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Exploring the Evolution of the Accessibility of Educational Facilities and Its Influencing Factors in Mountainous Areas: A Case Study of the Rocky Desertification Area in Yunnan, Guangxi, and Guizhou

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Abstract: The optimal allocation of educational resources has been a hot issue, and exploring the accessibility of educational facilities in poor mountainous areas helps to reasonably plan the layout of educational facilities and promote the balanced development of education. Taking the rocky desertification area in Yunnan, Guangxi, and Guizhou (YGGRD) as the study area, based on the POI data of educational facilities in the YGGRD in 2000, 2010 and 2019, this study explored the evolution of the accessibility of educational facilities in the YGGRD through raster accessibility. And the influencing factors were analyzed by the ordinary least square method (OLS) and geographically weighted regression model (GWR), and evaluated the model through cross validation. The results show that the overall accessibility of educational facilities improved significantly from 2000 to 2019. Educational facilities mainly have good accessibility and average accessibility. Poor accessibility areas are concentrated in the interprovincial border regions, and the boundary effect is significant. County accessibility, population density and rural per capita disposable income have a great impact on the accessibility of educational facilities in the YGGRD. It is suggested to strengthen the construction of educational facilities in the interprovincial border regions, relocate and integrate villages, and improve the education quality of township schools to improve the supply of rural educational resources.

Keywords: educational facilities; raster accessibility; geographically weighted regression; influencing factors

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1. Introduction

In 2015, the United Nations Sustainable Development Summit formulated 17 Sustainable Development Goals to guide global development from 2015 to 2030, of which Goal 4 is to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all. At the same time, this report stated the primary education enrolment rate in developing countries reached 91% at this stage, although worldwide 57 million children were still out of school [1]. The 19th National Congress of the Communist Party of China pointed out that the main contradiction of Chinese society is now the contradiction between people's growing need for a better life and unbalanced and insufficient development, and this contradiction is most prominent in rural areas [2]. Education, as an important area of urban-rural imbalance and insufficiency, has long been affected by factors such as the level of urban-rural economic and social development as well as the design of the education classification system that divides urban and rural areas. The gap is prominent, and the risk of rural education development becoming an impediment to China's future development cannot be underestimated [3]. Although the government has introduced a series of initiatives to vigorously promote urban and rural education equity in recent years regarding policy supply and resource allocation, the gap between urban and rural education is still prominent, and the imbalance between the supply and demand of education facilities needs to be addressed; thus, we fully understand that improving the spatial distribution and demand situation of rural basic education facilities is conducive to the effective spatial allocation and optimization of rural basic education facilities [4].

Accessibility is an important connotation of equity in public service facilities [5]. Hansen defined accessibility as the opportunities for each node in a transportation network to interact, and the main function is to provide opportunities for interactive communication [6]. The accessibility of educational facilities makes a distinction between spatial and nonspatial factors, and the existing research focuses on spatial accessibility. Therefore, scholars define the accessibility of educational facilities as the convenience degree of people to obtain educational services or reach educational facilities within a certain area, which can reflect the number of educational facilities available to students [7,8]. It is an important evaluation factor to study the rationality of the location allocation of educational resources within a certain space.

Research on accessibility in the fairness and rational distribution of public service facilities has been fruitful, and more attention has been given to the accessibility of educational facilities. The research mainly focuses on the following aspects: (1) school location selection and optimization analysis, which focuses on the selection of school locations and the relationship between schools and surrounding communities, and then focuses on how to optimize the accessibility of educational facilities [9–11]. (2) The spatial pattern and accessibility evolution analysis of educational facilities, which changes from single-year to multiyear dynamic research on the evolution of educational facilities accessibility, explores the uneven distribution and spatial optimization of educational facilities [8,12–14]. (3) Research on the change in accessibility after school consolidation, which analyzes the changes in school service radius and students' distance to school after school consolidation [15–18]. (4) Spatial differences in educational inequality and equity, which reveal the spatial equilibrium of resource allocation by comparing the degree of matching between the supply of educational facilities and the demand conditions within the service areas [19–22]. (5) Research on the relevant factors affecting educational facilities. The physical geographical environment is still an important factor limiting the accessibility of educational facilities, and socioeconomic factors such as population density are also important indicators of the accessibility of educational facilities [23–26].

Regarding research regions, scholars have conducted studies at different regional scales, such as province, county and community scales [12,19,27]. Existing studies have mainly focused on urban areas [21,28], and some scholars have conducted studies on the evolution of the accessibility of educational facilities in rural and poor mountainous areas, mostly using individual counties and districts as cases [13,22], with fewer studies on the overall situation in poor mountainous areas [7,27]. Regarding research methods, scholars have used the minimum distance model [29], potential model [7,12], Huff model [30,31], temporal accessibility [32,33], and two-step floating catchment area method [8,34]. These methods explore the accessibility of educational facilities and spatial optimization, mostly based on vector analysis methods, with less application of raster analysis methods. The raster analysis method builds a raster dataset that can reflect the cost of each raster by rasterizing or gridding various road and nonroad layers in all areas and measures the time cost of each raster to the nearest source location in the whole area based on the minimum cumulative cost algorithm, which can better reflect the accessibility of each location in the entire area [35]. Although scholars have performed much research on the accessibility of educational facilities, there are still insufficient studies: (1) there are fewer studies on educational facilities accessibility before and after the school consolidation and after optimization and integration at the current stage; (2) regarding research methods, less attention is given to raster accessibility, which can better reflect the accessibility of each location in areas; and (3) the overall accessibility of educational facilities in poor mountainous areas has been less researched.

Rocky desertification areas in Yunnan, Guangxi, and Guizhou (YGGRD) have complex terrains, barren soils, fragile habitats, frequent disasters, and backwards infrastructures [36]. The highway networks and traffic in mountainous areas are also vulnerable to natural disasters; thus, the road networks have obvious vulnerability characteristics [27]. The road network is an important factor that allows students to go to school, so it is important to understand the accessibility of educational facilities in the YGGRD to ensure the safety and efficiency of students' access to school. Therefore, this study took the YGGRD as the research object and analysed the spatial distributions and evolution characteristics of the accessibility of educational facilities in the YGGRD and the regional differences based on the documents issued by the state in 2001 and 2012 on the layout adjustment of compulsory education schools, and the optimization and integration of educational resources at the current stage. By selecting three time transects (2000, 2010, and 2019) we explored the main influencing factors of the accessibility of educational facilities at the present stage to provide decision support for the layout and planning of educational facilities of the YGGRD and other mountainous areas.

