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Urban-rural disparities in overweight and upper-tail BMI shifts among adolescents in Yunnan Province, China: A repeated cross-sectional analysis of three waves of school health examination data, 2021-2024

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Abstract

Background

Adolescent overweight and obesity are major public health concerns in China. However, recent evidence on urban-rural disparities is limited, particularly among adolescents in resource-limited areas of southwestern China.

Methods

We analyzed three waves of school health examination data collected in Yunnan Province, China, in 2021, 2023, and 2024 (N = 35,942 adolescents aged 12–18 years). Trained health professionals measured height and weight using standardized equipment. Overweight (including obesity) and obesity were defined according to the Chinese WS/T 586–2018 standard. We estimated age-standardized prevalence, examined wave-to-wave changes using stratified logistic regression, and estimated BMI shifts from the 5th to the 95th percentile using quantile regression with bootstrap 95% confidence intervals.

Results

In the study sample, age-standardized overweight prevalence was 25.6% in 2021, 30.1% in 2023, and 26.2% in 2024. The urban-rural gap widened from 4.0 percentage points in 2021 to 7.5 percentage points in 2024. By 2024, prevalence among rural adolescents had fallen below its 2021 level, whereas prevalence among urban adolescents remained higher than in 2021 in the full sample. Among urban adolescents, BMI at the 85th-95th percentiles also remained higher in 2024 than in 2021; among rural adolescents, BMI returned to or below 2021 levels across the distribution. Analyses restricted to schools represented in all three waves supported the widened urban-rural contrast but attenuated evidence of above-baseline urban prevalence in 2024. Differences in temporal patterns by ethnicity were modest.

Conclusions

The return of overall overweight prevalence toward its 2021 level by 2024 masked a wider urban-rural disparity and a more persistent elevation in upper-tail BMI among urban adolescents. Surveillance that examines the BMI distribution, together with targeted prevention, may better identify and address the groups with persistent excess burden.

1. Background

Adolescent overweight and obesity are major public health challenges. Over the past four decades, mean body mass index (BMI) and the prevalence of overweight and obesity have increased substantially

in both high-income and low- and middle-income countries, alongside changes in food environments, physical activity, and sedentary behavior associated with economic development and urbanization [1, 2]. Adolescence is a consequential period because weight status often tracks into adulthood, and excess adiposity during childhood and adolescence is associated with adverse growth, pubertal, and long-term health outcomes [3, 4]. In China, the prevalence of overweight and obesity among children and adolescents has increased rapidly since the 1980s and is now a major public health concern across provinces [3, 5–7].

Within China, adolescent overweight has historically been more prevalent in urban areas. National school-survey data from 1985 to 2019 show that overweight prevalence increased earlier and more sharply among urban children and adolescents, alongside differences in diet, active transportation, and school-related sedentary time associated with urbanization [3, 7, 8]. Although prevalence has also increased in rural areas as economic development has extended to inland and western provinces, urban-rural differences remain and vary across regions [9, 10]. These findings are consistent with the broader nutrition-transition literature, which shows that obesogenic environments spread unevenly across places and populations [11].

International evidence also shows that aggregate obesity trends can stabilize while inequalities between population subgroups persist or widen. Socioeconomic disparities in childhood overweight and obesity have increased in England [12], and studies from the United States have documented substantial racial, ethnic, socioeconomic, state, and regional inequalities in pediatric obesity and its trends [13–15]. Studies from sub-Saharan Africa and the Middle East have likewise reported geographic and socioeconomic patterning of obesity [16–18]. These findings indicate that overall trends may mask important heterogeneity between social groups.

This concern is especially relevant when surveillance relies on a single summary measure. Chinese studies of adolescent obesity have generally reported the prevalence of overweight and obesity or mean BMI [6, 10]. Prevalence estimates may conceal disproportionate changes at the upper end of the BMI distribution, where clinical and public health risks are concentrated [2, 19]. Distribution-sensitive methods that model BMI across percentiles can distinguish a broad shift in the entire distribution from a change concentrated in its upper tail [20]. Repeated cross-sectional designs can track such changes and subgroup disparities when longitudinal follow-up is unavailable [21].

Yunnan, a geographically and ethnically diverse province in southwestern China with a large rural population, provides an important setting for examining these questions. Communities across the province differ substantially in economic development, schooling context, and access to urbanized food environments. National findings and evidence from more urbanized settings may not generalize to Yunnan because its social structure, development, and ethnic composition differ [8, 10]. Previous surveillance documented long-term changes in undernutrition and overnutrition among school-aged populations in Yunnan from 1985 to 2019, but patterns after 2019 have not been characterized [22].

Three gaps motivate the present study. First, although pediatric BMI changes during and after the coronavirus disease 2019 (COVID-19) pandemic have been studied in the United States and Europe [23, 24], recent evidence for Chinese adolescents, particularly in less economically developed southwestern provinces, remains limited. Second, few studies have examined whether urban-rural disparities in adolescent overweight changed during this period in China. Third, prevalence-based summaries may obscure changes within the BMI distribution; examining multiple percentiles may therefore provide information that is relevant to prevention but is not captured by mean BMI or overall prevalence alone [19, 20].

