

1 **Regional trends and associated factors of childhood visual impairment: a case**  
2 **study in Shandong province, China**

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12 **Abstract**

13 **Background:** We analyze regional factors and spatial distribution of children's visual impairment in  
14 Shandong province, to explore the spatial changes brought by time and their influencing factors, so  
15 as to provide scientific basis for prevention of childhood visual impairment.

16 **Methods:** This study covers five complete cross-sectional surveys from 2013-2017, involving about  
17 29.24 million students. Spatial autocorrelation and hotspot analysis methods were used to analyze spatial  
18 features. The associated factors were analyzed by multinomial logistic regression.

19 **Results:** The visual impairment prevalence showed a trend of decreasing first and then increasing from  
20 2013-2017, with slight changes. In terms of regional spatial differences, Weihai and Yantai have the  
21 highest VI rates in all years, and there was a large-scale spatial aggregation phenomenon. The southern  
22 low-value clusters, however, showed a weakening year by year. Further exploration revealed that  
23 economic factors and number of full-time teachers were verified as risk factors for regional visual

24 impairment levels.

25 **Conclusions:** The slight rebound of the prevalence of visual impairment and the high rate in the eastern  
26 and northern regions of Shandong province need more attention. It is suggested that relevant departments  
27 should focus on the influence of regional economic and educational factors when formulating relevant  
28 strategies.

## 29 **Introduction**

30 Childhood is considered to be one of the most critical stages of growth and development, which has long  
31 been concerned from many aspects, such as the state, schools, families and individuals. How to create a  
32 healthier growth environment for children in the current situation (increasingly complex living  
33 environment) is an urgent problem to be solved. Among them, vision issues (such as visual impairment  
34 (VI), myopia, amblyopia, etc.) are most common and prominent. As a window for one to understand and  
35 observe the world, the importance of eyes is self-evident. In China, a populous country that has  
36 liberalized the Two-Child policy, the prevalence of myopia and other eye-related diseases among children  
37 and adolescents has been rising in recent years. For example, the VI rate with strong generality has  
38 rapidly increased almost 2.5-fold from 23.7% to 55% (1985-2014)<sup>[1]</sup>. From a global perspective, China  
39 is also the region with the highest prevalence of low vision per million people in the surveyed area  
40 (including Africa, America, Eastern Mediterranean, Europe, South-east Asia and Western Pacific)<sup>[2]</sup>. The  
41 visual impairment has become an urgent health problem in China, which requires cooperation of various  
42 departments.

43 Visual impairment refers to deficits in the ability of the person to perform vision-related activities  
44 of daily living. It also reflects the burden of vision loss for the person. If the unaided distance visual  
45 acuity (VA) of worse than 6/12 (logMAR < 0.5), it is judged as visual impairment. Studies have

46 confirmed that there are many causes for the occurrence of VI, including heredity (e.g. macular  
47 dystrophies and retinitis pigmentosa), diseases (e.g. refractive error, posterior segment (retinal) diseases,  
48 corneal degenerations and optic nerve head disease) and trauma, etc.<sup>[3-5]</sup> Compared with normal sight  
49 children, the overall quality of life (QoL) of visual impaired children is relatively lower<sup>[6]</sup>. This is not  
50 only manifested in physical health and psychological aspects (e.g. individual nutritional status <sup>[7]</sup> and  
51 depression<sup>[8]</sup>), but also in social relations and living environment <sup>[9]</sup>, and its impact will be lifelong. A  
52 recent study by Jones, N and other scholars found that visual impairment will affect the corresponding  
53 life skills (e.g. shopping and cooking) when it develops into adulthood <sup>[3]</sup>. In addition, visual impaired  
54 children will have a relatively lower level of participation in sports activities (the higher the degree of  
55 VI, the lower the level of participation) <sup>[3,10]</sup>. This phenomenon will not merely affect children's social  
56 interaction and exercise, but also give rise to a series of problems such as overweight and obesity <sup>[11,12]</sup>.

57 On the other hand, the relationship between visual impairment and economy is also inseparable.  
58 Research showed that for every 100% increase in gross domestic product (GDP), the risk of VI will rise  
59 by 20%, and the risk of moderate to severe VI will even increase by 27% <sup>[1]</sup>. Meanwhile, compared with  
60 normal children, visual impaired children are more likely to come from families with relatively higher  
61 economic level <sup>[10]</sup>. In China, the direct cost per patient due to VI is US\$ 6988.6 ± 10,834.3 per year, of  
62 which 70% is direct medical expenses and only less than 30% can be reimbursed <sup>[13]</sup>. A recent German  
63 study also showed that VI and blindness have brought huge social burden (annual cost is about EU€49.6  
64 billion) <sup>[14]</sup>. Furthermore, if patients suffer from chronic diseases such as hypertension, the risk of VI will  
65 be further increased <sup>[15]</sup>. The economic pressure brought by this multiple disease burden is obvious.