2. Materials and Methods

2.1. Study Area

The YGGRD is mainly located in the southeastern part of the Yunnan-Guizhou Plateau and it is a transition zone with the Guangxi Basin, bordering Vietnam in the south. It has a typical tectonic mountainous plateau terrain, with a wide distribution of carbonate rocks and has a large area of rocky desertification, and is one of the most typical areas of karst landscape development in the world [37]. The region involves 91 counties in Guangxi, Guizhou, and Yunnan Provinces and districts, with 35, 44 and 12 districts and counties, respectively. The YGGRD covers an area of 228,200 square kilometers, with a total population of 34,974,500 and the regional GDP of 94,847,500 yuan in 2019. The YGGRD had 1413 junior high schools in 2000, which increased to 1583 in 2010 and increased to 1673 in 2019. During 2000–2019, many of the small-scale schools in the townships were closed while new schools were built in county areas (Figure 1).

2.2. Data Source

The data sources include four aspects. First, for the junior high school location data, we get it through the API interface of Amap (https://lbs.amap.com/ (accessed on 20 October 2020)), the clean it, de-duplicate it and convert the coordinates of the acquired POI data, and reclassify the POI data. The basic information of the data contains latitude and longitude coordinates, school type, name, address and other fields, and then the junior high school location data were obtained by screening and matching to the county vector map. Second, road vectorized data were drawn according to the 2001 New China Traffic Atlas, 2010 China Traffic Atlas, and 2020 China Traffic Atlas. Third, raster data from the Resource and Environmental Sciences data centre of the Chinese Academy of Sciences, 30-metre DEM data, and 30-metre land use data for 2000, 2010 and 2018 were used. Fourth, socioeconomic data were obtained from the Guizhou Statistical Yearbook, Yunnan Statistics Yearbook, Guangxi Statistics Yearbook, and China's County Statistics Yearbook (villages and town volume) in 2020.

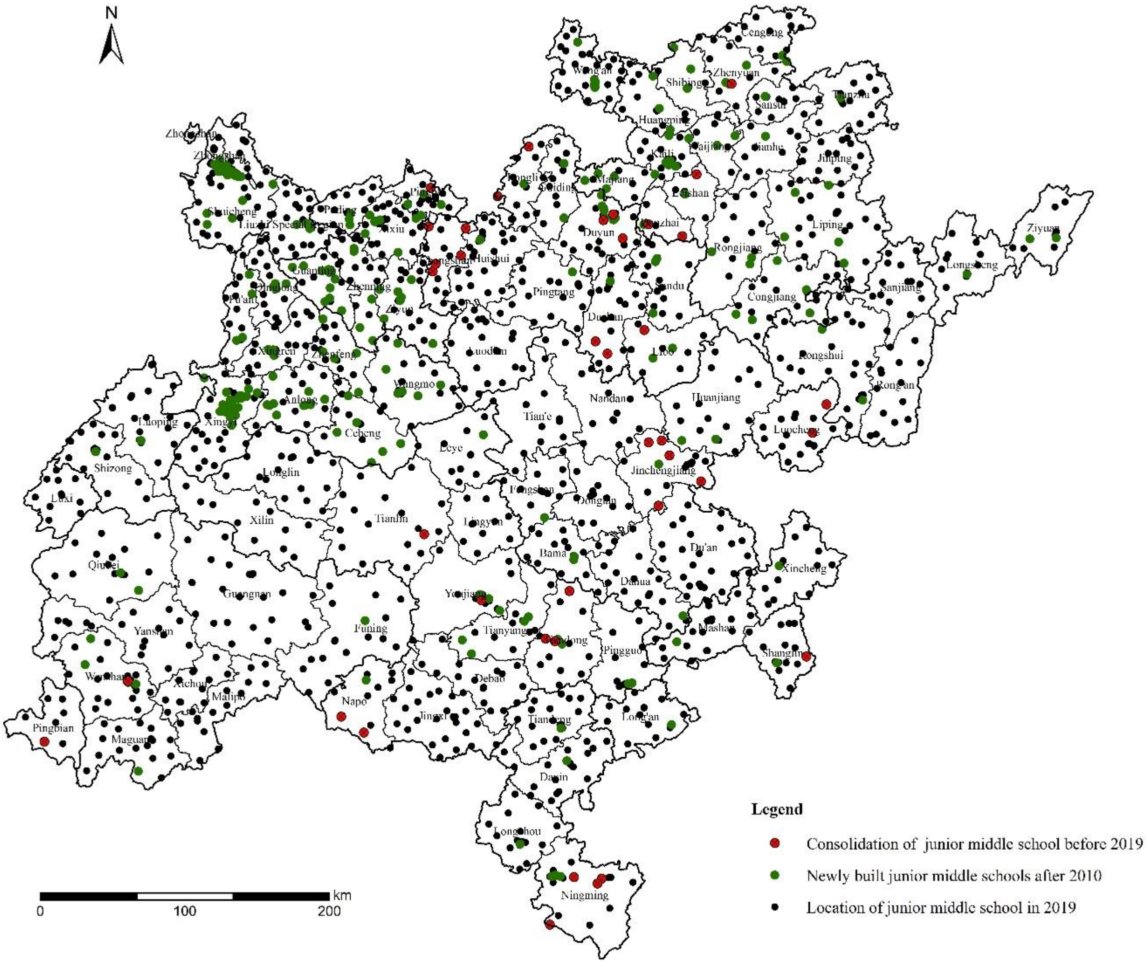


Figure 1. Spatial distribution of junior high school in the YGGRD.

