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Spatial variation of the relationship between transport accessibility and the level of economic development in Qinghai-Tibet Plateau, China

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Abstract: As an important component of China' transportation systems, for a long time, the insufficient performance of transport in Qinghai-Tibet Plateau (QTP) was a bottleneck restricting the economic growth and social development in this area. Nevertheless, the implementation of the western development strategy has accelerated the preliminary construction of comprehensive transport network since 2000. Due to the large area and significant geographical heterogeneity, there is a growing need to understand the relationship between transportation and economic development based on the perspective of spatial difference. By using GIS-based raster analysis and Geographically Weighted Regression (GWR) model, we investigated the spatial-temporal distribution of highway, railway and airport accessibility, respectively, and estimated the correlation and heterogeneity between transport accessibility and the level of economic development. Results revealed that: (1) Transport accessibility in the QTP improved by 53.38% in the past 15 years, which is specifically embodied in the improvement of both highway and railway. (2) Accessibility presented prominent differentiation in the space, increasing from west to east and reducing with the rise of elevation, specifically, the best accessibility area of the highway is below 4000m above sea level, while the area with an altitude of over 4000 m has the lowest aviation time cost. (3) In general, the long weighted average time cost to critical transport facilities posed significantly negative effect on county economic growth in QTP, more positively, the adverse effect gradually weakened over time. (4) Obvious heterogeneity exists at the influence of different transport accessibility factors on the level of economic development, reflecting both in the horizontal space and altitudinal belt. Therefore, region-specific policies should be addressed for the sustainable development

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of transport facilities as well as economy in the west mountain areas.

Keywords: Accessibility; Raster cost weighted; Geographically weighted regression; Economic effect; Spatial variations

Introduction

Accessibility is a critical variable to observe regional traffic network, which is also the determinant of regional economic and social development. The concept of accessibility was firstly put forward by Hansen (1959), which shows the opportunity of interactions between nodes in the traffic network, after which scholars in different disciplines gave diversified interpretations to the accessibility, among them, regional accessibility indicates the difficulty in interactions between a city (or region) and other cities (or regions) (Johnston 1994), which reflect the exchanges of material, energy, population and information between areas (Lu 1995), apparently, the origins, destinations and traffic systems are the three most important elements of the regional accessibility (Li and Lu 2005). Measurement methods of accessibility are various, mainly include network analysis method under the vector topological data structure and cost weighted distance method based on GIS raster analysis (Wang et al. 2017). Research scale ranges from international (Bowen 2000), national (Holl 2004), provincial (Castella et al 2005), economic zone (Hou and Li 2011), metropolitan (Wang et al. 2013) to county units (Shi et al. 2016), in which covering national county (O'Kelly and Horner 2003; Wang et al. 2011), provincial county (Liu and Zeng 2011) and mountain county (Wang et al. 2015; Liu et al. 2011; Ji and Liu 2018). Existing literature indicates that compared with the single mode of transport accessibility (for instance highway, railway, etc.), comprehensive transport accessibility could more fully reflect the realistic pattern of county accessibility, and the explanation for economic driver is also more convincing (Liu and Zeng 2011). With regard to mountain, traffic lines generally cross the alpine valleys, obvious regional heterogeneity remains both in the road network and traffic speed, undoubtedly, it is biased to represent the accessibility of the whole county by the resident center of county government (Liu et al. 2011), definitely, the raster algorithm comprehensively considers natural environment (such as landform, river and land use) as well as traffic conditions, which are able to describe leap passage (Ahlström et al. 2011) by means of sorting and classifying different surface features, and calculating spatial distance or time cost of object unit through iterative accumulation of adjacent grid (Dannenberg et al. 2011), which is applicable for the measurement of accessibility in mountain county.

The interplay between accessibility and economic development has been the focus of many studies (Vickerman 1995; Vickerman et al. 1999; Caschili et al. 2014), most firmly stressed on the contribution of accessibility improvement on promoting regional economy (Bottasso and Conti 2010; Liu et al 2011; Liu and Zeng 2011; Baldwin et al 2005). In contrast, others raised doubts about the results, proposed that the relationship between accessibility and economic development is not straightforward (Vikerman 1999), even found negative correlation between them (Paez 2004). More importantly, spatial variation of the effects may exist because locations vary in their growth mechanisms, areal characteristics and temporal contexts. Clearly, the effect of transportation on economic growth will depend on various circumstances and the environment, especially for China, disparities exists both in the inter-region and intra-region. Accordingly, partial scholars stressed variant economic influence exerted by transportation in different regional units and groups (Yu et al. 2012, 2013), especially for the central area and marginal area (Vickerman 1997; Keeble et al. 1982; Monzón et al. 2013). Furthermore, the extent of the mountainous region accounts for 74.9% of the mainland China's total area (Fang and Ying 2016). Mountain counties are characterized by heterogeneity owing to the difference of geomorphic condition and regional circumstances, which is significantly different from plains (Fang et al. 2014), the unbalanced development of transport accessibility will also produce non-stationary economic influence across vertical gradients (Yang et al. 2018), which has not attracted enough attention.