66 Globally, the number of visual impaired people among all ages reached about 285 million as early  
67 as 2010 <sup>[2]</sup>. Moreover, the current problem of VI in China has a clear tendency to be younger. Albeit the

68 older age group still occupies the majority in general, the prevalence of younger group has increased  
69 even more rapidly <sup>[1]</sup>. Therefore, this article will study the evolution of childhood vision problems in  
70 Shandong province (about 100 million people), a representative province in China, based on the VI  
71 prevalence of children aged 6-12. The aim was to find out the secular trend, regional distribution  
72 characteristics and related risk factors through the analysis on the visual impaired schoolchildren from  
73 2013 to 2017, so as to provide data support for the next policy adjustment and targeted preventive  
74 interventions by the government and relevant departments. Our ultimate goal is to create a healthier  
75 growth and living environment for children.

## 76 **Results**

### 77 **Basic characteristics of research subjects**

78 The sample was from the physical examination data of primary and secondary school students in  
79 Shandong province (2013-2017), and children aged 6-12 years old were selected as subjects (a total of  
80 29 237 771, mean (SD) age: 9.06 (1.91) years; 53.96% were boys), which basically covers whole school  
81 children in Shandong province. Among them, the sample size in these 5 years were 1 864 241, 5 859  
82 099, 6 685 362, 7 065 383 and 7 763 686 respectively. Basic information of children in each city can be  
83 found in Table 1.

### 84 **Basic information of visual impairment**

85 The total VI rates (T) for five years were relatively similar except for 2013 (14.87%), which fluctuated  
86 around 12%. The gap between different cities, however, was quite wide, especially in Weihai and Yantai,  
87 where the VI prevalence was the most prominent and has exceeding 20%. In general, VI rates presented  
88 a trend of decreasing first and then rising, like a concave curve (although no linear-by-linear association  
89 was detected,  $p = 0.707$ ). In 17 different cities of Shandong province, the differences of VI prevalence in

90 each year were statistically significant, and all showed the same trend (linear-by-linear association  $p <$   
91  $0.001$ ) except Weifang city ( $p = 0.214$ ). In addition, the trends for the mild (M) and moderate-severe (M-  
92 S) VI rate were similar to the total ( $r_{T\&M} = 0.980, p = 0.003$ ;  $r_{T\&M-S} = 0.982, p = 0.003$ ), and their results  
93 were very close (about 6%). The results were shown in Table 2 and Figure 1.

94 From figure 1, we found that the trends of VI rates for boys (B) and girls (G) were similar to that of  
95 the whole over the past 5 years ( $r_{T\&B} = 0.995, p < 0.001$ ;  $r_{T\&G} = 0.993, p = 0.001$ ). No matter the total VI  
96 prevalence, or the mild or moderate to severe VI rate, obvious gender differences were detected (female  
97 rates  $>$  male rates), and the differences were statistically significant ( $\chi^2_T = 69727.572, \chi^2_M = 18642.317,$   
98  $\chi^2_{M-S} = 49944.350, p < 0.001$ ). It is worth noting that the same results were obtained by comparing  
99 students from urban and rural areas separately ( $\chi^2_{urban} = 33506.411, \chi^2_{rural} = 39188.863, p < 0.001$ ).  
100 Besides, the single-sex curve clarified that the prevalence of mild and moderate to severe VI was similar  
101 from 2013-2017.

102 Compared with rural areas, urban regions had a higher VI prevalence, such as the overall rate  
103 ( $\chi^2_T = 313936.581, p < 0.001$ ), this gap was maintained at more than 6% every year. Meanwhile, the urban-  
104 rural gap in mild and moderate-severe morbidities were also significant ( $\chi^2_M = 96834.083,$   
105  $\chi^2_{M-S} = 205497.682, p < 0.001$ ). However, in contrast, the upward trend of urban areas has declined in  
106 2017. The results were shown in Figure 2.

107 In terms of age, there was a strong linear-by-linear association between VI prevalence and age (e.g.  
108  $r_{2015} = 0.960, p = 0.001$ ). The results (Figure 3) demonstrated that the trends in each year were relatively  
109 consistent, showing a trend that the prevalence of VI increases with age (from about 2% at the age of 6  
110 to 30% in 12 years old), and the difference between ages was statistically significant ( $\chi^2_T = 2409075.899,$   
111  $p < 0.001$ ). Among them, the rise in 2013 was even fierce, while that in the other 4 years was relatively

112 similar.

### 113 **Spatial Analysis Results**

114 The results of spatial analysis showed that from 2013 to 2017, the regions with high prevalence of VI  
115 among children aged 6-12 years in Shandong province were mainly concentrated in the eastern peninsula  
116 and the northern area. Likewise, the prevalence in the central region was slightly higher than that in  
117 surrounding counties. It is worth noting that two new high-value districts were added in 2017: the western  
118 (parts of Dezhou) and central (parts of Zibo) regions, and their prevalence were significantly higher than  
119 those in previous years. The results were shown in Figure 4.