2.3. Method

2.3.1. Raster Accessibility Analysis

Based on ArcGIS10.2, through the rasterization and analysis of the area, we obtained the accessibility analysis results of the study time periods and the cost of the area. The results of regional time and cost accessibility analysis were obtained by rasterizing the study area and were assigned to establish a speed raster map. In order to avoid the deviation caused by the above "isolated island" accessibility measurement, the definition of the research scope is not limited to the administrative regional boundary involved in the YGGRD, but also considers the radiation range. According to the requirements of the Ministry of education that the walking or driving time in rural areas should not exceed 40 minutes [24], we take the maximum speed, that is, the distance of 40min (40 km) from the national road as the radiation influence range of the area. First, we constructed a raster map for the area and graded the spatial features. For different grades of roads, the road raster speeds were assigned to different grades of roads [35,38,39]. For nonroad grids, the differences in speed restrictions by different land use types were considered; also, different elevations and slopes have a great influence on the speed, the speed restrictions increase significantly, especially, in areas with high elevations and steep slopes, so for the nonroad grids, further refinement of the assignments were needed according to elevation, slope and land use type [40–42] (Table 1). For areas with different attributes, raster area maps with speeds were generated by using a sequential overlay in the order of speeds from low to high. Considering the extent of the area, we develop a map that quantifies travel time to schools for 2019 at a spatial resolution of approximately 100 by 100 by integrating the whole surfaces that characterize factors affecting human movement rates. Based on the actual value of the raster, the speed raster map was converted to a time raster map. Finally, the given target point was calculated through the cost raster maps of the study time periods showing the spatial features and the spatial locations of the targets, and the traffic time range map of the targets were obtained by means of the software cost distance analysis module [41].

Table 1. Assignment of velocities to different surface grids in the YGGRD.

Spatial Object	Type	Speed (km/h)
Road	National road	60
	Provincial road	50
	County road	30
Land use type	Arable land	3.24
	Forestland	3
	Grassland	4.86
	Water bodies	1
	Wetlands	2
	Built-up land	5
	Unutilized land	3
Elevation	<2000 m	Assignment speed by land use type
	>2000 m	5
Slope	0–10	Assignment speed by land use type
	10–20	2
	>20	1

Different road time cost values were set according to the speeds of the different levels of roads, and the minimum cumulative accessibility of each raster to the junior high school at a spatial resolution of 100 × 100 was achieved with the cost distance analysis tool of GIS. A higher accessibility score represents a longer time to educational facilities and a lower accessibility level; conversely, it represents a shorter time to educational facilities and a better accessibility level. Referring to the requirement of the Ministry of Education that the walking or driving time in rural areas should not exceed 40 min (which also includes the division accessibility in existing studies and the accessibility characteristics of educational facilities in the YGGRD) [24,43], by using ArcGIS10.2, ratings from low to high were assigned, the accessibility time for each year into better accessibility (0–20 min), good accessibility (20–40 min), average accessibility (40–60 min), poor accessibility (60–80 min), and worse accessibility (>80 min).

2.3.2. Geographically Weighted Regression

The traditional linear regression model only estimates all samples and parameters globally and does not consider the spatial heterogeneity of spatial regression parameters; thus, the ordinary least square method (OLS) cannot be used for parameter estimation. The geographically weighted regression (GWR) model introduces the estimation of the effects of different regions, which can reflect the spatial nonstationarity of the parameters in different spaces, making the parameters vary by spatial location, and the results are more realistic [44–46]. Therefore, GWR analysis was used in this study, and its model structure is as follows:

$$y_i = \beta_0(u_i, v_i) + \sum_k \beta_k(u_i, v_i)x_{ik} + \varepsilon_i$$

where y is the accessibility of the educational facilities of the county; $\beta_0(u_i, v_i)$ is the regression coefficient at point i, indicating the degree of influence of the independent variable on the dependent variable; (u_i, v_i) is the spatial coordinate of the ith county; $\beta_k(u_i, v_i)$ is the value of the continuous function $\beta_0(u_i, v_i)$ for county i; x_{ik} is the value of the independent variable at point i; and ε is the residual error. This study adopted the Gaussian function to determine the weights and the Akaike information criterion (AIC) method to determine the optimal model.

In this paper, the coefficient of determination (R^2) and root mean square error (RMSE) are calculated to evaluate the fitting effect of the GWR model, and the k-fold cross validation method is used to test whether there is over fitting in the model.

3. Results

3.1. Spatial and Temporal Patterns of Educational Facility Accessibility in 2000–2019

3.1.1. The Accessibility of Educational Facilities has Improved Substantially

The average accessibility of educational facilities in each county was calculated by raster accessibility. From 2000 to 2019, the average accessibility time of educational facilities in the YGGRD decreased from 49.2 to 41.69, thus the accessibility was substantially improved, and the differences between regions continued to decrease (Table 2). In 2000, Puding (19.5 min) in the northwest and Leye (79.40 min) in the middle of the YGGRD had the best and worst educational facility accessibility values, respectively. In 2010 and 2019, Zhongshan District in the northwest and Funing in the south of the YGGRD had the best and worst educational facility accessibility values, respectively. From 2000 to 2019, Ningming had the highest improvement in the educational facility accessibility in the YGGRD, which was reduced from 75.88 to 40.86. The change rates of accessibility in Guanling Buyei and Miao Autonomous County were the highest (53.37%). The accessibility of educational facilities decreased by 7.37 min from 2000 to 2010 and increased by 0.04 min from 2010 to 2019, which is related to the great changes in the structure of the traffic network between 2000 and 2010, the large-scale construction of the road network and the improvement of the road level. With the rapid development of urbanization, a large rural population flowed to the county and cities after 2010. Meanwhile, school selection allowed many students to the county, which reduced the number of students in township areas; thus, schools with fewer students faced the integration of educational resources, and the accessibility of educational facilities worsened. There were great differences in the improvement range of the accessibility of educational facilities at different stages, and the school scale and traffic network construction in the YGGRD continue to be expanded and optimized.

Table 2. Extremes and averages of accessibility of educational facilities in the YGGRD, 2000–2019.

Year	Averages	Maximum	Minimum	Range
2000	49.2	79.40	19.59	59.81
2010	41.73	80.44	16.59	63.85
2019	41.69	60.04	19.49	40.55

3.1.2. Educational Facilities Mainly Have Good Accessibility and Average Accessibility Types

The statistical distributions of the accessibility of educational facilities in the YGGRD had close to normal distributions in 2000, 2010, and 2019 (Figure 2). On the whole, the median value of the data showed a decline followed by an increase, with a significant decline from 2000 to 2010 and a slight upwards trend from 2010 to 2019. From the longitudinal direction, the peaks in the area moved to lower values and gradually concentrated at approximately 40 min, indicating that the overall accessibility of educational facilities was getting better.

