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Title Page

An Exploratory Spatial Analysis of Overweight and Obesity among Children and Adolescents in Shandong, China

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Abstract

Objective: Identifying the spatial patterns of childhood overweight/obesity can help to guide resource allocation for preventive intervention in China. The aim of this study is to estimate rates of child overweight/obesity across counties within Shandong Province, using geographic techniques to identify sex-specific spatial patterns of childhood overweight/obesity as well as the presence of spatial clusters.

Design: Cross-sectional study.

Setting: Shandong Province in China.

Participants and Methods: 6,216,076 aged 7–18 years children and adolescents from the Children and Adolescent Physical Examination Database of Shandong Province were used in this study. Spatial patterns of sex-specific prevalence of childhood overweight and obesity were mapped. Global autocorrelation statistic (Moran's I) and the Local Indicator of Spatial Association (LISA) were applied to assess the degree of spatial autocorrelation,

Results: The overall prevalence of childhood overweight and obesity in Shandong province were 15.05% and 9.23% respectively. Maps of sex-specific prevalence of overweight/obesity demonstrate a marked geographical variation of children overweight/obesity in different regions. Prevalence of childhood overweight/obesity had a significant positive spatial autocorrelation among both boys and girls. LISA analysis identified significant clusters (or 'hot spots') of childhood overweight/obesity in the eastern coastal region, central region and southwestern region.

Conclusions: The prevalence of childhood overweight/obesity is highly spatially clustered. Geographically focused appropriate intervention should be introduced in currently childhood obesity prevention and control strategy.

Keywords: Overweight; Obesity; Child and adolescent; Spatial analysis; Geographic information systems

Strengths and limitations of this study

- This study is a census of children and adolescents aged 7-18 years old in publicly maintained schools in Shandong Province with a large sample size.
- Geographic techniques to identify sex-specific spatial patterns of childhood overweight/obesity as well as the presence of spatial clusters.
- The results are important for understanding the role that place might play in the health status and suggesting the importance of improving interventions and health-related policies that are thus far mainly based on assumptions of spatial homogeneity.
- The absence of detailed information at the individual level limited research on the determinants of overweight/obesity on targeted clustered areas.
- As a cross-sectional study, the temporal and spatial trends of overweight/obesity cannot be verified.

Introduction

Childhood obesity is one of the most serious public health challenges in the 21st century.[1] The prevalence of overweight and obesity among children and adolescent was rising rapidly in many developed countries and is affecting many low-and middle-income countries.[2-6] With rapid economic development over the past decades, China has also witnessed an increase in the prevalence of childhood obesity.[7,8] In 2010, the prevalence of overweight and obese among Chinese school-aged children were estimated to be 9.9% and 5.1% respectively, representing 30.43 million individuals.[9] A recent study showed that the detection rate of obesity among children and adolescents in China has increased by around 60 times from 1985 to 2014.[10]

Overweight and obesity in early life can lead to a serious health and economic burden.[11] Overweight and obese children are more likely to stay obese into adulthood, and develop noncommunicable diseases (NCDs) like diabetes and cardiovascular diseases at a younger age.[12-14] What's more, childhood obesity is associated with a higher chance of premature death and disability in adulthood.[15]

Given its high prevalence and severe impact on health outcomes, researchers had poured attention into the modifiable determinants of childhood obesity. Several studies in China have found that sociodemographic factors and behavioral factors (e.g., dietary intake, fast eating speed, physical inactivity) contribute to the risk of children and adolescents overweight or obese.[16-18] In addition, few studies also identified geographic location as an important risk factor for childhood obesity. The current literatures in China mostly focused on the comparison of childhood overweight/obesity across different regions, categorized by different socioeconomic status (SES).[8,19] However, the geographical relevance between adjacent regions, especially in terms of lifestyle and social factors, were often neglected in those studies. Considering the fact that the prevalence of overweight/obesity at one health region are likely to be correlated with prevalence in nearby regions, ignoring the clustering effect could potentially lead to biased estimation.[20] In addition, most of the analysis were conducted at a provincial/city level, making it difficult to infer implementation of local policies/ decisions of obesity prevention targeting smaller areas (i.e., counties).

Shandong Province is an important littoral province in East China with a population of 99.46 million in 2016, and covers an area of 156,700 square kilometers. It includes 140 counties belonging to 17 administration regions (Figure1). The prevalence of childhood obesity in Shandong Province in 2010 reached 15.8 and 7.1 % among boys and girls, respectively, which has caught up with developed countries.[21] In addition, the report of Children and Adolescent Physical Examination in Shandong province in 2015 showed that the overall overweight and obesity rates of children and adolescent were 30.8% and 12.8%, respectively, and the childhood overweight/obesity rates grew rapidly.[22]

The aim of this study is to estimate rates of childhood overweight/obesity at the county level and apply geographic techniques to examine the spatial patterns of childhood overweight/obesity, in particular to identify spatial cluster of areas with higher rates of childhood overweight/obesity.

Methods

Data sources and study design

Schoolchildren aged 7-18 years old were identified from the Children and Adolescent Physical Examination Database of Shandong Province. This database contains 7-18 years old students from all publicly primary and secondary schools and vocational schools. Children and Adolescent Physical Examination is organized by Health and Family Planning Commission of Shandong Province, and conducted by medical staffs from 1,373 medical institutions in the whole province. The examination rate was 93.96%, and data reporting rate was 100%. We extracted individual information of schoolchildren and adolescent, including codes of administrative divisions, age, sex, and measure of overweight and obesity. Body mass index (BMI) was calculated (Weight in kilograms divided by height in meters squared: kg/m^2). Childhood overweight and obesity were defined according to the classification reference in different age and gender of the Working Group for Obesity in China (WGOC), the cut-off points of which are 85th and 95th percentiles of BMI, respectively (Overweight: 85th percentile ≤ BMI < 95th percentile; Obesity: 95th percentile ≤ BMI).[23]

Using demographic data from the 2010 census as the standard population, we estimated age-standardized rates of overweight/obesity for schoolchildren and adolescent aged 7-18 years older at county level. The age-standardized rate is a value that represents the ratio of observed incidence of disease to expected incidence of disease, whereas a value of zero indicates an area with no observed overweight and obese cases.

This study included 140 counties (city districts, county-level cities, and counties, often referred to here as “counties”) of Shandong Province as spatial units. After data cleaning, 6,216,076 qualified schoolchildren (3,072,876 boys and 3,143,200 girls) aged 7-18 years were finally included for analysis. All children voluntarily joined this study and provided written informed consent. The geography files were provided by National

Administration of Surveying, Mapping and Geoinformation of China (NASG), the administrative organization in charge of surveying and mapping undertaking across China.

Statistical analysis

A two-part analysis was conducted: firstly, the spatial distribution of age-standardized overweight/obesity rates was mapped for boys and girls. Following this, the second part focused on two aspects of the spatial clustering: the overall 'global' spatial clustering in the prevalence of overweight/obesity and the 'local' patterns of overweight/obesity. Global Moran's *I* statistic is a measure of global spatial autocorrelation, a value representing the similarity in overweight/obesity rates between neighboring regions.[24] The Moran's *I* statistic ranges from +1 (for positive spatial autocorrelation where high values are proximal to other high values or low values adjacent to low values, i.e., clustering) to -1 (for negative autocorrelation where high values tend to be near low values, i.e., dispersion). A statistically significant (Z score≥1.96, P value<0.05) estimate of Moran's *I* indicates that neighboring counties have a similar prevalence rate of overweight/obesity and the cases are likely to cluster at county level. Nonsignificant values indicate no spatial autocorrelation or that the data are randomly distributed within the study's geographical boundaries. In the present analysis, neighbors were defined using rooks case adjacency, which considers that all regions with common borders are neighbors.

Moran's *I* statistic is a global test that does not identify where the clusters are located or what type of spatial autocorrelation is occurring (e.g. high-high cluster or low-low cluster etc.). To evaluate the existence of local clusters, it is necessary to use local statistics. The local indicator of spatial autocorrelation (LISA) was therefore applied as an indicator of local spatial association.[20] The local spatial autocorrelation decomposes the global measurement into the contributions for each geographic region, detecting homogeneity or heterogeneity in values around a given observation or used as diagnostics for outliers in global patterns. The LISA measures whether, for each health region, the standardized rate of overweight/obesity is closer to the values of its neighbors'. Inverse distance weighting squared is again used to conceptualize the spatial relationships. To ensure excellent statistical power and consider the computation times, 999 Monte Carlo replications were set, and clusters with statistical significance of $P<0.05$ were reported.

Cluster maps were created using the results of statistical testing to illustrate the local spatial patterns of significant positive and/or significant negative local spatial autocorrelation. The local spatial autocorrelation analysis results in five categories of health regions: (i) 'high–high' indicates clustering of high values of age-standardized overweight/obesity rates (positive LISA value), (ii) 'low–high' indicates that low values are adjacent to high values of age-standardized overweight/obesity rates (negative LISA value), (iii) 'low–low' indicates clustering of low values of age-standardized overweight/obesity rates (positive LISA value), (iv) 'high–low' indicates that high values are adjacent to low values of age-standardized overweight/obesity rates (negative LISA value), and (v) 'not significant' indicates that there is no spatial autocorrelation. All analyses were conducted using GeoDA[25] and ArcGis 10.3.

Results

In Shandong province, the overall age-standardized rate of overweight and obesity were 15.05% and 9.23% respectively, which were higher than the national average rates of 5.45% and 2.83%. Also, the rate of overweight was 17.40% for boys and 12.73% for girls; the rate of obesity was 10.49% for boys and 7.97% for girls. The age-standardized rate of overweight and obesity in county level were higher in boys than girls ($\chi^2=30.44$, $P<0.001$).

Age-standardized rates of overweight differed substantially across health regions ranging from 9.3% in Qihe, Dezhou to 24.94% in Penglai, Yantai for boys and from

8.19% in Linshu, Linyi to 19.15% in Longkou, Yantai for girls. Obesity rates varied substantially across health regions: from 3.59% in Changle, Weifang to 20.26% in Central District in Jining for boys and from 3.45% in Zhanhua, Liaocheng to 13.5% in Central District in Jining for girls. Age-standardized rates were also mapped by gender at county level, and then classified by the rates (Figure2 and Figure 3).

Based on the aforementioned, there was a marked geographical variation of children overweight/obesity in different regions indicating potential presence of spatial clusters or spatial heterogeneity. The Moran's I statistic was applied to test the overall spatial clustering. The results showed that there are significant positive spatial autocorrelations in the data. In particular, the Moran's I statistic of age-standardized overweight rates was 0.3736 (p-value=0.001) for boys and 0.3370 for girls (p-value=0.001). In addition, the Moran's I statistic of age-standardized obesity rates was 0.2312 (p-value=0.001) for boys and 0.1575 (p-value=0.006) for girls. The level of spatial autocorrelation across health regions for age-standardized overweight/obesity rates were slightly higher in boys than girls. For both sexes, the Moran's I statistic and corresponding p-values all suggest non-randomness in the overall spatial pattern of the age-standardized rates of overweight and obesity in Shandong province. Table 1 illustrates spatial correlation statistics and corresponding p-values as estimated by the Moran's I statistic.

