South African Journal of Clinical Nutrition 2026; 39(1):42–48
https://doi.org/10.1080/16070658.2025.2590864

SAJCN
ISSN 1607-0658 EISSN 2221-1268

RESEARCH ARTICLE

Describing the triple burden of malnutrition in adolescents in rural and urban South Africa

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Objectives: To describe the triple burden of malnutrition among a large, school-going sample of adolescents in rural Agincourt and urban Soweto, South Africa.
Design: Cross-sectional study.
Setting: Schools and community centres across rural Agincourt and urban Soweto, South Africa.
Subjects: 12 644 adolescents (mean age 15.5 years; 62% girls; 70.7% rural).
Measures: International Obesity Task Force cut-offs were used to calculate the prevalence of underweight, healthy weight, overweight, and obesity. Haemoglobin levels were measured in Soweto to assess the prevalence of anaemia.
Results: This large, population-based study reveals a high burden of malnutrition, with 34.9% of adolescents either underweight, overweight, or obese. Underweight prevalence was 14.3%, with relatively uniform distribution across sex and setting. Overweight and obesity were notably more prevalent in urban girls (32.3% and 7.0%, respectively), nearly doubling the rates observed in their rural peers (17.4% and 5.8%), and substantially higher than urban and rural boys (all < 6%). Boys consistently exhibited lower body fat percentage and fat mass index compared with girls across both settings. In a subsample of urban adolescents with haemoglobin data, anaemia was common, particularly in girls (31.6% vs. 10.2% in boys).
Conclusions: These findings highlight the complexity of the burden of malnutrition in adolescence, including both under- and over-nutrition with overlapping micronutrient deficiencies.

Keywords: adolescents, anaemia, malnutrition, obesity, overweight, rural, South Africa, underweight, urban

Introduction

Adolescence constitutes a critical biological developmental period, but it is also marked by the formation of health-related behaviours that have long-term implications for disease-risk trajectories extending into adulthood.[1,2] During this life stage, young people encounter increasingly dynamic food environments (food deserts and swamps), particularly in impoverished urban contexts, which contribute to malnutrition.[1,3] Understanding the triple burden of disease, which encompasses undernutrition (including underweight and stunting), micronutrient deficiencies, and the prevalence of overweight and obesity, is essential as these interlinked conditions influence adolescent health trajectories and broader public health outcomes.[3]

Despite significant economic improvements in a number of regions, stark differences remain between high and low- and middle-income countries (LMIC) in child growth and adiposity.[1,4] When examining growth patterns, Norris et al. showed girls and boys between 5 and 19 years in Africa, Asia, Latin America, and parts of Oceania fell below the World Health Organization's (WHO) Z-score for median height.[1] The converse was seen in high-income North America and Australasia, Europe, the Caribbean, and other parts of Oceania.[1] In contrast, body mass index (BMI) was consistently above the WHO median in all regions for girls. BMI in boys in sub-Saharan Africa, and South, East, Central, and Southeast Asia remained below the WHO median at all ages.[1] In girls from sub-Saharan Africa, there has been a shift from underweight to overweight and obesity with increasing age.[1] A 2020 South African review of adolescent nutrition highlighted the ongoing burden of both overweight and obesity, with a prevalence of 34% in adolescent girls aged 13–18 years and 14% in boys, with higher rates in both urban boys and girls compared with their rural counterparts.[3] This was coupled with a high prevalence of stunting ranging between 7% and 35%.[3] A scoping review on micronutrient anaemia found iron-deficiency anaemia prevalence ranged between 13% and 77% in eastern and southern Africans and 13–25% in South Africans aged 5–19 years.[5]

Supplemental file for this article can be accessed online at https://doi.org/10.1080/16070658.2025.2590864.

The concurrent escalation of overweight and obesity rates, coupled with the enduring challenges of stunting and micronutrient deficiencies, requires monitoring over time to understand shifts in these indicators. Contemporary prevalence data are essential for identifying population prevalences and informing the prioritisation of targeted interventions. Recognising this imperative, our study sought to characterise the prevalence of the triple burden of malnutrition within a substantial sample of school-going adolescents across both urban and rural settings in South Africa.