In summary, previous studies have demonstrated the critical role of transport accessibility improvement on regional economy, and the spatial varied returns have been increasingly recognized, which gave us a great deal of enlightenment. However, some important gaps still remained: (1) Little attention has been paid to the comparison of the different impact of accessibility in different transport facilities on economic development. (2) The influence of transport accessibility present spatial non-stationarity and heterogeneity, in view of the vast mountainous counties in western China, large gap exist in the internal space, among them, vertical gradient as the important socio-economic characteristic of mountain area has been largely ignored, few robust studies have examined the relationship between accessibility and economic development from the perspective of vertical spatial heterogeneity. (3) Few research have been attempted to investigate the changes of economic impact of accessibility over time.

The Qinghai-Tibet Plateau (QTP) is the main component of mountain areas in western China, as the Eurasian Continental Center, it is the international transportation hub between east and west Asia, joining south and north Asia (Zhu et al. 2018), the South and North Silk Road like ribbons surround QTP. Although the transportation infrastructure of the QTP has made remarkable progress since the founding of the People's Republic of China, especially since the implementation of the western development strategy in 2000, large amount of capital and information rapidly flood into this area, creating broad investment prospect, exerting a positive effect in the income increasing of farmers and herdsmen as well as economic expanding in the area to some extent, the transportation is still the bottleneck restricting the sustainable development of social economy in the region due to the harsh natural conditions, and significant uneven in the traffic infrastructure .

In the context, we take QTP (county scale) as the study unit. The purpose of this paper is to illustrate spatial-temporal evolution of transport accessibility as well as influence changes in regional economy since the implementation of the Western Development strategy. This helps promote sustainability of mountainous areas through the targeted transportation investments.

1 Materials and Methods

1.1 Study area

Qinghai-Tibet Plateau lies in the southwest of China, with greatly undulate terrain and a mean elevation of above 4000 m, which is the largest and highest plateau on earth, known as “the roof of the world” and “the third pole”, covering an area approximately 2.57 million square kilometers (Zhang et al. 2002) and accounting for 1/4 of national territory, including the whole area of the Tibet autonomous, a majority of Qinghai province, southwest of Xinjiang Uygur autonomous, south Gansu, west Sichuan and northwest of Yunnan province (Zhang et al. 2005), cross over about 30 degree of longitudes from the east to west and 13 degree of latitudes from the south to north. The region has a typical plateau continental climate, with the characteristics of strong radiation, low temperature, few precipitation and distinct dry and wet seasons. Total population in the QTP was 20.18 million in 2015, the population density was only 8 persons per square kilometer. The main transportation facilities such as Qinghai-Tibet Railway, Gongga international airport in Lhasa, Lianhuo expressway have become an important support for economic development (Figure 1). Agriculture and animal husbandry was the pillar sector of the regional economy.

1.2 Calculation of transport accessibility

In this study, the accessibility of a county is defined as the weighted average time cost it takes to reach the adjacent critical transport infrastructure, based on the raster cost weighted method, the calculation was to be carried out in three basic steps (Pan and Cong 2012; Wang et al. 2016; Wang et al. 2017):

(1) Preparing for raster data and decomposing regions into grids. Based on 1:4 million fundamental geographic databases in China and the function of layer vectorization of ArcGIS 10.1, traffic networks were rasterized separately by ALBERS equal-area conic projection, and then raster database of elements (including transportation infrastructure, water area, elevation, slope) were established with a spatial resolution of 1 km × 1 km.

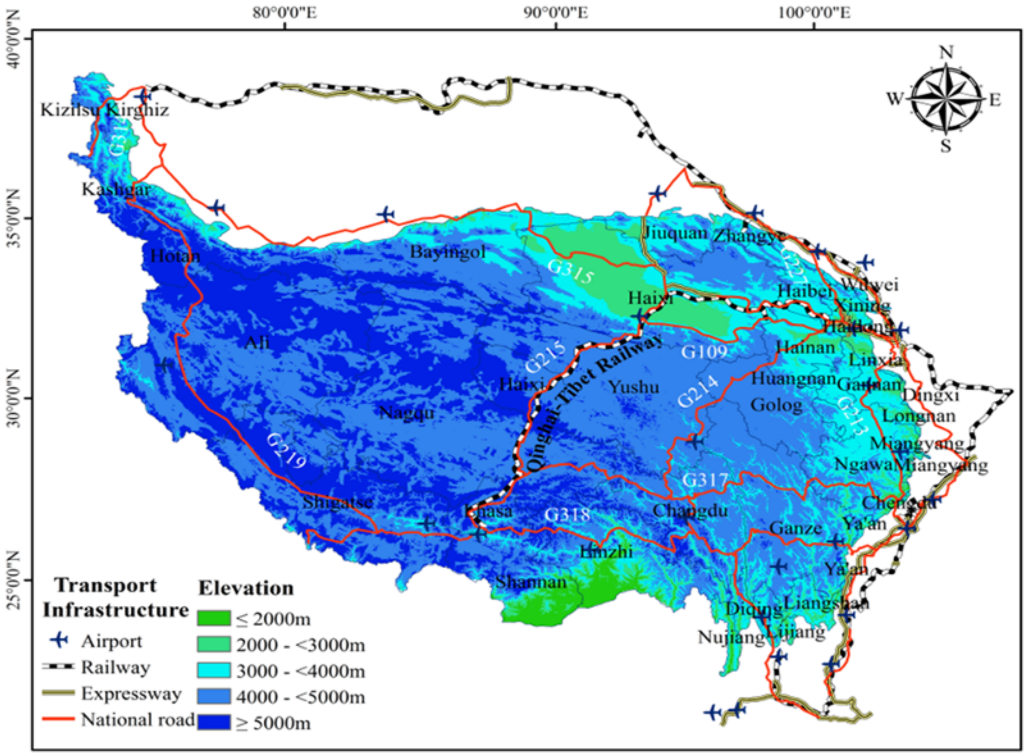

Figure 1 Transportation map of Qinghai-Tibet Plateau, China.