120 Focusing on the regional distribution of mild and moderate-severe VI (yellow and purple dots) in  
121 these maps, it was found that the aggregation phenomenon was prominent in the northeast of the  
122 peninsula and areas around Jiaozhou Bay. In addition, the cluster of central counties has become more  
123 and more distinct with the passage of time.

124 Further, this study analyzed the spatial relationships that may exist between regional differences in  
125 overall VI rates. The results (Table 3) illustrated that there was spatial aggregation of VI in Shandong  
126 province.

127 Based on the spatial aggregation characteristics of VI in Shandong province from 2013 to 2017, the  
128 cluster map was presented after hotspot analysis. In 2013, although data were relatively scarce, a large  
129 range of high-value aggregation areas were still detected in the eastern part of Shandong peninsula  
130 (Weihai, Yantai), while the cold spot region was mainly concentrated in the central part. The distribution  
131 characteristics in the following four years were relatively consistent, and clusters with high/low values  
132 were located in the eastern/southern regions. In addition, in some years, a small number of counties in  
133 the north/west (hot/cold spots) also showed aggregation.

134 Combined with the maps of various years, the range of hot spots has been fluctuating slightly, while  
135 the accumulation of cold spots has shown a trend of weakening year by year, especially in Zaozhuang  
136 and Linyi cities. The results were shown in Figure 5.

### 137 **Influencing factors Analysis**

138 After the collinearity diagnostics, five types of regional economic associated factors and one social  
139 influencing factor (including 137 counties in Shandong province): gross domestic product (GDP), the  
140 growth rate of GDP (GRGDP), general public budget expenditure (GPBE), total retail sales of consumer  
141 goods (CGTRS), per capita disposable income of rural households (RPCDI) and number of full-time  
142 teachers (FTT) were included in the multinomial logistic regression model. Among them, except  
143 GRGDP, the rest variables were weighted by regional population. Moreover, economic variables were  
144 recorded in units of CN ¥ 1000 per capita (approximately equal to US\$142.27), and the unit of FTT was  
145 1 person.

146 Studies have confirmed that RPCDI, GRGDP and FTT were risk factors for regional VI level.  
147 RPCDI played a role in promoting the "development" of regional VI in different grades, while the latter  
148 two indexes only worked in the highest grade (compared with the level 1). Besides, CGTRS was also  
149 verified as a risk factor (only in level 3). Nevertheless, GDP and GPBE showed no statistically significant  
150 effect on the degree of VI. The results were shown in Table 4.

### 151 **Discussion**

152 As a large country with a population of 1.4 billion, China has an equally large number of children. Since  
153 the Two-Child policy was completely liberalized in early 2016, the number of newborns has increased  
154 significantly. Meanwhile, the VI prevalence is also continuously rising.<sup>[1]</sup> In order to better deal with  
155 children's visual impairment and provide them with a healthy growth environment, this study selected

156 children from Shandong province as the research subjects, based on comprehensive demographic and  
157 economic indicators (domestic population ranking: 2<sup>nd</sup>, economic ranking: 3<sup>rd</sup>).

158 The study found that the VI rate of children in Shandong province from 2013 to 2017 showed a flat  
159 U-shaped trend, with a slight decrease and increase. Considering that the data for 2013 only covered  
160 counties with better economy (the economy has a positive effect<sup>[15]</sup>), the detection rate was higher than  
161 that of other years. Excluding it, there was a slow upward trend on the whole. Compared with previous  
162 study,<sup>[1]</sup> there were obvious differences. The reason for this phenomenon may be related to the gradual  
163 steady increase in children's living environment and economic factors in recent years, so the increase in  
164 VI rate has slowed down.

165 In terms of gender, statistically significant differences were detected. Whether the overall VI rate or  
166 mild, moderate-severe VI rates, the results of female group were significantly higher than those of male  
167 group. This is consistent with previous research results.<sup>[16-18]</sup> Although there is no direct evidence to prove  
168 the causes of this difference, according to other studies, we guessed that it may be affected by the  
169 following factors: We think the most important factor is that Chinese girls tend to be gentle and quiet  
170 under the traditional concept. Whether in study or sports, girls will spend more time indoors than boys.  
171 Furthermore, less outdoor activities will aggravate the degree of myopia.<sup>[19]</sup> Meanwhile, the higher  
172 prevalence of dry eye syndrome in women may be one of the reasons.<sup>[20]</sup> A hypothesis about hormone  
173 action may be another reason.<sup>[21]</sup> Sex hormone levels in myopic groups were often higher than those in  
174 non-myopic groups: Women were mainly affected by follicle stimulating hormone and luteinizing  
175 hormone, while men were influenced by luteinizing hormone and testosterone, and female have the  
176 higher luteinizing hormone levels.<sup>[22]</sup> In addition, the interaction between sex and steroidogenesis  
177 enzyme genes has also been proved to be a regulator of sex hormone metabolism and high myopia risk.<sup>[23]</sup>