Table 1 Spatial autocorrelation of age-standardized overweight/obesity rates in Shandong Province

	Moran's I	Z value	P value
Overweight			
Boys	0.3736	7.1726	0.001
Girls	0.3370	6.1104	0.001
Both sexes	0.2704	5.1601	0.001
Obesity			
Boys	0.2312	4.4350	0.001
Girls	0.1575	3.0727	0.006
Both sexes	0.1130	2.2082	0.014

We applied LISA to explore more information on the type and location of clustering. County-level LISA significant clusters were observed for both overweight and obesity (Fig.4 and Fig.5). For overweight boys, two larger hot spot (HH) was detected in the most counties of Yantai in eastern coastal region and Jining in southwest, and one smaller hot spot (HH) was found in Jinan in the central province. Two large cool spots (LL) were observed in the eastern and northwestern regions of Shandong province, and one smaller LL was found in a county in southwest. For the girls, the hot spot was comprised of the most counties in Yantai and two districts in Jinan and two counties in Jining. Two large cool spots were detected in the eastern regions (Fig.4). However, the pattern of clusters for obesity was different compared to that of overweight (Fig.5). For boys, the hot spot mainly distributed in the central region, and a small hot spot was detected in Qingdao in eastern coastal region. For girls, three hot spots were detected in Weihai in eastern coastal region, and in Jinan and Zibo in central region, and in Jining in southwest. In addition, several counties showed a dispersed pattern of cluster (HL or LH) as displayed in Fig. 4 and Fig.5.

Discussions

The present study aimed to estimate rates of overweight and obesity at the county level and apply geographical techniques to investigate the spatial variation of these rates across the province. The results illustrate the marked variability of overweight/obesity prevalence in Shandong province at the gender and health region level. The present study has indicated that the age-standardized rate of both overweight and obesity among boys was higher compared to girls. In addition to confirming the prevalence of overweight and obesity, our spatial analysis showed the presence of spatial heterogeneity using a significant positive spatial autocorrelation identified by Moran's I statistic for both boys and girls as well as the significant local clusters identified by LISA across the province.

The difference in overweight/obesity between boys and girls is consistent with results from previous studies in Shandong and throughout China.[26,27] Differences in age structure cannot explain this finding, as data have been age-standardized. Instead, in addition to the possible biologic/genetic factors, the difference may be related to the fact that girls are generally more concerned about their body shape compared to boys. A study reported that consumption of foods and beverages outside three main meals and potato chips were more popular in boys than in girls.[28]

The global spatial autocorrelation demonstrates that there is significant positive spatial autocorrelation in the data, which showed higher levels of correlation in similar overweight/obesity rates between neighboring counties in the whole provincial. The spatial patterns of overweight/obesity might be explained by the cluster of different influenced factors, such as socioeconomic status (SES) as well as living environments, nutritional habits and lifestyle characteristics.[29-31]

The LISA found also that the hot spots (HH) were detected in Yantai of eastern coastal region, Jinan in the central region and Jining in the southwestern inland region among both boys and girls. Again, the cold spots (LL) and other dispersed patterns of cluster (HL or LH) were observed. Some potential explanations for the different type of clusters are as follows. First, the regional SES is the most important factor responsible for the geographic differences in the prevalence of childhood obesity. Some previous studies had confirmed that the regional SES affected to the distribution of overweight/obesity positively in China, in other words, high SES youths are more likely to be overweight/obesity than other lower SES counterparts.[32] The evidence provided by research indicated that overweight/obesity prevalence was greater and increased more quickly in the coastal counterparts.[8] Eastern coastal region has high SES with more developed economy, the living standards, nutritional conditions and public health are better than other SES districts. Secondly, with the fast-growing Chinese economy, the rapid urbanization has narrowed the disparity between coastal and inland counterparts and became a potential contributor that cannot be ignored.[33,34] That is the reason why the hot spot of overweight and obesity for children also occurred in inland region.

In addition to the aforementioned factors, the change in the dietary habit and duration of physical activity accelerated the formation of 'obesogenic environment'.[35] The traditional Chinese diet is shifting toward a diet with high fat, high energy density and low dietary fiber, changes which have resulted in rapid increases in the prevalence of overweight and obesity and dietary-related chronic noncommunicable diseases.[36] With the increased availability and consumption of sugared products, such as candy, soft drinks and snacks, proliferation of fast food restaurants, this environmental shift is particularly striking in China.[8,32] Moreover, the popularity of smartphones and computer games brought the abundance of enticement that lead to reduced physical activity. Television viewing or surf the Internet besides reducing physical activity also leads to increased consumption of energy-rich foods through incessant commercial advertisement.[37] These factors lead to a rapid increase in the prevalence of overweight and obesity among children and adolescent.

The strength of this study is that the database comes from the Children and Adolescent Physical Examination Database of Shandong Province with a large sample size in Shandong Province, China. Examination survey provided direct measurements of weight and height, and avoided bias in self-reported data. The study detected a global spatial autocorrelation across whole provincial regions, and hot spots of overweight/obesity locally using spatial analysis. The results are important for understanding the role that place might play in the health status and suggesting the importance of improving interventions and health-related policies that are thus far mainly based on assumptions of spatial homogeneity.[38,39] In addition, the findings verified the effectiveness of spatial data analysis methods and in particular the helpful means of cluster analysis for public health professionals and policy makers.

This study has several limitations. First, the absence of detailed information at the individual level limited research on the determinants of overweight/obesity on targeted clustered areas. Second, the study may also be affected by the modifiable areal unit problem. The spatial scale used is not unique and typically arbitrary and modifiable, the spatial patterns of overweight/obesity identified may change depending on different scales. In addition, we only analyzed the data for one year, due to data availability, the temporal and spatial trends of overweight/obesity cannot be verified.

Conclusions

A high prevalence of childhood overweight/obesity was observed in Shandong Province, one of the populous provinces in China. There was geographical variation in childhood overweight and obesity, along with a tendency for regions to cluster based on the incidence of overweight and obesity. The present study validated and strengthened the sex-specific regional differences in the prevalence of childhood overweight/obesity, which previous studies had identified. In addition, the spatial clusters provide valuable information on the identification of local geographical variation and elevated risk of overweight/obesity in Shandong province. Therefore, prevention and health promotion interventions as well as effective allocation of resources and services should be implemented based on regional and population specific demands.

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Footnotes

Contributors: WZ planned the study, conducted the analysis and wrote the pater while being supervised by LZ*; JJ, LS helped to plan the study, including the instrumentation, and to revise the manuscript; JZ, LW, and HS accomplished the statistical analysis and contributed to revising the paper. All authors All authors contributed to the discussion of the paper, read and approved the final manuscript.

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Patient consent: Not required.

Ethics approval: This study was approved by the Academic Research Ethics Committee of Shandong University. Written informed consent was obtained from all participants.

Provenance and peer review: Not commissioned; externally peer reviewed.

Data sharing statement: No additional unpublished data.

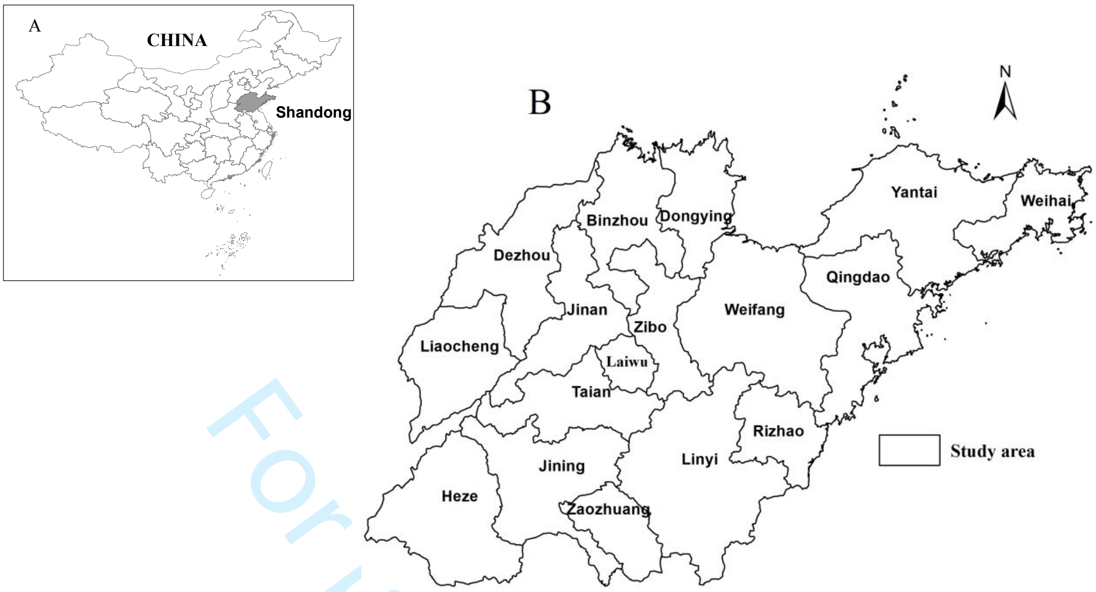

Fig. 1 A. Location of Shandong Province in China. B. Location of study area in Shandong Province

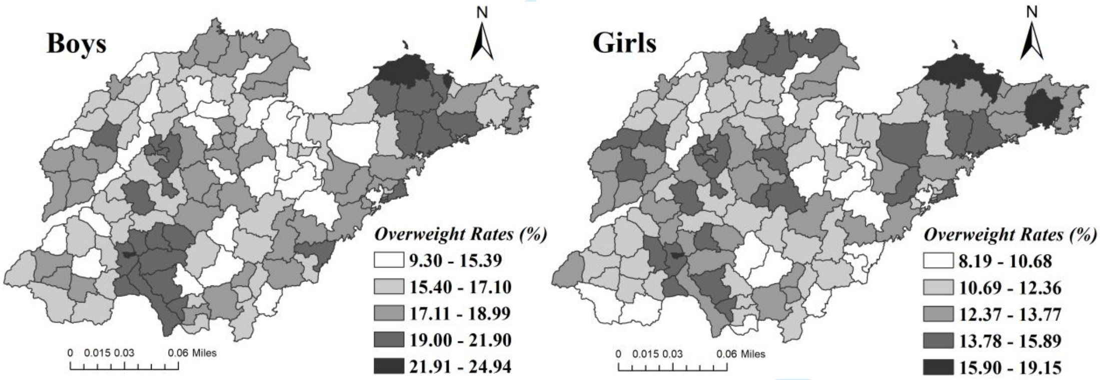

Fig. 2 Age-standardized overweight rates for boys and girls by county level in Shandong province