Using three waves of school health examination data collected in Yunnan Province in 2021, 2023, and 2024 (N = 35,942 adolescents aged 12–18 years), we examined in this paper: (1) age-standardized prevalence of overweight, including obesity, overall and by sex and urban-rural status; (2) changes across the BMI distribution, estimated separately for urban and rural adolescents; and (3) secondary patterns by ethnicity. By combining prevalence-based and distribution-based analyses, we assessed whether the overall return toward the 2021 level by 2024 differed by urban-rural status and across the BMI distribution.

2. Methods

2.1 Study design and setting

We conducted a repeated cross-sectional analysis of standardized school health examination records from Yunnan Province in southwestern China. Data were available for 2021, 2023, and 2024 from 12 participating schools. These schools were selected using a multistage cluster sampling method, with region being the first level of cluster and county being the second level of cluster. Within the final sampling unit, one school was randomly selected, and all students within that school aged 12–18 underwent the health examination. Only schools agreed to participate in the study were used for analysis in this study, resulting in 12 schools. Consequently, the data are not representative at the provincial level. Routine school health examinations were not conducted in 2022 because of disruptions related to the COVID-19 pandemic. The contributing data from the set of 12 schools varied across waves, with seven schools contributing data in all three waves and were included in a sensitivity analysis.

2.2 Participants

The study sample comprised adolescents aged 12–18 years who attended participating schools in Yunnan Province during each survey wave. Records were excluded if sex, urban-rural status, ethnicity, height, or weight was missing. We also excluded biologically implausible BMI values, clearly erroneous anthropometric measurements, and duplicate records within the same person-year. The final analytic sample included 35,942 records: 12,668 from 2021, 10,911 from 2023, and 12,363 from 2024.

2.3 Anthropometric measurement

Trained health professionals measured height and weight as part of routine school health examinations using standardized, calibrated instruments. Students were measured barefoot and wearing light clothing. Height was recorded to the nearest 0.1 cm and weight to the nearest 0.1 kg.

2.4 Outcome definitions

BMI was calculated as weight in kilograms divided by height in meters squared (kg/m^2). Overweight and obesity were classified using sex- and age-specific cutoffs from the Chinese national standard WS/T 586–2018 [25]. The primary outcome was overweight inclusive of obesity, defined as BMI at or above the applicable overweight cutoff. The secondary outcome was obesity, defined as BMI at or above the applicable obesity cutoff. A sensitivity analysis using the mutually exclusive category of overweight without obesity is presented in Supplementary Figure S1 (Additional file 1).

2.5 Social position variables

2.5.1 Urban–rural status

Urban-rural status was defined using household registration (hukou) recorded in school administrative files. Adolescents with non-agricultural hukou (city or town) were classified as urban, and those with agricultural hukou were classified as rural. We used hukou-based urban-rural status as the primary social-position measure.

2.5.2 Ethnicity

Ethnicity was obtained from school administrative records. Because several individual ethnic minority groups had small sample sizes, we compared Han adolescents with a combined category of all non-Han adolescents. This combined category is heterogeneous and may obscure differences among ethnic minority groups; ethnicity was therefore treated as a secondary social-position measure.

2.6 Covariates

Logistic regression models adjusted for age in single-year units, sex, urban-rural status, and ethnicity, except when the covariate defined the subgroup being analyzed. Quantile regression models were fitted separately for urban and rural adolescents and adjusted for age, sex, and ethnicity.

2.7 Statistical analysis

Analyses were conducted in R version 4.5.1 (R Foundation for Statistical Computing, Vienna, Austria). We used dplyr and tidyr for data management, ggplot2 for graphics, flextable for tables, broom for regression output, emmeans for model-based marginal estimates, quantreg for quantile regression, and furrr for parallel bootstrap computation. All tests were two-sided, and $p < 0.05$ was considered statistically significant for the primary analyses. Likelihood ratio tests used a chi-square approximation.

We summarized sample characteristics using counts and column percentages and compared their distributions across waves using Pearson chi-square tests. Crude and age-standardized prevalence of

overweight and obesity were estimated for each wave overall and by sex and urban-rural status; estimates by ethnicity were secondary. Direct age standardization used the pooled study population from all three waves as the internal standard. We calculated 95% confidence intervals for standardized prevalence using the normal approximation.

We used separate logistic regression models to estimate wave-to-wave changes in the odds of overweight within the overall sample and within strata defined by sex, urban-rural status, single-year age, and ethnicity. Survey wave was the exposure, with 2021 as the reference, and models included the remaining sociodemographic covariates when they varied within the stratum. Results are reported as odds ratios (ORs) with 95% confidence intervals (CIs). Corresponding models for obesity compared participants with obesity with those of normal weight and excluded participants who were overweight without obesity; these results are reported in Supplementary Table S2.

To assess changes across the BMI distribution [20], we fitted quantile regression models of BMI on survey wave at 19 quantiles from the 5th to the 95th percentile. Models were fitted separately for urban and rural adolescents and adjusted for age, sex, and ethnicity. Standard errors were estimated using 200 bootstrap replications, and 95% CIs were calculated from the bootstrap standard errors.