178 Differences between urban and rural areas were also detected: The prevalence of the three VI was  
179 higher in cities than that in countries. The gap in economic level has been considered as the main reason  
180 for this phenomenon.<sup>[15]</sup> Albeit the economic gap between urban and rural areas in China is narrowing,  
181 "faults" still exist. Urban children living in a pleasant environment have more opportunities to contact  
182 with electronic products and even become addicted to them. Affected by this, compared with rural  
183 children, sedentary lifestyle of urban students tends to be normalized, and their visual condition also  
184 deteriorates.<sup>[24,25]</sup>

185 At the age level, there was a strong positive correlation between VI rate and age. With the increase  
186 of age, the prevalence of VI among children also rose significantly. Multiple studies have confirmed this  
187 result.<sup>[16,26]</sup> When children are young, their eyeballs are smaller and their axes are shorter. The eyes are  
188 maintained in a state of hyperopia and have a certain "hyperopia reserve". After that, with the growth of  
189 children and the influence of various factors (such as increased schoolwork burden, more screen time,  
190 etc.), hyperopia reserve is consumed prematurely, and VI problems gradually become prominent and  
191 rapidly increase, like myopia. In addition, the higher school year also plays a negative role in visual  
192 development (e.g. study and exam pressure, reduced outdoor activity time).<sup>[27]</sup>

193 Through the integration of the annual distribution and the spatial aggregation maps, the high-value  
194 aggregation in the eastern part of the peninsula has been confirmed. As for the specific reason: Why  
195 cluster will be formed in this region, it is still unknown. Previous studies have shown that there was a  
196 certain association between VI and overweight and obesity<sup>[28]</sup>—mainly influenced by sports  
197 activities.<sup>[12,24]</sup> Likewise, previous research on obesity in the same population found that the high  
198 prevalence area was exactly consistent with the above results.<sup>[29]</sup> Initial speculation suggests that children  
199 in Yantai and Weihai cities may have less time for physical exercise. The relationship between VI,

200 exercise, overweight and obesity is like a two-way closed cycle, which interacts and affects each other  
201 (i.e. visual impaired children have less physical activity, and sedentary lifestyle will lead to high  
202 prevalence of obesity; And vice versa). For a long time, measures that can promote students' physical  
203 activities have been mentioned, and policies and systems are also constantly being updated, but the results  
204 have been poor. How to effectively implement the policy and improve the current situation is the real  
205 issue to be considered in the following work. Moreover, the influence of economy and day length cannot  
206 be ignored. Research by Cui, Dongmei and other scholars pointed out that axial growth and myopia  
207 progression will decrease with the increase of day length.<sup>[30]</sup> Therefore, they may be another cause of the  
208 high prevalence in central, eastern and northern regions.

209       Due to the large number of missing values in 2013, longitudinal comparison was not included. From  
210 2014-2017, the low-value aggregation range showed a narrowing feature (although the change was  
211 slight), and it was mainly concentrated in the southern areas. In this aspect, economic changes and the  
212 above-mentioned day length are mainly considered: The economic level of the southern region is lagging  
213 behind in all years, and the side effects brought by technology (e.g. massive open online course (MOOC),  
214 multimedia class, etc.) have slightly weaker impact on the students. On the other hand, the regional  
215 economy was still on the rise, which also explains the shrinking of the aggregations to some extent.

216       If subdivided by gender, the distribution characteristics (including total, mild and moderate to severe  
217 VI) were highly consistent with the overall, and the results for boys and girls were similar. Therefore,  
218 this article does not further explore the gender differences in regional distribution.

219       This study also included a variety of representative regional influencing factors, in order to conduct  
220 a more comprehensive discussion on the reasons of the above problems. After adjusting for confounding,  
221 through multiple logistic regression analysis, a total of three risk factors and one protection factor were

222 detected. They were: risk factors—RPCDI, GRGDP, CGTRS and FTT. When the regional VI level  
223 reached the fifth grade, they played the most significant role (except CGTRS). This means that compared  
224 with the underdeveloped areas, regions with higher RPCDI, GRGDP and FTT were more likely to  
225 develop into the regions with higher VI rate, and their risks were 2.540 (95% *CI*, 1.646-3.919), 1.123  
226 (95% *CI*, 1.007-1.252) and 1.050 (95% *CI*, 1.004-1.097) times of those with lower VI prevalence  
227 respectively. Hence, we found that there were inextricable links between the economy and VI. When the  
228 regional economy and per capita disposable income have increased significantly (especially in the  
229 underdeveloped rural areas), the stronger purchasing power under favorable conditions has greatly  
230 increased the affordability and consumption of electronic products, LED lamps and other items, and also  
231 accelerated the popularization of smart phones among younger people, thus making it easier to form an  
232 unfavorable eye-using environment. In addition, combined with the effects of long-term near work<sup>[31,32]</sup>  
233 and harmful lights,<sup>[33]</sup> it is not surprising that the prevalence of VI was relatively high. Moreover, the risk  
234 effect of CGTRS was also manifested in the above aspects.

