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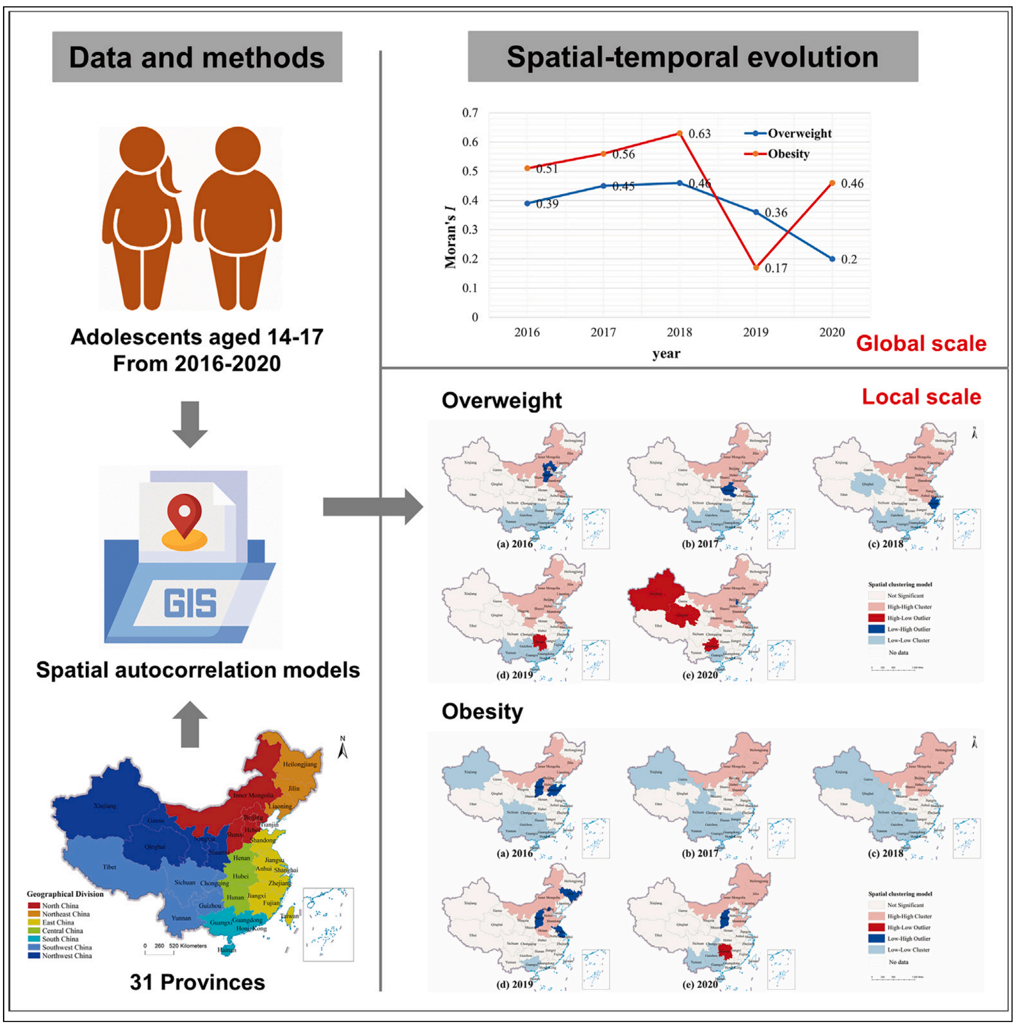


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## Highlights

Analyzed adolescent overweight/obesity rates' spatial-temporal evolution at macro scale

Geographic information influences overweight/obesity spread among adolescents

Identified priority areas and interventions for preventing adolescent overweight/obesity

Results inform cross-sector collaborations in adolescent obesity research

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# Spatial-temporal evolution of overweight and obesity among Chinese adolescents from 2016 to 2020

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## SUMMARY

**This study examines the spatial-temporal evolution of overweight and obesity among Chinese adolescents aged 14–17. Data from five national surveys conducted between 2016 and 2020 were analyzed to determine distribution patterns and trends. Results showed that overweight and obesity exhibit spatial clustering, with greater severity in the north and less severity in the south. The issue has spread from the northeast to the southwest of Mainland China. Using a local autocorrelation model, the regions were divided into a northern disease cold spot area (Inner Mongolia) and a southern disease hot spot area (Guangxi). Over the past five years, overweight rates among Chinese adolescents have not been effectively curbed, but obesity has shown some success in control and reversal until 2019. Future efforts should focus on the spatial-temporal pattern of disease spread, targeting hotspot areas and abnormal values for regional synergy and precise prevention and control.**

## INTRODUCTION

Chronic non-communicable diseases (NCDs) have become a major global public health problem in recent years, and overweight and obesity are among the major risk factors for chronic diseases.[1] More than 340 million children and adolescents aged 5–19 years were overweight or obese in 2016, and the number of adolescents with obesity has increased 10-fold in total compared to 1975.[2,3] The effects of obesity in childhood and adolescence are mainly reflected in an increased risk of various diseases, including cardiovascular disease, type 2 diabetes, and cancer, complications that significantly increase mortality.[4–6] Overweight and obesity in childhood and adolescence is also an important risk of obesity in adulthood. The risk of obesity in adulthood is five times higher in obese adolescents than in normal-weight adolescents, and about 80% of obese adolescents remain obese in adulthood.[7,8] However, overweight and obesity in children and adolescents can still be prevented and controlled;[9,10] the evolutionary trends of overweight and obesity can be considered as a basis for establishing, implementing, and evaluating policies and programs aimed at alleviating these conditions.[11] Although trends in the evolution of overweight and obesity vary from country to country,[12] it is important to monitor the evolution of overweight and obesity over time in order to estimate the magnitude of the problem in context and to assess whether adolescent health promotion initiatives at all levels of government have the desired effect.[13]

Geographic information systems (GIS) are potentially powerful tools for evidence-based practice in public health because they can identify spatial epidemiology or spatial distribution characteristics of the incidence of various diseases and allow efficient and rational allocation of relevant medical resources in a spatial environment.[14] GIS allows researchers to perform data mining operations such as cleaning processing, modeling analysis and visualization of spatial data related to specific known locations on the earth's surface, such as points (location of schools), lines (traffic road networks) or surfaces (epidemic risk areas). One of the most useful applications of GIS is the ease of incorporating specific environments and spatial locations into the dataset.[15] It has been shown that changes in residential environments are associated with increases in obesity.[16] Considering that overweight as well as obesity detection rates among adolescents in the study area may be associated with the occurrence of the disease in adjacent areas, the absence of a clear and up-to-date understanding of the role of spatial location in obesity may lead to biased estimates and more uncertainty in the analysis of environmental factors of obesity. This may also hinder the translation of findings from obesogenic behavioral and spatial studies into evidence-based behavioral and environmental governance for combating the spread of obesity emerging in adolescent populations.[17]

However, the majority of studies on overweight and obesity among Chinese adolescents still focus on the investigation and prevention and control measures of overweight and obesity in different populations, the influence of government policies at all levels of overweight and obesity, and the biological and sociological causes of overweight and obesity.[18–20] The descriptions of the evolutionary trends of overweight