Methods

Study sites and population

This is a cross-sectional study that enrolled adolescents from two sites within South Africa. The urban site was Soweto, a historically disadvantaged urban area of the City of Johannesburg covering 200 km^2 with over 1.3 million people (6 400/km^2). The rural location was Agincourt in Bushbuckridge subdistrict, northeast South Africa, an area typical of marginalised former 'homelands', covering 450 km^2 with some 117 000 people in 22 500 households distributed across 31 adjacent villages.[6] This was a convenience sample of adolescents between the ages of 13 and 19 years who were approached to participate in the study from 36 schools or in the community (3 churches, 6 community halls, 31 gazebos set up in outdoor open spaces). Multilingual trained researchers explained the study, and all participants provided written informed consent or assent prior to participation. Where the participants were under the age of 18 years, written consent was obtained from a parent or legal guardian.

The study was approved by the Human Ethics Research Committee of the University of the Witwatersrand, Johannesburg, South Africa (M210827). We also obtained approval from the provincial Gauteng Department of Health and Department of Education (8/4/4/1) and the Mpumalanga Department of Education and Department of Health (MP_202203_001).

Anthropometry

Weight and body fat percentage were measured using calibrated Omron body composition monitor BF511 digital scales (OMRON Healthcare, Kyoto, Japan), and height was measured using a portable SECA 213 stadiometer (SECA, Hamburg, Germany) with adolescents standing barefoot and maintaining an upright posture. Trained researchers measured height and weight in triplicate to the nearest 0.1 cm and 0.1 kg, and the average of three measurements was used. We derived BMI from weight and height (BMI = weight [kg]/height [m$^{2]}$). For adolescents < 18 years, we used sex- and age-specific BMI cutoffs from the International Obesity Task Force (IOTF), and for participants ≥ 18 years of age the standard adult classification system for BMI was used.[7] Fat Mass Index (FMI) was derived from body fat percentage and height (FMI = body fat percentage/height [cm^2]). For adolescents < 19 years, height-for-age z-scores (HAZ) were generated using the 2007 World Health Organization (WHO) growth references (WHO Reference 2007)[8] with the WHO AnthroPlus program.[9] Stunting was calculated as a HAZ < −2. Stunting was not calculated for participants aged 19 years, as the WHO 2007 growth reference values are defined only for individuals up to 18 years of age. Consequently, height-for-age z-scores could not be generated for this age group, and these participants were excluded from stunting analyses.

Anaemia

In Soweto only, a capillary blood sample taken from a finger prick was collected using a lancet, from the ring finger of the non-dominant hand. Haemoglobin was measured using the HemoCue 801 analyser (HemoCue, Ängelholm, Sweden). Haemoglobin values were adjusted for all Soweto adolescents to account for Johannesburg's altitude (HB value adjusted down by 0.5 g/dl for altitudes at 1 700 m above sea level).[10] Participant's haemoglobin levels were classified as healthy HB ≥12 g/dl; anaemia 7–12 g/dl and severe anaemia HB < 7 g/dl.[11] Adolescents classified as having severe anaemia were referred for follow-up to the nearest primary health care facility.

Statistics

Study data were captured directly into and managed using REDCap (Research Electronic Data Capture) hosted at the University of Witwatersrand.[12,13] Data analysis was conducted using IBM SPSS Statistics for Windows, version 30.0.0.0 (172) (IBM Corp, Armonk, NY, USA). GraphPad Prism 5.03 (GraphPad Software, San Diego, CA, USA) was used for the graphical designs of figures. Data were assessed for normality using visual inspection of histograms, skewness, and kurtosis; for continuous variables with approximately symmetric distributions, we summarised using means and standard deviations; otherwise, medians and IQRs were used. Categorical data were presented as frequencies and percentages. Chi-square, independent t-tests and one-way ANOVAs were performed to assess differences, respectively, and Bonferroni post hoc analyses were conducted.