As a secondary analysis, we assessed whether temporal patterns differed by ethnicity by comparing a pooled logistic regression model containing a wave-by-ethnicity interaction with a main-effects model using a likelihood ratio test. Interaction coefficients were exponentiated and reported as ORs with 95% CIs. We also generated age-specific adjusted prevalence curves using logistic regression models with quadratic age terms and model-based marginal estimates from emmeans (Supplementary Figure S2).

To assess the influence of changes in school composition across waves, we repeated the principal subgroup logistic regression and urban-rural quantile regression analyses in the seven schools that contributed data in all three waves (N = 30,002). In this repeated-school sample, subgroup logistic regression models were limited to the overall, sex-specific, and urban-rural comparisons (Supplementary Table S3 and Supplementary Figure S3). We report age-standardized prevalence, ORs, and quantile regression coefficients with 95% CIs. Supplementary Table S1 provides detailed crude prevalence estimates by wave and subgroup.

2.8 Use of generative AI and AI-assisted technologies in manuscript preparation

During manuscript preparation, the authors used OpenAI Codex to assist with English-language editing, including improvements to grammar, clarity, concision, and consistency. The authors reviewed and revised all suggested changes and take full responsibility for the accuracy, integrity, and final content of the manuscript. The tool was not used to generate or analyze study data, conduct statistical analyses, interpret findings, or create references.

3. Results

3.1 Sample characteristics

The analytic sample included 35,942 adolescents aged 12–18 years: 12,668 in 2021, 10,911 in 2023, and 12,363 in 2024 (Table 1). Boys represented 54.3% of the 2021 sample and 52.2% of the 2024 sample ($p < 0.01$). The proportion of urban participants was 50.8% in 2021, 66.4% in 2023, and 53.5% in 2024. The proportion of ethnic minority adolescents was 15.1%, 33.3%, and 30.4%, respectively. Because sample composition differed significantly across waves, subsequent analyses used age standardization and multivariable adjustment.

Table 1
Sociodemographic characteristics of participants

Characteristics	**Survey Year**			**P-value**
	2021	**2023**	**2024**	
N (Total)	12668	10911	12363	
Sex				< 0.01
Boy	6878 (54.3)	5887 (54.0)	6449 (52.2)	
Girl	5790 (45.7)	5024 (46.0)	5914 (47.8)	
Age Group				< 0.01
12	917 (7.2)	648 (5.9)	770 (6.2)	
13	1991 (15.7)	1059 (9.7)	1079 (8.7)	
14	1971 (15.6)	1278 (11.7)	1156 (9.4)	
15	2105 (16.6)	2563 (23.5)	3275 (26.5)	
16	2199 (17.4)	2390 (21.9)	2950 (23.9)	
17	2420 (19.1)	2183 (20.0)	2417 (19.6)	
18	1065 (8.4)	790 (7.2)	716 (5.8)	
Area				< 0.01
Urban	6430 (50.8)	7245 (66.4)	6613 (53.5)	
Rural	6238 (49.2)	3666 (33.6)	5750 (46.5)	
Ethnicity				< 0.01
Han	10757 (84.9)	7276 (66.7)	8608 (69.6)	
Minorities	1911 (15.1)	3635 (33.3)	3755 (30.4)	

Notes: Values are number (column percentage). P-values were obtained from chi-square tests comparing the distribution across survey waves.

3.2 Overall temporal patterns in overweight and obesity

Figure 1 presents crude and age-standardized prevalence of overweight, including obesity, and obesity across the three waves for the total sample, boys, and girls. In the total sample, age-standardized overweight prevalence increased from 25.6% in 2021 to 30.1% in 2023 and then declined to 26.2% in 2024. Obesity prevalence followed a similar pattern, increasing from 9.9% to 12.7% and then declining to 10.8%. Thus, population-level prevalence in 2024 was close to, but slightly higher than, the 2021 level.

Patterns differed by sex. Among girls, overweight prevalence increased from 21.6% in 2021 to 25.9% in 2023 and declined to 20.3% in 2024; obesity prevalence was 7.0%, 9.5%, and 7.4%, respectively. Among boys, overweight prevalence was 29.1%, 33.8%, and 31.5%, and obesity prevalence was 12.5%, 15.4%, and 13.9%. Crude and age-standardized estimates were similar, suggesting that differences in age composition contributed little to these patterns (Supplementary Table S1).

Note

Solid lines indicate age-standardized prevalence; dashed lines indicate crude prevalence. Dotted horizontal lines indicate pooled crude prevalence across all survey years.

3.3 Urban–rural disparities in overweight and obesity

Figure 2 presents age-standardized prevalence of overweight and obesity by urban-rural status. Urban adolescents had higher prevalence than rural adolescents in every wave. Overweight prevalence among urban adolescents increased from 27.7% in 2021 to 32.6% in 2023 and declined to 29.7% in 2024. Among rural adolescents, prevalence increased from 23.7% to 25.1% and then declined to 22.2%. The urban-rural difference in overweight prevalence increased from 4.0 percentage points in 2021 to 7.5 percentage points in both 2023 and 2024.