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**Table 1. Overweight and obesity prevalence among adolescents in seven geographic divisions in China in 2020**

| | Sample | | | Overweight Rate (%) | | | Obesity Rate (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| Region | Both | Male | Female | Both | Male | Female | Both | Male | Female |
| Northeast China | 4372 | 2192 | 2180 | 18.18 | 18.72 | 17.64 | 18.38 | 21.41 | 15.36 |
| East China | 10742 | 5377 | 5365 | 16.51 | 16.92 | 16.09 | 11.68 | 13.22 | 10.13 |
| North China | 7784 | 3913 | 3871 | 18.33 | 18.81 | 17.85 | 14.86 | 17.28 | 12.44 |
| Central China | 4483 | 2248 | 2235 | 17.17 | 18.46 | 15.88 | 10.03 | 11.70 | 8.35 |
| South China | 4574 | 2273 | 2301 | 10.35 | 11.39 | 9.30 | 6.03 | 6.73 | 5.33 |
| Southwest China | 7271 | 3595 | 3676 | 12.89 | 11.69 | 14.10 | 6.44 | 6.07 | 6.80 |
| Northwest China | 8312 | 4161 | 4151 | 16.34 | 15.61 | 17.06 | 10.68 | 10.03 | 11.34 |
| $\chi 2$ | – | | | 216.18 | 134.65 | 104.66 | 634.67 | 479.98 | 206.73 |
| *P* | | | | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |

and obesity among adolescents also mostly consider time series only,[21,22] ignoring the spatial and temporal diffusion process of overweight and obesity among adolescents, and mainly focus on the distribution of overweight and obese people in specific counties and cities or the analysis of monitoring results based on public health site data.[14,23,24] Overall, studies on the spatial and temporal transmission characteristics of adolescents overweight and obesity on a large macroscopic scale in China have not yet been fully developed. Moreover, China is located in the eastern part of Asia and Europe and on the west coast of the Pacific Ocean and is a coastal country. The total land area is about 9.6 million square kilometers. The terrain is high in the west and low in the east, with a step-like distribution. It has a great span of southeast and northwest, a variable climate environment, almost all types of terrain, and diverse human and economic social phenomena developed under its complex and diverse land cover information, with significant geographical outliers and cluster patterns. Therefore, for China, which is a vast, densely populated country with large differences in natural and social environments, studying the spatial pattern and spatial and temporal evolution trends of adolescent obesity and overweight through GIS is of great significance for future research on the characteristics of adolescent overweight and obesity as well as prevention and control. Careful monitoring of long-term trends in overweight and obesity among adolescents is essential for evaluating the potential effectiveness of various national and international initiatives and for guiding the development of country-specific health policies.[25] The current spatial and temporal evolutionary patterns of overweight and obesity among Chinese adolescents can provide valuable insights for other countries, particularly low- and middle-income countries undergoing rapid socio-economic development. This information can assist these countries in preparing for the potential increase in rates of overweight and obesity among adolescents in the future. The application of GIS in the study of adolescent overweight and obesity can provide methodological support for scholars working in the field of global health. This enables them to identify high-risk areas, optimize the spatial allocation of emergency resources, and formulate more precise interventions to enhance the effectiveness of prevention and control. It also facilitates the comprehensive utilization of the abundant spatial localization information present in overweight and obesity data.[26,27]

In view of this, to fill the gap described above, this study will use overweight and obesity detection rates as indicators to measure the overweight and obesity status of adolescents in each region, quantify the spatial-temporal evolution patterns of overweight and obesity among Chinese adolescents by applying various spatial-temporal statistical analysis tools such as spatial autocorrelation models, identify priority prevention and control regions, and propose corresponding regionalized countermeasures. Specifically, we will address the following research questions:

A. What exactly is the spatiotemporal evolution pattern of overweight and obesity among adolescents in Chinese provinces during 2016–2020?
B. How to determine the key prevention and control areas as well as the corresponding prevention and control measures according to the spatial and temporal evolution of overweight and obesity among Chinese adolescents?

## RESULTS

### Spatial patterns of overweight and obesity

There were large differences in overweight and obesity rates among adolescents between the seven geographic regions of China in 2020 (Table 1). The top two regions with higher rates of overweight and obesity were North China (Overweight: 18.33%, Obesity: 14.86%) and Northeast China (Overweight: 18.18%, Obesity: 18.38%). In these two regions, nearly one-fifth of adolescents were overweight or obese. The overweight and obesity rates also differed significantly between genders (Overweight: $\chi 2 = 24.54$, $p < 0.01$, Obesity: $\chi 2 = 49.03$, $p < 0.01$), with male adolescents in northern and central China having higher overweight and obesity rates than females, with the largest difference in obesity rates between genders in northeastern China, where males were 6.05% higher than females. However, the western region of China showed regional characteristics in that the overweight and obesity rates of female adolescents were higher than those of male adolescents.

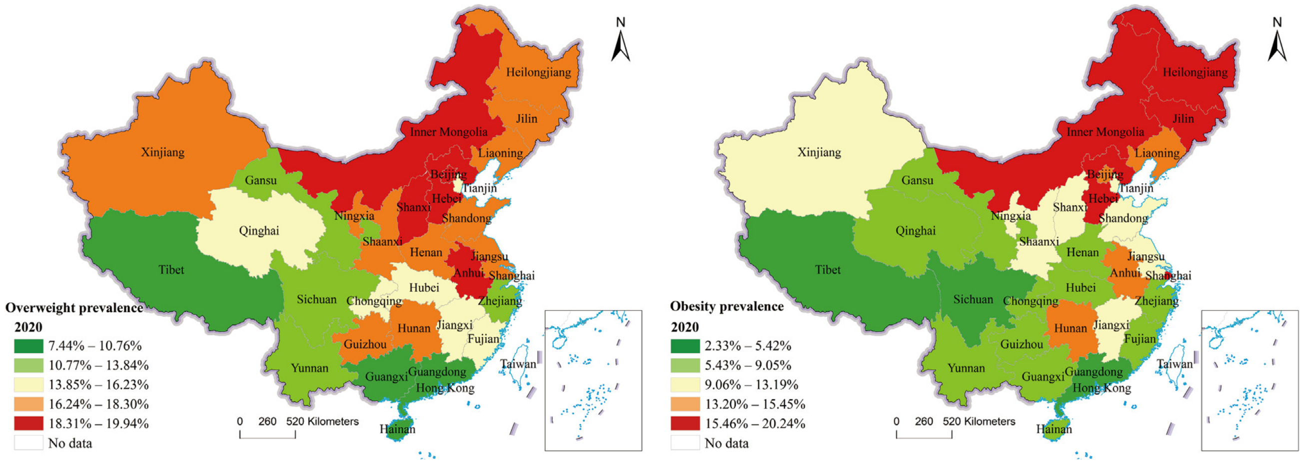


**Figure 1. Spatial patterns of overweight and obesity among Chinese adolescents in 2020.**

The spatial pattern of overweight and obesity rates among adolescents in 31 administrative units of China refined to the provincial spatial scale was mapped by Natural Breaks (Jenks) (Figure 1). The spatial patterns in 2020 varied significantly across provinces in China. Areas with high values of overweight rates are mainly concentrated in Inner Mongolia, Hebei, Beijing, Tianjin, Shanxi, and Anhui, while areas with lower overweight rates are mainly in the south of China, such as Guangdong, Guangxi, Hainan, and Tibet. The spatial pattern of obesity rate among Chinese adolescents is more clustered than the overweight rate, and the highest obesity rate is concentrated in Heilongjiang, Jilin, Inner Mongolia and Hebei in Northeast and North China, while the number of obese people in Shanghai, which is located in East China, is also very high. The regions with lower obesity rates are mainly located in Tibet, Sichuan and Guangdong, and the spatial trend of overweight and obesity rate shows the characteristic of gradually decreasing from northeast to southwest of China.