The educational facilities were dominated by areas with good accessibility and average accessibility in the YGGRD from 2000 to 2019 (Table 3). Students in more than 30% of counties could reach schools within 40 min, as stipulated by the Ministry of Education, among which students in Puding could reach their schools within 20 min in 2000. There were 49 counties with average accessibility, namely, 53.85% of the areas could be reached between 40 and 60 min; however, there were still 14 counties in which junior high school students were unable to reach their schools within 1 h. In 2010, the number of counties in which students reach their schools within 40 min increased to 50, which accounted for

54.95% of the YGGRD. Students in the Puding County and Zhongshan District could reach junior high schools within 20 min, and the number of districts that could reach schools between 40 and 60 min decreased to 31, while students in Funing required more than 80 min. In 2019, the number of regions with good and better accessibility decreased by 3 compared to 2010, while the number of regions with average accessibility increased by 3 compared to 2010, accounting for 37.36% of the YGGRD, and there were still 10 counties with poor accessibility.

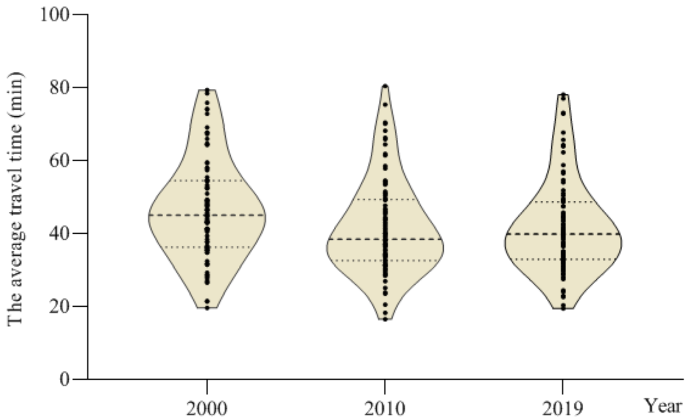


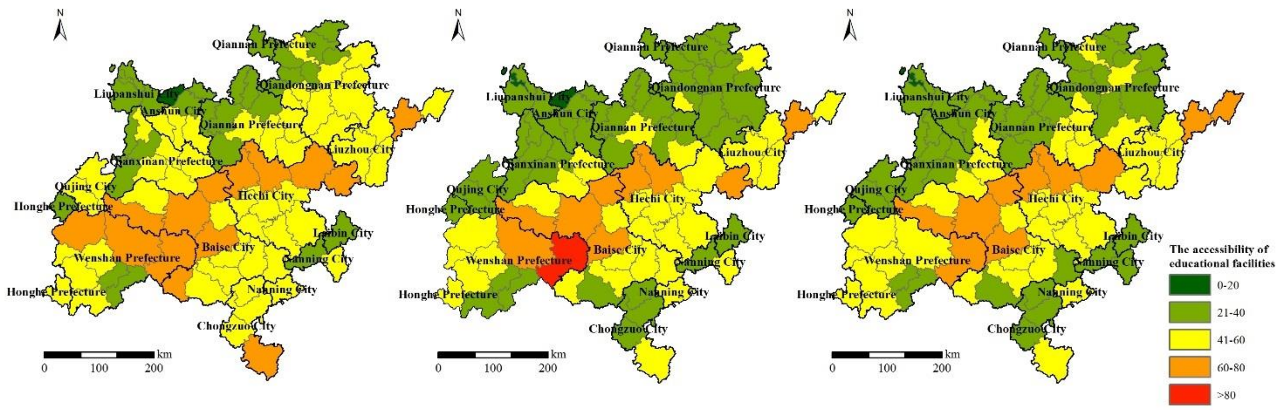
Figure 2. Distribution of the average accessibility of educational facilities in the YGGRD.

Table 3. Accessibility grading statistics of educational facilities under different accessibility types.

Year	Better Accessibility		Good Accessibility		Average Accessibility		Poor Accessibility		Worse Accessibility	
	County	Percentage	County	Percentage	County	Percentage	County	Percentage	County	Percentage
2000	1	1.10	27	29.67	49	53.85	14	15.38	0	0
2010	2	2.20	48	52.75	31	34.07	9	9.89	1	1.10
2019	1	1.10	46	50.55	34	37.36	10	10.99	0	0

3.1.3. The Accessibility of the Interprovincial Border Counties Is Poor

Spatially, the accessibility of educational facilities in the three different periods gradually improved from the centre of interprovincial border counties to their peripheries, and the characteristics of "poor inside and good outside" were obvious (Figure 3). The areas with good accessibility are concentrated in most areas of Guizhou, with dense road networks in the northwest, and in Jingxi, Tianwei, Pingguo, and Masan and other counties in Guangxi, with relatively flat terrain and dense road networks in the southeast. The areas with poor accessibility and worse accessibility are located along the interprovincial border, extending in a belt shaped area in the northeast-southwest direction, mainly located in Tianlin, Leye, Tian'e, and Nandan and other counties at the interprovincial border between Guizhou and Guangxi, as well as Funing and Xilin and other counties on the border between Yunnan and Guangxi. These areas have complex geomorphological conditions, steep roads, and poor facility accessibility, and thus the administrative boundary effect was prominent. Therefore, the accessibility level of educational facilities is influenced not only by the location and number of school facilities but also by their geographical locations and transportation infrastructures.