Table 1 Time costs for main objects in Qinghai-Tibet Plateau

Year	Cost	Objects							
		Railway	Expressway	National highway	Provincial highway	County highway	River	Station	Buffer
2000	Speed (km/h)	100	100	50	40	25	-	120	1
	Time cost (h)	0.010	0.010	0.020	0.025	0.040	-	0.008	1.000
2015	Speed (km/h)	120	120	60	50	30	-	140	1
	Time cost (h)	0.008	0.008	0.017	0.020	0.033	-	0.007	1.000

Note: "-" indicates the null value.

(2) Assigning a time cost to each cell which presents the cost per unit distance for moving through the cell. According to the relative research (Wu et al. 2015) and actual situation of the region, the different travel speeds were assigned to different years of surface (Table 1), it is notable that expressways and railways are closed except for its entrances and stations, therefore buffer zones with a certain width were set at both sides of expressways and railways assigned with the minimum access speed (1km/h), while cell at the junction of expressways and railway stations were assigned high value (Shen et al. 2011), which ensure low grade roads linked with expressways and railways by stations. Additional values in terms of slope were assigned to the non-road grids, besides, large waters and lakes were regarded as barrier layer. All velocity raster maps were superimposed and transformed into a time cost raster map, the average number of hours taken by 1km of the travel was calculated by the formula:

$$\text{cost} = \sum_{k=1}^{m} \frac{1}{v} \quad (1)$$

Cost indicates travel time (hour), v represents the assigned speed value of each spatial objects, m is the number of grids.

(3) Estimating the weighted average time cost. By executing the cost weighted command in Arcgis10.1 software, minimum travel times from each grid unit to main roads (including national highway, provincial highway, entrance and exit of expressway), railways (covering provincial capital station, municipal station and county-level station), and airports (comprising international airport

Table 2 Assessment indicator system for transport accessibility and the weight value in Qinghai-Tibet Plateau

Target Layer	Principle layer	Element layer	Weight
Accessibility	Minimum time to highway trunk(0.317)	National highway	(0.167)
		Provincial highway	(0.097)
		Express entrance and exit	(0.736)
	Minimum time to railway station (0.386)	Provincial capital station	(0.460)
		Municipal station	(0.283)
		County-level station	(0.257)
	Minimum time to airport station (0.297)	International airports	(0.439)
		Large and medium airports	(0.309)
		Small airports	(0.252)

station, large and medium airport station and small airport station) were estimated, weights of transport facilities of all types were obtained based on the entropy method (Table 2), further the weighted average time cost of each grid in the county was denoted as county accessibility.

$$R_a = \sum_{x=1}^{s} W_h \times T_{ah} \quad (2)$$

$$A_i = \sum_{k=1}^{m} R_a / m \quad (3)$$

Where, R_a indicates weighted average time cost of the a_{th} grid point, T_{ah} demonstrates the minimum time cost from the a_{th} grid unit to the h_{th} kind of transport facilities, W_h implies the weights of transport facilities of h type, s is the number of transport facilities, A_i indicates the weighted average time cost of i county, m is the number of grids in the county scope. According to this formula, transport facilities including highway, railway, airport as well as comprehensive accessibility can be respectively estimated. The smaller value of A_i signifies the better accessibility.

1.3 Spatial autocorrelation analysis

We use the spatial autocorrelation analysis to check agglomeration of space, which is the basis for establishing Geographically Weighted Regression. Here, Moran's I index was carried out to test the spatial autocorrelation of the independent variable and dependent variable. The formula is as follows:

$$Moran's\ I = \frac{n \sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij}(y_i - \bar{y})(y_j - \bar{y})}{\sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij} \sum_{i=1}^{n} (y_i - \bar{y})^2} \quad (4)$$

Where, n indicates the number of counties, y_i and y_j are the logarithm value of the GDP per unit land area (LGDP) (or the logarithm value of accessibility factors) of county i and county j respectively, $\bar{y}$ demonstrates the mean value of y in all samples, w_{ij} indicates the binary adjacent spatial weight matrix. The value of *Moran's I* range between -1 and 1, the index greater than 0 demonstrates the positive autocorrelation between regions, conversely, the negative autocorrelation is detected if the index is less than 0, besides, the spatial unit presents the random distribution pattern when the value of *Moran's I* is 0.

1.4 Econometric model of the economic influence of transport accessibility

Ordinary least square (OLS) is a global model assumes the variables have homogeneity over the study area and generates one regression coefficient for the whole spatial system (Gilbert and Chakraborty 2011), which emphasizes similarities across space, it can be formulated as:

$$y_i = \beta_0 + \sum_{i=1}^{k} \beta_k x_{ik} + \varepsilon_i \quad (5)$$

Where, y_i is the value of dependent variable at point i, β_0 is constant parameter, β_k indicates the regression coefficients of the k_{th} independent variable, x_{ik} represents the value of the k_{th} independent variable at location i, ε_i is the random error term.

