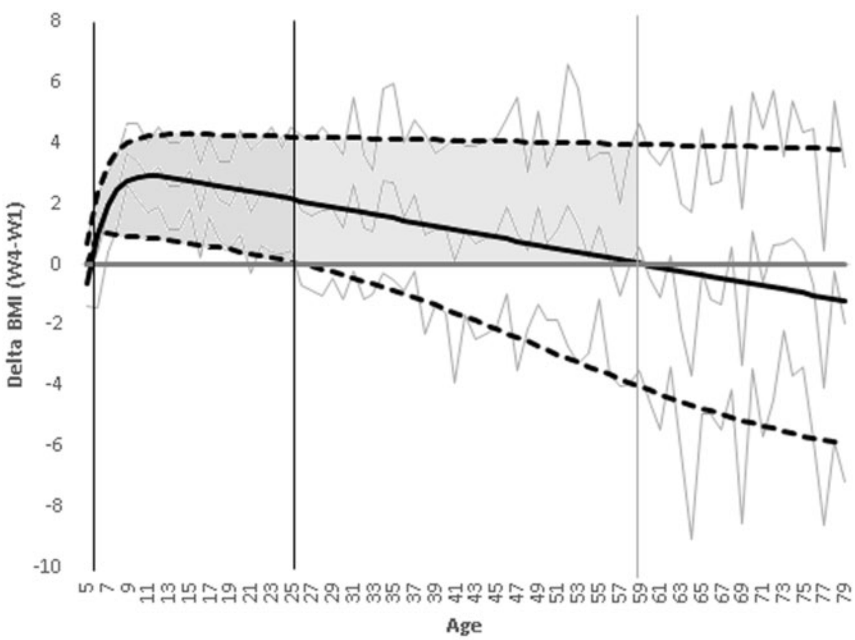

Figure 2. Change in BMI by age from 2008 to 2014–15 with 95% CIs for change included. (Note: orange band highlights age bands with significant increases in mean BMI from 2008 to 2014–15, and grey region highlights adult age bands with increased BMI from 2008 to 2014–15, but which were not statistically significant due to low sample size).

obese (BMI-for-age z-score $\geq +1$) was observed when comparing 2014–15 with 2008. A consistent, but less pronounced, rise in the proportion of adults (aged 19+) who were overweight and/or obese was observed when comparing the later survey round with the baseline (Figure 3b).

A further stratification of the change in BMI by age, gender and ethnicity suggests that the major contributor to the increasing mean BMI in younger age groups was among African and non-African females (Figure 4a). Gain in mean BMI was observed across all socioeconomic/urban-rural groups among the 8–25-year-old population, but most prominently among younger female children aged 8–10 years living in middle- to high-income households in urban formal areas, and among lower-income households in urban informal settlements. The largest gains in BMI in younger children occurred in the middle socioeconomic status (SES) group, followed by high SES (Figure 4b). Notably there were also BMI gains in the low SES group, among children aged 8–12 years. The largest gains by geotype occurred in the urban sector (formal and