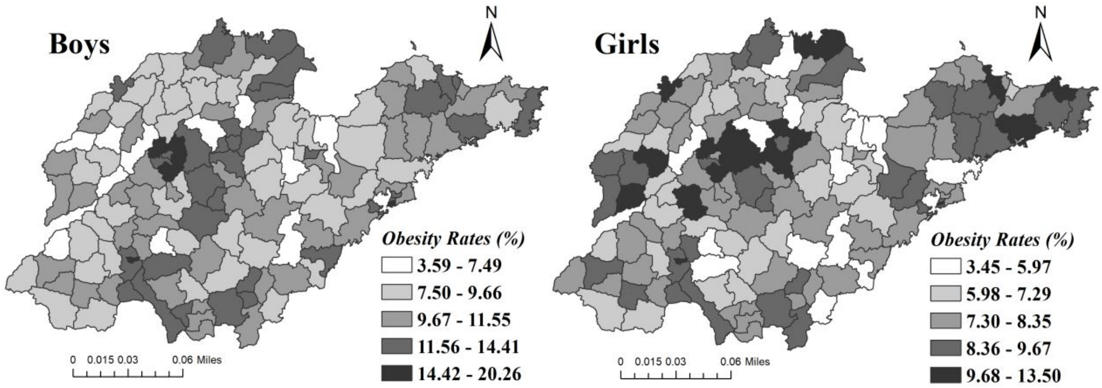

Fig. 3 Age-standardized obesity rates for boys and girls by county level in Shandong province

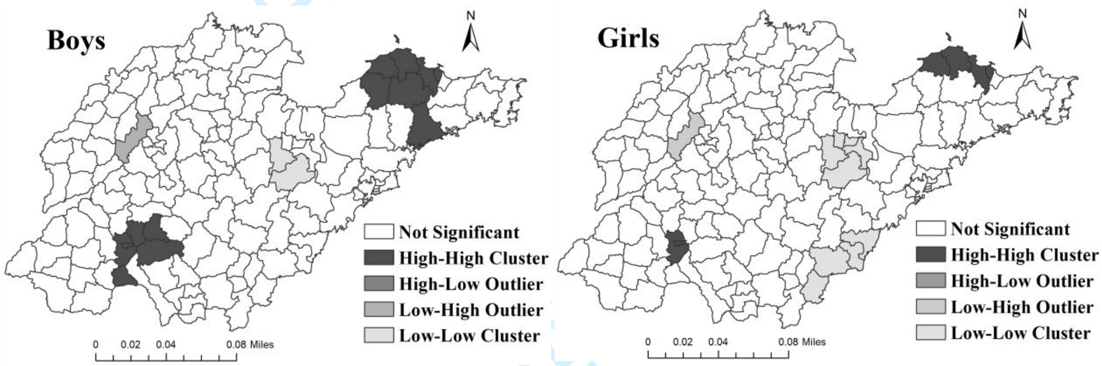

Fig. 4 LISA cluster maps for age-standardized overweight rates by county level in Shandong Province

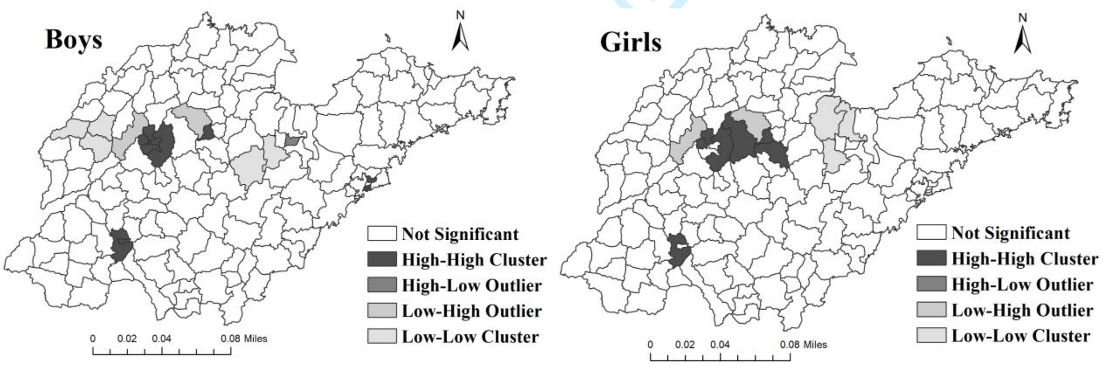

Fig. 5 LISA cluster maps for age-standardized obesity rates by county level in Shandong Province

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3
Objectives	3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	5
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	*5*
Bias	9	Describe any efforts to address potential sources of bias	
Study size	10	Explain how the study size was arrived at	5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	5
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	6-7
		(*b*) Describe any methods used to examine subgroups and interactions	6-7
		(*c*) Explain how missing data were addressed	
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	7
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	7
		(b) Indicate number of participants with missing data for each variable of interest	
Outcome data	15*	Report numbers of outcome events or summary measures	8
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	8

		(*b*) Report category boundaries when continuous variables were categorized	8
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	8
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	9
Discussion			
Key results	18	Summarise key results with reference to study objectives	9
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	12
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	10-12
Generalisability	21	Discuss the generalisability (external validity) of the study results	
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	15

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

An Exploratory Spatial Analysis of Overweight and Obesity among Children and Adolescents in Shandong, China

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Keywords:	Overweight, Obesity, Child and adolescent, Spatial analysis, Geographic location

Title Page

An Exploratory Spatial Analysis of Overweight and Obesity among Children and Adolescents in Shandong, China

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Abstract

Objective: Identifying the spatial patterns of childhood overweight/obesity (OW/OB) can help to guide resource allocation for preventive intervention in China. The aim of this study is to estimate rates of childhood OW/OB across counties within Shandong Province, using geographic techniques to identify sex-specific spatial patterns of childhood OW/OB as well as the presence of spatial clusters.

Design: Cross-sectional study.

Setting: Shandong Province in China.

Participants and Methods: Data on 6,216,076 children and adolescents aged 7-18 years from the Primary and Secondary Schoolchildren Physical Examination Database for Shandong Province were used in this study. Spatial patterns of sex-specific prevalence of childhood OW/OB were mapped. Global autocorrelation statistic (Moran's I) and the Local Indicator of Spatial Association (LISA) were applied to assess the degree of spatial autocorrelation.

Results: The overall prevalence of childhood OW/OB in Shandong province were 15.05% and 9.23% respectively. Maps of sex-specific prevalence of OW/OB demonstrate a marked geographical variation of childhood OW/OB in different regions. Prevalence of childhood OW/OB had a significant positive spatial autocorrelation among both boys and girls. LISA analysis identified significant clusters (or 'hot spots') of childhood OW/OB in the eastern coastal region, central region and southwestern region.

Conclusions: The prevalence of childhood OW/OB is highly spatially clustered. Geographically focused appropriate intervention should be introduced in currently childhood OW/OB prevention and control strategy.

Keywords: Overweight; Obesity; Child and adolescent; Spatial analysis; Geographic location

Strengths and limitations of this study

- With a large sample size, this study is a secondary analysis of census database of primary and secondary schoolchildren aged 7-18 years old in publicly maintained schools in Shandong Province.

- Geographic techniques to identify sex-specific spatial patterns of childhood OW/OB as well as the presence of spatial clusters.
- This study provided information of understanding the role that place might play in the health status and the prevention of disease. This study also suggested the importance of improving interventions and health-related policies that based on assumptions of spatial heterogeneity.
- The absence of detailed information at the individual level limited research on the determinants of OW/OB on targeted clustered areas.
- As a cross-sectional study, the temporal and spatial trends of OW/OB cannot be verified.

Introduction

Childhood obesity is one of the most serious public health challenges in the 21st century.[1] The prevalence of overweight and obesity (OW/OB) among children and adolescent has been rising rapidly in many developed countries and is affecting many low-and middle-income countries.[2-5] With rapid economic development over the past decades, China has also witnessed an increase in the prevalence of childhood obesity.[6,7] In 2013, approximately 23.0% and 14.0% of Chinese boys and girls aged 2–19 years were overweight or obese.[8] Overweight and obese children are more likely to stay obese into adulthood, and develop non-communicable diseases (NCDs) like diabetes and cardiovascular diseases at a younger age.[9-11] Even worse, childhood obesity is associated with a higher chance of premature death and disability in adulthood.[12]

Given its high prevalence and severe impact on health outcomes, researchers had poured attention into the modifiable determinants and driving factors of childhood OW/OB. Several studies have found that childhood OW/OB is multifactorial and complex and is considered to result when various genetic, behavioral, environmental, physiological, social and cultural factors interact.[13-16] It is increasingly recognized that where we live has an impact on our health. For example, the term "built environment" mainly determined leisure-time physical activity through the availability of parks, playgrounds or sport clubs, road traffic and transportation systems, and influenced dietary behavior by spatial accessibility to food through the patterns of food outlets and restaurants.[17] Changes in the lived in and built environment have been connected to the rise of obesity.[18,19] However, the geographical relevance between adjacent regions, especially in terms of lifestyle and social factors, were often neglected in current studies in Chinese schoolchildren. Considering the fact that the prevalence of OW/OB at one health region are likely to be correlated with prevalence in nearby regions, ignoring the clustering effect could potentially lead to biased estimation.[20]

Geographic Information System (GIS) is a potentially ‘powerful evidence-based practice tool’ in community health, as they enable the identification of spatial epidemiology or the incidence of disease and can allow for effective allocation of resource in a spatial setting.[21] GIS have been employed in several innovative studies of OW/OB. For example, to explore regional variations and spatial clustering of obesity rates; to identify locations for targeted obesity intervention efforts.[16,18,22-24] In addition, most of the previous analysis were conducted using large geographical units such as provincial or city level, making it difficult to provide effective implementation of local policies or decisions for obesity prevention. Selecting the most appropriate scale or the smaller geographical areas (i.e., counties) makes the obesity interventions more targeted.

Shandong Province is an important littoral province in East China with a population of 99.46 million in 2016, and covers an area of 156,700 square kilometers. It includes 140 counties belonging to 17 administration regions (Figure1). The prevalence of childhood obesity in Shandong Province in 2010 reached 15.83% and 7.12% among boys and girls, respectively.[25] In addition, the report of Primary and Secondary Schoolchildren Physical Examination in Shandong province in 2015 showed that the overall overweight and obesity rates of children and adolescent were 30.8% and 12.8%, respectively.[26] The childhood OW/OB rates in Shandong province grew rapidly which has caught up the prevalence of childhood OW/OB in developed countries.[27]

Hence, the present study aimed to estimate rates of childhood OW/OB at the county level and apply geographic techniques to examine the spatial patterns of childhood OW/OB by gender, in particular to identify spatial cluster of areas with higher rates of childhood OW/OB.