## Spatial-temporal association of overweight and obesity

### *Global spatial autocorrelation analysis*

The global spatial autocorrelation analysis was performed in ArcGIS 10.7, the global Moran's *I* and significance test results are shown in Table 2 and Figure 2. The global Moran's *I* for overweight prevalence were all positive, ranging from 0.20 to 0.46, with statistically significant values in all years. This indicates that the overweight rate of adolescents showed a spatially positive correlation at the global level in China with a significant spatial aggregation rather than a random distribution state. The global Moran's *I* change in overweight rate from 2016 to 2020 can be divided into 2 phases, with a relatively large increase in global Moran's *I* from 2016 to 2018, from 0.39 to a peak of 0.46, subsequently the global Moran's *I* for overweight rate shows a substantial decrease in 2019 and drops to a minimum value of 0.20 in 2020. 2018 was the year with the most obvious spatial clustering characteristics of the overweight rate among adolescents nationwide in China. Compared with the global Moran's *I* value of 0.39 at the start of 2016, the global Moran's I decreased substantially from 2016 to 2020, indicating that the spatial aggregation of adolescent overweight in China is weakening and the distribution of overweight in each province tends to be dispersed.

The global Moran's *I* for adolescent obesity rates were all positive, ranging from 0.17 to 0.63. Compared with the overweight rate, the spatial clustering of the obesity rate is stronger. The global Moran's *I* change of the obesity rate from 2016 to 2020 can be divided into 3 phases with significant fluctuations. The global Moran's *I* for obesity rates increased rapidly and peaked at 0.63 between 2016 and 2018, with the clustering of obesity rates increased during these three years. The global Moran's *I* for obesity decreased substantially to 0.17 in 2018–2019, approximating that the obesity rate is in a random distribution in China, but the spatial correlation was not statistically significant in that year. The Moran's *I* climb to 0.46 in 2019–2020. The change in the spatially positive correlation of obesity rates decreases compared to 2016, but the index has more ups and downs over the 5-year period.

### *Local indicator of spatial association (LISA)*

A local spatial autocorrelation model was constructed and four statistically significant spatial patterns between overweight and obesity rates that may occur between 2016 and 2020 in each province were visualized by the LISA cluster map(Figures 3 and 4).The light red and light blue in figures indicate that there is a positive spatial correlation between the overweight and obesity rate in the region, showing a spatial pattern of clustered distribution, indicating high-high cluster and low-low cluster, respectively. The dark red and dark blue indicate that there is a negative spatial correlation between overweight and obesity in the region, showing a spatial pattern of dispersed distribution, indicating high-low outlier and low-high outlier, respectively.

The overweight situation of adolescents in Jilin, Liaoning, Inner Mongolia, Beijing, Tianjin, Shanxi, Shandong, and Jiangsu in 2016 showed a high spatial pattern of high aggregation, and the overweight rate of adolescents in these areas was significantly higher than that of the

**Table 2. Overweight and obesity global Moran's *I* calculations for Chinese adolescents, 2016–2020**

| Overweight | Moran's *I* | p value | Obesity | Moran's *I* | p value |
|---|---|---|---|---|---|
| 2016 | 0.39 | <0.01 | 2016 | 0.51 | <0.01 |
| 2017 | 0.45 | <0.01 | 2017 | 0.56 | <0.01 |
| 2018 | 0.46 | <0.01 | 2018 | 0.63 | <0.01 |
| 2019 | 0.36 | <0.01 | 2019 | 0.17 | 0.07 |
| 2020 | 0.20 | <0.01 | 2020 | 0.46 | <0.01 |

surrounding provinces and belonged to hotspot regions. Hebei is surrounded by high-value areas, yet the area itself has a low overweight rate and belongs to a low-high outlier spatial pattern. Fujian, Guangdong, Guangxi, Hunan, Guizhou, Yunnan, and Hainan, which are located in the southern region of China, have a low number of overweight adolescents and show a spatial pattern of low-low clustering. At this time there was no spatial pattern of high-low outlier throughout China. Provinces with a high-high cluster pattern further increased in 2017, with Shanghai showing significant high values of overweight and a shift to a high-high cluster pattern in Hebei province, which originally had a low overweight rate. The overweight rate among adolescents showed a spread and diffusion across Chinese provinces. In 2017, Henan was in a spatial pattern of low-high outlier, surrounded by provinces with high overweight rates in the northern region. Meanwhile, Fujian in the southern region is no longer at low adolescent overweight rates, and the number of provinces with low overweight rates has further decreased. Statistically significant areas of high overweight concentration continued to expand in the southwest of China in 2018. The overweight rate in Henan shifted from low to high values, and the overweight rate in Anhui increased further. The spatial pattern of low-high outlier continues to migrate southward into Zhejiang, which is in the eastern coastal region. The provinces in the spatial pattern of low-low clustering of overweight rates in southern China further narrowed, and the low values of overweight in Hunan were no longer statistically significant, however, Qinghai achieved some success in overweight prevention and control in 2018, transforming into a cold spot region with statistically significant low values of overweight rates. In 2019, the overall number of regions where high values of overweight rates are clustered is relatively stable, but there is a small provincial shift, with Anhui and Shanghai in East China no longer at significant high values, replaced by Ningxia and Shaanxi, with signs of overweight rates spreading to the central and western regions. A new spatial pattern of high-low outlier was added in 2019, which is located in Hunan, a province that used to be in a region with a low overweight rate in 2016–2018. The area of the region with a low overweight rate in the low-low cluster spatial pattern is further reduced, with the overweight rate in Qinghai no longer at a low value and the overweight rate in Fujian returning to a low value. The area of the region with high-high cluster of overweight rates in China reaches the maximum in 2020, and Henan joins the high-value region, while Tianjin's overweight situation improved in that year and is in the spatial pattern of low-high outlier. The area of regions with statistically significant low overweight rates decreased significantly, leaving only Guangxi and Hainan. Meanwhile, Guizhou and Xinjiang and Qinghai, which are in the western region of China, showed a massive outbreak of overweight adolescents, shifting to a spatial pattern of high-low outlier (Table 3).

The change in spatial and temporal patterns of obesity rate among Chinese adolescents has a large difference compared to the overweight rate. The provinces with obesity rate in high-high cluster spatial pattern in 2016 were Jilin, Liaoning, Inner Mongolia, Beijing, Tianjin, and Hebei. Shanxi and Shandong, which are adjacent to high-value clusters, are in a state of low obesity rate and belong to the spatial pattern of low-high outlier. Within regions with generally low obesity values, there was no spatial pattern of high-low outlier in 2016. The area of the region in the low-low cluster is similar to that of the region with a higher obesity rate, mainly distributed in two directions, which are Guangdong, Guangxi, Hunan, Guizhou, Yunnan, Hainan, Sichuan and Chongqing in the south, and Xinjiang in the west. There was a small increase in regions with high-high cluster of obesity rates in 2017, with the provinces that increased being Heilongjiang and Shandong, which was previously in a low-high outlier spatial pattern. The provinces with the lower obesity rate increased and connected into a patch, and the new