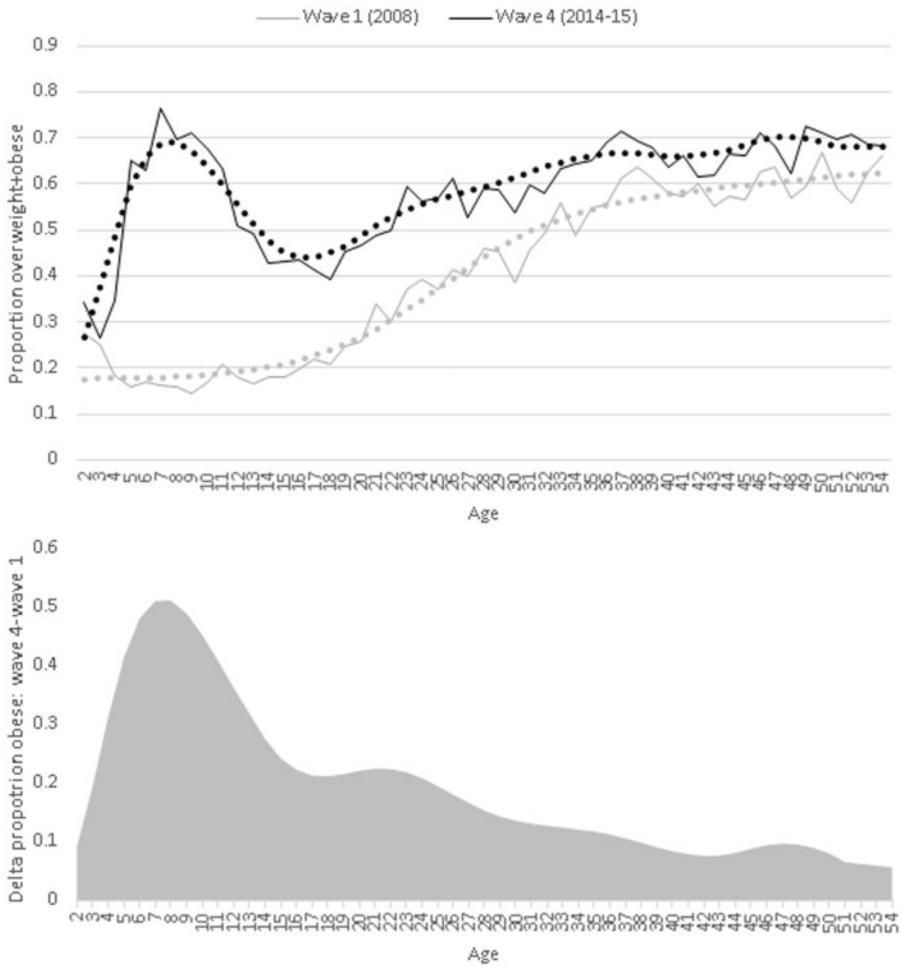

Figure 3. Proportion of overweight and/or obese by age and survey round.

informal) in the 8–12-year age band (Figure 4c), which indicated a + 4 BMI unit gain over the period. The rural sector did not display as large an increase in BMI in this age band as compared with the formal sector; however, there was a notable gain in BMI in the rural sector over the period (+2 BMI units through most age bands).

Mean BMI change by district was heterogeneous across the country (Figure 5; Table A2, available as Supplementary data at *IJE* online). The largest gains (+2.5 mean BMI increase from 2008 to 2015) were observed in parts of four of the nine provinces, namely: KwaZulu-Natal, Free State, North West and Limpopo. Surprisingly, the urban metropolitan municipalities (Buffalo City, City of Cape Town, Ekurhuleni, eThekwini, City of Johannesburg, City of Tshwane, Mangaung, and Nelson Mandela Bay) did not register the largest gains in mean BMI over this period.

Discussion

In summary, the highest rate of BMI increase was among children aged 5 to 11 years, with a higher rate of BMI gain among in females. Medium SES households indicated the highest gain in BMI in the 8–19 age band, with low SES households displaying the least gain in BMI between 5 and 21 years. Urban adolescents displayed greater gains in BMI than rural adolescents, but between 16 and 19 years urban households in informal settlements had a lower BMI than those in rural households. These results show that the rate of mean BMI increase in South Africa over a 7-year period was substantially higher than the global mean gain.[2]

This rapid increase is especially problematic in LMICs that are subject to both economic and lifestyle transitions.[30] The rapid growth in obesity is especially prevalent in sub-Saharan Africa (SSA), which has experienced a growth in gross domestic product (GDP), exposure to globalization, greater disposable income and unprecedented levels of urban migration which result in the establishment of large urban informal settlements. A combination of these factors has driven a nutrition transition that refers to changing dietary patterns primarily driven by availability of cheap energy-dense foodstuffs, increased consumption of saturated fats/animal proteins and growing sugary