Results

The study enrolled 12 644 adolescents, and the mean age of the population was 15.5 years, with 62% of the total sample comprising girls and 70.7% living in rural Agincourt. Of the adolescents < 19 years of age (n = 12 340), 5% were linear growth stunted, with urban boys having the highest prevalence (stunting was not calculated for adolescents aged 19). The overall prevalence of malnutrition based on BMI status in this study was 34.9%. Specifically, the overall underweight prevalence was 14.3% with similar prevalences across the rural-urban and gender groups. The overall prevalence of overweight and obesity was 16.0% and 4.6% respectively, with the prevalence in boys similarly low in both the urban (overweight: 5.6%; obesity: 2.0%) and rural sites (overweight: 5.6%; obesity: 2.1%), while there was a higher prevalence for both overweight (32.3%) and obesity (7.0%) in urban girls compared with their rural peers (overweight: 17.4%; obesity: 5.8%) (Table 1). Within each setting's study population, boys had a greater prevalence of being underweight and a lower prevalence of being overweight or obese when compared with girls (Figure 1). The percentage gender distribution by weight-status group is reflected in Figure 2 by respective site, and, as anticipated, urban girls have the greatest malnutrition risk. The mean bio-impedance derived body fat percentage of the total population was 22.4% (SD 10.6), and the concomitant derived fat mass index was 5.1 kg/m^2 (SD 3.4). Bio-impedance-derived body fat percentage by site and sex was 30.2% (SD 9.6) and 14.8% (SD 7.2) for urban females and males, respectively and 26.8% (SD 8.5) and 13.5% (SD 6.5) for rural females and males, respectively.

In a subsample of urban adolescents with haemoglobin data, haemoglobin levels were lower in girls (12.5 ± 1.6 g/dl) compared with boys (14.4 ± 1.9 g/dl) (see Table 1), and, consequently, the prevalence of mild and severe anaemia was higher in the girls compared with the boys (31.6% vs. 10.2%

Table 1: Characteristics of the study population

Variable	Total $n = 12\ 644$	Urban female $n = 2\ 550$	Urban male $n = 1\ 285$	Rural female $n = 5\ 300$	Rural male $n = 3\ 509$	*p*-value
Sex, female, *n* (%)	7 850 (62.1)					
Site, urban, *n* (%)	3 835 (30.3)					
Age, years (mean SD)	15.5 ± 1.6	15.6 ± 1.7	15.7 ± 1.8	15.2 ± 1.4[a]	15.7 ± 1.6[c]	< 0.001
Height, cm (mean SD)	161.1 ± 8.3	156.8 ± 6.4	162.8 ± 9.4[a]	159.5 ± 6.2[a]	166.1 ± 9.1[b,c]	< 0.001
Weight, kg (mean SD)	54.8 ± 11.8	55.7 ± 12.7	51.5 ± 10.9[a]	55.1 ± 11.9	54.9 ± 11.2[b]	< 0.001
Stunting, *n* (%)[#]; $n = 12\ 340$	622 (5.0)	174 (7.1)	143 (11.7)	112 (2.1)	193 (5.6)	< 0.001
BMI (mean SD)	21.1 ± 4.2	22.6 ± 4.7	19.3 ± 3.0[a]	21.6 ± 4.3[a]	19.7 ± 3.2[b,c]	< 0.001
Underweight, *n* (%)[†]	1 810 (14.3)	387 (15.2)	274 (21.3)	643 (12.1)	506 (14.4)	< 0.001
Healthy weight, *n* (%)[†]	8 291 (65.1)	1 157 (45.4)	913 (71.1)	3 426 (64.6)	2 735 (77.9)	
Overweight *n* (%)[†]	2 018 (16.0)	828 (32.3)	72 (5.6)	923 (17.4)	195 (5.6)	
Obese, *n* (%)[†]	585 (4.6)	178 (7.0)	26 (2.0)	308 (5.8)	73 (2.1)	
Overweight or obese, *n* (%)[†]	2 603 (20.6)	1 006 (39.5)	98 (7.6)	1 231 (23.2)	268 (7.6)	
Body fat percentage (mean SD)*, $n = 12\ 192$	22.4 ± 10.6	30.2 ± 9.6	14.8 ± 7.2[a]	26.8 ± 8.5[a]	13.5 ± 6.5[b,c]	< 0.001
Derived Fat Mass Index (mean SD)*; $n = 12\ 192$	5.1 ± 3.4	7.2 ± 3.6	3.1 ± 2.1[a]	6.1 ± 3.2[a]	2.8 ± 2.0[c]	< 0.001
Anaemia	($n = 1\ 709$)	($n = 1\ 020$)	(HB $n = 689$)			
Hb, g/dl (mean SD)	13.3 ± 1.9	12.5 ± 1.6	14.4 ± 1.9			< 0.001
Anaemia (mild or severe), *n* (%)[‡]	392 (22.9)	322 (31.6)	70 (10.2)			< 0.001
– Anaemic & underweight, *n* (%)	65 (16.6)					
– Anaemic & healthy weight, *n* (%)	222 (56.6)					
– Anaemic & overweight, *n* (%)	70 (17.9)					
– Anaemic & obese, *n* (%)	35 (8.9)					