OLS depends on two basic hypotheses: inconstant variance of error term and uncorrelated model residuals (Tu and Xia 2008), conversely, the OLS model predictions are biased and its efficiency should be suspect (Su et al. 2012; Yang et al. 2018). Apparently, the traditional statistical models neglect the spatial non-stationarity of variables, which cannot reflect the true characteristics of the data in space, therefore Fotheringham et al. (1980) proposed Geographically Weighted Regression (GWR) model based on the local smoothing techniques (Wheeler and Tiefelsdorf 2005), which is a powerful method to exam local relationships, embedding spatial locations in linear regression models and adopting local weighted lest squares method, separate regression equation was generated for each observation point, and thus the

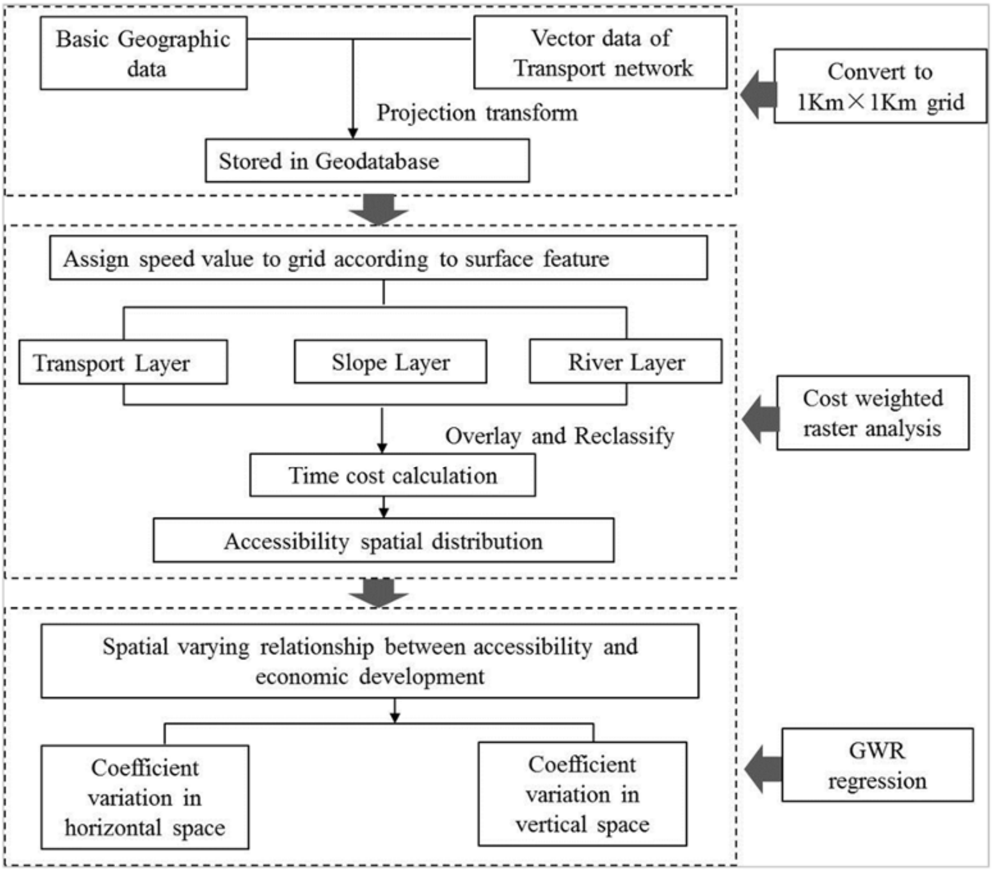

Figure 2 Framework structure of this study.

spatial nonstationary across space between dependent and independent variables can be assessed (Wang et al. 2016). The local regression models contribute to more appropriate descriptions and predictions (Foody 2003), presented as follows:

$$y_i = \beta_0(u_i, v_i) + \sum_{i=1}^{k} \beta_k(u_i, v_i)\, x_{ik} + \varepsilon_i \quad i = 1, 2, \dots n. \tag{6}$$

Where, (u_i, v_i) means the spatial position of i, $\beta_0(u_i, v_i)$ indicates the intercept for location i, $\beta_k(u_i, v_i)$ expresses the local parameter estimate for independent variable x_k at location i, other variables are consistent with the previous formula (5). The regression coefficient is obtained from the estimated by local weighting of adjacent position i with weighted least squares method (WLS):

$$\beta_k(u_i, v_i) = (X^T W(u_i, v_i) X)^{-1} X^T W(u_i, v_i) y_i \tag{7}$$

Where X and X^T indicate the matrix and the transpose matrix of independent variable, $W(u_i, v_i)$ refers to weighting matrix. Since the county area differ greatly in the QTP, Adaptive bi-square kernel i s more appropriate.

$$W_{ij} = \begin{cases} [1 - (\frac{d_{ij}}{d_{max}})^2]^2 & d_{ij} \le b \\ 0 & d_{ij} > b \end{cases} \tag{8}$$

Where d_{ij} stands for Euclidean distance between the central point i and the sampling point j, b presents the bandwidth. Fotheringham suggested that when Akaike Information Criterion (AIC) of GWR model reaches the minimum, the bandwidth b is optimal (Fotheringham et al. 2002), d_{max} is the max distance from the m_{th} farthest county to the regression county.

In light of the high correlations among independent indicators, the spatially varying relationships between economic development and transport accessibility indicators were analyzed by univariate GWR model in order to avoid the potential multicollinearity. The logarithm of GDP per unit land area (LGDP) was used as dependent variables, and logarithms of the weighted average time cost of each transport facilities were employed as independent variables separately.