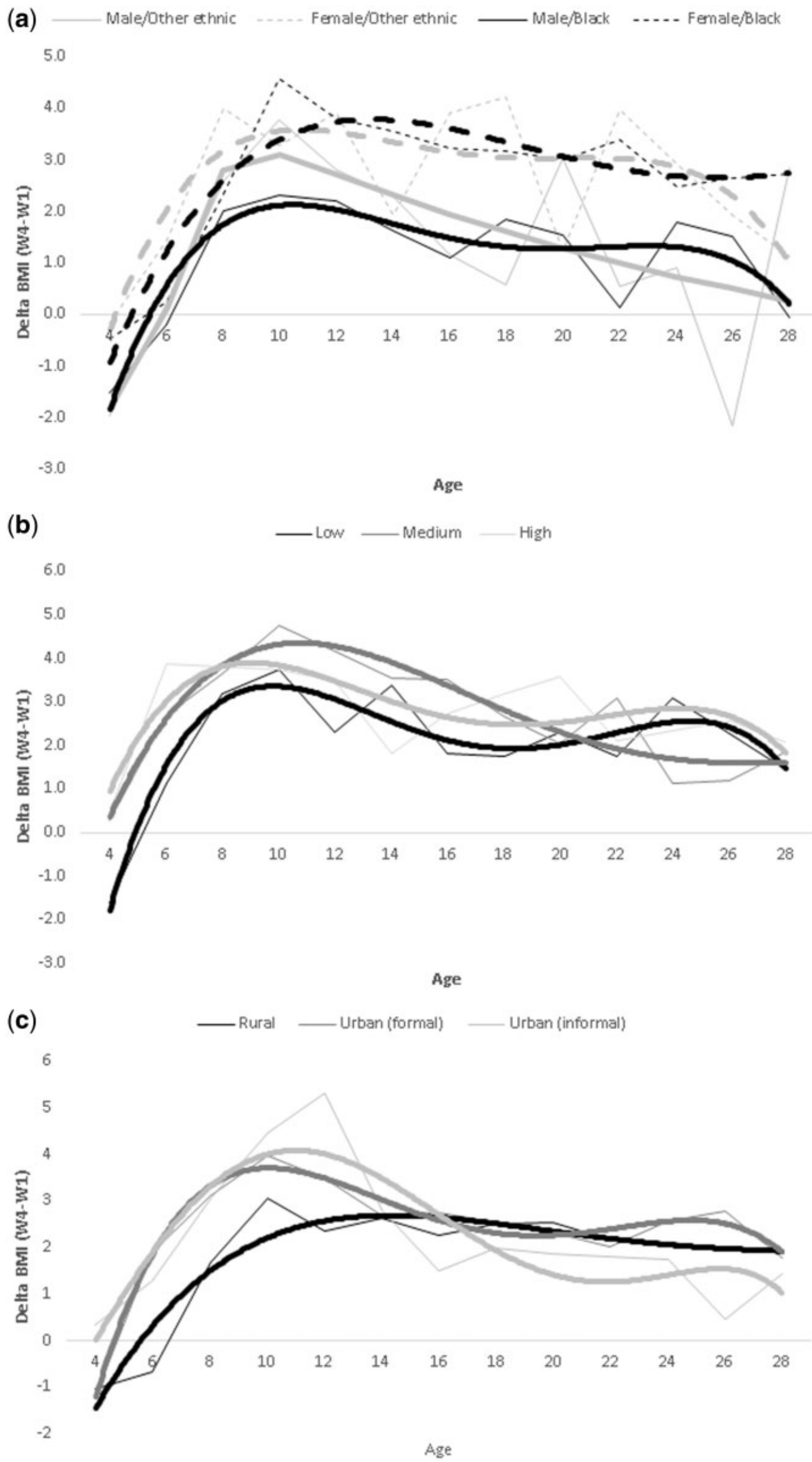

Figure 4. Change in BMI for subjects aged 4–29 years of age (by 2-year age band) from 2008 to 2014–15. (Note: dashed lines are actual data and solid bold lines of same colour are fitted smooth non-linear curves).

beverage consumption.[31] Our results confirm rapidly rising levels of obesity in South Africa, particularly in the urban sector (formal and informal). It is significant, however, that the rate of change of obesity in the younger population, as reflected in our results, exceeds those found in other South African studies.[21,32]

Gender appears to influence BMI gains in South Africa, especially in female school-aged children between 8 and