Methods

Data sources and study design

This study comprised a cross-sectional secondary data analysis of the spatial distribution of childhood OW/OB, using data from Primary and Secondary Schoolchildren Physical Examination Database of Shandong Province. This database contains schoolchildren aged 7-18 years old from all publicly primary and secondary schools and vocational schools in 2017.

Shandong Province began to conduct health checkups for primary and secondary schoolchildren in 2009 according to the requirements of National Health Commission of China, and apply free health checkup for them every year. Primary and Secondary Schoolchildren Physical Examination is organized by Health Commission of Shandong Province (The author Wang Lu is one of leaders of the investigation team). The contents of the medical examination mainly include: medicine and surgery, ophthalmology, stomatology, physical indicators and physiological function indicators. The specific process is as follows. Before the physical examination, the Health Commission of Shandong Province selected and published the declared medical and health institutions. According to the published list of medical institutions, educational institutions select the nearest institution to enter schools for health examination of students. All measurements were performed by well-trained health professionals in each medical institution using the same type of apparatus and followed the same procedures and the uniform date. During the period of physical examination, a special supervision team went to each physical examination site to conduct quality inspections. After physical examination, the medical institutions responsible for the physical examination directly input the physical examination data into the Primary and Secondary Schoolchildren Physical Examination Database of Shandong Province. After the data entry, the expert working group will conduct a random sampling checkup of all the entered physical examination data to ensure the data quality.

The physical examination was conducted by medical staffs from 1,373 medical institutions in the whole province. The physical examination rate was 93.96%, and data reporting rate was 100%. All children voluntarily joined this study and provided written informed consent. We extracted individual information of schoolchildren and adolescent, including codes of administrative divisions, age, gender, and measure of height and weight. Body mass index (BMI) was calculated (Weight in kilograms divided by height in meters squared: kg/m^2). Childhood OW/OB were defined according to the classification reference in different age and gender of the Working Group for Obesity in China (WGOC), the cut-off points of which are 85th and 95th percentiles of BMI, respectively (Overweight: 85th percentile≤BMI<95th percentile; Obesity: BMI≥95th percentile).[28] Using demographic data from the 2010 census as the standard population, we estimated age-standardized rates of OW/OB for schoolchildren and adolescent aged 7-18 years older at county level. The age-standardized rate is a value that represents the ratio of observed incidence of disease to expected incidence of disease, whereas a value of zero indicates an area with no observed overweight and obese cases.

This study included 140 counties (city districts, county-level cities, and counties, often referred to here as “counties”) of Shandong Province as spatial units. In practice, county is a basic unit of administrative region in China, and is also the registered permanent residence of the schoolchildren, which implements the national policies toward population health and health promotion directly. In addition, China's unique household registration system and student roll management system stipulates that primary school and secondary school must be completed in the household registration area, that is, in the county.

Statistical analysis

A two-part analysis was conducted: firstly, the spatial distribution of age-standardized OW/OB rates was mapped for boys and girls. Following this, the second part focused on two aspects of the spatial clustering: the overall 'global' spatial clustering in the prevalence of OW/OB and the 'local' patterns of OW/OB.

Global Moran's *I* statistic is a measure of global spatial autocorrelation, a value representing the similarity in OW/OB rates between neighboring regions, and the mathematical definition of Moran's I is as follows.[29,30]

$$\text{Moran's I} = \frac{N\sum_{i=1}^{N}\sum_{j=1}^{N}W_{ij}(x_i-\bar{x})(x_j-\bar{x})}{\left(\sum_{i=1}^{N}\sum_{j=1}^{N}W_{ij}\right)\sum_{i=1}^{N}(x_i-\bar{x})^2} \quad (i \neq j)$$

Where W_{ij} is the spatial weights assigned to pairs of units (i.e. counties) between observations i and j, N is equal to the total number of pixels.

The Moran's *I* statistic ranges from +1 (for positive spatial autocorrelation where high values are proximal to other high values or low values adjacent to low values, i.e., clustering) to -1 (for negative autocorrelation where high values tend to be near low values, i.e., dispersion). A statistically significant (Z score≥1.96, P value<0.05) estimate of Moran's *I* indicates that neighboring counties have a similar prevalence rate of OW/OB and the cases are likely to cluster at county level. Nonsignificant values indicate no spatial autocorrelation or that the data are randomly distributed within the study's geographical boundaries. In the present analysis, neighbors were defined using rooks case adjacency, which considers that all regions with common borders are neighbors.

Moran's *I* statistic is a global test that does not identify where the clusters are located or what type of spatial autocorrelation is occurring (e.g. high-high cluster or low-low cluster etc.). To evaluate the existence of local clusters, it is necessary to use local statistics. The local indicator of spatial autocorrelation (LISA) was therefore applied as an indicator of local spatial association.[20] The local spatial autocorrelation decomposes the global measurement into the contributions for each geographic region, detecting homogeneity or heterogeneity in values around a given observation or used as diagnostics for outliers in global patterns. The LISA measures whether, for each health region, the standardized rate of OW/OB is closer to the values of its neighbors'. Inverse distance weighting squared is again used to conceptualize the spatial relationships. To ensure excellent statistical power and consider the computation times, 999 Monte Carlo replications were set, and clusters with statistical significance of P<0.05 were reported. Cluster maps were created using the results of statistical testing to illustrate the local spatial patterns of significant positive and/or significant negative local spatial autocorrelation. The local spatial autocorrelation analysis results in five categories of health regions: (i) 'high–high' indicates clustering of high values of age-standardized OW/OB rates (positive LISA value), (ii) 'low–high' indicates that low values are adjacent to high values of age-standardized OW/OB rates (negative LISA value), (iii) 'low–low' indicates clustering of low values of age-standardized OW/OB rates (positive LISA value), (iv) 'high–low' indicates that high values are adjacent to low values of age-standardized OW/OB rates (negative LISA value), and (v) 'not significant' indicates that there is no spatial autocorrelation. All analyses were conducted using GeoDA[31] and ArcGis 10.3. The geography files were provided by National Administration of Surveying, Mapping and Geo-information of China (NASG), the administrative organization in charge of surveying and mapping undertaking across China.

Patient and public involvement

No patients or public were involved in this study.

Results

Participants

After data cleaning, 6,216,076 qualified schoolchildren aged 7-18 years were finally included for analysis. Participating children were primarily Han ethnicity (>80%) and were approximately equally distributed across sex (50.57% girls) with a mean (SD) age of 10.94(2.62) years.

Prevalence of overweight and obesity

In Shandong province, the overall age-standardized rate of OW/OB were 15.05% and 9.23% respectively, which were higher than the national average rates of 5.45% and 2.83%. Also, the rate of overweight was 17.40% for boys and 12.73% for girls; the rate of obesity was 10.49% for boys and 7.97% for girls. The age-standardized rate of OW/OB in county level were higher in boys than girls (χ^2=30.44, P<0.001).

Age-standardized rates of overweight differed substantially across health regions ranging from 9.3% in Qihe, Dezhou to 24.94% in Penglai, Yantai for boys and from 8.19% in Linshu, Linyi to 19.15% in Longkou, Yantai for girls. Obesity rates varied substantially across health regions: from 3.59% in Changle, Weifang to 20.26% in Central District in Jining for boys and from 3.45% in Zhanhua, Liaocheng to 13.5% in Central District in Jining for girls. Age-standardized rates were also mapped by gender at county level, and then classified by the rates (Figure2 and Figure 3).

Spatial autocorrelation and cluster identification

Based on the aforementioned, there was a marked geographical variation of children overweight/obesity in different regions indicating potential presence of spatial clusters or spatial heterogeneity. The Moran's I statistic was applied to test the overall spatial clustering. The results showed that there are significant positive spatial autocorrelations in the data. In particular, the Moran's I statistic of age-standardized overweight rates was 0.3736 (p-value=0.001) for boys and 0.3370 for girls (p-value=0.001). In addition, the Moran's I statistic of age-standardized obesity rates was 0.2312 (p-value=0.001) for boys and 0.1575 (p-value=0.006) for girls. The level of spatial autocorrelation across health regions for age-standardized OW/OB rates were slightly higher in boys than girls. For both sexes, the Moran's I statistic and corresponding p-values all suggest non-randomness in the overall spatial pattern of the age-standardized rates of overweight and obesity in Shandong province. Table 1 illustrates spatial correlation statistics and corresponding p-values as estimated by the Moran's I statistic.

Table 1 Spatial autocorrelation of age-standardized overweight/obesity rates in Shandong Province

	Moran's I	Z value	P value
Overweight			
Boys	0.3736	7.1726	0.001**
Girls	0.3370	6.1104	0.001**
Both sexes	0.2704	5.1601	0.001**
Obesity			
Boys	0.2312	4.4350	0.001**
Girls	0.1575	3.0727	0.006**
Both sexes	0.1130	2.2082	0.014*

Note: **P<0.01; *P<0.05.

We applied LISA to explore more information on the type and location of clustering. County-level LISA significant clusters were observed for both OW/OB (Fig.4 and Fig.5). For overweight boys, two larger hot spot (HH) was detected in the most counties of Yantai in eastern coastal region and Jining in southwest, and one smaller hot spot (HH) was found in Jinan in the central province. Two large cool spots (LL) were observed in the eastern and northwestern regions of Shandong province, and one smaller LL was found in a county in southwest. For the girls, the hot spot was comprised of the most counties in Yantai and two districts in Jinan and two counties in Jining. Two large cool spots were detected in the eastern regions (Fig.4). However, the pattern of clusters for obesity was different compared to that of overweight (Fig.5). For boys, the hot spot mainly distributed in the central region, and a small hot spot was detected in Qingdao in eastern coastal region. For girls, three hot spots were detected in Weihai in eastern coastal region, and in Jinan and Zibo in central region, and in Jining in southwest. In addition, several counties showed a dispersed pattern of cluster (HL or LH) as displayed in Fig. 4 and Fig.5.

Discussions

The present study illustrates the marked variability of OW/OB prevalence in Shandong province at the gender and health region level. The results also indicated that the age-standardized rate of both overweight and obesity among boys was higher compared to girls. Our spatial analysis showed the presence of spatial heterogeneity using a significant positive spatial autocorrelation identified by Moran's I statistic for both boys and girls as well as the significant local clusters identified by LISA across the province.

The first concern is the Primary and Secondary Schoolchildren Physical Examination Database of Shandong Province. The census of physical examination for primary and secondary schoolchildren began in Shandong Province in 2009 and examine the physical condition of primary and secondary schoolchildren every year. With a census dataset, the physical health of every students can be mastered in addition to provide evidence for understanding the overall health of students. Several researches have explored the childhood health with the data from the National Surveys on Chinese Students' Constitution and Health in Shandong Province. The survey is conducted every five years and the data is obtained by sampling method, and the existence of sampling errors makes the data less stable. Although the census design increases the accuracy and stability of the data, the absence of other information at the individual level limited research on the factors of schoolchildren's health, such as socioeconomic factors, parental background, and psychological status.