(**a**) (**b**) (**c**)

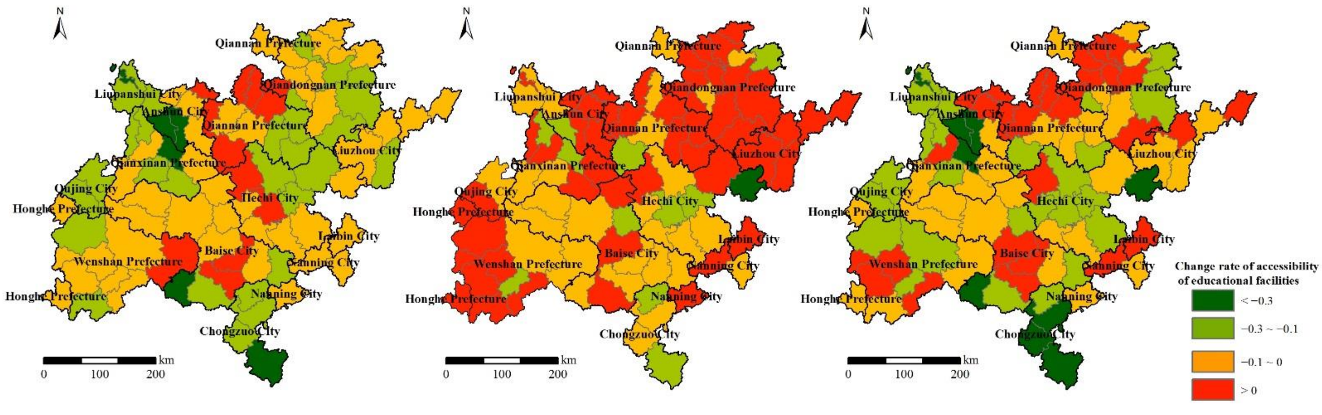
Figure 3. Evolution of accessibility pattern of educational facilities in the YGGRD, 2000–2019: (**a**) The accessibility of educational facilities in 2000; (**b**) The accessibility of educational facilities in 2010; (**c**) The accessibility of educational facilities in 2019.

3.2. Spatio-Temporal Evolutionary Characteristics of the Accessibility of Educational Facilities in 2000–2019

The improvement range of accessibility of educational facilities at different time periods is quite different. According to the intervals of >0, −0.1~0, −0.3~−0.1, and <−0.3, the change rate of educational facilities accessibility was divided into 4 classes of reverse growth, low-speed growth, medium-speed growth, and high-speed growth, and spatial statistics and characterization were performed (Table 4, Figure 4). Tian'e, Changshun, Longli, Duyun, Pingba, and Majiang in the interprovincial border area were in reverse growth in 3 of the periods, which mainly originated from the influence of geographic locations and the school resource integration program. The accessibility of educational facilities of reverse growth, low-speed growth, and medium-speed growth accounted for approximately 30% of the total in 2000–2019, showing a three-pronged trend, with reverse growth areas concentrated in the north, northeast, and southwestern counties, encircling medium-speed and low-speed growth areas, and there were nine regions with high-speed growth, accounting for 10% of the YGGRD. The low-speed and medium-speed growth areas accounted for more than 80% in 2000–2010, and the high-speed growth areas included Zhongshan District, Guanling, Ningming, Zhengfeng, Napo and Zhenning Buyi and Miao Autonomous County. The reverse growth areas were concentrated in the interprovincial border areas, which were roughly distributed along the line from the north to the south of "Changshun, Luodian, Tian'e and Donglan counties". The western part of the line was mainly a low-speed growth area, and the eastern part was a medium-speed growth area. Reverse growth and low growth areas were dominant in 2010 and 2019, with reverse growth areas accounting for more than half of the total and the reverse growth areas were concentrated in the north, northeastern and southwestern counties surrounding the low-speed and medium-speed growth areas, in which more schools were constructed in the county. Rural schools were integrated and their number decreased in this stage.

Table 4. Graded statistics of the rate of change in accessibility of educational facilities, 2000–2019.

Year	Reverse Growth		Low-Speed Growth		Medium-Speed Growth		High-Speed Growth	
	County	Percentage	County	Percentage	County	Percentage	County	Percentage
2000–2010	12	13.19	45	49.45	28	30.77	6	6.59
2010–2019	51	56.04	28	30.77	11	12.09	1	1.10
2000–2019	28	30.77	29	31.87	25	27.47	9	9.89



(a) (b) (c)

Figure 4. Rate of change in accessibility of educational facilities in the YGGRD: (**a**) 2000–2010; (**b**) 2010–2019; (**c**) 2000–2019.

3.3. Analysis of Factors Influencing the Accessibility of Educational Facilities in the YGGRD

When discussing the factors affecting the accessibility of educational facilities, in addition to geographic environment, there are not only physical factors but also socioeconomic development factors to further quantitatively identify the influence status of the spatial distribution of educational facilities. Exploring the accessibility of educational facilities in 2019 was more conducive to making recommendations on the layout and development of the existing educational facilities. Therefore, based on the characteristics of the accessibility of educational facilities in the development process and the availability of data in the YGGRD, the accessibility of educational facilities was taken as the dependent variable, and the independent variable indicators were mainly selected from four categories and six indicators of geographical location, economic development, population distribution and social level (Table 5).

Table 5. Index system of accessibility of educational facilities in the YGGRD.

Type	Index	Description
Geographical location	County accessibility	The average travel time to the location of county government
Population distribution	Population density	Permanent resident population/Land Area
Economic development	Per capita GDP	Per capita GDP
	Industrialization level	Proportion of secondary industry
Social level	Financial support	Per capita average public budget expenditure
	Living standard	Rural per capita disposable income

3.3.1. Analysis of the Influencing Factors Based on OLS Model

First, SPSS software was used to standardize the Z scores of the six indicator variables shown in Table 5. The variance inflation factor (VIF) was used to test for multicollinearity, and the OLS model was used to test the average relationships between the accessibility of educational facilities and the explanatory variables. In 2019, the VIF values of all variables were less than 7.5, there was no multicollinearity among the variables, and the model setting was reasonable (Table 6). According to the OLS model fitting results, the coefficient of determination R^2 and the corrected coefficient of determination adjusted R^2 of the model reached 0.61 and 0.58, respectively. The results showed that county accessibility, per capita general public budget expenditure, and rural per capita disposable income were positively correlated with the accessibility of educational facilities in the YGGRD, and other explanatory variables were negatively correlated with the accessibility of educational facilities in the YGGRD. Among them, county accessibility, population density, and rural per capita disposable income were significantly correlated with educational facility accessibility, indicating that these three variables were the main factors influencing educational facility accessibility. The Koenker (BP) statistic showed that the OLS model changed throughout the area, namely, there was heterogeneity between educational facility accessibility and explanatory variables. Therefore, a GWR model is needed to address the spatial instability.

Table 6. OLS model test results.