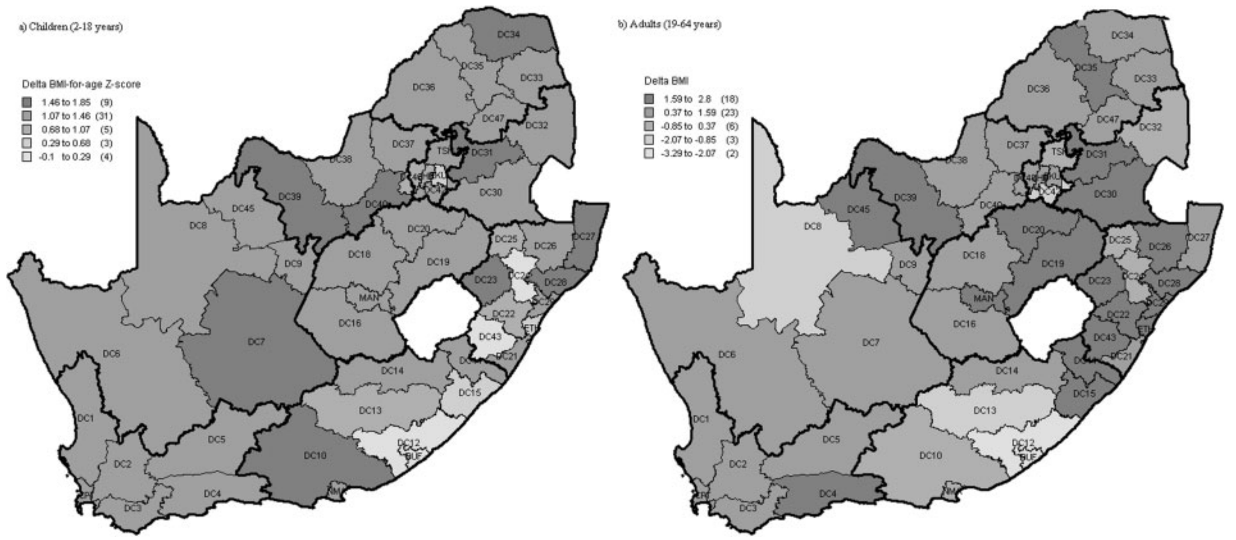

Figure 5. Map of mean BMI change by district from 2008 to 201–15 (please see Table A2 for codes and underlying data, available as Supplementary data at *IJE* online).

12 years of age. It is interesting to note, however, that another South African study found that BMI for women increased from 25.8 kg/m^2 in 1980 to > 29 kg/m^2 in 2008 (higher than the average global BMI gain over this period for women of + 1.46), illustrating that BMI gain was higher for females of all age categories.[32] South African overweight/obesity differs markedly by gender, as a result of adolescent males having lower energy intakes and engaging in higher levels of physical activity than adolescent females.[20,33] Behavioural and cultural phenomena often assume that a fat child is both healthy and happy, and that they are HIV-negative.[20] The Third South African National Youth Risk Behaviour Survey (YRBS)[21] also reported that only 49% of learners ate fresh fruit often, and only 40% ate at least a cup of vegetables a day. Other important factors include a higher risk for urban adolescents because of relentless marketing, close proximity to low-cost energy-dense foodstuffs and increasing disposable income.[20,34] Other potential factors include depression, stress, noise pollution and insufficient sleep, all of which are sometimes related to urbanization pressures, and especially to metropolitan areas.[13,35]

Data on 9–10-year-old children from 12 countries, including both high- and low-income groups within each country, suggest that South African children drink sugar-sweetened beverages and sports drinks more than four times per week, which was higher than any other country surveyed.[36,37] South African adolescents, therefore, have among the highest consumption of sugar sweetened beverages (SSBs) among children aged 9–10 years.[37] Drinking one SSB /day increases adult likelihood of being overweight/obese by 27% and child likelihood by 55%.[38–40] SSBs lead to weight gain as result of their high added sugar content and low ability to make an individual feel full (sated), thus resulting in an 'incomplete compensatory reduction in energy intake at subsequent meals after intake of liquid calories'.[40] Despite increased SSB consumption being a likely contributing factor for this rapid risk in BMI in this age group, it would however not operate in isolation, as the relationship between SSBs and weight gain is likely confounded by the influences of other dietary and lifestyle factors.