235 As another risk factor, the number of full-time teachers should also receive more attention from the  
236 education department. This study found that the risk of a region with abundant teacher resources evolving  
237 into an area with high VI level was 1.051 times that of a region with low VI level. The schoolwork  
238 pressure caused by teachers may have contributed to this result. Although this problem has been  
239 improved in primary schools, it can't be ignored due to the difficulty of entering a higher school (limited  
240 enrollment quota). Meanwhile, as the paramount part of the teaching process, teachers' behaviors,  
241 attitudes and professional teaching methods will affect children's health.<sup>[34-36]</sup> Under the background that  
242 Chinese parents attach great importance to traditional education, children's burden is already heavy, so  
243 teachers should further optimize their behaviors and attitudes to create a health environment for the

244 childhood growth. However, the specific reasons for this result is still unknown. We suggested that future  
245 research should focus more on the teachers, so as to further explore the specific causes of this association.

246 This is the first systematic study on the visual impairment of children aged 6-12 in Shandong  
247 province from 2013 to 2017, and the differences among them were expounded from various aspects. The  
248 sample involved in the study is huge, and the results are highly credible and regionally representative.  
249 Nevertheless, this research also has some limitations: 1) The year covered by this study is only 5 years,  
250 and the data in 2013 are missing a lot. Due to the limited conditions, the data in other years cannot be  
251 supplemented, so the results of trend analysis are for reference only. 2) Family, school and other related  
252 associated factors<sup>[17,32,37]</sup> were not included in this research, and the impacts of schools' and families'  
253 differences among districts on VI cannot be verified. The above problems need further study.

## 254 **Methods**

### 255 **Data Source**

256 The sample came from students' physical examination data from September to December every year in  
257 Shandong province, totaling 5 years (i.e. 2013-2017). After adjusting for age and gender, the missing  
258 data and the error records beyond the scope of the visual chart (totaling 430,421) were eliminated. A  
259 total of 29 237 771 schoolchildren aged 6-12 years were included (person-time), covering whole primary  
260 schools in all 17 cities (137 counties) in Shandong province. The sample sizes in this data for different  
261 years ranged from 1 864 242 to 7 763 686, and the annual girl to boy ratio and urban to rural ratio  
262 approximately equaled 1:1.2 and 1:1.7, respectively.

### 263 **Measurement Methods**

264 According to the *Measures for the administration of health examination of primary and middle school*  
265 *students* <sup>[38]</sup> and the *Measures for the implementation of health examination management for primary*

266 *and middle school students in Shandong province* <sup>[39]</sup>, the National Health Commission of the People's  
267 Republic of China, the Ministry of Education of the People's Republic of China and the Shandong  
268 Provincial Education Department stipulate that students in school should have a physical examination  
269 every school year. This program was organized by the health administrative department at or above the  
270 county level, with rigorous training covering all medical professionals who participated in physical  
271 examination. All experimental protocols were approved by the Health Commission of Shandong  
272 Province and its subordinate institutions (Physical Examination Office of Shandong Province) and all  
273 physical examination methods were carried out in accordance with the *Physical examination methods*  
274 *for primary and middle school students in Shandong province* <sup>[40]</sup>. In addition, the informed consent  
275 provided by the Physical Examination Office of Shandong Province was delivered to the student's parents  
276 through schools' teachers. After the examination, students and parents will receive feedback in the form  
277 of reports.

278 According to the requirements of *Health examination methods for primary and secondary schools*  
279 *in Shandong province*, all physical examinations procedures were carried out in accordance with  
280 regulations and using standardized professional instruments. The data involved in this study were  
281 obtained through physical measurements and did not involve laboratory examinations.

282 Visual acuity was measured using a standard logarithmic E chart of vision (in line with the national  
283 standard GB11533—2011, International Classification for Standards (ICS) 13.100) <sup>[41]</sup>. Students need to  
284 keep the naked eye to participate in the test. During vision inspection, students should maintain a distance  
285 of 5m from the instrument, and the sight line of the tested person should be consistent with the height of  
286 the visual chart (line "5.0"). Then, the left eye and the right eye are covered by the eye mask in turn, and  
287 the VA of the corresponding eye was detected. The reading of the smallest line that can be seen clearly

288 by the subject was the VA of the relevant eye, and the value was recorded.

### 289 **Judging Criteria for Visual Impairment**

290 All children had been diagnosed with visual impairment according to the 11<sup>th</sup> International Classification  
291 of Diseases (ICD-11) issued by World Health Organization (WHO) in 2018 <sup>[42]</sup>. According to the actual  
292 situation in China (i.e., the visual chart used in children's physical examination does not involve the  
293 detection range of less than 6/60) and previous studies <sup>[1,43]</sup>. In this study, visual impairment was divided  
294 into mild and moderate-severe categories. Mild VI was defined as unaided distance VA of worse than  
295 6/12 ( $\log\text{MAR} < 0.5$ ) and that of equal to or better than 6/18 ( $\log\text{MAR} \geq 0.3$ ) in the worse eye, moderate  
296 to severe VI was defined as unaided distance VA worse than 6/18 ( $\log\text{MAR} < 0.3$ ) in the worse eye.