Obesity prevalence showed a similar pattern. Among urban adolescents, prevalence increased from 11.2% in 2021 to 14.1% in 2023 and declined to 12.6% in 2024. Among rural adolescents, prevalence increased from 8.7% to 10.0% and then declined to 8.8%. The urban-rural difference in obesity prevalence increased from 2.5 percentage points in 2021 to 3.8 percentage points in 2024. Therefore, the return of population-level prevalence toward the 2021 level masked different patterns for urban and rural adolescents.

Note

Solid lines indicate age-standardized prevalence; dashed lines indicate crude prevalence. Orange = urban (municipal); green = rural (county-level). Error bars = 95% CIs.

3.4 Shifts across the BMI distribution

Figure 3 presents adjusted differences in BMI relative to 2021 at 19 quantiles from the 5th to the 95th percentile, estimated separately for urban and rural adolescents.

Among urban adolescents, the adjusted 2023-versus-2021 difference increased from approximately 0.3 kg/m^2 at the 10th percentile to approximately 0.9 kg/m^2 at the 85th percentile. For 2024 versus 2021, BMI was close to or slightly below the 2021 level at the 5th-45th percentiles, but the difference became positive above the median and reached approximately 0.6 kg/m^2 at the 95th percentile. Thus, the upper end of the urban BMI distribution remained higher in 2024 than in 2021 even though BMI near the median had returned toward the 2021 level.

Among rural adolescents, the adjusted 2023-versus-2021 difference was approximately 0.3 kg/m^2 across most percentiles and increased modestly at the upper end of the distribution. The 2024-versus-2021 difference was negative across the distribution, ranging from approximately − 0.3 to -0.2 kg/m^2 and approaching zero at the highest percentiles.

These results indicate that the return of overall prevalence toward the 2021 level masked an elevation in upper-tail BMI among urban adolescents that was not observed among rural adolescents.

Note

Blue = 2023 vs. 2021; red = 2024 vs. 2021. Shaded areas = 95% bootstrap CIs (200 replications).

Adjusted for sex, age, and ethnicity within each urban–rural stratum.

3.5 Adjusted stratified analysis

Table 2 presents adjusted ORs for overweight in 2023 and 2024 relative to 2021. In the overall sample, the odds of overweight were higher in 2023 (OR = 1.20; 95% CI: 1.13–1.27) but did not differ statistically from 2021 in 2024 (OR = 1.02; 95% CI: 0.96–1.08).

Table 2
Stratified analysis of wave-to-wave changes in overweight (inclusive of obesity) risk, with 2021 as reference

Subgroup	No. of Participants	2021 (Ref)	2023 OR (95% CI)	2024 OR (95% CI)
Total				
Overall	35942	1.00 (Ref)	1.20 (1.13–1.27)	1.02 (0.96–1.08)
Sex				
Boys	19214	1.00 (Ref)	1.17 (1.08–1.26)	1.09 (1.01–1.18)
Girls	16728	1.00 (Ref)	1.23 (1.13–1.35)	0.92 (0.84–1.01)
Area				
Urban	20288	1.00 (Ref)	1.26 (1.17–1.36)	1.10 (1.02–1.19)
Rural	15654	1.00 (Ref)	1.11 (1.01–1.23)	0.93 (0.85–1.01)
Age group				
12 years	2335	1.00 (Ref)	0.97 (0.78–1.21)	0.83 (0.67–1.03)
13 years	4129	1.00 (Ref)	1.24 (1.05–1.47)	1.10 (0.93–1.30)
14 years	4405	1.00 (Ref)	1.09 (0.93–1.28)	1.01 (0.86–1.19)
15 years	7943	1.00 (Ref)	1.20 (1.05–1.37)	1.02 (0.90–1.16)
16 years	7539	1.00 (Ref)	1.20 (1.05–1.37)	0.95 (0.84–1.09)
17 years	7020	1.00 (Ref)	1.17 (1.02–1.34)	1.03 (0.91–1.18)
18 years	2571	1.00 (Ref)	1.76 (1.38–2.25)	1.43 (1.12–1.82)
Ethnicity				
Han	26641	1.00 (Ref)	1.22 (1.14–1.30)	1.06 (0.99–1.13)
Minorities	9301	1.00 (Ref)	1.09 (0.96–1.24)	0.89 (0.78–1.01)

Note: Each row is a separate logistic regression fitted to the designated subgroup. The outcome is overweight inclusive of obesity (BMI ≥ age- and sex-specific overweight cutoff) versus normal weight. Models adjusted for age (continuous), sex, urban–rural status, and ethnicity except the stratification variable. OR = odds ratio; CI = confidence interval; Ref = reference category (2021).