The difference in OW/OB between boys and girls is consistent with results from previous studies in Shandong and throughout China.[32,33] Differences in age structure cannot explain this finding, as data have been age-standardized. Instead, in addition to the possible biologic/genetic factors, behavioral factors, family environment and psychological factors (e.g. body image perceptions) are also related to OW/OB in children. On a behavioral level, girls report being more attentive to food and its effects on health and weight control.[34] A study reported that consumption of foods and beverages outside three main meals and potato chips were more popular in boys than in girls.[35] Moreover, a review of studies found that boys are also higher users of TV and video games than girls, and these sedentary behaviors has also been associated with body composition and BMI.[36] There is some evidence that misconceptions about a child's weight status were prevalent among parents and grandparents, and boys' weight status was more frequently underestimated than girls.[37] On a psychological level related to body image, girls self-perceive as overweight more often than do boys.[38]

The global spatial autocorrelation demonstrates that there is significant positive spatial autocorrelation in the data, which showed higher levels of correlation in similar OW/OB rates between neighboring counties in the whole provincial. The spatial patterns of OW/OB might be explained by some possible reasons of neighborhood characteristics. First, neighboring county residents may share similar socio-economic backgrounds, a well-established correlate to obesity.[39] Second, as residents in neighboring areas are likely to share similar lifestyles in relation to diet, nutritional habits and physical activity, it could be that residents of adjacent areas with similar obesity rates, share behaviors that promote this condition.[18] Moreover, adjacent areas also share similar social and built characteristics and therefore the clustered areas may also share similar features. It is worth noting that the racial/ethnic differences might also be a possible reason. A previous study shown that living in neighborhoods with a higher proportion of foreign-born residents is associated with reduced child obesity risk.[40] Further research would be necessary to tease out the actual mechanism driving the gradient in OW/OB in these areas. In addition, prospective cohort studies and experimental studies were needed to explore the long-term effects of neighborhood environment directly to the development of obesity.

The LISA found also that the hot spots (HH) were detected in Yantai of eastern coastal region, Jinan in the central region and Jining in the southwestern inland region among both boys and girls. Again, the cold spots (LL) and other dispersed patterns of cluster (HL or LH) were observed. Some potential explanations for the different type of clusters are as follows. First, the regional SES might be the influenced factor responsible for the geographic differences in the prevalence of childhood obesity. Some previous studies had confirmed that the regional SES affected to the distribution of OW/OB positively in China, in other words, high SES youths are more likely to be OW/OB than other lower SES counterparts.[41] The evidence provided by research indicated that OW/OB prevalence was greater and increased more quickly in the coastal counterparts.[7] Eastern coastal region has high SES with more developed economy, the living standards, nutritional conditions and public health are better than other SES districts. Secondly, with the fast-growing Chinese economy, the rapid urbanization has narrowed the disparity between coastal and inland counterparts and became a potential contributor that cannot be ignored.[42,43] That is the reason why the hot spot of OW/OB for children also occurred in inland region. In addition to the aforementioned factors, the traditional Chinese diet is shifting toward a diet with high fat, high energy density and low dietary fiber on the whole, changes which have resulted in rapid increases in the prevalence of OW/OB.[44] Moreover, television viewing or surf the Internet besides reducing physical activity also leads to increased consumption of energy-rich foods through incessant commercial advertisement.[45] These factors lead to a rapid increase in the prevalence of overweight and obesity among children and adolescent.

The strength of this study is that the data comes from the Primary and Secondary Schoolchildren Physical Examination Database with a large sample size in Shandong Province, China. Examination survey provided direct measurements of weight and height, and avoided bias in self-reported data. The results are important for understanding the role that place might play in the health status and suggesting the importance of improving interventions and health-related policies that are thus far mainly based on assumptions of spatial homogeneity. In addition, the findings verified the effectiveness of spatial data analysis methods and in particular the helpful means of cluster analysis for public health professionals and policy makers. For instance, based on the potential explanations for the identified clusters, existing policies and practices could provide funding for physical education as well as recreation centers in communities most in need. Furthermore, it may be advantageous from the perspective that exploring areas of low prevalence to ascertain which factors might decrease risk of the population. Further research is required to explore the underlying mechanism for the increased levels of OW/OB on clustered areas, and investigate the impact of area level characteristics on the spatial patterns identified.

This study has several limitations. First, the absence of detailed information at the individual level limited research on the determinants of OW/OB on targeted clustered areas. Second, the study may also be affected by the modifiable areal unit problem. The spatial scale used is not unique and typically arbitrary and modifiable, the spatial patterns of OW/OB identified may change depending on different scales. In addition, we only analyzed the data for one year, due to data availability, the temporal and spatial trends of OW/OB cannot be verified.

Conclusions

A high prevalence of childhood OW/OB was observed in Shandong Province, one of the populous provinces in China. There were marked sex-specific regional differences in the prevalence of childhood OW/OB, along with a tendency of spatial correlation of the childhood OW/OB. In addition, the spatial clusters provide valuable information on the identification of local geographical variation and elevated risk of OW/OB in Shandong province. Therefore, prevention and health promotion interventions as well as effective allocation of resources and services should be implemented based on regional and population specific demands. For the hot spots of childhood OW/OB, resource allocation is mainly concentrated in three aspects. First, through the health education of parents, they are encouraged to establish a healthy lifestyle, which in turn affects children's cognition and diet behavior; In addition, the schools should develop appropriate health strategies, including education on nutrition knowledge, increased physical activity, and encourage children to establish health behaviors; Furthermore, government should provide more interventions for hot spots of childhood OW/OB, including developing dietary guidelines, increasing community exercise facilities, and conducting health education.

Acknowledgment

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Footnotes

Contributors: Wenzhe Qin planned the study, conducted the analysis and wrote the pater while being supervised by Lingzhong Xu*; Lu Wang, Jiajia Li, Long Sun helped to plan the study, including the instrumentation, and to revise the manuscript; Jiao Zhang and Hui Shao accomplished the statistical analysis and contributed to revising the paper. All authors contributed to the discussion of the paper, read and approved the final manuscript.

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Data sharing statement: No additional unpublished data.

Figure legends: Figure 1. Location of study area in Shandong Province, China (The map has obtained permission from National Administration of Surveying, Mapping and Geoinformation of China (NASG))

Figure 2. Age-standardized overweight rates for boys and girls by county level in Shandong province (The map has obtained permission from National Administration of Surveying, Mapping and Geoinformation of China (NASG))

Figure 3. Age-standardized obesity rates for boys and girls by county level in Shandong province (The map has obtained permission from National Administration of Surveying, Mapping and Geoinformation of China (NASG))

Figure 4. LISA cluster maps for age-standardized overweight rates by county level in Shandong Province (The map has obtained permission from National Administration of Surveying, Mapping and Geoinformation of China (NASG))

Figure 5. LISA cluster maps for age-standardized obesity rates by county level in Shandong Province (The map has obtained permission from National Administration of Surveying, Mapping and Geoinformation of China (NASG))

Figure 1. Location of study area in Shandong Province, China(The map has obtained permission from National Administration of Surveying, Mapping and Geoinformation of China (NASG))

174x118mm (300 x 300 DPI)

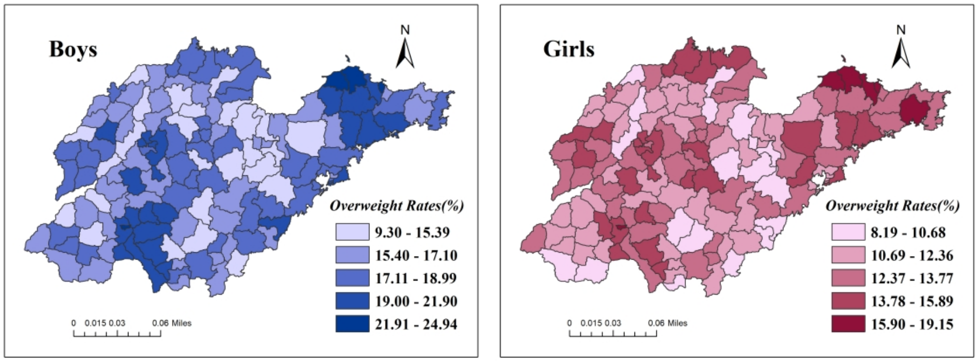

Figure 2.Age-standardized overweight rates for boys and girls by county level in Shandong province(The map has obtained permission from National Administration of Surveying, Mapping and Geoinformation of China (NASG))

411x159mm (300 x 300 DPI)

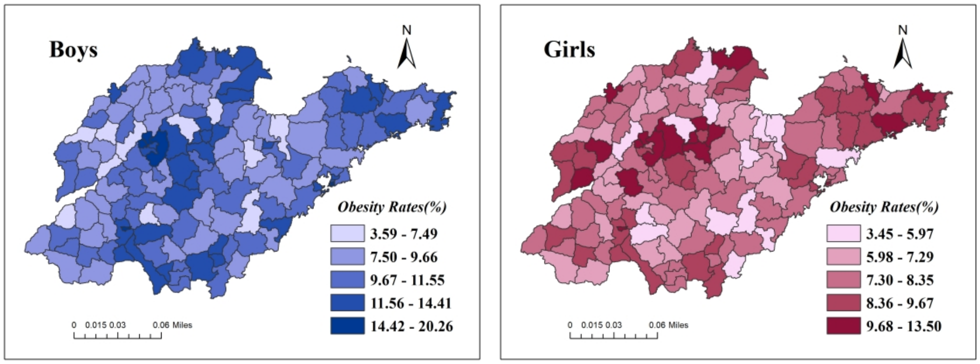

Figure 3. Age-standardized obesity rates for boys and girls by county level in Shandong province(The map has obtained permission from National Administration of Surveying, Mapping and Geoinformation of China (NASG))

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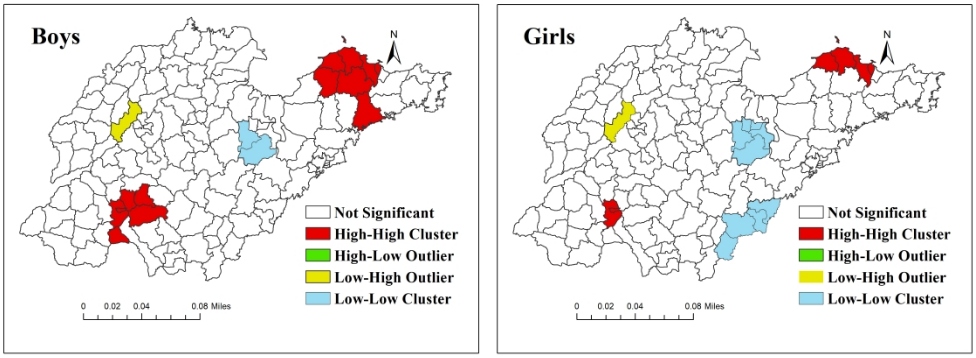