### 297 **Other Data**

298 In terms of influencing factors, seven regional associated factors (obtained from the *Shandong Statistical*  
299 *Yearbook* over the years) were included, covering gross domestic product (GDP), the growth rate of GDP  
300 (GRGDP), general public budget expenditure (GPBE)—state financial expenditures that are spent on  
301 public services, education, medical care and social security, etc., total retail sales of consumer goods  
302 (CGTRS)—sales amount of physical commodities for non-production and non-business purposes  
303 (including catering services), number of full-time teachers (FTT)—weighted by the number of students  
304 in the region, representing the number of teachers per thousand students, and per capita disposable  
305 income of rural households (RPCDI). Meanwhile, in order to effectively reduce the impact of population  
306 differences in different areas, this study weighted the regional associated factors by their population  
307 (except GRGDP). In addition, based on the annual VI prevalence range and the effect of mapping, the  
308 regional VI level was divided into 5 grades from low to high (ranging from 0% to 35%, with every seven  
309 percentage points recorded as a level).

310 **Statistical Analysis**

311 Raw data was extracted through SQL Sever2017, and SPSS 22.0 was used to analyze the data. The  
312 measurement data were described by the mean (standard deviation), and t-tests and linear correlation  
313 were used for inter-group comparison. The counting data was expressed by the rate (%), and the  
314 comparative analysis between groups was tested by chi-square tests. Furthermore, multinomial logistic  
315 regression analysis was used to analyze population-weighted associated factors. A probability level of  $p$   
316  $< 0.05$  represented the result with statistical significance.

317 **Spatial Analysis**

318 ArcGIS 10.2 software was used to analyze spatial distribution, regional variation differences, etc. In light  
319 of the distribution range of VI rates, this study artificially divided it into 5 levels. Besides, in order to  
320 find out whether there is spatial clustering and its variation trend in the Shandong province, spatial  
321 autocorrelation (Global Moran's I) and hotspot analysis (Getis-Ord  $G_i^*$ ) were applied to this study.

322 Spatial autocorrelation (Global Moran's I) is a method for measuring spatial autocorrelation based  
323 on element locations and element values, which is used to evaluate whether the pattern expressed is  
324 clustered, dispersed, or random. It evaluates the significance of data results by calculating the Moran's I  
325 index value,  $z$ -score and  $p$ -value. If the index in the dataset tend to cluster spatially (aggregation of similar  
326 values), the Moran's index will be positive. Conversely, the index will be negative. If positive cross-  
327 product values balance negative cross-product values, the index will be near zero <sup>[44]</sup>.

328 The clustering of high and low values was obtained through hotspot analysis (calculation the Getis-  
329 Ord  $G_i^*$  statistic for each feature in a dataset). After a partial sum of a feature and its neighbors was  
330 compared with the sum of all features, if the local sum was significantly different from the expected local  
331 sum that it cannot be randomly generated, a statistically significant  $z$ -score will be resulted. Based on the

332 resultant  $z$ -scores and  $p$ -values, the location where the high-value or low-value elements cluster in space  
 333 can be illustrated.

334 The Getis-Ord local statistic is given as:

$$335 \quad G_i^* = \frac{\sum_{j=1}^n w_{i,j} x_j - \bar{X} \sum_{j=1}^n w_{i,j}}{S \sqrt{\frac{[n \sum_{j=1}^n w_{i,j}^2 - (\sum_{j=1}^n w_{i,j})^2]}{n-1}}}$$

336 Where  $x_j$  is the attribute value for feature  $j$ ,  $w_{i,j}$  is the spatial weight between feature  $i$  and  
 337  $j$ , and:

$$338 \quad \bar{X} = \frac{\sum_{j=1}^n x_j}{n}$$

$$339 \quad S = \sqrt{\frac{\sum_{j=1}^n x_j^2}{n} - (\bar{X})^2}$$

340 The  $G_i^*$  statistic returned for each feature in the dataset is the  $z$ -score. For statistically significant  
 341 positive  $z$ -scores, the larger the  $z$ -score is, the more intense the clustering of high values (hot spot). The  
 342 opposite clustering method is called cold spot [45].

### 343 **Patient and public involvement**

344 No patients or public were involved in this study.

### 345 **Conclusions**

346 In conclusion, there was a significant phenomenon of high prevalence and aggregation of visual  
 347 impairment in the eastern region of Shandong province, and economic and educational factors have  
 348 played a certain role in the development of regional visual impairment. The slight rebound of the VI  
 349 prevalence in recent years was also worthy of vigilance. Based on the research results presented by  
 350 various regions, it is suggested that relevant departments should improve children's VI status (especially  
 351 in Weihai and Yantai) according to their own economic and educational conditions and relevant policies  
 352 (*Healthy China 2030, Healthy China Action*, etc.). Moreover, it is necessary to promote the reform and



353 implementation of quality-oriented education (e.g. 1000m race<sup>[24]</sup>) and expedite the application and  
354 popularization of assistive technologies.<sup>[46]</sup> Prevention and treatment should be combined to  
355 comprehensively improve children's living environment and reduce the VI rate.