The estimates differed by urban-rural status and sex. Among urban adolescents, the odds of overweight were higher in both 2023 (OR = 1.26; 95% CI: 1.17–1.36) and 2024 (OR = 1.10; 95% CI: 1.02–1.19) than in 2021. Among rural adolescents, the odds were higher in 2023 (OR = 1.11; 95% CI: 1.01–1.23), whereas the 2024 estimate was not statistically different from 2021 (OR = 0.93; 95% CI: 0.85–1.01). Boys had

higher odds in 2024 than in 2021 (OR = 1.09; 95% CI: 1.01–1.18), whereas the estimate for girls was not statistically different from 2021 (OR = 0.92; 95% CI: 0.84–1.01).

Among Han adolescents, the odds of overweight were higher in 2023 than in 2021 (OR = 1.22; 95% CI: 1.14–1.30), whereas the 2024 estimate was not statistically different from 2021 (OR = 1.06; 95% CI: 0.99–1.13). Among ethnic minority adolescents, neither the 2023 estimate (OR = 1.09; 95% CI: 0.96–1.24) nor the 2024 estimate (OR = 0.89; 95% CI: 0.78–1.01) differed statistically from 2021. Age-stratified estimates generally followed the overall pattern, except among 18-year-olds, for whom odds remained higher in 2023 (OR = 1.76) and 2024 (OR = 1.43).

Analyses restricted to the seven schools represented in all three waves (N = 30,002) showed a similar urban-rural contrast but attenuated evidence of above-baseline urban prevalence in 2024 (Supplementary Table S3 and Supplementary Figure S3). In this repeated-school sample, the 2024 OR was 0.98 (95% CI: 0.90–1.07) among urban adolescents and 0.85 (95% CI: 0.77–0.93) among rural adolescents. Quantile regression in the repeated-school sample continued to show a more persistent upper-tail elevation among urban than rural adolescents.

Table 2
Adjusted changes in overweight risk by subgroup and survey year

Subgroup	No. of Participants	2021 (Ref)	2023 OR (95% CI)	2024 OR (95% CI)
Total				
Overall	35942	1.00 (Ref)	1.20 (1.13–1.27)	1.02 (0.96–1.08)
Sex				
Boys	19214	1.00 (Ref)	1.17 (1.08–1.26)	1.09 (1.01–1.18)
Girls	16728	1.00 (Ref)	1.23 (1.13–1.35)	0.92 (0.84–1.01)
Area				
Urban	20288	1.00 (Ref)	1.26 (1.17–1.36)	1.10 (1.02–1.19)
Rural	15654	1.00 (Ref)	1.11 (1.01–1.23)	0.93 (0.85–1.01)
Age group				
12 years	2335	1.00 (Ref)	0.97 (0.78–1.21)	0.83 (0.67–1.03)
13 years	4129	1.00 (Ref)	1.24 (1.05–1.47)	1.10 (0.93–1.30)
14 years	4405	1.00 (Ref)	1.09 (0.93–1.28)	1.01 (0.86–1.19)
15 years	7943	1.00 (Ref)	1.20 (1.05–1.37)	1.02 (0.90–1.16)
16 years	7539	1.00 (Ref)	1.20 (1.05–1.37)	0.95 (0.84–1.09)
17 years	7020	1.00 (Ref)	1.17 (1.02–1.34)	1.03 (0.91–1.18)
18 years	2571	1.00 (Ref)	1.76 (1.38–2.25)	1.43 (1.12–1.82)
Ethnicity				
Han	26641	1.00 (Ref)	1.22 (1.14–1.30)	1.06 (0.99–1.13)
Minorities	9301	1.00 (Ref)	1.09 (0.96–1.24)	0.89 (0.78–1.01)

Note: Each row is a separate logistic regression fitted to the designated subgroup. The outcome is overweight inclusive of obesity (BMI ≥ age- and sex-specific overweight cutoff) versus normal weight. Models adjusted for age (continuous), sex, urban–rural status, and ethnicity except the stratification variable. OR = odds ratio; CI = confidence interval; Ref = reference category (2021).

4. Discussion

4.1 Summary of findings

In this repeated cross-sectional analysis of 35,942 adolescents aged 12–18 years in Yunnan Province, overweight prevalence increased from 2021 to 2023 and then declined toward the 2021 level in 2024. This overall pattern differed by urban-rural status. The urban-rural gap in overweight prevalence widened, and quantile regression showed a more persistent elevation at the upper end of the BMI distribution among urban adolescents. Analyses restricted to schools represented in all three waves supported the wider urban-rural contrast, although evidence that urban prevalence remained above its 2021 level in 2024 was attenuated. Temporal differences by ethnicity were comparatively modest.

4.2 Urban–rural disparities widened during a period of social disruption

The higher prevalence of adolescent overweight in urban areas is consistent with Chinese studies linking urbanization and changes in diet and physical activity to higher overweight and obesity prevalence among urban children and adolescents [3, 5, 7, 8]. Although earlier provincial research suggested that increasing rural prevalence could narrow the urban-rural gap [9], the gap in our Yunnan sample increased from 4.0 percentage points in 2021 to 7.5 percentage points in 2023 and remained at 7.5 percentage points in 2024.