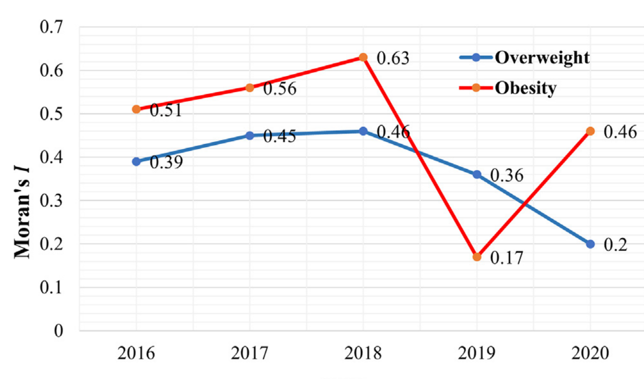


**Figure 2. Temporal trends of the Global Moran's I of overweight and obesity in Chinese adolescents, 2016–2020.**

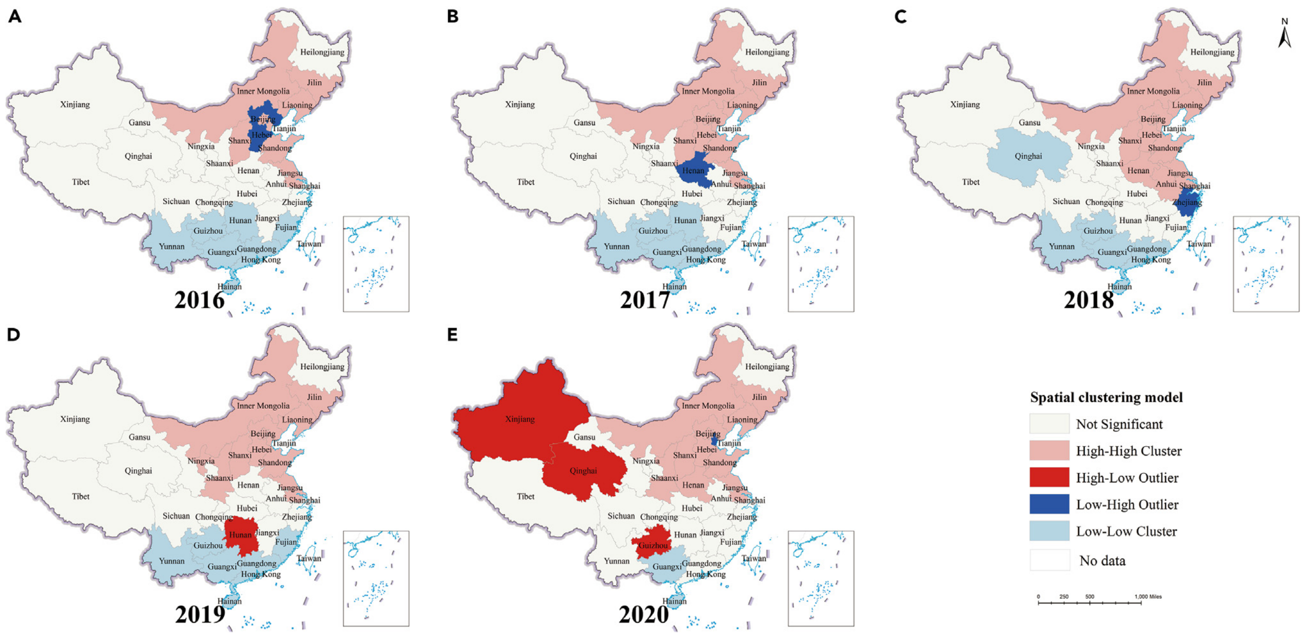


**Figure 3. LISA cluster maps of the distribution of overweight in Chinese adolescents, 2016–2020**
(A) 2016, (B) 2017, (C) 2018, (D) 2019 and (E) 2020.

provinces, Gansu and Jiangxi, were in a statistically significant low-low cluster spatial pattern. There was no spatial pattern of low-high outlier versus high-low outlier in 2017, and provinces with higher and lower obesity rates showed significantly polarized regional characteristics. The spatial polarization of obesity rates across regions became more pronounced in 2018. Although there is still no spatial pattern of both low-high outlier and high-low outlier, the area of regions with high and low-value clusters of obesity rates has further expanded. The increase in the area of the region of high-value clusters was relatively small, with the addition of Shanxi only, and the rate of spread of obesity rates in the northern region was mitigated. The area of regions with low-value clustering increased significantly, with the addition of Qinghai. The control

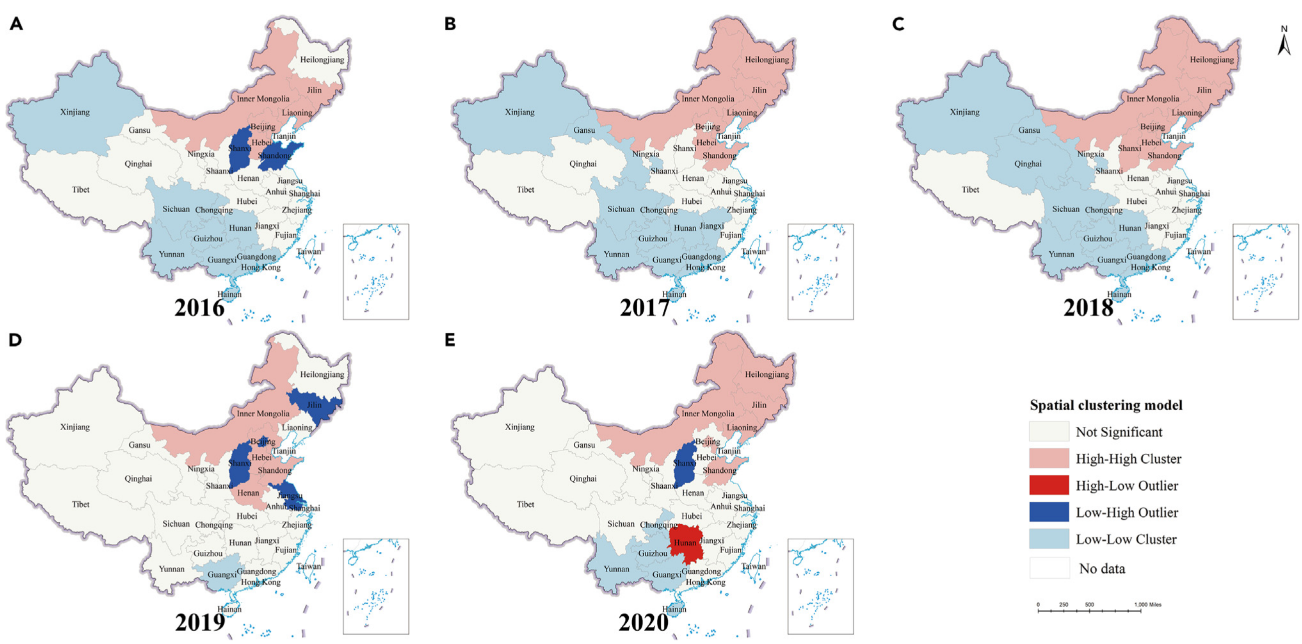


**Figure 4. LISA cluster maps of the distribution of obesity in Chinese adolescents, 2016–2020**
(A) 2016, (B) 2017, (C) 2018, (D) 2019 and (E) 2020.


**Figure 5. The study area: China's 34 provincial administrative units.**

effect of adolescent obesity rates in the western and southern regions is obvious. The spatial pattern of obesity rate in 2019 changed considerably, in which the provinces with high-high clusters not only decreased, but also changed from high values to statistically significant low values in some areas, such as Jilin, Beijing, Shanxi, and Jiangsu. Some provinces with persistently high obesity rates over several years, such as Heilongjiang, Liaoning and Jilin, which are in the northeast, achieved some reduction in 2019. Only Guangxi was in the spatial pattern of low-low cluster in 2019, and combined with the above changes in the spatial-temporal relationship of obesity rates and the spatial distribution of obesity rates, it can be seen that the number of provinces with low obesity rates further increased in that year, resulting in low obesity rates between neighboring provinces in the western and southern regions, and there was no significant difference in low values of obesity rates between each neighbor, so the LISA did not detect a significant statistical significance. Four spatial patterns of obesity rates coexist in 2020, with an increase in the area of areas with high values of obesity rates, and significant increases in obesity rates in Heilongjiang, Jilin, and Liaoning. The provinces with low-high outlier decreased significantly, with only Shanxi remaining. The number of provinces with low-low clusters of obesity rates in the southern region of China has rebounded, with Hainan, Chongqing, Guizhou, and Yunnan returning to low values of obesity rates. However, it is worth noting that a new spatial pattern of high-low outliers was added this year. Hunan was the first province to break out with a high obesity rate when all neighboring provinces had low obesity rates. We found that the local spatial autocorrelation pattern of adolescent obesity rates in 31 Chinese provinces showed a different development pattern from that of overweight rates. The spatial-temporal pattern evolution of the adolescent obesity rate in China can be roughly divided into 2 stages: The first stage is from 2016 to 2019, first from the regional changes of low-low clusters, in which the area of provinces with significantly low values of obesity rate keeps