Furthermore, overweight children and adolescents have a very high likelihood (70%) of becoming overweight adults[41] who have a significantly higher risk of non-communicable diseases35,13 that substantially reduce life expectancy outcomes and increase health care costs, as well threatening the attainment of 2030 Sustainable Development Goals.[42]

The consequences of a sharp increase in non-communicable disease, as a result of the obesity epidemic, is likely to surpass smoking as a leading cause of disability-adjusted years,[43] A previous study demonstrated that the cost of care for major non-communicable diseases, such as cardiovascular disease and diabetes, is and will be beyond the coping capacities of individuals, households and families as well as governments (increased health care costs and lost GDP) in most African countries.[44] The effect of the increased burden on the health care systems is also likely to overtax public and private health budgets, as well as increase externality costs and promote poorer public sector service. A study by Sturm *et al.* suggests that a rise in the total expenditure per individual with increasing BMI from a minimum of under ZAR 14,000 per individual in the healthy BMI range of 20–24.9, and an increasing expenditure trend with acceleration when the BMI ≥ 30 to ZAR 17,000+.[45] Total expenditure for diabetes mellitus in

South Africa was between ZAR 11.5 and 20 billion in 2010 (7–12% of total health expenditure), and is predicted to rise to ZAR 14.4–26.2 billion by 2030.[46]

Beyond the direct health care cost, there is also the macro-economic impact due to increased body mass, which cannot be discounted.[47] This operates through the economic burden on households through lost wages of prime-aged adults due to disability or death; and the cost of and further intensification of the poverty cycle, in already vulnerable households.[48] Overweight/obesity is also likely to reduce the productive life of working individuals and negatively impact on local GDP though absenteeism.

Interventions to mitigate against childhood/early adolescent obesity will result in major savings in public health costs. 'According to the first South African National Health and Nutrition Examination Survey (SANHANES-1), it appears that the most significant increase in waist circumference, as well as overweight and obesity, occur between 15 and 35 years of age. As this represents childbearing age, it may be the perfect window of opportunity to intervene, not only to optimise the health of the mother but also of her offspring'.[49] It has been estimated that the cost of obesity/overweight has increased from 6.5% to 9.1% of annual medical spending in national health budgets.[13] More balanced home-cooked meals, and changes to healthier foodstuffs in school feeding programmes and tuckshops, are urgently needed.[13,20,35] Our data suggest that whereas rural BMI has increased, the rate of increase in urban informal and formal sectors has been greater. This suggests that there is still time to target rural areas before the prevalence of overweight and obesity increases to 'urban' levels, and before these individuals migrate to urban areas; such targeted prevention may be most efficient, and could have a significant impact on the future obesity in South Africa.[19] The twin scourge of undernutrition and obesity in children and simultaneous challenge of rapid urbanization is particularly prevalent in many developing countries,[50] and innovative policy should include community-level lifestyle interventions, school-based initiatives, local transport and urban planning, physical activity and media campaigns that are supported by broader interventions to focus on food marketing for children, nutritional labelling and legal (fiscal) action.[4] These types of policy must ensure that they simultaneously target both rich and poor communities.

Fiscal measures (such as taxes) represent the most cost-effective approach per head at ZAR 0.20 (in 2010).[51] South African children have an especially high consumption of SSBs relative to other LMIC and HIC.33,34 This is likely part of the explanation for the high observed risk in mean BMI over the period in the 8–10 age demographic, based on our findings. Sugary drinks sales are projected to grow by 2.4% per year based on current trajectories, and will result in an increase of obesity of 16% by 2017, with 20% of this increase likely due to SSBs. In absolute terms, this translates into an increase of 280 000 cases, with most of this burden among young South Africans.[52] Evidence from modelling in South Africa suggests that a 20% sugary beverage excise tax (health promotion levy) would have prominent impacts on the growing obesity epidemic.[53] Further cost-effective strategies include more stringent food advertising regulations, at a projected cost of ZAR 0.90 per person.[51] To stem the tide of the fast-growing obesity epidemic among South African children and adolescents, there is urgency in passing mandatory bans on unhealthy food advertising to children, and regulating transparent front-of pack-food labelling, in addition to the aforementioned fiscal approaches.