R^2	Adjusted R^2	AIC	VIF	BP Statistic
0.61	0.58	189.05	<7.5	8.20

3.3.2. Spatial Heterogeneity Analysis of Factors Based on the GWR Model

The results of the GWR model operation are shown in Table 7. The coefficient of determination R^2 and the corrected coefficient of determination of the model were 0.69 and 0.62, respectively, which were higher than the OLS coefficient of determination and the corrected coefficient of determination, and the AIC value was lower than that of the OLS model. The fitting performance of the GWR model was better than that of the OLS model, and there were no local multiplicities between variables. From the median values of the parameter estimates of GWR regression, we found that county accessibility, proportion of secondary industry, per capita general public budget expenditure and rural per capita disposable income were positively correlated with the accessibility of educational facilities in the YGGRD, while per capita GDP and population density were negatively correlated with the accessibility of educational facilities in the YGGRD.

Table 7. Results of GWR model regression parameters.

Independent Variable	Minimum	25% Quantile	Median	75% Quantile	Maximum
County accessibility	0.31	0.45	0.51	0.57	0.61
Per capita GDP	−0.13	−0.10	−0.05	0.01	0.14
Proportion of secondary industry	−0.11	0.002	0.02	0.05	0.13
Population density	−0.60	−0.45	−0.37	−0.31	−0.23
Per capita general public budget expenditure	0.01	0.12	0.17	0.20	0.21
Rural per capita disposable income	0.04	0.11	0.14	0.24	0.47
R^2	0.69				
Adjusted R^2	0.62				
AIC	187.24				
Bandwidth	268,938.72				

To more intuitively characterize the spatial heterogeneity of each factor on the accessibility of educational facilities in the YGGRD, the coefficients of each explanatory variable in the regression results of the GWR model were spatially visualized and expressed (Figure 5).

1. Geographical location

The geographical location is characterized by county accessibility. The county accessibility had a positive influence on the accessibility of educational facilities in the YGGRD, which showed a band distribution from the northeast to the southwest, and all counties showed a strong positive correlation between county accessibility and educational facilities accessibility because there are more junior high schools in the county, transportation is more convenient, educational facilities are in better condition, areas close to the county are also vulnerable to the radiation effect of the county, and the accessibility of education facilities is good.

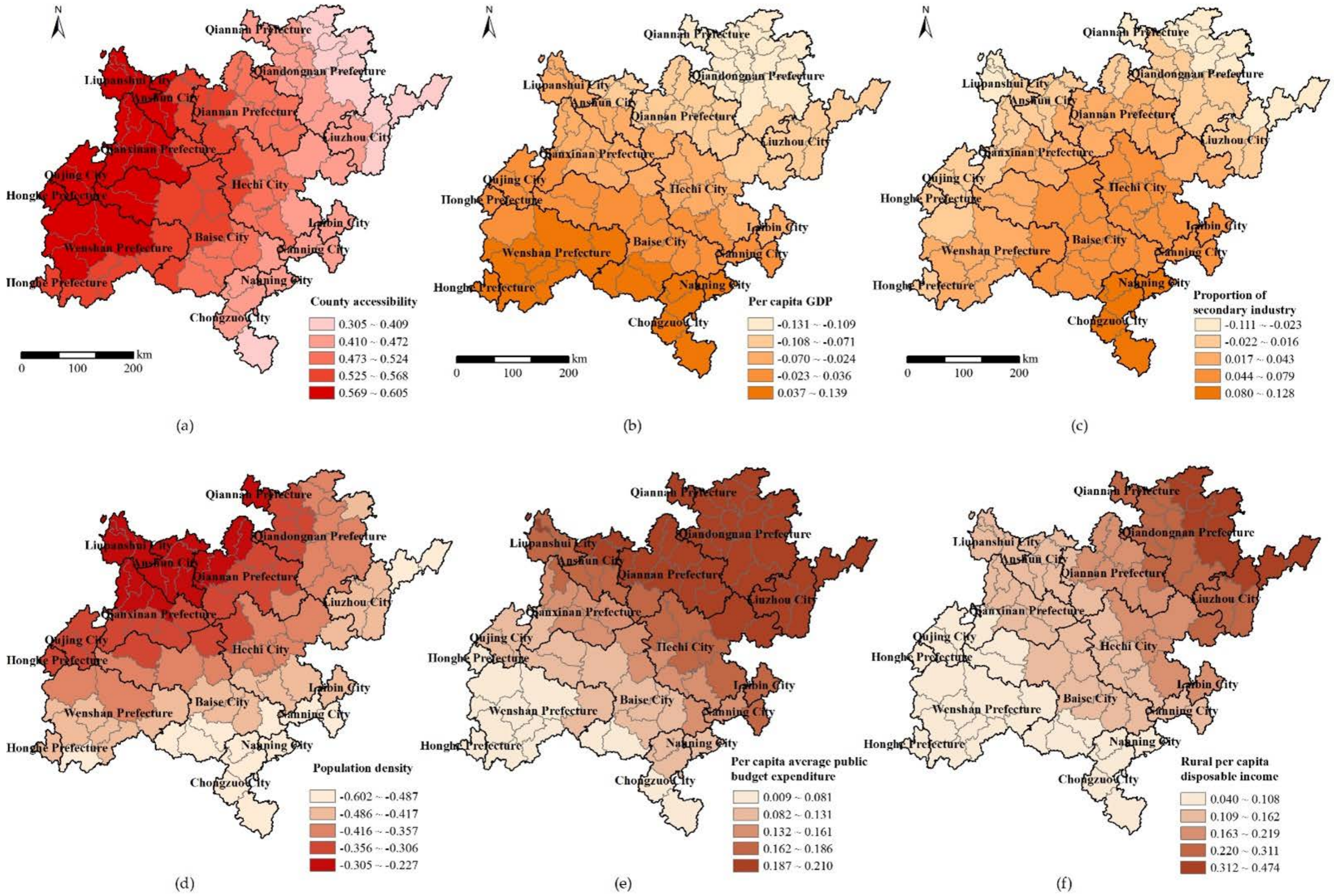


Figure 5. Spatial distribution of regression parameters for accessibility of educational facilities in the YGGRD: (**a**) County accessibility; (**b**) Per capita GDP; (**c**) Proportion of secondary industry; (**d**) Population density; (**e**) Per capita general public budget expenditure; (**f**) Rural per capita disposable income.