Figure 4. LISA cluster maps for age-standardized overweight rates by county level in Shandong Province(The map has obtained permission from National Administration of Surveying, Mapping and Geoinformation of China (NASG))

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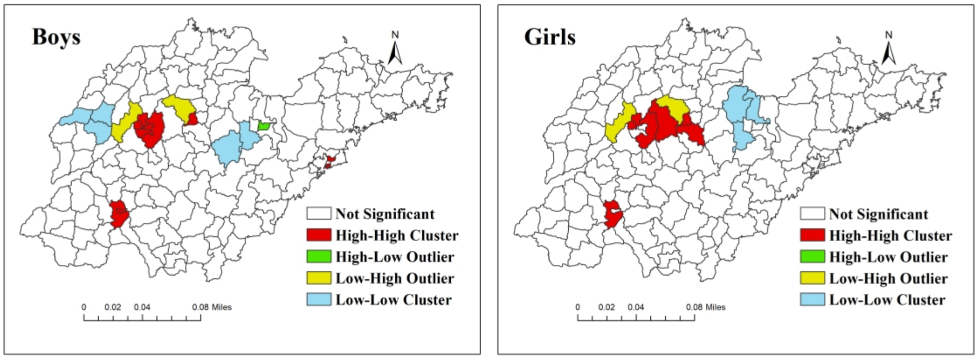

Figure 5. LISA cluster maps for age-standardized obesity rates by county level in Shandong Province(The map has obtained permission from National Administration of Surveying, Mapping and Geoinformation of China (NASG))

409x154mm (300 x 300 DPI)

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	1
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	2
Objectives	3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	4	Present key elements of study design early in the paper	4
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	5
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	*4*
Bias	9	Describe any efforts to address potential sources of bias	
Study size	10	Explain how the study size was arrived at	7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	5
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	6-7
		(*b*) Describe any methods used to examine subgroups and interactions	6-7
		(*c*) Explain how missing data were addressed	
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	7
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	7-8
		(b) Indicate number of participants with missing data for each variable of interest	
Outcome data	15*	Report numbers of outcome events or summary measures	8-9
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	8-9

		(*b*) Report category boundaries when continuous variables were categorized	8-9
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	8-9
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	9
Discussion			
Key results	18	Summarise key results with reference to study objectives	9-10
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	13
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	10-12
Generalisability	21	Discuss the generalisability (external validity) of the study results	
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	17

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Title Page

An Exploratory Spatial Analysis of Overweight and Obesity among Children and Adolescents in Shandong, China

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Abstract

Objective: Identifying the spatial patterns of childhood overweight/obesity (OW/OB) can help to guide resource allocation for preventive intervention in China. This study aims to estimate rates of childhood OW/OB across counties within Shandong Province, using geographic techniques to identify sex-specific spatial patterns of childhood OW/OB as well as the presence of spatial clusters.

Design: Cross-sectional study.

Setting: Shandong Province in China.

Participants and Methods: Data on 6,216,076 children and adolescents aged 7-18 years from the Primary and Secondary Schoolchildren Physical Examination Database for Shandong Province were used in this study. Spatial patterns of sex-specific prevalence of childhood OW/OB were mapped. Global autocorrelation statistic (Moran's I) and the Local Indicator of Spatial Association (LISA) were applied to assess the degree of spatial autocorrelation.

Results: The overall prevalence of childhood OW/OB in Shandong province were 15.05% and 9.23% respectively. Maps of the sex-specific prevalence of OW/OB demonstrate a marked geographical variation of childhood OW/OB in different regions. Prevalence of childhood OW/OB had a significant positive spatial autocorrelation among both boys and girls. LISA analysis identified significant clusters (or 'hot spots') of childhood OW/OB in the eastern coastal region, central region, and southwestern region.

Conclusions: The prevalence of childhood OW/OB is highly spatially clustered. Geographically focused appropriate intervention should be introduced in current childhood OW/OB prevention and control strategy.

Keywords: Overweight; Obesity; Child and adolescent; Spatial analysis; Geographic location

Strengths and limitations of this study

- With a large sample size, this study is a secondary analysis of census database of primary and secondary schoolchildren aged 7-18 years old in publicly maintained schools in Shandong Province.

- Geographic techniques to identify sex-specific spatial patterns of childhood OW/OB as well as the presence of spatial clusters.
- This study provided information on the role that place might play in the health status and the prevention of disease, and improving interventions and health-related policies based on spatial heterogeneity.
- The absence of detailed information at the individual level limited research on the determinants of OW/OB on targeted clustered areas.
- As a cross-sectional study, the temporal and spatial trends of OW/OB cannot be verified.

Introduction

Childhood obesity is one of the most serious public health challenges in the 21st century.[1] The prevalence of overweight and obesity (OW/OB) among children and adolescent has been rising rapidly in many developed countries and is affecting many low-and-middle-income countries.[2-5] With rapid economic development over the past decades, China has also witnessed an increase in the prevalence of childhood obesity.[6,7] In 2013, approximately 23.0% and 14.0% of Chinese boys and girls aged 2–19 years were overweight or obese.[8] Overweight and obese children are more likely to stay obese into adulthood, and develop non-communicable diseases (NCDs) like diabetes and cardiovascular diseases at a younger age.[9-11] Even worse, childhood obesity is associated with a higher chance of premature death and disability in adulthood.[12]

Given its high prevalence and severe impact on health outcomes, researchers had poured attention into the modifiable determinants and driving factors of childhood OW/OB. Several studies have found that childhood OW/OB is multifactorial and complex and is considered to result when various genetic, behavioral, environmental, physiological, social and cultural factors interact.[13-16] It is increasingly recognized that where we live has an impact on our health. For example, the term "built environment" mainly determined leisure-time physical activity through the availability of parks, playgrounds or sports clubs, road traffic, and transportation systems, and influenced dietary behavior by spatial accessibility to food through the patterns of food outlets and restaurants.[17] Changes in the lived in and the built environment have been connected to the rise of obesity.[18,19] However, the geographical relevance between adjacent regions, especially in terms of lifestyle and social factors, were often neglected in current studies in Chinese schoolchildren. Considering the fact that the prevalence of OW/OB at one health region are likely to be correlated with prevalence in nearby regions, ignoring the clustering effect could potentially lead to biased estimation.[20]

Geographic Information System (GIS) is a potentially ‘powerful evidence-based practice tool’ in community health, as they enable the identification of spatial epidemiology or the incidence of disease and can allow for effective allocation of resource in a spatial setting.[21] GIS has been employed in several innovative studies of OW/OB. For example, to explore regional variations and spatial clustering of obesity rates; to identify locations for targeted obesity intervention efforts.[16,18,22-24] In addition, most of the previous analysis was conducted using large geographical units such as provincial or city level, making it difficult to provide effective implementation of local policies or decisions for obesity prevention. Selecting the most appropriate scale or the smaller geographical areas (i.e., counties) makes the obesity interventions more targeted.

Shandong Province is an important littoral province in East China with a population of 99.46 million in 2016, and covers an area of 156,700 square kilometers. It includes 140 counties belonging to 17 administration regions (Figure1). The prevalence of childhood obesity in Shandong Province in 2010 reached 15.83% and 7.12% among boys and girls, respectively.[25] In addition, the report of Primary and Secondary Schoolchildren Physical Examination in Shandong province in 2015 showed that the overall overweight and obesity rates of children and adolescent were 30.8% and 12.8%, respectively.[26] The childhood OW/OB rates in Shandong province grew rapidly which has caught up the prevalence of childhood OW/OB in developed countries.[27]

Hence, the present study aimed to estimate rates of childhood OW/OB at the county level and apply geographic techniques to examine the spatial patterns of childhood OW/OB by gender, in particular to identify spatial cluster of areas with higher rates of childhood OW/OB.

Methods

Data sources and study design

This study comprised a cross-sectional secondary data analysis of the spatial distribution of childhood OW/OB, using data from Primary and Secondary Schoolchildren Physical Examination Database of Shandong Province. This database contains schoolchildren aged 7-18 years old from all public primary and secondary schools and vocational schools in 2017.

Shandong Province began to conduct health checkups for primary and secondary schoolchildren in 2009 according to the requirements of the National Health Commission of China, and apply free health checkup for them every year. Primary and Secondary Schoolchildren Physical Examination is organized by the Health Commission of Shandong Province (The author Wang Lu is one of the leaders of the investigation team). The contents of the medical examination mainly include medicine and surgery, ophthalmology, stomatology, physical indicators, and physiological function indicators. The specific process is as follows. Before the physical examination, the Health Commission of Shandong Province selected and published the declared medical and health institutions. According to the published list of medical institutions, educational institutions select the nearest institution to enter schools for health examination of students. All measurements were performed by well-trained health professionals in each medical institution using the same type of apparatus and followed the same procedures and the uniform date. During the period of physical examination, a special supervision team went to each physical examination site to conduct quality inspections. After the physical examination, the medical institutions responsible for the physical examination directly input the physical examination data into the Primary and Secondary Schoolchildren Physical Examination Database of Shandong Province. After the data entry, the expert working group will conduct a random sampling checkup of all the entered physical examination data to ensure the data quality.

The physical examination was conducted by medical staffs from 1,373 medical institutions in the whole province. The physical examination rate was 93.96%, and data reporting rate was 100%. All schoolchildren voluntarily joined this study, and both schoolchildren and their parents/guardians were provided written informed consent. We extracted individual information of schoolchildren and adolescent, including codes of administrative divisions, age, gender, and measure of height and weight. Body mass index (BMI) was calculated (Weight in kilograms divided by height in meters squared: kg/m^2). Childhood OW/OB was defined according to the classification reference in different age and gender of the Working Group for Obesity in China (WGOC), the cut-off points of which are 85th and 95th percentiles of BMI, respectively (Overweight: 85th percentile≤BMI<95th percentile; Obesity: BMI≥95th percentile).[28] Using demographic data from the 2010 census as the standard population, we estimated age-standardized rates of OW/OB for schoolchildren and adolescents aged 7-18 years older at the county level. The age-standardized rate is a value that represents the ratio of observed incidence of disease to the expected incidence of disease, whereas a value of zero indicates an area with no observed overweight and obese cases.

This study included 140 counties (city districts, county-level cities, and counties, often referred to here as “counties”) of Shandong Province as spatial units. In practice, county is a basic unit of the administrative region in China and is also the registered permanent residence of the schoolchildren, which implements the national policies toward population health and health promotion directly. In addition, China's unique household registration system and student roll management system stipulates that primary school and secondary school must be completed in the household registration area, that is, in the county. Primary and junior middle school admission is according to the admission dicing system based on the proximity principle. There is no big difference between the school districts and residence districts. Although few high school students need to go to school far away from their residential areas, these students are difficult to distinguish. This study included 'county' as spatial units, both the school district and the residential area are in one county. This greatly avoids the difference in childhood obesity rates due to differences between school districts and residential areas.