**Table 3. Regions of the four spatial association modes of overweight in Chinese adolescents, 2016–2020**

| year | High-High Cluster | High-Low Outlier | Low-High Outlier | Low-Low Cluster |
|---|---|---|---|---|
| 2016 | Jilin-Liaoning-Inner Mongolia-Beijing-Tianjin-Shanxi-Shandong-Jiangsu | – | Hebei | Fujian-Guangdong-Guangxi-Hunan-Guizhou-Yunnan-Hainan |
| 2017 | Jilin-Liaoning-Inner Mongolia-Beijing-Tianjin-Hebei-Shanxi-Shandong-Jiangsu-Shanghai | – | Henan | Guangdong-Guangxi-Hunan-Guizhou-Yunnan-Hainan |
| 2018 | Jilin-Liaoning-Inner Mongolia-Beijing-Tianjin-Hebei-Henan-Shanxi-Shandong-Jiangsu-Anhui-Shanghai | – | Zhejiang | Guangdong-Guangxi- Guizhou-Yunnan-Hainan-Qinghai |
| 2019 | Jilin-Liaoning-Inner Mongolia-Beijing-Tianjin-Hebei-Ningxia-Shanxi-Shandong-Jiangsu-Shaanxi | Hunan | – | Fujian-Guangdong-Guangxi-Guizhou-Yunnan-Hainan |
| 2020 | Jilin-Liaoning-Inner Mongolia-Beijing-Hebei- Shanxi-Henan-Shandong-Jiangsu-Shaanxi | Xinjiang-Qinghai-Guizhou | Tianjin | Guangxi-Hainan |

Table 4. Regions of the four spatial association modes of obesity in Chinese adolescents, 2016–2020

| year | High-High Cluster | High-Low Outlier | Low-High Outlier | Low-Low Cluster |
|---|---|---|---|---|
| 2016 | Jilin-Liaoning-Inner Mongolia-Beijing-Tianjin-Hebei | – | Shanxi-Shandong | Guangdong-Guangxi-Hunan-Guizhou-Yunnan-Hainan-Sichuan-Chongqing-Xinjiang |
| 2017 | Heilongjiang-Jilin-Liaoning-Inner Mongolia-Tianjin-Hebei-Shandong | – | – | Jiangxi-Guangdong-Guangxi-Hunan-Guizhou-Yunnan-Hainan-Sichuan-Chongqing-Gansu-Xinjiang |
| 2018 | Heilongjiang-Jilin-Liaoning-Inner Mongolia-Beijing-Tianjin-Hebei-Shandong-Shanxi | – | – | Guangdong-Guangxi-Hunan-Guizhou-Yunnan-Hainan-Sichuan-Chongqing-Gansu-Qinghai-Xinjiang |
| 2019 | Inner Mongolia-Hebei-Shandong-Henan | – | Jilin-Beijing-Shanxi-Jiangsu | Guangxi |
| 2020 | Heilongjiang-Jilin-Liaoning-Inner Mongolia-Beijing-Tianjin-Shandong | Hunan | Shanxi | Guangxi-Hainan-Chongqing-Guizhou-Yunnan |

increasing, and the provinces are connected with each other to form a slice of overall low obesity rate. Second, the area of the region of high-high clusters had a small increase in 2016–2017, stabilized in 2017–2018, and for the first time in 2019, the area of the region of high-high clusters of obesity rate shrank, and some provinces were in the situation of high obesity rate of adolescents all year round was alleviated. The second phase is 2019–2020, in which a small rebound is seen in the high obesity region, with a return to high values in provinces located in the northeast region. A new outbreak of provinces with high values of obesity has also occurred in the low-low clustered regions, implying a small trend of an overall rise in adolescent obesity rates in all regions of China in 2020 (Table 4).

## DISCUSSION

### Spatial-temporal evolution analysis

Since the promulgation of the National Physical Fitness Standards for Students (Revised 2014) by the Chinese Ministry of Education, overweight and obesity rates among adolescents in 2016–2020 show a spatial pattern in 31 Chinese provinces that is more severe in the northern regions and generally less severe in the southern regions, and there is a trend of spreading from the northeast to the southwest of mainland China. Obesity is both a chronic, recurring, progressive disease and a complex social problem. Overweight and obesity among Chinese adolescents are driven by a multi-level, multi-faceted combination of policy, environmental, economic, social, and behavioral factors.[19] This study is based on the Chinese National Student Physical Fitness Research Project, and the age and gender composition ratios of each annual survey are basically the same, with roughly the same sample size in each province. We used the results of the sample size calculation directly in the calculation of overweight and obesity rates for the whole country and for each student group to ensure comparability across years, which has the advantage of avoiding statistical bias due to the uneven influence of different groups in the composition of the population and also facilitates international comparison of results across countries and years.[28] Many policy recommendations for obesity prevention and control in China are mainly derived from research results and experiences in other countries, and there is a lack of empirical research evidence in China to support the development and implementation of obesity prevention and control policies. Therefore, it is urgent to conduct multi-disciplinary cross-fertilization research to develop obesity prevention and control policies suitable for China's national conditions, and to identify appropriate management and interventions for overweight and obese groups and individuals. In this study, we discovered and quantified the spatial pattern and spatial-temporal evolution characteristics of overweight and obesity among adolescents from a systematic perspective through geographic information science, which can support the study of overweight and obesity epidemic trends among Chinese adolescents and guide the allocation of public health resources and the precise implementation of prevention and control measures. For other countries experiencing rapid economic development and urbanization, similar to China, the spatial-temporal evolutionary characteristics identified in this study can serve as a benchmark for evaluating the health status of local adolescents in relation to adolescent overweight and obesity in their respective countries. At the same time, the methodology utilized in this study can serve as a model for researchers in other countries to implement strategies aimed at mitigating the rising rates of overweight and obesity among adolescents in their respective regions. Although overweight and obesity are partly determined by genetic factors, the obesogenic environment also plays a non-negligible role in the development of the obesity phenomenon.[29] Conducting research on the obesogenic environment is crucial for developing comprehensive interventions that effectively address specific factors in both the macro- and micro-environments. This research aims to slow down or prevent the spread of obesity epidemics worldwide.[30] We must develop a systematic and integrated approach to obesity interventions. This can be achieved by promoting synergy and coordinated action among all relevant parties, including governments, international organizations, and interdisciplinary scientific research teams.[31]

The spreading trends of overweight and obesity in Chinese adolescents over time derived from this study are similar to existing studies.[22,32] On this basis, we used spatial autocorrelation analysis to study the spatial and temporal evolutionary trends of overweight and obesity rates among Chinese adolescents, and to explore the spatial distribution characteristics of overweight and obesity rates among Chinese adolescents in various regions at a deeper level.