2. Economic development

Regarding the per capita GDP, 70.33% of counties showed a negative correlation trend with the influence of the accessibility of educational facilities in the YGGRD, which was a spatially striped and gradually increasing trend from northeast to southwest, similar to the spatial distribution trend of the per capita GDP. High value areas were concentrated in the Chongzuo City of Guangxi and the Wenshan Prefecture of Yunnan, which had better economic development in the southwest, and low value areas were distributed in the Qiandongnan Prefecture and Guilin City in the northeast and other regions, which indicated that areas with better economic development had better infrastructure conditions, more complete educational facility distribution, a larger proportion of teachers and other resources, and better accessibility of educational facilities.

The proportion of secondary industry had a positive effect on the accessibility of educational facilities on the whole, which gradually increased from the northwest to the southeast. The areas with high values of the secondary industry proportion parameter were distributed in the southeast parts of Tiandeng, Longan, Daxin, Longzhou and Ningming County, and the areas with low values were concentrated in the northern parts of Guizhou regions. There were regional differences in the accessibility of educational facilities between areas with high industrialization levels, and the degree of industrialization had less influence on the accessibility of educational facilities, indicating that industrialization did not well drive the construction of educational and other infrastructures.

3. Population distribution

The influence of the population density on the accessibility of educational facilities in the YGGRD showed a negative correlation, with significant regional differences in spatial influence and a weakening trend from northwest to southeast, indicating that population agglomeration in the northwest promoted better accessibility of educational facilities. Population agglomeration is an important basis for settlement formation and infrastructure construction, and this result is consistent with studies that have concluded that population agglomeration has a significant driving effect on the distribution of educational facilities [13].

4. Social development level

The impact of per capita average public budget expenditure on the accessibility of educational facilities in the YGGRD showed a positive correlation, and the high value areas were concentrated in the northeastern region. The government provided a great deal of financial support to poor areas, while poor areas that were in remote locations lack educational facilities, and had poor traffic accessibility, and the role of investment in education was not significant. Thus, it is still necessary to increase financial investment in poor areas, especially the support of educational investment.

The effect of rural per capita disposable income on the accessibility of educational facilities in the YGGRD showed a positive correlation, and regarding spatial heterogeneity, the high value areas were concentrated in the northeast, and the low value areas were concentrated in the districts and counties in the southwestern part of Yunnan Province, showing a spatial trend of gradually increasing from the southwest to the northeast. This might be because the poor education infrastructures in the YGGRD, and the improvement of people's living standards urged them to send their children to school in areas with better education levels, which resulted in the closure and consolidation of some villages and towns due to insufficient school attendance, while families with lower income levels still attended nearby schools. Therefore, the improvement of access to schools for students in rural areas and school choice for access to quality educational resources in towns are important topics that need attention.

3.3.3. Cross Validation of GWR Model

Through 10-fold cross validation, the determination coefficient R^2 is 0.75, and RMSE is 0.5, which indicates that GWR model is basically not over-fitting. We analyzed the relative influence with the accessibility of educational facilities (Figure 6). From the degree of influence of explanatory variables on the accessibility of educational facilities, it can be seen that county accessibility > per capita GDP > per capita general public budget expenditure > proportion of secondary industry > population density > rural per capita disposable income. County accessibility has the greatest influence on the accessibility of educational facilities, which also indicates that location has the greatest influence on the distribution and quantity of schools. And economic development has the important impact on the accessibility of educational facilities, which indicates the importance of improving per capita GDP and proportion of secondary industry to the education layout.

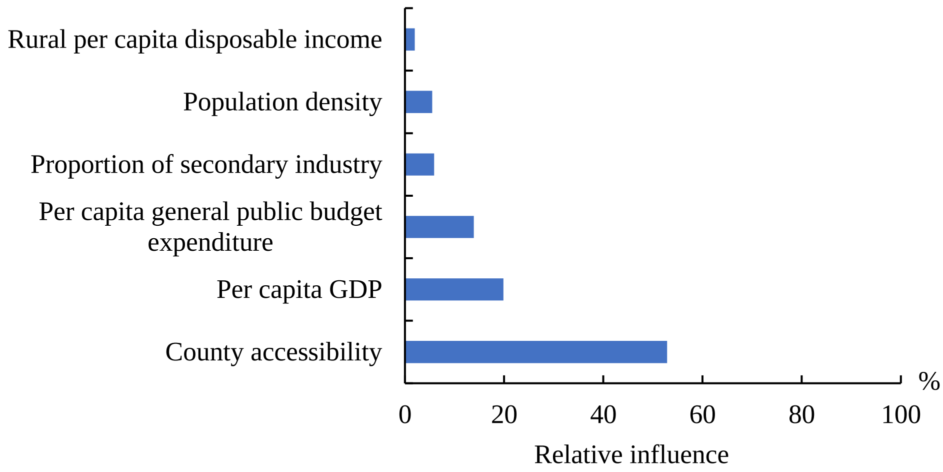


Figure 6. Variable interpretation degree diagram.

4. Discussion

The main purpose of this study was to explore the temporal and spatial evolution of the accessibility of educational facilities in the YGGRD and its influencing factors before and after the policy of school consolidation and at the current stage with the optimization and integration of educational resources. The results showed that although the accessibility of educational facilities has changed, the overall improvement has been prominent, and the differences between regions have been narrowing. This was consistent with the result observed in the existing research, which showed that the construction of road network had a significant influence on the convenience of inhabitants [27]. County accessibility, population density and rural per capita disposable income were the main factors affecting the accessibility of educational facilities in the YGGRD. Cross validation fully proved that GWR model had a good simulation effect. The influence factors were consistent with previous findings that location and population had an important influence on the spatial distribution of educational facilities [13,26].