The study has several limitations. First, smaller sample sizes and hence less precision among smaller ethnic groups. For example, few data on the SA coloured population impacted on our ability to assess change in BMI by age group. Second, lower response as well as greater attrition rates were observed in certain social strata in the NIDS survey. The highest attrition rates occurred in wealthier population groups (Whites/Asians/Indian), and the lowest attrition rates in poorer households (Africans/Coloured).[54] These differences between respondents and non-respondents were taken into account using adjusted sampling weights based on observed characteristics. However, one still cannot exclude the possibility that unobserved differences might have biased the results of our study. Third, a relatively high number of missing or invalid weight/height measurements (~20–25%) may have introduced selection bias. Fourth, despite extensive interviewer training and standardization of study protocol, we cannot discount the effect of inter-observer variability across the different study districts.

Conclusions

We have demonstrated a major deviation from the current understanding of patterns of BMI increase, in that the rate of increase is substantially greater in the South African context than the global pattern. This refined understanding of BMI changes in a range of demographic and geographical variables provides opportunity for more innovative (tailored) intervention programmes.

Supplementary Data

Supplementary data are available at *IJE* online.

Acknowledgements

The South African National Income Dynamics Study (SA-NIDS) was conducted by the Southern Africa Labour and Development Research Unit (SALDRU) based at the University of Cape Town's

School of Economics. We thank them for making these data publicly available.

Conflict of interest: None declared.

Funding

N.D. is supported by a post-doctoral scholarship from the National Research Foundation, South Africa. This study forms part of the Sustainable and Healthy Food Systems (SHEFS) project supported by the Wellcome Trust's Our Planet, Our Health programme (grant number 205200/Z/16/Z). K.H. is supported by the IDRC Canada (grant no: 108424-001). The funders of the study had no role in study design, data collection, data analysis, data interpretation or writing of the report.