[a]Denotes statistically significant difference from urban females.
[b]Denotes statistically significant difference from urban males.
[c]Denotes statistically significant difference from rural females.
[†]< 18 years, we used sex- and age-specific BMI cutoffs from the International Obesity Task Force (IOTF), and for participants ≥ 18 years of age the standard adult classification system for BMI was used.[7]
[‡]Healthy HB > = 12 g/dl; anaemia 7–12 g/dl. and severe anaemia HB < 7 g/dl (World Health Organization)[11].
[#]Stunting was calculated as a HAZ < −2 (WHO Reference 2007)[8].
*Body composition parameters were derived using bioelectrical impedance analysis.

respectively). Importantly, mild or severe anaemia co-occurred with underweight, overweight, and obesity: among girls with mild or severe anaemia, nearly half (45.6%) had a coexisting malnutrition (underweight or overweight/obese). Among boys with mild or severe anaemia, a third (32.7%) were similarly co-morbid.

Discussion

The findings from this study underscore the syndemic nature of adolescent malnutrition in South Africa, where stunting, underweight, overweight/obesity, and anaemia coexist. Urban girls appear most vulnerable, with alarmingly high rates of overweight and obesity (nearly 40%) paralleled by higher body fat and a one-third anaemia prevalence. Similarly, rural girls demonstrate concerning statistics, closely mirroring the trends observed in their urban counterparts around overweight/obesity and adiposity. By older adulthood (40+ years), adiposity is entrenched: data from six African cohorts of middle-aged women and men's BMI was calculated in 10 702 participants (55% female) and was significantly higher in women than men at nearly all sites. The highest prevalence of obesity was observed at the three South African sites (42.3–66.6% in women and 2.81–17.5% in men) and the lowest in West Africa (1.25–4.22% in women and 1.19–2.20% in men). Conversely, the prevalence of underweight in South African women is low (0.6% in Soweto and 2.1% in Agincourt).[14] Taken together, these data suggest that the trajectory from adolescence to adulthood — where ~22% of adolescents are already overweight/obese — feeds into high adult obesity, underscoring the need for early preventative public health interventions to interrupt cumulative metabolic and micronutrient risk in later adulthood.

In South Africa, malnutrition patterns from young adulthood into later life show a clear age gradient and a persistent 'triple burden'.

These figures reinforce the point of a public health concern in adolescent girls that spans both macronutrient excess and micronutrient deficiency. Both are associated with an increased risk of a range of non-communicable diseases.[15]

Overweight/obesity is a well-established risk factor for hypertension, coronary heart disease, sudden cardiac death, and stroke.[16] A study conducted in healthy adolescents has shown that total body fat is associated with chronic low-grade inflammation.[17] Micronutrient anaemia has also been shown to drive inflammation.[18,19] Chronic low-grade systemic inflammation driven by either overweight or obesity negatively impacts nutrient absorption and handling, potentially creating a perpetuating cycle of inflammation.[20–23] Overweight and obesity, along with micro-nutrient anaemia, are associated with increased risk of type-2 diabetes through elevation of plasma-free fatty acids and the resultant insulin resistance.[24,25] In our urban adolescents, the co-occurrence of mild or severe anaemia with both under- and over-nutrition challenges traditional dichotomies of malnutrition. The fact that over half of mild or severely anaemic adolescents were within a healthy weight range, and a