## 356 **Declarations**

### 357 **Ethics approval and consent to participate**

358 This study was exempted from need of ethical approval by the Research Ethics Committees of Shandong  
359 Center for Disease Control and Prevention. Ethics approval was not available in this study because we  
360 did not include any data of students' personal information, including name, identity information, address,  
361 telephone number, etc. None of the authors in this study had access to identifying patient information  
362 during the analysis of the data. This study only showed the secondary aggregated data on county-level,  
363 therefore, waived off ethical approval. However, informed consent was still included in the  
364 implementation of this physical examination.

365 **Authorship contributions** LH and JJ conceived and designed the study. LW provided the source  
366 data of the study. LH and JJ prepared software and performed the statistical analysis. LH prepared the  
367 manuscript and interpreted the data. JJ and LW assisted with the editing of the paper and provided critical  
368 comments. JJ and LW revised it critically for important intellectual content. All authors read and  
369 approved the final manuscript.

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### 373 **Competing interests**

374 The authors declare that they have no competing interests.

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377 **Consent of publication**

378 Not applicable.

379 **Availability of data and materials**

380 The datasets generated and/or analysed during the current study are not publicly available due the data  
381 is confidential, but are available from the corresponding author on reasonable request.

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## 516 **Figure legends**

517 **Figure 1.** Trends in overall and gender-specific visual impairment (VI) among children in Shandong  
518 province from 2013 to 2017

519 **Figure 2.** Trends in urban and rural visual impairment (VI) among children in Shandong province from  
520 2013 to 2017

521 **Figure 3.** Age trends of visual impairment (VI) among children in Shandong province from 2013 to 2017

522 **Figure 4.** Spatial distribution of total visual impairment (VI) among children in Shandong province from  
523 2013 to 2017. Figure Legends: Labels A to E represent the spatial distribution maps of each year from  
524 2013 to 2017.

525 **Figure 5.** Spatial aggregation of visual impairment (VI) among children in Shandong province from  
526 2013 to 2017. Figure Legends: Labels A to E represent the spatial cluster maps of each year from 2013  
527 to 2017.

**Table 1** Information of children in different cities of Shandong province from 2013 to 2017

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City	Number of children (mean age (years))				
	2013	2014	2015	2016	2017
Binzhou	- <sup>a</sup>	249 557(8.91)	251 354(8.93)	252 737(8.97)	272 209(8.95)
Dezhou	35 673(9.00)	357 337(8.85)	360 762(8.82)	421 942(8.84)	441 156(8.90)
Dongying	48 955(8.95)	118 448(8.91)	131 950(8.93)	140 396(9.00)	144 435(9.01)
Heze	- <sup>a</sup>	870 954(8.66)	919 634(8.72)	953 536(8.80)	1 025 622(8.86)
Jinan	201 006(8.77)	272 641(8.76)	403 972(8.79)	435 378(8.85)	470 622(8.87)
Jining	17 802(9.38)	532 320(8.79)	581 734(8.82)	672 818(8.88)	722 942(9.06)
Laiwu	25 985(9.20)	66 054(9.12)	60 871(9.18)	73 363(9.06)	72 568(9.06)
Liaochen	1 007(9.24)	152 313(8.56)	453 943(8.63)	523 583(8.65)	591 048(8.79)
Linyi	188 051(8.74)	618 792(8.70)	776 428(8.74)	714 024(8.73)	1 049 007(8.83)
Qingdao	482 202(8.77)	550 205(8.74)	561 041(8.76)	601 326(8.92)	615 741(9.01)
Rizhao	74 876(8.76)	192 778(8.85)	192 202(8.94)	211 653(8.94)	210 700(8.97)
Taian	157 793(9.10)	337 878(9.04)	341 652(8.99)	346 422(9.02)	359 240(8.98)
Weihai	80 748(8.80)	129 262(8.78)	132 928(8.68)	142 225(8.86)	151 096(8.98)
Weifang	112 438(8.53)	570 382(8.72)	600 495(8.86)	613 485(9.04)	636 462(9.19)
Yantai	202 825(8.99)	329 707(8.93)	322 536(8.85)	342 520(9.02)	348 904(9.10)
Zaozhuang	7 478(8.40)	270 160(8.58)	323 092(8.55)	346 292(8.68)	374 907(8.85)
Zibo	227 402(8.92)	240 331(8.94)	270 768(8.94)	273 683(9.02)	277 027(9.08)