This pattern is consistent with evidence that overall obesity trends can stabilize while inequalities between subgroups persist or widen. Studies from England and the United States have documented socioeconomic, racial, ethnic, state, and regional inequalities in obesity trends [12, 13, 15]. Geographic and urban-rural differences have also been reported in other settings [16, 17]. The Yunnan findings add evidence from an understudied region of China to this broader literature on heterogeneous obesity trends.

Several mechanisms could contribute to the different urban and rural patterns. Urban food environments, transportation patterns, and school routines may sustain lower physical activity and greater access to energy-dense foods after an acute disruption ends [3, 11]. Urban-rural status in Yunnan may also capture differences in institutional context, daily movement, and food access associated with uneven development. However, the present data did not measure these mechanisms directly.

The repeated cross-sectional design does not identify the causes of the wider urban-rural gap, and the observed differences should not be interpreted as causal effects of the COVID-19 pandemic. The data show that prevalence changed differently among urban and rural adolescents between the observed waves. In analyses restricted to schools represented in all three waves, the urban-rural contrast persisted, but evidence that urban prevalence remained above its 2021 level in 2024 was attenuated. Changes in school composition may therefore explain part of the full-sample pattern, although they do not fully explain the wider urban-rural difference.

4.3 Upper-tail stickiness and implications for intervention targeting

Prevalence estimates cannot show whether changes in BMI occurred throughout the distribution or were concentrated among adolescents at its upper end. Quantile regression addressed this limitation by estimating changes across the BMI distribution [2, 19, 20]. Among urban adolescents, the 2023-versus-2021 difference increased across percentiles. By 2024, BMI at the lower and middle percentiles had returned toward the 2021 level, whereas BMI at the upper percentiles remained higher. Among rural adolescents, BMI in 2024 was at or below the 2021 level across the distribution. The repeated-school analysis showed the same general contrast, although the magnitude of the urban difference was attenuated.

These distributional findings show that prevalence alone may understate persistent changes among adolescents at the upper end of the BMI distribution. Conclusions about disparities can also vary according to the measure of adiposity used [26, 27]. In the present study, the interpretation of recovery differed when we examined percentile-specific BMI changes rather than only the prevalence threshold.

The findings are also consistent with pediatric studies that reported greater pandemic-era BMI increases among groups already at elevated risk [23, 24]. Changes in physical activity, food intake, or daily routines may be more difficult to reverse among adolescents at the upper end of the BMI distribution, although these behaviors were not measured in our study. Distributional changes in BMI may also have implications for later cardiometabolic disease burden [28].

The results support the use of both population-wide and higher-risk prevention approaches [29]. Provincial surveillance reports could supplement overall overweight prevalence with selected BMI percentiles reported separately by urban-rural status. Because school health examinations already collect measured height and weight, these indicators could be calculated without additional data collection. Schools and health services could then use the combined prevalence and distributional information to identify where more intensive assessment and prevention may be needed. The effectiveness and potential harms of targeted approaches should be evaluated before routine implementation.

Among most age groups, the odds of overweight in 2024 did not differ statistically from the 2021 level. The exception was 18-year-olds (OR = 1.43; 95% CI: 1.12–1.82). The age-specific result was secondary and should therefore be interpreted cautiously and confirmed in other samples. Future studies should examine whether school demands, physical activity, diet, or other age-related factors account for this pattern.

Repeated cross-sectional surveillance can identify changing subgroup disparities even when the same individuals are not followed over time [21]. Combining this design with distribution-sensitive methods may help distinguish broad population shifts from changes concentrated among adolescents at higher BMI percentiles.

4.4 Ethnic patterns

Temporal patterns were broadly similar among Han and ethnic minority adolescents. The interaction analysis provided limited evidence that changes differed by ethnicity, and the secondary contrast suggesting a greater return toward baseline among ethnic minority adolescents in 2024 should be interpreted cautiously.

The combined ethnic minority category includes groups that differ in geography, socioeconomic conditions, and food environments. In Yunnan, ethnicity is also associated with rural residence and regional development, so the observed comparisons may reflect these correlated factors. Larger studies with disaggregated ethnic categories and adequate urban-rural stratification are needed to assess ethnic differences more precisely.

4.5 Strengths and limitations

The study has several strengths. It analyzed a large sample from three waves of routine school health examinations in an understudied province of southwestern China. Height and weight were measured rather than self-reported. The analysis also combined age-standardized prevalence, multivariable logistic regression, quantile regression, and a repeated-school sensitivity analysis. This approach identified differences across the BMI distribution that would not have been apparent from prevalence estimates alone.

Several limitations should be considered. First, the repeated cross-sectional design did not follow individuals over time and cannot identify which adolescents contributed to upper-tail changes. Second, no data were available for 2022, so the timing and shape of changes between 2021 and 2023 cannot be determined. The observed wave-to-wave differences should not be interpreted as causal effects of pandemic-related disruption. Third, sample composition varied across waves, particularly by urban-rural status and ethnicity. Adjustment and age standardization may not eliminate residual confounding from changes in participating schools or other unmeasured factors. Analyses restricted to schools represented in all three waves supported the wider urban-rural contrast but attenuated evidence of above-baseline urban prevalence in 2024. Fourth, urban-rural status was based on hukou and may not reflect current residence or the full socioeconomic circumstances of participants. We lacked individual-level measures such as parental education and household income. Fifth, combining all non-Han participants may obscure differences among ethnic minority groups. Finally, the participating schools were not described as a probability sample of Yunnan Province; estimates should therefore be interpreted as findings from the study sample rather than as province-wide prevalence estimates.