The results of the spatial autocorrelation analysis in this study showed that at the global scale, the overweight and obesity rates of Chinese adolescents in 2016–2020 had a strong positive spatial correlation, and their spreading diffusion pattern was basically consistent with the first law of geography. Although the overall spatial clustering of overweight and obesity decreased during the 5 years, it showed different patterns of change within different years. The positive spatial correlations of both overweight and obesity rates increased and peaked from 2016 to 2018, when the clustering characteristics of overweight and obesity among adolescents were strongest and the spatial distribution characteristics were more typical. Since 2018, the spatial patterns of overweight rate and obesity rate have begun to show local differences, and the spatial clustering of overweight rate has been in a decreasing state. Combined with the results obtained from the standard deviation elliptical autocorrelation analysis, during the period 2018–2020, the overweight rate of adolescents has appeared to spread massively in various regions of China, and the spatial pattern tends to be randomly distributed without obvious regularity and direction. The spatial pattern of obesity rate, on the other hand, fluctuated and finally returned to the same state as in 2016, and considering that the spatial pattern in 2019 was not statistically significant, the change in spatial pattern of obesity rate still needs to be supplemented by subsequent longitudinal studies for a more accurate judgment. At the provincial scale, the overall overweight and obesity rates of Chinese adolescents show a spatial pattern of severe in the north and mild in the south, with intermediate areas in transition. Therefore, the local spatial autocorrelation of the occurrence of overweight and obesity rates among Chinese adolescents can be divided into two major zones: the northern zone represented by Inner Mongolia (including Inner Mongolia, Jilin, Liaoning, Hebei, Beijing, etc.) and the southern zone represented by Guangxi (including Guangxi, Yunnan, Guizhou, Hainan, Guangdong, etc.). These two major areas form a high-value hot spot area where high clustering of overweight and obesity occurs and a low-value cold spot area where low clustering of overweight and obesity occurs, respectively. In contrast, the provinces in the high-low outlier and low-high outlier spatial patterns are more sporadically located, mainly at the edges of agglomeration regions, as a transition from clustering distribution to random distribution. At the same time, there are large differences between the spatial and temporal patterns of overweight and obesity rates at the provincial scale. The local spatial autocorrelation patterns of adolescent overweight rates in 31 provinces of China showed a strong regular development. Over time, the area of high overweight concentration has been spreading from northeastern China to adjacent provinces in a southwestern direction, and by 2020, the area of high overweight concentration will be close to half of China's national territory, and the area where the overweight rate was previously low is shrinking. Five years on, the overweight rate among Chinese adolescents has not been effectively curbed and is spreading to a greater extent. The effect of related public health and health interventions is not optimistic. In contrast, obesity prevention and control among Chinese adolescents achieved some success in 2016–2019, effectively curbing or even reversing the growth of the spread of obesity in 31 provinces. However, the obesity spread among adolescents rebounded in 2020, most likely due to the outbreak of COVID-19 in late 2019, the static closed management measures adopted by the Chinese government to ensure the life safety and health of the nation, and the restricted activity space of the adolescent population thus leading to insufficient physical activity.[33,34] The epidemic has also had a degree of negative impact on China's livelihood and economy, which has indirectly led to changes in the lifestyle of Chinese adolescents.[34,35] Due to data and time constraints, the current data are not sufficient to determine whether the spatial pattern of overweight and obesity in 2020 will persist in subsequent years but judging from the currently available 5-year data, it is expected that the high prevalence areas of overweight and obesity in China will remain concentrated in the north for a long time in the future. Future prevention and control must focus on the spatial pattern of overweight and obesity spread based on traditional public health interventions and strengthen research on the spatial-temporal coupling mechanism of overweight and obesity spread in order to achieve regional synergy and precise prevention and control.

## Suggestions for regionalized responses

The whole life cycle theory provides an important perspective for public health interventions. Behaviors at one stage of life influence and are influenced by other stages. Health and development in adolescence simultaneously affect health in adulthood and even in old age, and ultimately the health and development of the next generation.[36] At the same time, people who have become overweight and obese during this period have a higher difficulty in losing weight compared with those who start to become obese in adulthood,[37] so it is important to seize the adolescent period, which is at a critical stage, and start as early as possible to prevent and control the spread of overweight and obesity in adolescents and even obesity and chronic diseases in adulthood. Current research in China on topics related to overweight and obesity in adolescents has yielded remarkable results in terms of obesity interventions and models.[38] Since the spread of the obesity epidemic is compounded by a variety of factors,[39] relevant prevention and control measures for the adolescent student population are not only the responsibility of the education sector, but also require the mobilization of substantial participation from other sectors to pool their efforts for joint development. First, social organizations should be encouraged and supported to participate and support should be strengthened, and for the problem of overweight and obesity, local governments should actively seek joint cooperation with social organizations and research institutions and integrate resources across departments, such as disease prevention and control centers in health departments, sports nutrition departments in food and drug departments, healthy city planning agencies in urban and rural planning departments, and various profit-oriented social sports organizations, to carry out multiform scientific research and research and give full play to their synergistic role in the prevention and control of overweight and obesity in adolescents.[40] Second, with the help of intelligent cutting-edge technology and interdisciplinary research methods, we should deepen our understanding of the influence mechanism of overweight and obesity through the construction of various platform systems and theoretical models, further excavating information related to the prevention and control of overweight and obesity in adolescents and give reference to decision makers in different sectors as a supplement to mainstream public health intervention programs. Current research at the intersection of public health and geographic information science has received joint attention from multiple disciplines in the post-epidemic era. In this study, the construction of a spatial autocorrelation model revealed that four spatial structural patterns coexist in the distribution states of overweight and obesity rates among adolescents in various regions of China with obvious regularities. Therefore, for different regional aggregation types, different treatment methods should be adopted to achieve refined and differentiated management. High-high clustering areas generally have higher rates of overweight and obesity, and for areas where the spread of overweight and obesity among adolescents is more serious, joint multi-sectoral intervention should be achieved. Local governments need to respond to the central government's decision to implement policies to reduce students' excessive homework burden and the burden of out-of-school training, while actively promoting policies to increase students' outdoor activity time and physical training and education. The planning and management of social organizations are reasonably adjusted, and certain preferential policies are given to institutions related to the promotion of regional physical health levels, such as sports medicine, physical fitness, and non-disciplinary training such as physical and aesthetic education, to provide financial and policy support and appropriate reductions in their earned income.[41] In addition, it is necessary to improve the standardization of the regional student physical fitness testing system, implement a clear accountability mechanism, raise the ideological attention of schools, and strengthen the training of teachers who are at the front line of physical education work. Improve the system related to physical education middle and high school examinations, integrate physical education into the assessment in a more reasonable and fair manner, so as to enhance the active participation of families in the prevention and control of overweight and obesity among students, and promote the development of synergistic cooperation between families and schools. High-low dispersion areas have the implication of lower prevalence around areas with higher rates of overweight and obesity, while the spatial pattern of low-high dispersion has the opposite implication. These two spatial patterns are outliers in the local autocorrelation model, so for such spatial patterns of overweight and obesity anomalies, the first step should be to investigate the relevant areas where the outliers appear and whether there are irregularities such as active or passive misreporting and omission of the real student physical fitness measurements by schools in the area in order to cope with work. Secondly, for the management of real overweight and obesity rate abnormal areas, examine in detail the possible causes of their occurrence and strengthen the interlinkage between regions to jointly drive their overweight and obesity control efforts. At the same time, emphasis should be placed on developing a measurement and evaluation system for overweight and obesity and analyzing the various evolutionary possibilities of overweight and obesity among students by combining the prediction results of the simulation system with monitoring mechanisms to serve as a timely public health safety warning. The low-low clusters have formed an area with a low overall incidence of overweight and obesity. Such areas should carry out more analysis of students' sports preferences at different levels of physical fitness, integrate regional cultural and folkloric characteristics, develop sports that meet students' interests, attract more students to actively participate and develop lifelong sports habits. At the same time and with due consideration to the physical fitness education of the few overweight and obese student groups in these regions, schools should classify students according to their own physical fitness level and actual participation in physical exercise and set different grades of target requirements. Achieve precise care for all types of students and maintain the good momentum of low overweight and obesity in the region.