References

1. Collaboration NRF. Trends in adult body-mass index in 200 countries from 1975 to 2014: a pooled analysis of 1698 population-based measurement studies with 19· 2 million participants. *Lancet* 2016;**387**:1377–96.
2. Finucane MM, Stevens G, Cowan M *et al*. Global Burden of Metabolic Risk Factors of Chronic Diseases Collaborating Group (Body Mass Index). National, regional, and global trends in body-mass index since 1980: systematic analysis of health examination surveys and epidemiological studies with 960 country-years and 9.1 million participants. *Lancet* 2011;**377**: 557–67.
3. GBD 2015 Collaborators. Health effects of overweight and obesity in 195 countries over 25 years. *N Engl J Med* 2017;**377**: 13–27.
4. Malik VS, Willett WC, Hu FB. Global obesity: trends, risk factors and policy implications. *Nat Rev Endocrinol* 2013;**9**:13–27.
5. Kitahara CM, Flint AJ, de Gonzalez AB *et al*. Association between class III obesity (BMI of 40–59 kg/m^2) and mortality: a pooled analysis of 20 prospective studies. *PLoS Med* 2014;**11**: e1001673.
6. World Health Organization. *Global Health Risks: Mortality and Burden of Disease Attributable to Selected Major Risks*. Geneva: World Health Organization, 2009.
7. Berrington de Gonzalez A, Hartge P, Cerhan JR *et al*. Body-mass index and mortality among 1.46 million white adults. *N Engl J Med* 2010;**2010**:2211–19.
8. Collaboration ERF. Separate and combined associations of body-mass index and abdominal adiposity with cardiovascular disease: collaborative analysis of 58 prospective studies. *Lancet* 2011;**377**:1085–95.
9. Collaboration PS. Body-mass index and cause-specific mortality in 900 000 adults: collaborative analyses of 57 prospective studies. *Lancet* 2009;**373**:1083–96.
10. Lu Y, Hajifathalian K, Ezzati M, Woodward M, Rimm E, Danaei G. The Global Burden of Metabolic Risk Factors for Chronic Diseases Collaboration (BMI Mediated Effects). Metabolic mediators of the effects of body-mass index, overweight, and obesity on coronary heart disease and stroke: a pooled analysis of 97 prospective cohorts with 18 million participants. *Lancet* 2014;**383**:970–83.
11. Collaboration GBM. Body-mass index and all-cause mortality: individual-participant-data meta-analysis of 239 prospective studies in four continents. *Lancet* 2016;**388**:776–86.
12. Ng M, Fleming T, Robinson M *et al*. Global, regional, and national prevalence of overweight and obesity in children and adults during 1980-2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet* 2014;**384**:76681.
13. Spruijt-Metz D. Etiology, treatment, and prevention of obesity in childhood and adolescence: A decade in review. *J Res Adolesc* 2011;**21**:129–52.
14. World Health Organization. *Global Action Plan for the Prevention and Control of Noncommunicable Diseases 2013-2020*. Geneva: WHO, 2013.
15. Kontis V, Mathers CD, Rehm J *et al*. Contribution of six risk factors to achieving the 25 × 25 non-communicable disease mortality reduction target: a modelling study. *Lancet* 2014;**384**: 427–37.
16. Finucane MM, Stevens GA, Cowan MJ *et al*. National, regional, and global trends in body-mass index since 1980: systematic analysis of health examination surveys and epidemiological studies with 960 country-years and 91 million participants. *Lancet* 2011;**377**:557–67.
17. Beaglehole R, Bonita R, Ezzati M *et al*. NCD Countdown 2025: accountability for the 25 × 25 NCD mortality reduction target. *Lancet* 2014;**384**:105–07.
18. Sartorius B, Veerman LJ, Manyema M, Chola L, Hofman K. Determinants of obesity and associated population attributability, South Africa: empirical evidence from a national panel survey, 2008-2012. *PloS One* 2015;**10**:e0130218.
19. Cois A, Day C. Obesity trends and risk factors in the South African adult population. *BMC Obes* 2015;**2**:42.
20. Rossouw HA, Grant CC, Viljoen M. Overweight and obesity in children and adolescents: the South African problem: review article. *S Afr J Sci* 2012;**108**:1–7.
21. Reddy SP, Resnicow K, James S *et al*. Rapid increases in overweight and obesity among South African adolescents: comparison of data from the South African National Youth Risk Behaviour Survey in 2002 and 2008. *Am J Public Health* 2012; **102**:262–68.
22. Akseer N, Al-Gashm S, Mehta S, Mokdad A, Bhutta ZA. Global and regional trends in the nutritional status of young people: a critical and neglected age group. *Ann N Y Acad Sci* 2017;**1393**: 3–20.
23. Coovadia H, Bland R, Tollman SM *et al*. Implications of mortality transition for primary health care in rural South Africa: a population-based surveillance study. Commentary. *Lancet* 2008;**372:**893–901.
24. Sartorius BK, Chersich MF, Mwaura M *et al*. Maternal anaemia and duration of zidovudine in antiretroviral regimens for preventing mother-to-child transmission: a randomized trial in three African countries. *BMC Infect Dis* 2013;**13**:1.
25. World Health Organization. *WHO Child Growth Standards: Growth Velocity Based on Weight, Length and Head Circumference: Methods and Development*. Geneva: World Health Organization, 2009.
26. Preece M, Baines M. A new family of mathematical models describing the human growth curve. *Ann Hum Biol* 1978;**5**: 1–24.