5. Conclusions

In this study sample of adolescents in Yunnan, overweight prevalence increased from 2021 to 2023 and returned toward the 2021 level in 2024. The overall pattern masked a wider urban-rural disparity and a more persistent elevation at the upper end of the BMI distribution among urban adolescents. Sensitivity analyses supported the wider urban-rural contrast but weakened evidence that urban prevalence in 2024

remained above its 2021 level. Reporting BMI distributions alongside prevalence may improve surveillance by identifying subgroup-specific changes that aggregate estimates do not capture.

Abbreviations

COVID-19
Coronavirus disease 2019
BMI
Body mass index
CI
Confidence interval
OR
Odds ratio

Declarations

Ethics approval and consent to participate

This study was approved by the IRB Review Board of the First People's Hospital of Yunnan Province (Approval No. KHLL2021-KY092). Informed consent was obtained from participants' parents or legal guardians by school teachers before students participated in health examinations. Consent forms were sent via mail and/or messaging within the WeChat app. All participating students provided verbal assent before being examined.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Author Contribution

Jidong Huang conceptualized the study and designed the analytical protocol. Hang Yang conducted the statistical analyses and drafted the initial manuscript, with contributions from Liwen Liang and Jidong Huang. Liwen Liang collected and compiled the data. Yanhong Du and Yu Cao reviewed and revised the manuscript. All authors had full access to and verified the underlying data, critically reviewed, edited, and approved the final version of the manuscript. The corresponding author is responsible for the decision to submit for publication.

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Data Availability

The individual-level school health examination data cannot be publicly shared because they contain sensitive personal information and are subject to institutional data-sharing restrictions. Aggregated data underlying the findings are available from the corresponding author upon reasonable request, subject to approval by the data custodian.

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Figures



Figure 1

Overweight and obesity prevalence among adolescents by sex and survey year in Yunnan Province