Based on the spatial evolution of educational facilities accessibility in this paper, it is can be seen that the accessibility of educational facilities is influenced by natural location such as terrain and many social and economic factors. Physical and geographical factors have laid down the basic pattern of the spatial distribution of educational facilities, including natural background features such as terrain, location. And socioeconomic factors, which are important factors for the improvement and optimization of educational facilities accessibility, mainly including population density, per capita GDP and other factors. Thus, the mechanism framework that affects the accessibility of educational facilities in the YGGRD is mainly constructed from the following aspects (Figure 7). (1) Regarding geographical location, terrain factors and location conditions affect the distribution of the number and location of schools and have an important influence on the spatial layout and accessibility of schools [13,24,27]. (2) The distribution of population is an important influence on the accessibility of educational facilities. A densely populated area will attract the gathering of educational resources. Correspondingly, schools in this area are densely distributed, and the accessibility of educational facilities is good [13,26]. (3) Economic development provides human, material and financial resources for education and provides a good material foundation for education development, which is consistent with the results of previous studies [23,25]. (4) The improvement of the level of social development drives high-quality educational resource development, increases investment in educational resources, and improves the quality of education [26].

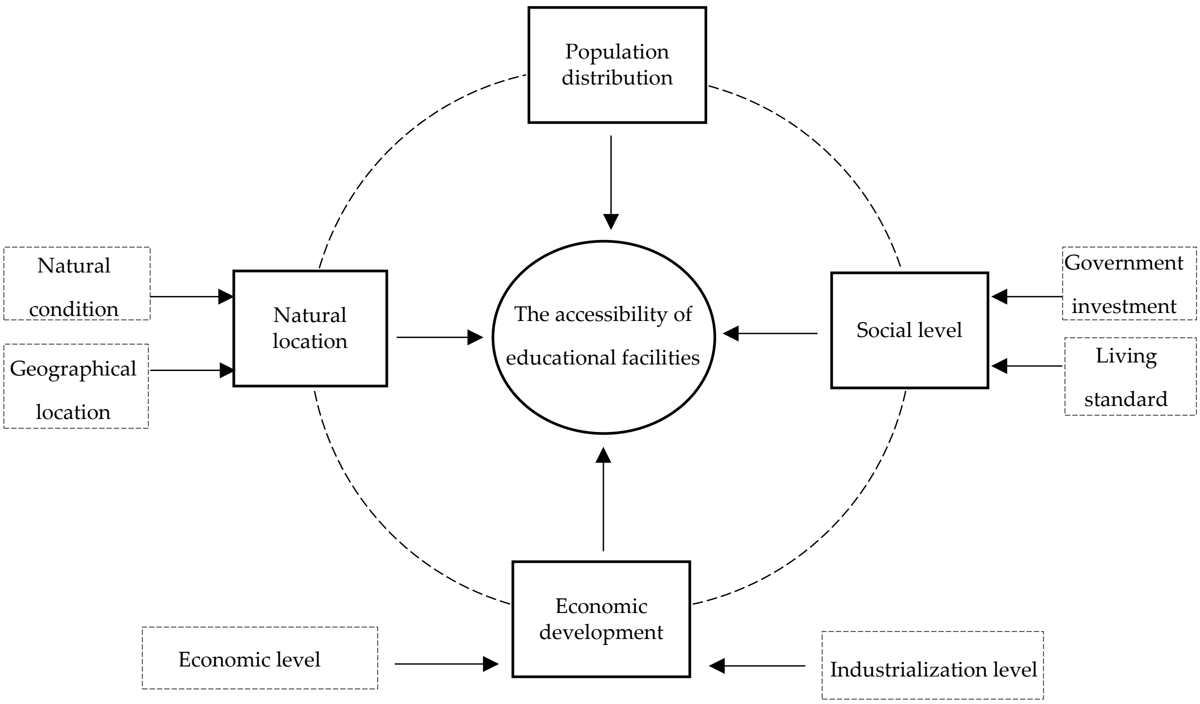


Figure 7. Framework of impact mechanism on accessibility of educational facilities in the YGGRD.

Understanding the distributions of the accessibility of educational facilities, and making up for the shortage of educational resources in the YGGRD, is of great significance for the layout and optimization of educational facilities and for promoting the implementation of rural revitalization strategies in the new era. The proposed framework can be easily applied to other regions, and the findings derived from this paper can also help other mountainous areas in designing their own education policies. (1) Strengthen the construction of educational facilities in interprovincial border areas and optimize the construction of the intraregional traffic network. The interprovincial border areas are easily marginalized and forgotten due to administrative, topographical and other factors, making educational facilities less accessible and less usable. (2) In villages with very small populations and high altitudes, village relocation and consolidation are practical options to promote population agglomeration and optimize the allocation of educational resources. The scattered population in these areas and the significant terrain barrier effect lead a shortage of educational facilities and poor quality. (3) Increase investment in education by introducing high-quality teacher resources, improving the quality of education in township schools, and developing collaboratively with high-quality schools in the county. With the rapid development of urbanization, a large number of students go to the county schools to study, the number of students in township schools has decreased, and the loss of excellent teachers is serious.

This study has some limitations. First, this article explores accessibility from the supply and service capacity of educational facilities, without considering the situation of demand. Second, the research on accessibility focuses on the changes in the number of schools, not on the quality of schools. The quality of the education should be further explored, which needs to be further improved in subsequent research on the accessibility of educational facilities. In addition, urban and rural education disparities are increasingly prominent, and the trend of education urbanization is intensifying. Paying attention to urban and rural education differences is an important direction for future research.

5. Conclusions

We discussed the evolution of the temporal and spatial patterns of the accessibility of educational facilities in the YGGRD and enriched the research on the accessibility evolution of educational facilities in poverty-stricken areas. The research results and the influencing factors of the accessibility of educational facilities at the current stage described in this article also provide a reference for the adjustment and layout of educational facilities. The results show that the overall accessibility of educational facilities has improved substantially, and educational facilities are mainly rated as having good accessibility and average accessibility. The accessibility of educational facilities is the result of the combined effect of natural and socioeconomic factors. County accessibility, population density and rural per capita disposable income are the main factors affecting the accessibility of educational facilities in the YGGRD. Namely, location factors determine the spatial distribution of educational facilities, and economic and social development is an important driving force for the improvement and optimization of educational facilities accessibility. Although this paper attempted to use the raster accessibility to get closer to the actual accessibility of educational facilities based on the road network, land use type and topography, the impact of subjective needs, such as the number of students, school quality and other factors have not been considered. Therefore, we should deeply understand the actual situation in subsequent research and add demand indicators to get a more realistic school situation.

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