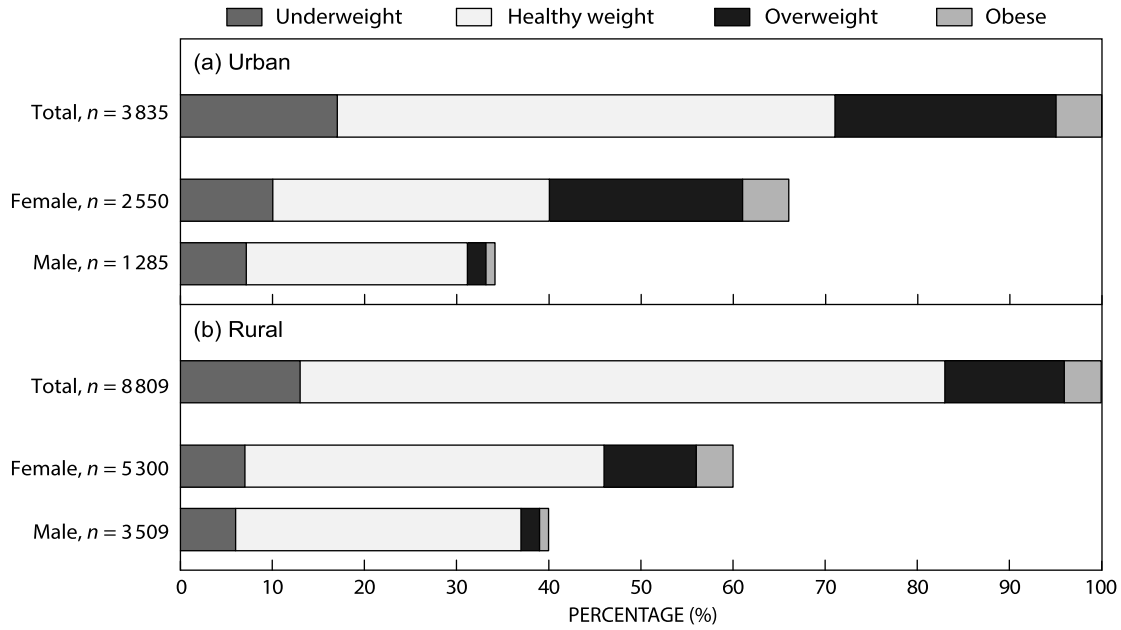

Figure 1: (A) Proportion of underweight, healthy weight, overweight, and obesity in the urban Soweto population, and for girls and boys respectively (urban $n = 3\,835$, urban female $n = 2\,550$, urban male $n = 1\,285$). (B) Proportion of underweight, healthy weight, overweight, and obesity in the rural Agincourt population, and for rural girls and boys respectively.

significant proportion were either underweight or overweight/obese, underscores the need for integrated screening beyond anthropometry alone. The high prevalence of anaemia in the context of overweight/obesity may reflect diet quality deficits, chronic inflammation, or reproductive iron demands in adolescent girls.

Micro-nutrient anaemia may also indirectly impact overweight and obesity and efforts to mitigate weight gain. Iron-deficiency anaemia is often associated with feelings of fatigue and low energy as a result of reduced oxygen supply, which may consequently reduce physical activity and give rise to an increase in sedentary behaviour.[26] Underweight is also associated with a number of health risks and serves as a predictor of mortality.[27] One study found that approximately half of underweight adults had one cardiometabolic condition, and 12% had two or more.[28] In addition to the impact of overweight and obesity, and anaemia, on adolescent health, they are also linked to less favourable pregnancy and birth outcomes.[29,30] Overweight and obesity during pregnancy have been linked to gestational diabetes and pre-eclampsia in the mother and low birthweight, foetal growth restriction, and a long-term risk of obesity and metabolic dysfunction in the offspring.[29] Micro-nutrient anaemia during pregnancy has also been linked to preterm birth, low birthweight, and developmental delays in infants.[30] Low birthweight in turn has been linked to adverse health outcomes, including risk of diabetes and obesity later in life.[31] In summary, underweight, overweight, obesity, and both maternal over-nutrition and under-nutrition are all linked to adverse health outcomes in offspring later in life, highlighting the significant importance of intervention in adolescents entering their reproductive years.