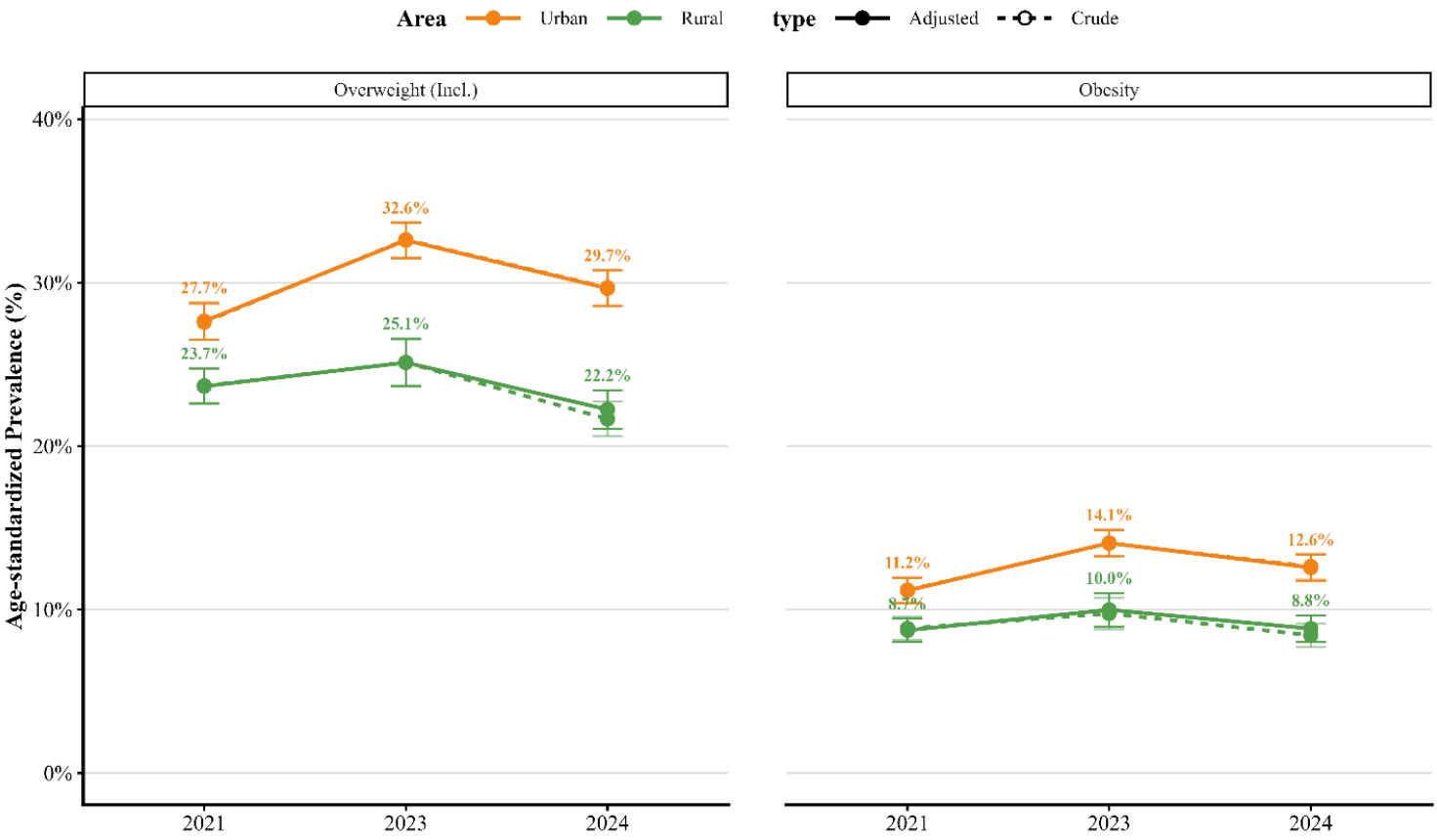


Figure 2

Urban-rural disparities in overweight and obesity prevalence by survey year in Yunnan Province

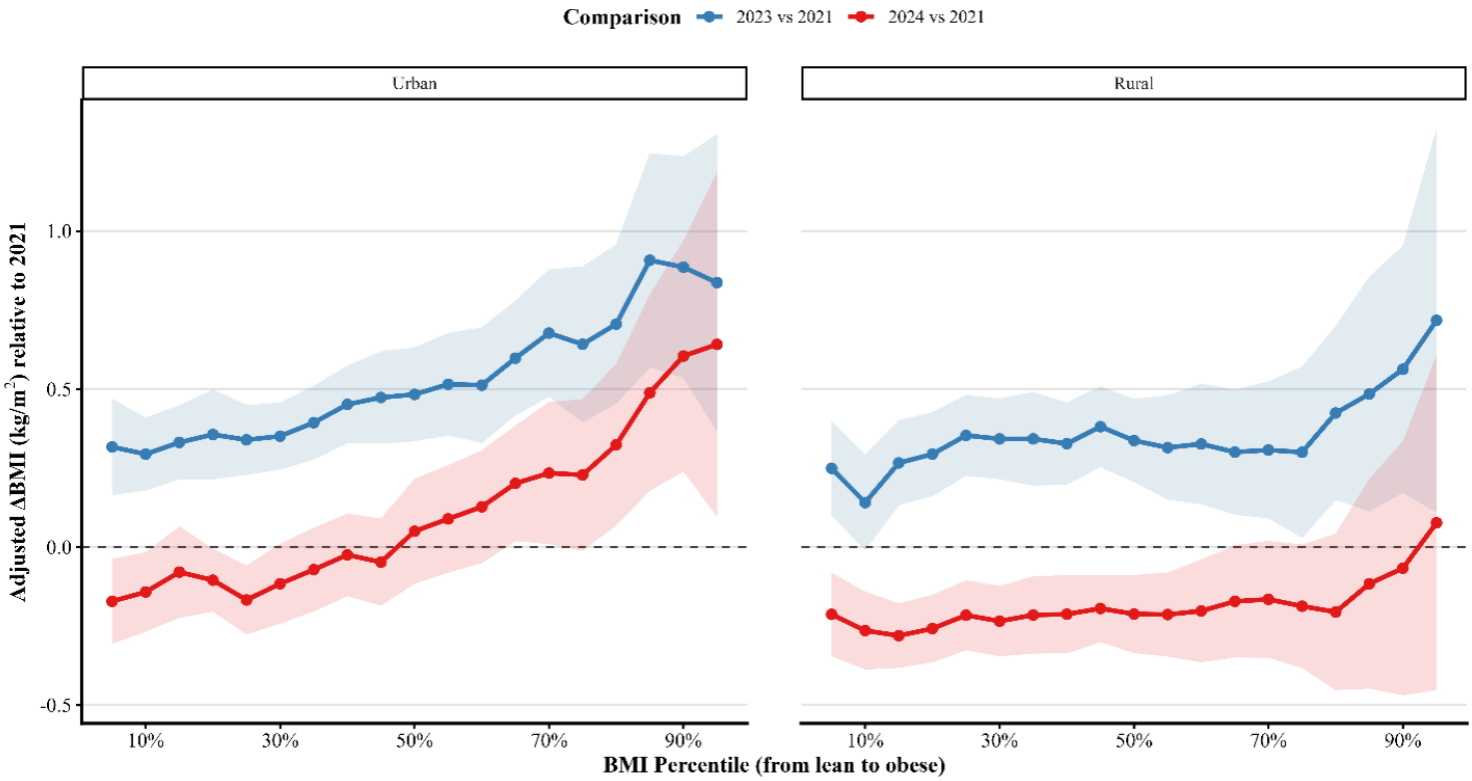


Figure 3

Urban-rural differences in BMI shifts across percentiles relative to 2021

Supplementary Files

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- Table2StratifiedOROverweight.docx
- Table1Sociodemographics.docx
- YunnanYouthOverweightManuscriptSupplementalMaterials.docx