All of these tests were implemented in GWR

4.0 software, afterwards, the local parameter estimates values were mapped to give clear visualization of the spatially variant relationships, all mappings were performed in ArcGIS 10.1 and Microsoft Excel. The technical route of the paper is as follows (Figure 2)

1.5 Data source

Social economic data were provided by the China County Statistical Yearbook (2001 and 2016). Digital elevation model data for the study area were derived from ASTERG-DEM data with a resolution of 90m. Data on roads and rivers were from the Chinese highway atlas published by Planet Map Publishing house (2000 and 2015) and the vector map of 1:4 million fundamental element version respectively. According to the passenger volume from Statistical Data on Civil Aviation of China (2001 and 2016), we defined the provincial capital airport with regular international flights as the international airport, airport with more than 50,000 passengers in 2000 and above 100,000 passengers in 2015 as the large and medium-sized airport, and the remaining was small-sized airport.

2 Results and Discussion

2.1 Spatial distribution of accessibility

Generally, weighted average time cost of railway is higher than both highway and airport (Table 3), and showing the most fluctuations (Table 4). Accessibility of the whole plateau has been significantly improved during the decades, time cost of highway, railway, airport and comprehensive transport facilities in 2015 were reduced by 56.85%, 53.87%, 48.48% and 53.38% respectively, indicating the significant improvement of accessibility occurring.

Time cost gradually decreased from west to east, taking on obvious characters of circle layer (Figure 3). Indeed, eastern area is relatively flat, with the advantageous location and developed transport networks, while the west is confronted with the constraints factors including severe natural environment, wide distribution of frozen soil and high relief amplitude, which is not conducive to the construction of transport facilities resulting in the relatively backward level of social economic development and regional imbalance.

Table 3 Weighted average time cost of different transport facilities in Qinghai-Tibet Plateau in 2000 & 2015

Elevation (m)	County ratio (%)	Highway time cost (h)		Railway time cost (h)		Airport time cost (h)		Comprehensive time cost (h)	
		2000	2015	2000	2015	2000	2015	2000	2015
<2000	7.58	13.75	4.56	14.06	8.65	14.21	8.99	14.01	7.45
2000-<3000	18.48	15.19	6.61	17.82	10.88	20.23	10.73	17.07	9.48
3000-<4000	27.01	15.04	6.45	16.01	10.89	19.46	11.05	16.72	9.53
4000-<5000	40.76	35.41	15.28	36.99	13.75	26.02	12.23	33.23	13.79
⩾5000	6.16	54.58	25.24	57.61	22.40	38.28	20.05	50.91	22.60
Entire	100	25.72	11.10	27.32	12.60	23.01	11.85	25.53	11.90

Table 4 Fluctuations of weighted average time cost of different transport facilities in Qinghai-Tibet Plateau in 2000 & 2015

Elevation (m)	Highway time cost (h)		Railway time cost (h)		Airport time cost (h)		Comprehensive time cost (h)	
	2000	2015	2000	2015	2000	2015	2000	2015
<2000	0.84~40.36	0.19~13.84	1.11~43.70	0.55~27.20	4.63~30.63	1.78~21.63	2.07~38.77	0.80~21.31
2000-<3000	2.53~61.63	0.42~31.72	2.93~63.22	2.57~30.99	11.47~42.15	4.61~24.41	6.83~53.10	2.97~28.97
3000-<4000	4.35~45.51	1.10~29.18	3.77~56.25	3.10~36.56	13.27~43.85	5.13~33.01	7.95~47.82	3.54~32.67
4000-<5000	13.23~66.19	5.39~33.29	10.90~78.46	5.79~38.57	16.74~46.84	6.65~30.33	14.51~65.18	7.24~32.82
⩾5000	41.91~65.27	16.91~32.67	38.99~73.49	10.81~33.48	26.91~43.13	12.27~25.75	36.32~61.87	13.18~29.06
Entire	0.84~66.19	0.17~33.29	1.11~78.46	0.55~38.57	4.63~46.84	1.78~33.01	2.07~65.18	0.80~32.67