<sup>a</sup> The symbol ('-') represents a missing value

**Table 2** Visual impairment (VI) of children in different cities of Shandong province from 2013 to 2017

City	Total VI rate (%)	$\chi^2$ value	<i>p</i> -value
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	2013	2014	2015	2016	2017		
Binzhou	- <sup>a</sup>	11.04	9.32	11.01	8.58	1325.08	< 0.001
Dezhou	7.17	11.00	10.88	11.72	14.63	4448.80	< 0.001
Dongying	15.99	18.07	18.68	19.78	18.27	380.16	< 0.001
Heze	- <sup>a</sup>	5.85	5.75	7.21	8.05	5657.60	< 0.001
Jinan	13.09	13.83	13.38	13.97	14.38	287.43	< 0.001
Jining	18.23	10.12	10.70	11.10	10.86	1348.03	< 0.001
Laiwu	15.97	18.33	18.02	19.79	20.57	358.02	< 0.001
Liaochen	6.95	9.85	7.68	8.50	8.38	736.83	< 0.001
Linyi	9.51	7.67	8.49	9.48	10.36	3978.22	< 0.001
Qingdao	15.14	13.89	13.95	16.08	17.09	3453.35	< 0.001
Rizhao	14.03	13.54	12.01	10.57	10.24	1729.40	< 0.001
Taian	12.57	12.29	12.97	12.51	14.95	1427.22	< 0.001
Weihai	21.92	22.53	20.42	20.71	20.47	276.64	< 0.001
Weifang	12.27	12.73	12.28	12.22	12.59	102.39	< 0.001
Yantai	22.77	21.05	20.01	22.57	22.74	1129.04	< 0.001
Zaozhuang	7.23	9.53	9.13	9.38	11.39	1350.70	< 0.001
Zibo	14.75	15.62	14.96	16.14	18.12	1440.65	< 0.001

<sup>a</sup> The symbol ('-') represents a missing value

**Table 3** Spatial autocorrelation of visual impairment (VI) among children in Shandong province from 2013-2017

Year	Moran's I index	Variance	z-score <sup>a</sup>	p-value
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2013	0.40	0.01	4.76	< 0.001
2014	0.56	0.01	10.57	< 0.001
2015	0.53	0.01	10.32	< 0.001
2016	0.59	0.01	11.44	< 0.001
2017	0.53	0.01	10.26	< 0.001

<sup>a</sup>  $|z| > 2.58$  indicates that the probability of randomly generating this clustering pattern is less than 1%

**Table 4** Correlation between regional associated factors and visual impairment (VI) of children in Shandong province from 2013 to 2017

Regional VI level	Factors	$\beta$	S.E.	Wald	$p$	$Exp(\beta)$	95% CI for $exp(\beta)$	
							Lower bound	Upper bound
2	Intercept	-2.853	1.257	5.149	0.023			
	GDP	0.014	0.010	1.813	0.178	1.014	0.994	1.035
	GRGDP	0.017	0.027	0.395	0.530	1.017	0.964	1.074
	GPBE	0.045	0.107	0.174	0.676	1.046	0.848	1.289
	CGTRS	-0.001	0.023	0.004	0.950	0.999	0.955	1.044
	FTT	-0.001	0.006	0.047	0.829	0.999	0.987	1.011
	RPCDI	0.267	0.109	6.035	0.014	1.305	1.055	1.615
3	Intercept	-6.998	1.424	24.137	0.000			
	GDP	0.018	0.011	2.850	0.091	1.018	0.997	1.040
	GRGDP	0.006	0.032	0.035	0.851	1.006	0.945	1.070
	GPBE	0.014	0.111	0.017	0.897	1.014	0.817	1.260

	CGTRS	0.048	0.023	4.516	0.034	1.050	1.004	1.097
	FTT	0.001	0.008	0.008	0.929	1.001	0.986	1.016
	RPCDI	0.414	0.118	12.345	0.000	1.514	1.201	1.907
4	Intercept	-11.221	1.940	33.459	0.000			
	GDP	0.013	0.012	1.149	0.284	1.013	0.990	1.036
	GRGDP	-0.022	0.040	0.302	0.583	0.978	0.905	1.058
	GPBE	0.030	0.118	0.063	0.802	1.030	0.818	1.297
	CGTRS	0.028	0.026	1.236	0.266	1.029	0.979	1.081
	FTT	-0.001	0.012	0.005	0.943	0.999	0.976	1.022
	RPCDI	0.681	0.146	21.820	0.000	1.976	1.485	2.630
5	Intercept	-20.582	3.342	37.939	0.000			
	GDP	0.016	0.014	1.330	0.249	1.016	0.989	1.045
	GRGDP	0.116	0.055	4.345	0.037	1.123	1.007	1.252
	GPBE	-0.001	0.133	0.000	0.991	0.999	0.769	1.297
	CGTRS	0.021	0.033	0.419	0.518	1.022	0.958	1.090
	FTT	0.049	0.010	25.675	0.000	1.051	1.031	1.071
	RPCDI	0.932	0.221	17.738	0.000	2.540	1.646	3.919

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