To contextualise our current findings, we compared data collected in girls in the same urban and rural settings in 2007.[32,33] Between 2007 and 2023, the change in prevalence of overweight and obesity increased in all age groups, with the greatest increase in the urban site and in 15-year-olds in both sites. Urban girls experienced nearly double the increase and began with an average prevalence approximately 8% higher than rural girls in 2007. In both groups, the largest increase in prevalence was seen in the 15-year age groups (urban age 13: +5%; age 15: +16%; age 17: +13%; rural age 13: +6%; age 15: +9%; age 17: +8%) (Figure S1). This indicates a rapid increase in weight gain in mid- to late adolescence, in line with findings for girls in sub-Saharan Africa.[1] This is of significant concern as previous research, both in this[34] and other populations[35,36] in girls, has shown that adiposity in adolescents serves as a predictor for elevated blood pressure and overweight and obesity in adulthood.

Collectively, these findings call for urgent multisectoral interventions targeting both ends of the malnutrition spectrum. Global strategies to address adolescent malnutrition have focused on education, health, food systems, household resources, regulations, social and community influences, and multi-sectoral approaches.[37] Specifically, these have included:

- School-based programmes: feeding, nutritional education, and creating healthy food environments.
- Macronutrient and micronutrient supplementation.
- Community engagement: involving community organisations in education and access to healthy foods.
- Legislation and regulations: limiting unhealthy food access, promoting nutrient-rich foods, and taxing unhealthy foods.
- Promotion of physical activity: safe exercise spaces, sports opportunities, and physical education.

While numerous single-issue focused interventions exist, they have been focused primarily in high-resource areas; as such, effective long-term change may require contextually relevant and location-specific multidimensional interventions addressing several barriers to health synchronously. In both urban and rural South African settings, individuals, particularly