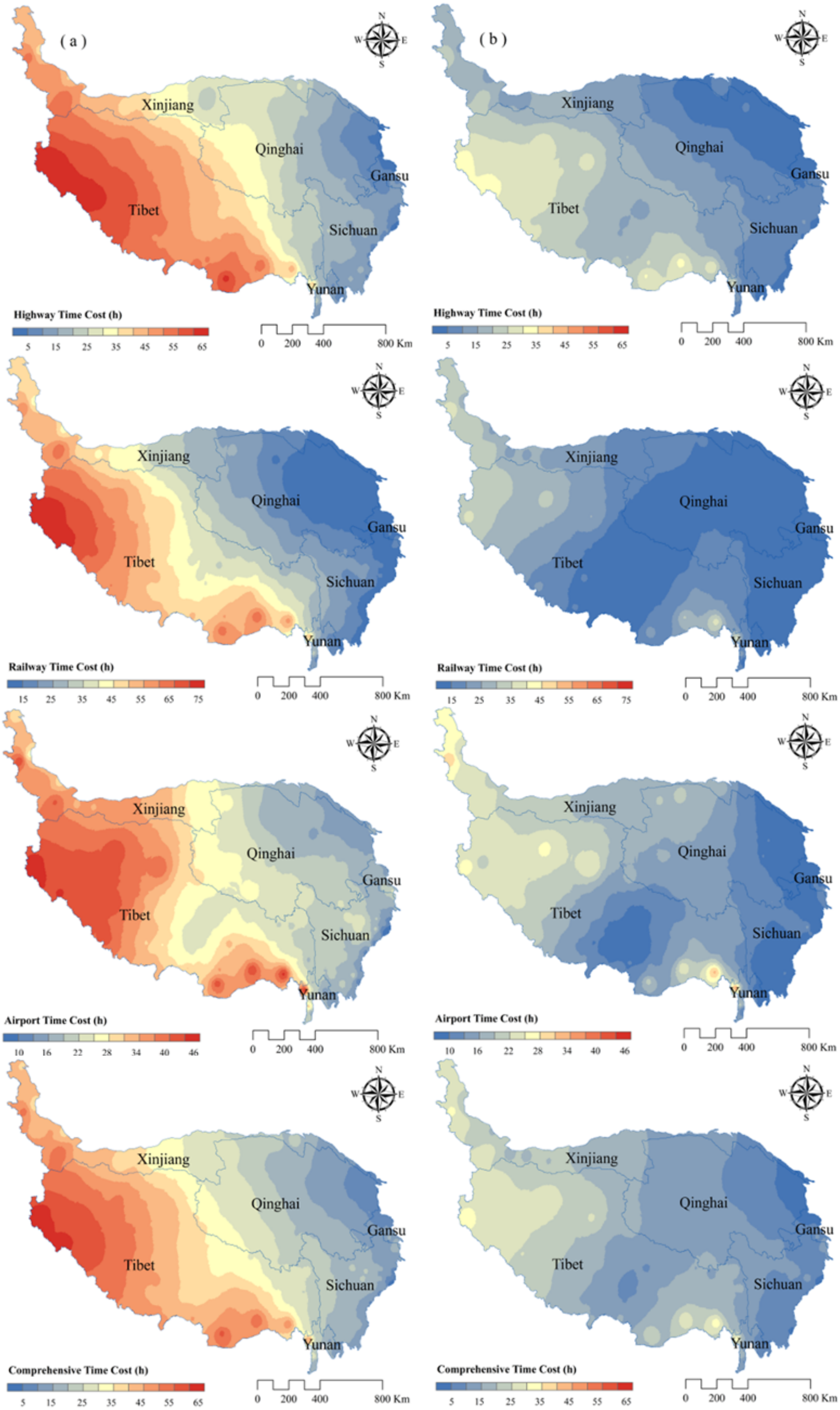

Figure 3 The weighted average time cost of different transport facilities in Qinghai-Tibet Plateau of year (a) 2000 & (b) 2015.

To investigate the vertical spatial characteristics of accessibility, based on the elevation range of the study area, QTP is divided into five elevation belts on the basis of intervals of 1000 m. Generally, the weighted average time cost showed approximately linear with the altitude, namely, the accessibility capacity was gradually reduced with elevation increasing. Weighted average time cost in the zone below 2000 m was relatively low, while presented the largest value when above 5000 m (Figure 4, Table 3).Variation in the four accessibility indicators at different altitudes was observed, in 2000, the disparity was mainly reflected in the railway, whereas the gradient gap was predominantly found in the highway accessibility in 2015. In relation to the accessibility distribution at each altitudinal belt, weighted average time cost of highway was the lowest below the 2000 m, followed by railway and airport. At the altitude of 2000-3000 m, time cost showed a trend of highway<railway<airport, but airport accessibility was greatly improved in 2015. With regard to the zone between 3000-4000 m, time cost of highway was lower than railway and airport in the course of research time. As to the zone above 4000 m, airport time cost was lower than the others (Figure 4, Table 4).

In terms of the average change of accessibility, low time cost expanded from east to southwest, which is closely associated to the operation of theQinghai-Tibet Railway, inversely, high time cost shrink to west and southeast of Tibet. Besides, weighted time cost at each altitudinal zone in 2015 decreased dramatically in comparison with the year of 2000, and the absolute differences of the time cost in descending order were the area above 5000 m, 4000-5000 m, 2000-3000 m, 3000-4000 m, below 2000 m, which is related to traffic background of each region, the foundation of transport facilities in high altitudinal area was poor, demonstrating greater improvement space, conversely, low altitude area with superior transport infrastructure and the integral lifting was much more difficult. Apparently, highway