27. World Health Organization. *WHO Child Growth Standards: Head Circumference-for-age, Arm Circumference-for-age, Triceps Skinfold-for-age and Subscapular Skinfold-for-age: Methods and Development*. Geneva: World Health Organization, 2007.
28. World Health Organization. *Waist Circumference and Waist-hip Ratio*. Geneva: WHO, 2011.
29. Janssen I, Katzmarzyk PT, Ross R. Body mass index, waist circumference, and health risk: evidence in support of current National Institutes of Health guidelines. *Arch Intern Med* 2002; **162**:2074–79.
30. Poskitt E. Countries in transition: underweight to obesity non-stop? *Ann Trop Paediatr* 2009;**29**:1–11.
31. Steyn NP, Mchiza ZJ. Obesity and the nutrition transition in Sub-Saharan Africa. *Ann N Y Acad Sci* 2014;**1311**:88–101.
32. Rossouw HA, Grant CC, Viljoen M. Overweight and obesity in children and adolescents: The South African problem. *S Afr J Sci* 2012;**108**:1–7.
33. Brodersen NH, Steptoe A, Boniface DR, Wardle J. Trends in physical activity and sedentary behaviour in adolescence: ethnic and socioeconomic differences. *Br J Sports Med* 2007;**41**: 140–44.
34. Case A, Menendez A. Sex differences in obesity rates in poor countries: evidence from South Africa. *Econ Hum Biol* 2009;**7**: 271–82.
35. Gupta N, Goel K, Shah P, Misra A. Childhood obesity in developing countries: epidemiology, determinants, and prevention. *Endocr Rev* 2012;**33**:48–70.
36. Mikkilä V, Vepsäläinen H, Saloheimo T *et al*. An international comparison of dietary patterns in 9–11-year-old children. *Int J Obes Suppl* 2015;**5**:S17–S21.
37. Katzmarzyk PT, Broyles ST, Champagne CM *et al*. Relationship between soft drink consumption and obesity in 9–11 years old children in a multi-national study. *Nutrients* 2016;**8**:770.
38. Malik VS, Popkin BM, Bray GA, Després J-P, Hu FB. Sugar-sweetened beverages, obesity, type 2 diabetes mellitus, and cardiovascular disease risk. *Circulation* 2010;**121**:1356–64.
39. Hu FB, Malik VS. Sugar-sweetened beverages and risk of obesity and type 2 diabetes: epidemiologic evidence. *Physiol Behav* 2010;**100**:47–54.
40. Malik VS, Pan A, Willett WC, Hu FB. Sugar-sweetened beverages and weight gain in children and adults: a systematic review and meta-analysis. *Am J Clin Nutr* 2013;**98**:1084–102.
41. Lifshitz F. Obesity in children. *J Clin Res Pediatr Endocrinol* 2008;**1**:53.
42. Lim SS, Fullman N, Murray CJ, Mason-Jones AJ. Measuring the health-related Sustainable Development Goals in 188 countries: a baseline analysis from the Global Burden of Disease Study 2015. *Lancet* 2016;**388**:1813–50.
43. Hurt RT, Kulisek C, Buchanan LA, McClave SA. The obesity epidemic: challenges, health initiatives, and implications for gastroenterologists. *Gastroenterol Hepatol* 2010;**6**:780.
44. Kengne AP, Mchiza ZJ-R, Amoah AGB, Mbanya J-C. Cardiovascular diseases and diabetes as economic and developmental challenges in Africa. *Prog Cardiovasc Dis* 2013;**56**: 302–13.
45. Sturm R, An R, Maroba J, Patel D. The effects of obesity, smoking, and excessive alcohol intake on health care expenditure in a comprehensive medical scheme. *S Afr Med J* 2013;**103**:840–44.
46. Zhang Y, Bi P, Hiller JE. Meteorological variables and malaria in a Chinese temperate city: A twenty-year time-series data analysis. *Environ Int* 2010;**36**:439–45.
47. Chaker L, Falla A, Lee SJ *et al*. The global impact of non-communicable diseases on macro-economic productivity: a systematic review. *Eur J Epidemiol* 2015;**30**:357–95.
48. Trogdon J, Finkelstein E, Hylands T, Dellea P, Kamal-Bahl S. Indirect costs of obesity: a review of the current literature. *Obes Rev* 2008;**9**:489–500.
49. Pearson J, Watson E, Lambert E, Micklesfield L. The role of physical activity during pregnancy in determining maternal and foetal outcomes. *S Afr J Sports Med* 2015;**27**:93–96.
50. Swinburn BA, Sacks G, Hall KD *et al*. The global obesity pandemic: shaped by global drivers and local environments. *Lancet* 2011;**378**:804–14.
51. Cecchini M, Sassi F, Lauer JA, Lee YY, Guajardo-Barron V, Chisholm D. Tackling of unhealthy diets, physical inactivity, and obesity: health effects and cost-effectiveness. *Lancet* 2010; **376**:1775–84.
52. Tugendhaft A, Manyema M, Veerman LJ, Chola L, Labadarios D, Hofman KJ. Cost of inaction on sugar-sweetened beverage consumption: implications for obesity in South Africa. *Public Health Nutr* 2016;**19**:2296–304.
53. Manyema M, Veerman LJ, Chola L *et al.* The potential impact of a 20% tax on sugar-sweetened beverages on obesity in South African adults: A mathematical model. *PloS One* 2014;**9**:e105287.
54. Finn A, Leibbrandt M, Levinsohn J. Income Mobility in South Africa: Evidence from the First Two Waves of the National Income Dynamics Study. 2012. http://hdl.handle.net/11090/174 (8 June 2017, date last accessed).