## Conclusions

In this study, we investigated the spatial and temporal evolution characteristics and trends of overweight and obesity rates among Chinese adolescents during 2016–2020 using a large sample of adolescents, mainly based on geographic information science theory, using spatial statistical methods, including global and local spatial autocorrelation, standard deviation ellipse analysis, and center of gravity trajectory migration algorithms. Relying on the Chinese National Student Physical Fitness Standards Program. Currently, China has the highest number of overweight and obese people in the world, and obesity has become a serious public health problem. The obesity problem in China is caused by a multilevel and multifaceted combination of policy, environmental, economic, ,social and behavioral factors. GIS and spatial statistics provide macro-scale and meso-scale perspectives in overcoming this challenge, which can assist in inferring the important time points and possible causes of the outbreak of overweight and obesity in China from the spatial and temporal characteristics of the actual occurrence of overweight and obesity in adolescents, and can identify the high prevalence and potential risk areas of overweight and obesity in adolescents, which can provide reference for joint prevention and control in multiple sectors.

## Limitations of the study

In this study, we tried our best to ensure that the results are accurate and credible; however, due to the scale limitations of overweight and obesity statistics, this study was conducted only at the provincial level, and in future work, the study area should be scaled down to a finer spatial scale, such as the prefectural and municipal as well as county scales with the support of more detailed data so that more accurate findings can be drawn. Apart from this, the present study on overweight and obesity among Chinese adolescents was mainly an exploratory spatial data analysis and failed to clearly quantify the specific reasons for the above spatial and temporal associations between overweight and obesity among adolescents. In the future, we intend to conduct an empirical spatial analysis by establishing spatial-temporal regression models to explore the causes and driving mechanisms of the formation and changes of spatial-temporal patterns of overweight and obesity among adolescents, based on existing studies in conjunction with other variables, such as economic factors, transportation factors, and population mobility factors.

## STAR★METHODS

Detailed methods are provided in the online version of this paper and include the following:

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## SUPPLEMENTAL INFORMATION

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## AUTHOR CONTRIBUTIONS

Conceptualization, Z.T., H.Z., and Z.K.; methodology, Z.T., H.Z., X.H., and X.J.; software, Z.T., H.Z., and J.Y.; validation, Z.K., X.H., and X.J.; formal analysis, Z.T., H.Z., and J.Y.; investigation, Z.T., H.Z., and J.Y.; resources, Z.T., H.Z., X.H., and X.J.; data curation, Z.T., H.Z., X.H., and X.J.; writing—original draft preparation, Z.T., H.Z., Z.K., and J.Y.; writing—review and editing, Z.T., H.Z., and J.Y.; visualization, Z.T., H.Z., and J.Y.; supervision, Z.K., X.H., and X.J.; project administration, Z.T., H.Z., and Z.K.; funding acquisition, Z.K., X.H., and X.J. All authors have read and agreed to the published version of the manuscript.

## DECLARATION OF INTERESTS

The authors declare no conflict of interest.

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# STAR★METHODS

## KEY RESOURCES TABLE

| REAGENT or RESOURCE | SOURCE | IDENTIFIER |
|---|---|---|
| Deposited data | | |
| China Standard Map at the Provincial Scale | China Standard Map Service System | http://bzdt.ch.mnr.gov.cn/index.html |
| BMI of high school students in 31 provinces of China | Chinese National Student Physical Fitness Standards | Data S1 |
| Overweight detection rate of high school students in 31 provinces of China | Chinese National Student Physical Fitness Standards | Data S2 |
| Obesity detection rate of high school students in 31 provinces of China | Chinese National Student Physical Fitness Standards | Data S3 |
| Software and algorithms | | |
| SPSS | 27 | https://www.ibm.com/ |
| ArcMap | 10.8 | https://www.esri.com/en-us/home |
| Adobe Illustrator | 2023 | https://www.adobe.com/products/illustrator.html |

## RESOURCE AVAILABILITY

### Lead contact

Further information and requests for data and code files should be directed to and will be fulfilled by the lead contact, Xiao Hou (houxiao0327@bsu.edu.cn).

## MATERIALS AVAILABILITY

This study did not generate new unique materials.

### Data and code availability

(1) This study analyzes existing, publicly available data which are listed in the key resources table. The data we analysis can be found in Data S1–S3.
(2) This study does not report original code, which is available for academic purposes from the lead contact.
(3) Any additional information required to reanalyze the data reported in this paper is available from the lead contact upon request.

## METHOD DETAILS

### Survey design and populations

High school students (14–17 years old) from 31 provinces who participated in the Chinese National Student Physical Fitness Standards (CNSPFS) testing program for five consecutive years from 2016 to 2020 were used as the study population. This program relies on the Chinese National Student Physical Fitness Standard (2014 Revised Edition) and aims to strengthen the monitoring of the physical fitness status of Chinese students, improve the evaluation mechanism of school sports, and provide an important reference for evaluating changes in student health levels in various regions.[42] The results of the annual physical fitness test are submitted to the Ministry of Education and feedback to the education department of each provincial government in the form of results reports, and reported to the State Council, the National Committee of the Chinese People's Political Consultative Conference and other government agencies through various channels. The results of the student physical fitness monitoring are publicized and reported in the Chinese mainstream media, making outstanding contributions to completely reversing the decline in the physical fitness of Chinese adolescents.[43,44]

A multistage stratified whole-group sampling design was used to maintain consistency in sampling and assessment methods across survey years.[45] Based on the distribution of the sampled schools in each area, the sample was divided into 4 categories of students by urban (male and female) and rural (male and female), for equal sampling. The determination of the sample size takes into account the overall level of students in each location, based on the ranking of the economic development level of each prefecture-level city within the 31 provinces. Each province has prefecture-level cities that are divided into four types of sampling areas: type 1 (provincial capital city and core area), type 2, type 3, and type 4. The partial results of the division of sampling areas by provinces in China are shown in below table.

The partial results of the division of sampling areas by provinces in China

| Province | Sampling areas 1 | Sampling areas 2 | Sampling areas 3 | Sampling areas 4 |
|---|---|---|---|---|
| Beijing | **Urban area:** Dongcheng, Xicheng **Rural area:** Shunyi, Daxing | **Urban area:** Chaoyang, Haidian **Rural area:** Changping, Tongzhou | **Urban area:** Fengtai **Rural area:** Fangshan, Huairou, Miyun | **Urban area:** Shijingshan, Haidian **Rural area:** Changping, Tongzhou |
| Shanghai | **Urban area:** Huangpu, Pudong New Area **Rural area:** Minhang, Jiading | **Urban area:** Yangpu, Jingan **Rural area:** Baoshan, Songjiang | **Urban area:** Xuhui, Changning **Rural area:** Qingpu, Jinshan | **Urban area:** Putuo, Hongkou **Rural area:** Fengxian, Chongming |
| Guangdong | Guangzhou | Shenzhen, Foshan, Dongguan, Huizhou, Zhongshan, Zhuhai | Maoming, Zhanjiang, Jiangmen, Zhaoqing, Jieyang, Shantou, Qingyuan | Yangjiang, Shaoguan, Meizhou, Chaozhou, Heyuan, Shanwei, Yunfu |

One municipality from each type of sampling area was selected as the sampling site using a randomized approach, one high school in an urban area and one in a rural area were selected from the sampling site. A total of eight schools in each province were sampled, stratified by grade level, and two classes per grade level were sampled for a total of 60 students to take the physical fitness test. The sample size was guaranteed to be at least 1400 students per province, covering a total of 31 provinces in mainland China excluding Hong Kong, Macao and Taiwan. Prior to testing, all potential participants provided written school and parental informed consent to ensure that participating students were free of disease and injury and fit to participate in the physical fitness test. The final samples obtained from 2016 to 2020 were 47614, 46886, 48645, 67591, and 48308, respectively.