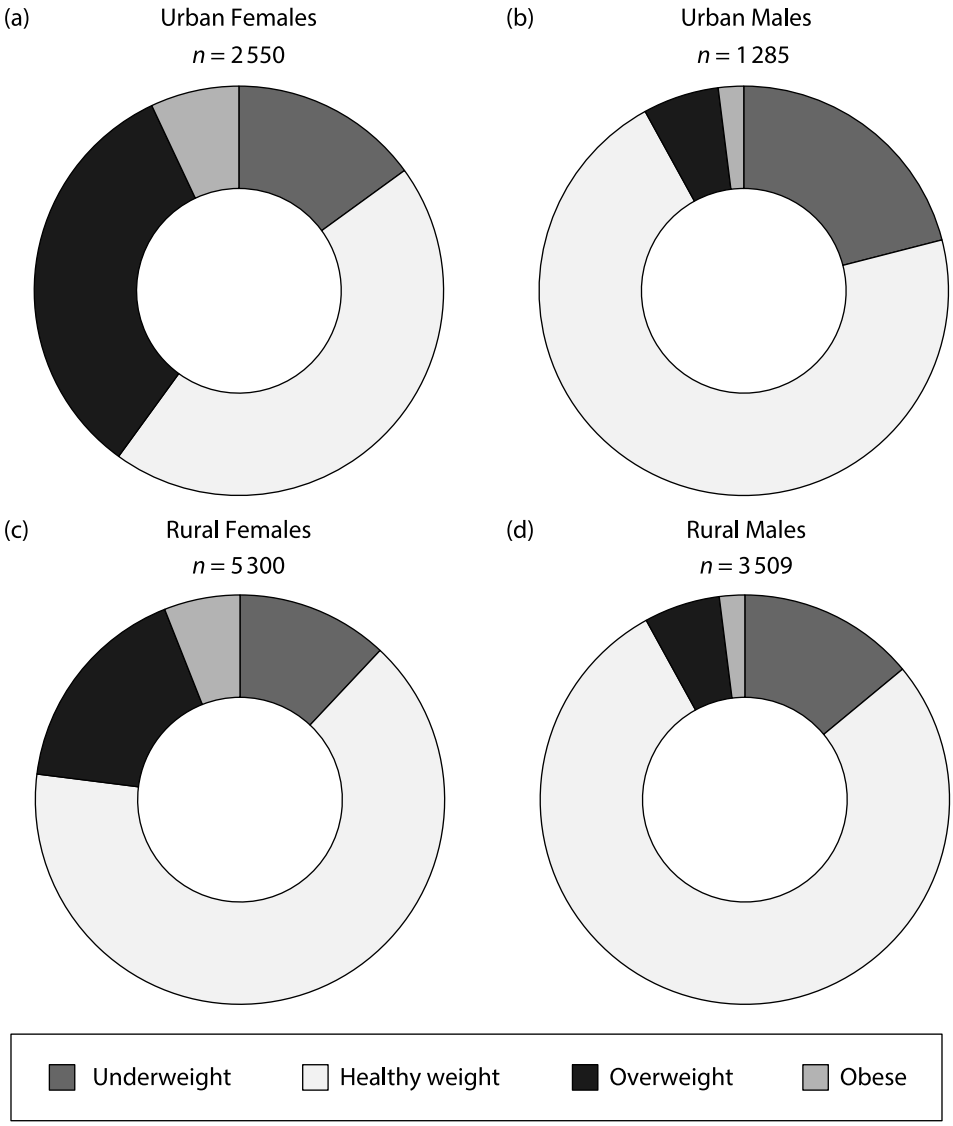

Figure 2: Percentage of underweight, healthy weight, overweight, and obesity in (A) urban females, (B) urban males, (C) rural females, and (D) rural males.

adolescents, face persistent and evolving obstacles to health-seeking, often compounded by limited agency over their health and food choices.[38] These challenges, combined with a resource-constrained healthcare system, underscore the urgent need for integrated multidimensional interventions tailored to the South African context and specifically designed for adolescents.[39] In South Africa, policy responses should focus on prioritising food insecurity, unhealthy food environments, and poor dietary diversity, while ensuring iron and micronutrient adequacy. School- and community-based programmes should incorporate nutrition education, routine anaemia screening, and gender-responsive approaches that consider adolescent girls' unique risks.

Despite providing valuable insights through a large and diverse sample of South African adolescents, this study has several limitations. Data collection was predominantly school-based, and restrictions from the local department of education in the rural site prohibited blood sample collection on school premises, thereby hindering anaemia screening efforts. Additionally, in the urban setting, not all participants consented to fingerprick blood sample collection for haemoglobin analysis, which constrained the comprehensive assessment of anaemia across both sites. To address some of these gaps, adolescent anaemia is currently being investigated through a separate community study in rural Agincourt.

In conclusion, the escalating prevalence of overweight and obesity alongside persistent underweight highlights a complex and evolving nutritional landscape among urban and rural adolescents. Particularly alarming is the concurrent presence of overweight, obesity, high body fat indices and anaemia in adolescent girls, underscoring the profound and multifaceted impact on their health and that of future generations. Addressing this compounded burden requires urgent, innovative, and comprehensive interventions aimed at preventing and mitigating the intertwined challenges of malnutrition in all its forms.

Author contributions

All authors were involved in the conception and planning of the study. SHC carried out the data analyses, generated figures and tables, interpreted the data, and undertook the writing of the paper. SHC and SAN did the literature search. LKM, NC, SC, EM, KKO, SMT, and KK read and contributed to the final

version. All authors provided edits and approved the final version.

Disclosure statement – No potential conflict of interest was reported by the authors.

Funding – The SAMRC/Wits Rural Public Health and Health Transitions Research Unit and Agincourt Health and Sociodemographic Surveillance System, a node of the South African Population Research Infrastructure Network (SAPRIN), is supported by the Department of Science, Technology and Innovation (DSTI), Department of Health and Social Care (DHSC), the Foreign, Commonwealth & Development Office (FCDO), the UK Medical Research Council (MRC), the University of the Witwatersrand, and the Medical Research Council, South Africa, and the Wellcome Trust, UK as funders of this Joint Global Health Trial (grants 058893/Z/99/A; 069683/Z/02/Z; 085477/Z/08/Z; 085477/B/08/Z, MR/V005790/2), and the SAMRC/Wits Developmental Pathways for Health Research Unit by the South African Medical Research Council and the University of the Witwatersrand, Johannesburg, South Africa. SJS and KKO are supported by the UKRI Medical Research Council (MC_UU_00006/2) and the NIHR Cambridge Biomedical Research Centre (NIHR203312).

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Received: 28-07-2025 Accepted: 12-11-2025