Statistical analysis

A two-part analysis was conducted: firstly, the spatial distribution of age-standardized OW/OB rates was mapped for boys and girls. Following this, the second part focused on two aspects of the spatial clustering: the overall 'global' spatial clustering in the prevalence of OW/OB and the 'local' patterns of OW/OB.

Global Moran's *I* statistic is a measure of global spatial autocorrelation, a value representing the similarity in OW/OB rates between neighboring regions, and the mathematical definition of Moran's I is as follows.[29,30]

$$\text{Moran's I} = \frac{N\sum_{i=1}^{N}\sum_{j=1}^{N}W_{ij}(x_i-\bar{x})(x_j-\bar{x})}{\left(\sum_{i=1}^{N}\sum_{j=1}^{N}W_{ij}\right)\sum_{i=1}^{N}(x_i-\bar{x})^2} \quad (i \neq j)$$

Where W_{ij} is the spatial weights assigned to pairs of units (i.e. counties) between observations *i* and *j*, *N* is equal to the total number of pixels.

The Moran's *I* statistic ranges from +1 (for positive spatial autocorrelation where high values are proximal to other high values or low values adjacent to low values, i.e., clustering) to -1 (for negative autocorrelation where high values tend to be near low values, i.e., dispersion). A statistically significant (Z score≥1.96, P value<0.05) estimate of Moran's *I* indicates that neighboring counties have a similar prevalence rate of OW/OB and the cases are likely to cluster at the county level. Nonsignificant values indicate no spatial autocorrelation or that the data are randomly distributed within the study's geographical boundaries. In the present analysis, neighbors were defined using rooks case adjacency, which considers that all regions with common borders are neighbors.

Moran's *I* statistic is a global test that does not identify where the clusters are located or what type of spatial autocorrelation is occurring (e.g., high-high cluster or low-low cluster, etc.). To evaluate the existence of local clusters, it is necessary to use local statistics. The local indicator of spatial autocorrelation (LISA) was, therefore applied as an indicator of local spatial association.[20] The local spatial autocorrelation decomposes the global measurement into the contributions for each geographic region, detecting homogeneity or heterogeneity in values around a given observation or used as diagnostics for outliers in global patterns. The LISA measures whether, for each health region, the standardized rate of OW/OB is closer to the values of its neighbors'. Inverse distance weighting squared is again used to conceptualize the spatial relationships. To ensure excellent statistical power and consider the computation times, 999 Monte Carlo replications were set, and clusters with statistical significance of $P<0.05$ were reported.

Cluster maps were created using the results of statistical testing to illustrate the local spatial patterns of significant positive and significant negative local spatial autocorrelation. The local spatial autocorrelation analysis results in five categories of health regions: (i) 'high–high' indicates clustering of high values of age-standardized OW/OB rates (positive LISA value), (ii) 'low–high' indicates that low values are surrounded by high values of age-standardized OW/OB rates (negative LISA value), (iii) 'low–low' indicates clustering of low values of age-standardized OW/OB rates (positive LISA value), (iv) 'high–low' indicates that high values are surrounded by low values of age-standardized OW/OB rates (negative LISA value), and (v) 'not significant' indicates that there is no spatial autocorrelation. All analyses were conducted using GeoDA[31] and ArcGIS 10.3. The geography files were provided by the National Administration of Surveying, Mapping, and Geo-information of China (NASG), the administrative organization in charge of surveying and mapping undertaking across China.

Patient and public involvement

No patients or public were involved in this study.

Results

Participants

After data cleaning, 6,216,076 qualified schoolchildren aged 7-18 years were finally included for analysis. Participating children were primarily Han ethnicity (>80%) and were approximately equally distributed across sex (50.57% girls) with a mean (SD) age of 10.94(2.62) years.

Prevalence of overweight and obesity

In Shandong province, the overall age-standardized rate of OW/OB was 15.05% and 9.23% respectively, which were higher than the national average rates of 5.45% and 2.83%. Also, the rate of overweight was 17.40% for boys and 12.73% for girls; the rate of obesity was 10.49% for boys and 7.97% for girls. The age-standardized rate of OW/OB in the county level was higher in boys than girls (χ^2=30.44, P<0.001).

Age-standardized rates of overweight differed substantially across health regions ranging from 9.3% in Qihe, Dezhou to 24.94% in Penglai, Yantai for boys and from 8.19% in Linshu, Linyi to 19.15% in Longkou, Yantai for girls. Obesity rates varied substantially across health regions: from 3.59% in Changle, Weifang to 20.26% in Central District in Jining for boys and 3.45% in Zhanhua, Liaocheng to 13.5% in Central District in Jining for girls. Age-standardized rates were also mapped by gender at the county level and then classified by the rates (Figure2 and Figure 3).

Spatial autocorrelation and cluster identification

Based on the aforementioned, there was a marked geographical variation of children overweight/obesity in different regions indicating potential presence of spatial clusters or spatial heterogeneity. The Moran's I statistic was applied to test the overall spatial clustering. The results showed that there are significant positive spatial autocorrelations in the data. In particular, the Moran's I statistic of age-standardized overweight rates was 0.3736 (p-value=0.001) for boys and 0.3370 for girls (p-value=0.001). In addition, the Moran's I statistic of age-standardized obesity rates was 0.2312 (p-value=0.001) for boys and 0.1575 (p-value=0.006) for girls. The level of spatial autocorrelation across health regions for age-standardized OW/OB rates were slightly higher in boys than girls. For both sexes, the Moran's I statistic and corresponding p-values all suggest non-randomness in the overall spatial pattern of the age-standardized rates of overweight and obesity in Shandong province. Table 1 illustrates spatial correlation statistics and corresponding p-values as estimated by the Moran's I statistic.

Table 1 Spatial autocorrelation of age-standardized overweight/obesity rates in Shandong Province

	Moran's I	Z value	P value
Overweight			
Boys	0.3736	7.1726	0.001**
Girls	0.3370	6.1104	0.001**
Both sexes	0.2704	5.1601	0.001**
Obesity			
Boys	0.2312	4.4350	0.001**
Girls	0.1575	3.0727	0.006**
Both sexes	0.1130	2.2082	0.014*

Note: **P<0.01; *P<0.05.

We applied LISA to explore more information on the type and location of clustering. County-level LISA significant clusters were observed for both OW/OB (Fig.4 and Fig.5). For overweight boys, two larger hot spots (HH) was detected in the most counties of Yantai in eastern coastal region and Jining in the southwest, and one smaller hot spot (HH) was found in Jinan in the central province. Two large cool spots (LL) were observed in the eastern and northwestern regions of Shandong province, and one smaller LL was found in a county in southwest. For the girls, the hot spot was comprised of the most counties in Yantai and two districts in Jinan and two counties in Jining. Two large cool spots were detected in the eastern regions (Fig.4). However, the pattern of clusters for obesity was different compared to that of overweight (Fig.5). For boys, the hot spot mainly distributed in the central region, and a small hot spot was detected in Qingdao in the eastern coastal region. For girls, three hot spots were detected in Weihai in the eastern coastal region, and in Jinan and Zibo in the central region, and Jining in the southwest. Also, several counties showed a dispersed pattern of the cluster (HL or LH) as displayed in Fig. 4 and Fig.5.

Discussions

The present study illustrates the marked variability of OW/OB prevalence in Shandong province at the gender and health region level. The results also indicated that the age-standardized rate of both overweight and obesity among boys was higher compared to girls. Our spatial analysis showed the presence of spatial heterogeneity using a significant positive spatial autocorrelation identified by Moran's I statistic for both boys and girls as well as the significant local clusters identified by LISA across the province.

The first concern is the Primary and Secondary Schoolchildren Physical Examination Database of Shandong Province. The census of physical examination for primary and secondary schoolchildren began in Shandong Province in 2009 and examined the physical condition of primary and secondary schoolchildren every year. With a census dataset, the physical health of every student can be mastered in addition to provide evidence for understanding the overall health of students. Several types of research have explored childhood health with the data from the National Surveys on Chinese Students' Constitution and Health in Shandong Province. The survey is conducted every five years, and the data is obtained by sampling method, and the existence of sampling errors makes the data less stable. Although the census design increases the accuracy and stability of the data, the absence of other information at the individual level limited research on the factors of schoolchildren's health, such as socioeconomic factors, parental background, and psychological status.

The difference in OW/OB between boys and girls is consistent with results from previous studies in Shandong and throughout China.[32,33] Differences in age structure cannot explain this finding, as data have been age-standardized. Instead, in addition to the possible biologic/genetic factors, behavioral factors, family environment and psychological factors (e.g., body image perceptions) are also related to OW/OB in children. On a behavioral level, girls report being more attentive to food and its effects on health and weight control.[34] A study reported that consumption of foods and beverages outside three main meals and potato chips were more popular in boys than in girls.[35] Moreover, a review of studies found that boys are also higher users of TV and video games than girls, and these sedentary behaviors have also been associated with body composition and BMI.[36] There is some evidence that misconceptions about a child's weight status were prevalent among parents and grandparents, and boys' weight status was more frequently underestimated than girls.[37] On a psychological level related to body image, girls self-perceive as overweight more often than do boys.[38]

The global spatial autocorrelation demonstrates that there is significant positive spatial autocorrelation in the data, which showed higher levels of correlation in similar OW/OB rates between neighboring counties in the whole province. The spatial patterns of OW/OB might be explained by some possible reasons for neighborhood characteristics. First, neighboring county residents may share similar socio-economic backgrounds; a well-established correlate to obesity.[39] Second, as residents in neighboring areas are likely to share similar lifestyles about diet, nutritional habits, and physical activity, it could be that residents of adjacent areas with similar obesity rates, share behaviors that promote this condition.[18] Moreover, adjacent areas also share similar social and built characteristics and therefore the clustered areas may also share similar features. It is worth noting that racial/ethnic differences might also be a possible reason. A previous study has shown that living in neighborhoods with a higher proportion of foreign-born residents is associated with reduced child obesity risk.[40] Further research would be necessary to tease out the actual mechanism driving the gradient in OW/OB in these areas. In addition, prospective cohort studies and experimental studies were needed to explore the long-term effects of neighborhood environment directly to the development of obesity.