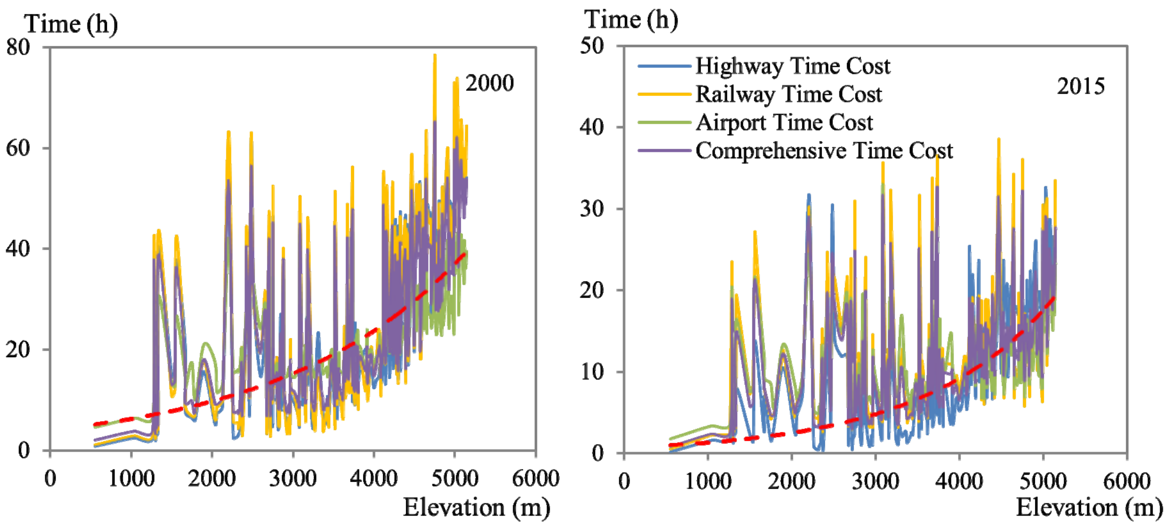

Figure 4 Vertical performance of weighted average time cost of different transport facilities in Qinghai-Tibet Plateau in 2000 & 2015 respectively.

Table 5 Spatial autocorrelation analysis results of dependent and independent variables by Arcgis 10.1 software

Parameter	2000			2015		
	Moran's I	Z-score	P-value	Moran's I	Z-score	P-value
LnLGDP	0.625	15.057	0.000	0.766	14.211	0.000
LnAhighway	0.811	19.464	0.000	0.789	18.956	0.000
LnArailway	0.838	20.087	0.000	0.709	17.070	0.000
LnAairport	0.695	16.763	0.000	0.691	16.619	0.000
LnAcc	0.813	19.494	0.000	0.736	17.691	0.000

Notes: LGDP means gross domestic product per unit land area; Ahighway, Arailway, Aairport, Acc denotes the weighted average time cost of highway, railway, airport, comprehensive transport facilities respectively.

accessibility achieved the most prominent improvement below 4000 m, while railway accessibility was improved remarkably above 4000 m during the study time.

2.2 Spatial variation of the relationship between transport accessibility and economy

2.2.1 Fitness of GWR model

Moran's I index showed both of the independent and dependent variables in the two study years was positively spatial auto-correlated at 1% significance level (Table 5), implies that the distribution of accessibility and economic development in each county were not completely random, but showing spatial agglomeration features, which does not satisfy the condition of independence and random distribution assumption of traditional regression model, accordingly, the classical linear regression results based on OLS are biased (Sun et al 2014), and thus, it is necessary and feasible to analyze the influence of transport accessibility on economy by GWR model.

The statistical comparison between the global and local models revealed that there is a significant improvement in prediction by applying the semiparametric GWR method (Table 6). The adjusted R^2 for the GWR models were much higher than those for the OLS models while the AICc value and Residual Squares value were significantly lower compared to those of OLS models. Subsequently, Monte Carlo Test was carried out for each estimated parameters, all of the accessibility indicators were approved by significant test, showing obvious spatial non-stationary and heterogeneity, and the regional difference of the transport accessibility influence on the level of economic development was discussed in details.

2.2.2 The influence of transport accessibility on regional economy

R^2 of all the univariate GWR models is above 0.65, it means that accessibility factors played vital role in the development of regional economy. In view of the remarkable disparity in transport accessibility and economic base among the study regions, we can reasonably consider that the different role in the economic development for each sub region. Sequentially, spatial varying influence of transport accessibility on economic development was measured, and the map of output elasticities were drawn up both in the horizontal (Figure 5) and vertical (Figure 6) dimensions, allowing a visual interpretation of the results.

According to the mean coefficient of weighted average time cost on GDP per unit land area estimated by GWR (Table 7), negative correlations were measured in all of the transport facilities, indicating that economic development level was tightly associated with transportation skeleton line, the higher economic development level the region was, the more convenient to access transport facilities. In terms of comprehensive accessibility, 1% increase in the average time cost resulted in 2.446% LGDP decrease in 2000, while the correlation between them gradually decreased in 2015, with the elasticity coefficient of -1.420. The reason for this is the improvement outbound traffic conditions reduced the constraints for the regional development and provided wide space to spur economic growth. For the elasticity coefficients of the three transport accessibility, highway accessibility exerted the largest impact on economy, followed by railway, while airport accessibility played a minor role.

Table 6 Comparison of parameters between Ordinary least square (OLS) and Geographically Weighted Regression (GWR) models

Model	Parameter	2000				2015			
		R^2	R^2_{adj}	AICc	Residual square	R^2	R^2_{adj}	AICc	Residual square
OLS	LnAhighway	0.573	0.569	703.288	340.05	0.579	0.570	812.38	604.52
	LnArailway	0.558	0.554	710.701	352.27	0.587	0.494	817.01	617.92
	LnAairport	0.619	0.616	679.23	303.24	0.562	0.558	821.62	631.93
	LnAcc	0.589	0.585	695.279	327.33	0.449	0.446	813.43	607.30
GWR	LnAhighway	0.776	0.7459	605.518	178.78	0.655	0.592	661.17	226.13
	LnArailway	0.783	0.755	597.69	172.70	0.659	0.597	658.54	223.38
	LnAairport	0.816	0.789	567.606	146.61	0.653	0.589	662.26	228.02
	LnAcc	0.794	0.767	587.599	164.32	0.654	0.590	662.23	226.97

Notes: Ahighway, Arailway, Aairport, Acc denotes the weighted average time cost of highway, railway, airport, comprehensive transport facilities respectively.