## Data collection

The CNSPFS test consists of three main dimensions: physical form, physiological function and athletic quality. In this study, the body mass index (BMI = body weight (*kg*)/height ($m^2$)) was calculated from the height and weight indicators in the physical morphology dimension as the main index for diagnosing overweight and obesity in students. The test staff all received pre-service training and assessment tests, and the quality of field tests met the requirements. Detailed test items can be found in the previously available literature.[46,47] After the test, the BMI scale in the CNSPFS was used to determine whether the BMI of high school students in 31 Chinese provinces among 2016–2020 was overweight or obesity, and the thresholds for overweight and obesity for each gender and grade level are shown in below table.

The Body Mass Index (BMI) scale for Chinese high school students in CNSPFS

| | | BMI_Male (kg/m$^2$) | | | BMI_Female (kg/m$^2$) | | |
|---|---|---|---|---|---|---|---|
| Rank | Score | Grade 1 | Grade 2 | Grade 3 | Grade 1 | Grade 2 | Grade 3 |
| Normal | 100 | 16.5–23.2 | 16.8–23.7 | 17.3–23.8 | 16.5–22.7 | 16.9–23.2 | 17.1–23.3 |
| Underweight | 80 | ≤16.4 | ≤16.7 | ≤17.2 | ≤16.4 | ≤16.8 | ≤17.0 |
| Overweight | 80 | 23.3–26.3 | 23.8–26.5 | 23.9–27.3 | 22.8–25.2 | 23.3–25.4 | 23.4–25.7 |
| Obesity | 60 | ≥26.4 | ≥26.6 | ≥27.4 | ≥25.3 | ≥25.5 | ≥25.8 |

The overweight and obesity detection rate of each region is equal to the number of overweight and obese people in the region divided by the total sample size of the region (See Data S1–S3).

The study area of this paper is 31 provinces located in mainland China (except Hong Kong, Macao and Taiwan), which belong to seven major geographic regions of China (see below table).

The seven geographical divisions of China

| Region | Provinces |
|---|---|
| Northeast China | Heilongjiang, Jilin, Liaoning |
| East China | Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Taiwan |
| North China | Beijing, Tianjin, Shanxi, Hebei, Inner Mongolia |
| Central China | Henan, Hubei, Hunan |
| South China | Guangdong, Guangxi, Hainan, Hong Kong, Macao |
| Southwest China | Sichuan, Guizhou, Yunnan, Chongqing, Tibet |
| Northwest China | Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang |

The data is presented in the format of 1:1,000,000 electronic maps, provided by China National Geographic Information Public Service Platform, including surface elements of provinces, prefectures and counties, and line elements of the ten-dashed line and the islands in the South China Sea, as readable and correctable vector files (Figure 5). Through ArcGIS10.7, the overweight and obesity detection rates were matched with the national administrative district vectorization layer using the codes of administrative districts as matching variables to establish a spatial analysis database.

## Statistical analysis

We initially employed chi-square tests to evaluate whether there was any variation in the impact of region and gender on rates of adolescent overweight and obesity in a sample of seven geographic regions. We then used spatial autocorrelation modeling to examine the spatial-temporal changes in rates of overweight and obesity among adolescents. Spatial autocorrelation model is a method used to describe the correlation between a variable in a spatial region and the same variable in the neighboring space.[48] Given a set of elements and associated attributes, the tool assesses whether the expressed pattern is clustered, random or dispersed. With the development of spatial statistical techniques and the understanding of the spatial distribution of diseases, spatial autocorrelation plays a very important role in the analysis of the public health.[49] The first law of geography suggests that "everything is correlated with everything else, but neighboring things are more similar." Therefore, spatial autocorrelation also exists in disease data.[50] The classical regression model assumes that the observed data follows an independent and homogeneous distribution. However, the presence of spatial autocorrelation in spatial data undermines the effectiveness of the classical regression model in statistical analysis. This, in turn, hampers the accuracy of identifying factors that influence diseases.[51] Therefore, conducting spatial autocorrelation analysis is necessary before undertaking spatial statistical modeling of diseases. Spatial autocorrelation analysis is not only the foundation for identifying the spatial distribution characteristics of diseases but also the basis for spatial regression modeling of diseases.[52] In this study, we applied Moran's $I$ statistic for global spatial autocorrelation and local indicators of spatial autocorrelation (LISA) to analyze whether there is a correlation between the spread of overweight and obesity in Chinese adolescents at the overall and local levels and the direction of correlation.

Global spatial autocorrelation is used to derive the average degree of association between overweight and obesity detection rates among adolescents at the national level across provinces by comparing the mean values of specific attributes aggregated over the overall region with the values of the attributes on each spatial unit. For determining whether the migration of overweight and obesity is aggregated across China, Moran's $I$ is a more commonly used global association index with the formula shown below:

$$I = \frac{n \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}(x_i - \overline{x})(x_j - \overline{x})}{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} \sum_{i=1}^{n} (x_i - \overline{x})^2} \quad \text{(Equation 1)}$$

In Equation 1, $n$ is the number of unit areas in the study space, representing the number of provincial administrative blocks; $x_i$, $y_i$ refer to the attribute values of each spatial unit, representing the spread of overweight and obesity among Chinese adolescents. $\overline{x}$ is the mean value of all coordinates; $w_{ij}$ represents the spatial weight matrix, which is assigned to 1 if the $i$-th and $j$-th spatial units are adjacent to each other and assign a value of 0 to the spatial weight matrix if the opposite is true. The global Moran's $I$ take values in the range [-1, 1]. A larger absolute value of Moran's $I$ means a stronger data correlation, When Moran's $I > 0$, it means that the attributes of spatial things show spatial positive correlation; when Moran's $I < 0$, it means that the attributes of spatial things show spatial negative correlation; when Moran's $I = 0$, it means that the attributes of spatial things show spatial random distribution pattern. Moran's $I$ is usually tested for significance using the standardized statistic $Z$ score.[53]

Global spatial autocorrelation analysis is based on the assumption of spatial smoothness, which can only reflect the overall spatial agglomeration degree of the study area and cannot identify the local spatial state of individual spatial units. For the reality of spatial local non-smoothness, it is also necessary to examine the possible local spatial agglomeration patterns at different spatial locations through local spatial autocorrelation analysis. Local spatial autocorrelation is used to examine the degree of spatial variability between each region and its surrounding areas to identify spatial heterogeneity and can be a good complement to global spatial autocorrelation.[54] In this study, we examined the overweight and obesity of adolescents in provincial administrative regions one by one from the provincial scale and derived the distribution status of overweight and obesity of adolescents in each province in the adjacent space. The spatial agglomeration and diffusion states are judged according to the similarity of overweight and obesity in each provincial administrative region and its neighboring provincial administrative regions with the following equations:

$$I = \frac{(x_i - \overline{x})}{S^2} \sum_{j=1}^{n} w_{ij}(x_j - \overline{x}) \quad \text{(Equation 2)}$$

In Equation 2, $n$ is the number of provincial administrative regions, $w_{ij}$ represents the spatial weight matrix, $x_i$ and $y_i$ represent the overweight and obesity detection rates of adolescents in the $i$-th and $j$-th provincial administrative regions, and $\overline{x}$ is the provincial summary mean of overweight and obesity detection rates. After obtaining the local Moran's $I$, this study used the Local indicator of spatial association (LISA) for analysis and presented the results of local spatial correlation analysis with aggregation plots. The LISA cluster map will show four significant spatial patterns[55]: High-High cluster, representing the high level of overweight and obesity spread among students in the region and neighboring regions; Low-Low Cluster, representing the low level of overweight and obesity spread among students in the region and neighboring regions; High-Low Outlier, representing the high level of overweight and obesity spread among students in the region surrounded by neighboring low level regions; Low-High Outlier, representing the high rate of overweight and obesity detection among students in the vicinity of the low level of overweight and obesity spread among students in the region.