The LISA found also that the hot spots (HH) were detected in Yantai of the eastern coastal region, Jinan in the central region and Jining in the southwestern inland region among both boys and girls. Again, the cold spots (LL) and other dispersed patterns of the cluster (HL or LH) were observed. Some potential explanations for the different type of clusters are as follows. First, the regional SES might be the influenced factor responsible for the geographic differences in the prevalence of childhood obesity. Some previous studies had confirmed that the regional SES affected to the distribution of OW/OB positively in China, in other words, high SES youths are more likely to be OW/OB than other lower SES counterparts.[41] The evidence provided by research indicated that OW/OB prevalence was greater and increased more quickly in the coastal counterparts.[7] Eastern coastal region has high SES with a more developed economy, the living standards, nutritional conditions, and public health are better than other SES districts. Secondly, with the fast-growing Chinese economy, the rapid urbanization has narrowed the disparity between coastal and inland counterparts and became a potential contributor that cannot be ignored.[42,43] That is the reason why the hot spot of OW/OB for children also occurred in the inland region. In addition to the aforementioned factors, the traditional Chinese diet is shifting toward a diet with high fat, high energy density and low dietary fiber on the whole, changes which have resulted in rapid increases in the prevalence of OW/OB.[44] Moreover, television viewing or surf the Internet besides reducing physical activity also leads to increased consumption of energy-rich foods through incessant commercial advertisement.[45] These factors lead to a rapid increase in the prevalence of overweight and obesity among children and adolescent.

The strength of this study is that the data comes from the Primary and Secondary Schoolchildren Physical Examination Database with a large sample size in Shandong Province, China. Examination survey provided direct measurements of weight and height and avoided bias in self-reported data. The results are important for understanding the role that place might play in the health status and suggesting the importance of improving interventions and health-related policies that are thus far mainly based on assumptions of spatial homogeneity. In addition, the findings verified the effectiveness of spatial data analysis methods and in particular the helpful means of cluster analysis for public health professionals and policymakers. For instance, based on the potential explanations for the identified clusters, existing policies and practices could provide funding for physical education as well as recreation centers in communities most in need. Furthermore, it may be advantageous from the perspective that exploring areas of low prevalence to ascertain which factors might decrease the risk of the population. Further research is required to explore the underlying mechanism for the increased levels of OW/OB on clustered areas, and investigate the impact of area-level characteristics on the spatial patterns identified.

This study has several limitations. First, the absence of detailed information at the individual level limited research on the determinants of OW/OB on targeted clustered areas. Second, the study may also be affected by the modifiable areal unit problem. The spatial scale used is not unique and typically arbitrary and modifiable; the spatial patterns of OW/OB identified may change depending on different scales. Also, we only analyzed the data for one year, due to data availability, the temporal and spatial trends of OW/OB cannot be verified.

Conclusions

A high prevalence of childhood OW/OB was observed in Shandong Province, one of the populous provinces in China. There were marked sex-specific regional differences in the prevalence of childhood OW/OB, along with a tendency of spatial correlation of the childhood OW/OB. In addition, the spatial clusters provide valuable information on the identification of local geographical variation and elevated risk of OW/OB in Shandong province. Therefore, prevention and health promotion interventions, as well as effective allocation of resources and services, should be implemented based on regional and population-specific demands. For the hot spots of childhood OW/OB, resource allocation is mainly concentrated in three aspects. First, through the health education of parents, they are encouraged to establish a healthy lifestyle, which in turn affects children's cognition and diet behavior; In addition, the schools should develop appropriate health strategies, including education on nutrition knowledge, increased physical activity, and encourage children to establish health behaviors; Furthermore, the government should provide more interventions for hot spots of childhood OW/OB, including developing dietary guidelines, increasing community exercise facilities, and conducting health education.

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Footnotes

Contributors: Wenzhe Qin planned the study, conducted the analysis and wrote the paper while being supervised by Lingzhong Xu*; Lu Wang, Jiajia Li, Long Sun helped to plan the study, including the instrumentation, and to revise the manuscript; Jiao Zhang and Hui Shao accomplished the statistical analysis and contributed to revising the paper. All authors contributed to the discussion of the paper, read and approved the final manuscript.

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Patient consent for publication: Obtained.

Ethics approval: This study was approved by the Academic Research Ethics Committee of Shandong University.

Provenance and peer review: Not commissioned; externally peer reviewed.

Data sharing statement: No additional unpublished data.

Figure legends: Figure 1. Location of the study area in Shandong Province, China (The map has obtained permission from National Administration of Surveying, Mapping and Geoinformation of China (NASG))
Figure 2. Age-standardized overweight rates for boys and girls by county level in Shandong province (The map has obtained permission from National Administration of Surveying, Mapping and Geoinformation of China (NASG))
Figure 3. Age-standardized obesity rates for boys and girls by county level in Shandong province (The map has obtained permission from National Administration of Surveying, Mapping and Geoinformation of China (NASG))
Figure 4. LISA cluster maps for age-standardized overweight rates by county level in Shandong Province (The map has obtained permission from National Administration of Surveying, Mapping and Geoinformation of China (NASG))

Figure 5. LISA cluster maps for age-standardized obesity rates by county level in Shandong Province (The map has obtained permission from National Administration of Surveying, Mapping and Geoinformation of China (NASG))

Figure 1. Location of study area in Shandong Province, China(The map has obtained permission from National Administration of Surveying, Mapping and Geoinformation of China (NASG))

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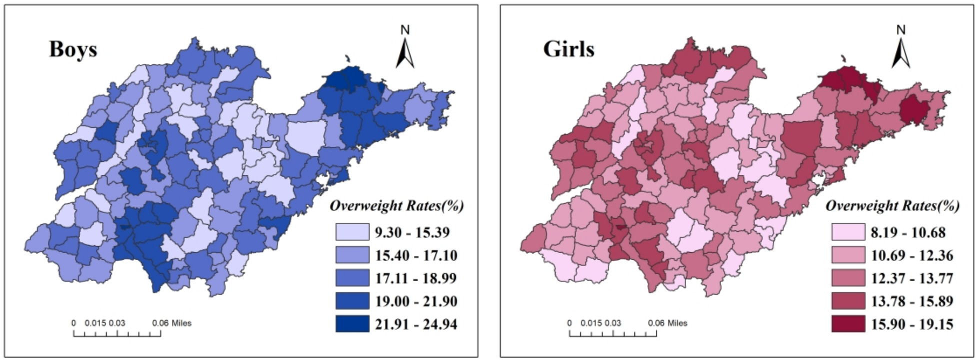

Figure 2.Age-standardized overweight rates for boys and girls by county level in Shandong province(The map has obtained permission from National Administration of Surveying, Mapping and Geoinformation of China (NASG))

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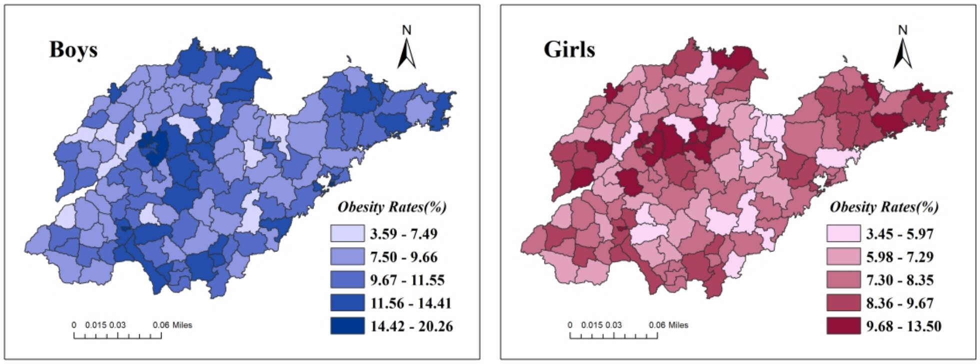

Figure 3. Age-standardized obesity rates for boys and girls by county level in Shandong province(The map has obtained permission from National Administration of Surveying, Mapping and Geoinformation of China (NASG))

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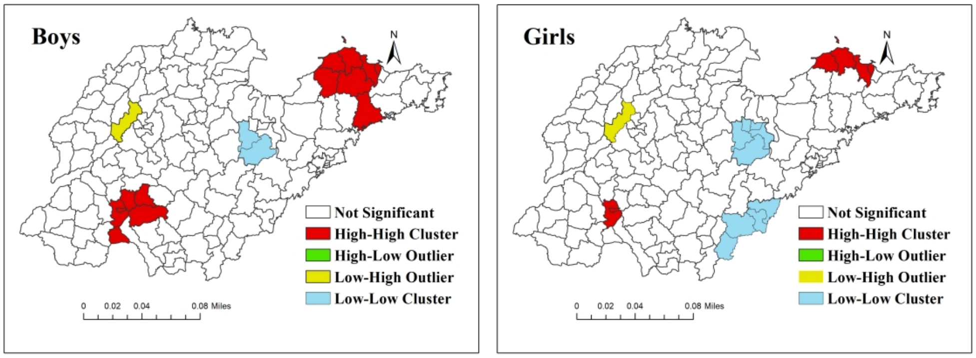

Figure 4. LISA cluster maps for age-standardized overweight rates by county level in Shandong Province(The map has obtained permission from National Administration of Surveying, Mapping and Geoinformation of China (NASG))

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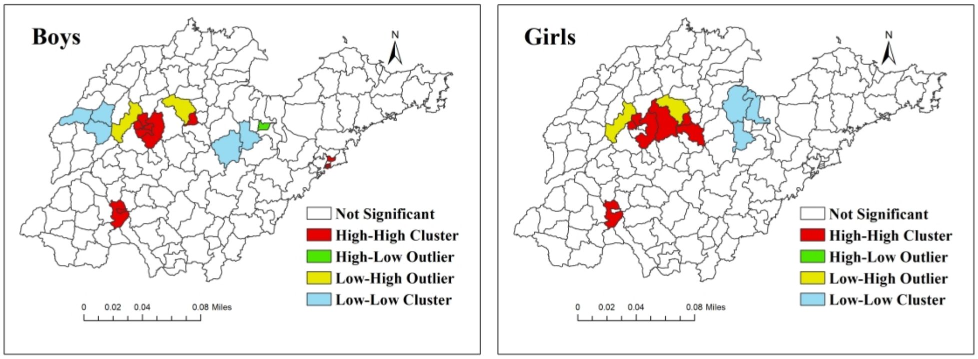

Figure 5. LISA cluster maps for age-standardized obesity rates by county level in Shandong Province(The map has obtained permission from National Administration of Surveying, Mapping and Geoinformation of China (NASG))

409x154mm (300 x 300 DPI)

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	1
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	2
Objectives	3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	4	Present key elements of study design early in the paper	4
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	5
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	*4*
Bias	9	Describe any efforts to address potential sources of bias	
Study size	10	Explain how the study size was arrived at	7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	5
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	6-7
		(*b*) Describe any methods used to examine subgroups and interactions	6-7
		(*c*) Explain how missing data were addressed	
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	7
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	7-8
		(b) Indicate number of participants with missing data for each variable of interest	
Outcome data	15*	Report numbers of outcome events or summary measures	8-9
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	8-9

		(*b*) Report category boundaries when continuous variables were categorized	8-9
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	8-9
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	9
Discussion			
Key results	18	Summarise key results with reference to study objectives	9-10
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	13
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	10-12
Generalisability	21	Discuss the generalisability (external validity) of the study results	
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	17

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.