Distinct spatial variations and directional heterogeneity were observed in the marginal effect of the accessibility factors in the entire QTP area. Namely, the accessibility factors in different space had both positive and negative coefficients, suggesting that they had varied effects on the level of economic development (Table 7). The fluctuation range of comprehensive time cost coefficients was (-6.588, 1.105) in 2000, and decreased to (-3.462, 1.240) in 2015, it means gaps in the influence of comprehensive accessibility gradually narrowed. In respect to the fluctuation of accessibility coefficient of different transport facilities, highway accessibility exhibited larger range than the other two transport facilities both in 2000 and 2015. Moreover, comparing with 2000, the coefficient range of the three transport accessibility decreased in 2015, among them, railway accessibility showed the greatest reduction.

2.2.3 Coefficient variations of transport accessibility in the horizontal space

As shown in Figure 5, the significant spatial variation characteristics of the accessibility factors on the level of economic development were visualized over space.

In relation to the highway accessibility, positive influence of highway time cost was detected in the border between Qinghai, Sichuan and Tibet autonomous region in the year of 2000, and the positive coefficient was concentrated in the western part of the national highway G317 in 2015, demonstrating the economic growth in this particular region was not sensitive to the highway

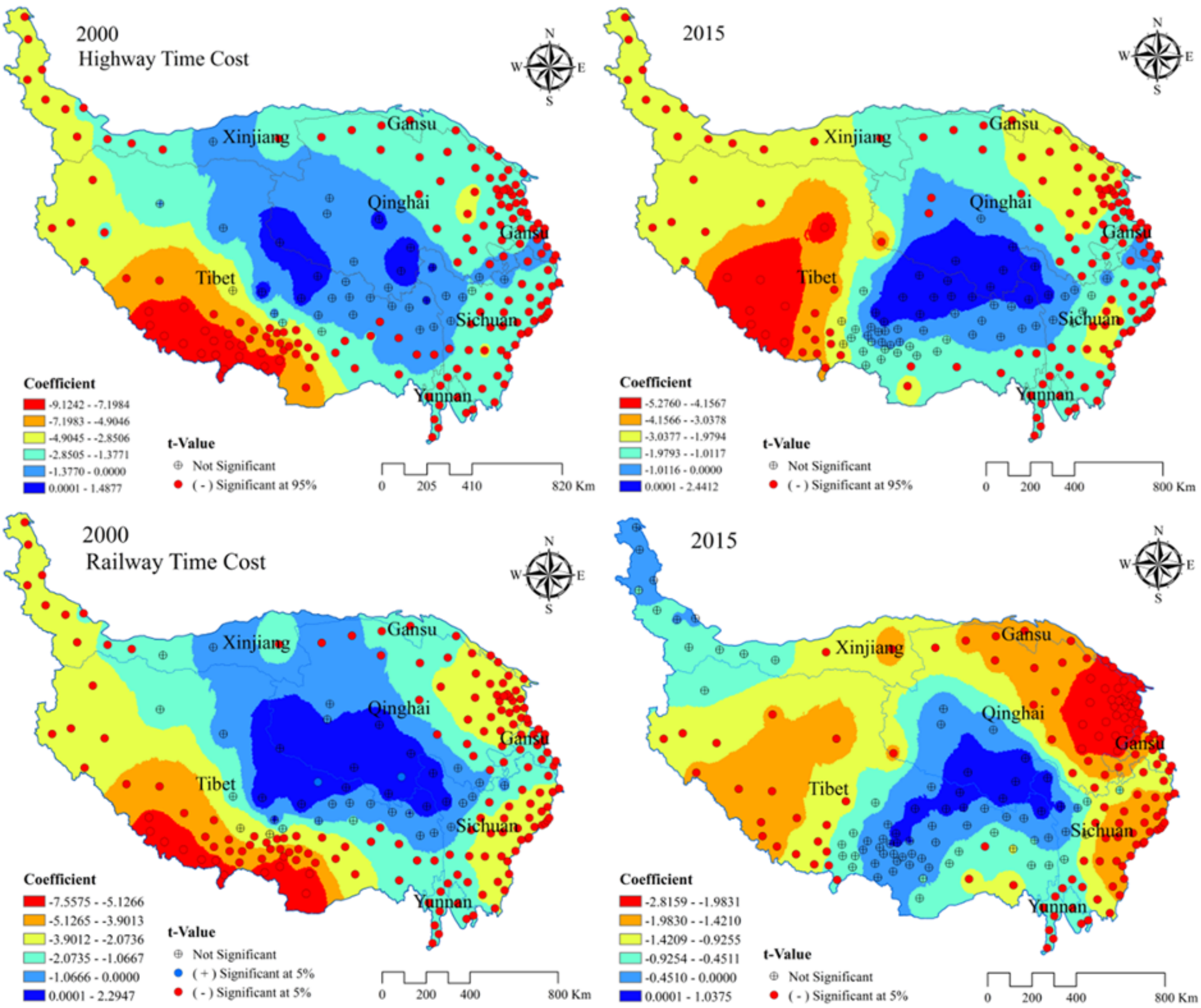

Figure 5 Spatial distribution of accessibility factors regression coefficient and its t-value in Qinghai-Tibet Plateau for the year of 2000 & 2015. (-To be continued-)

(-Continued-)

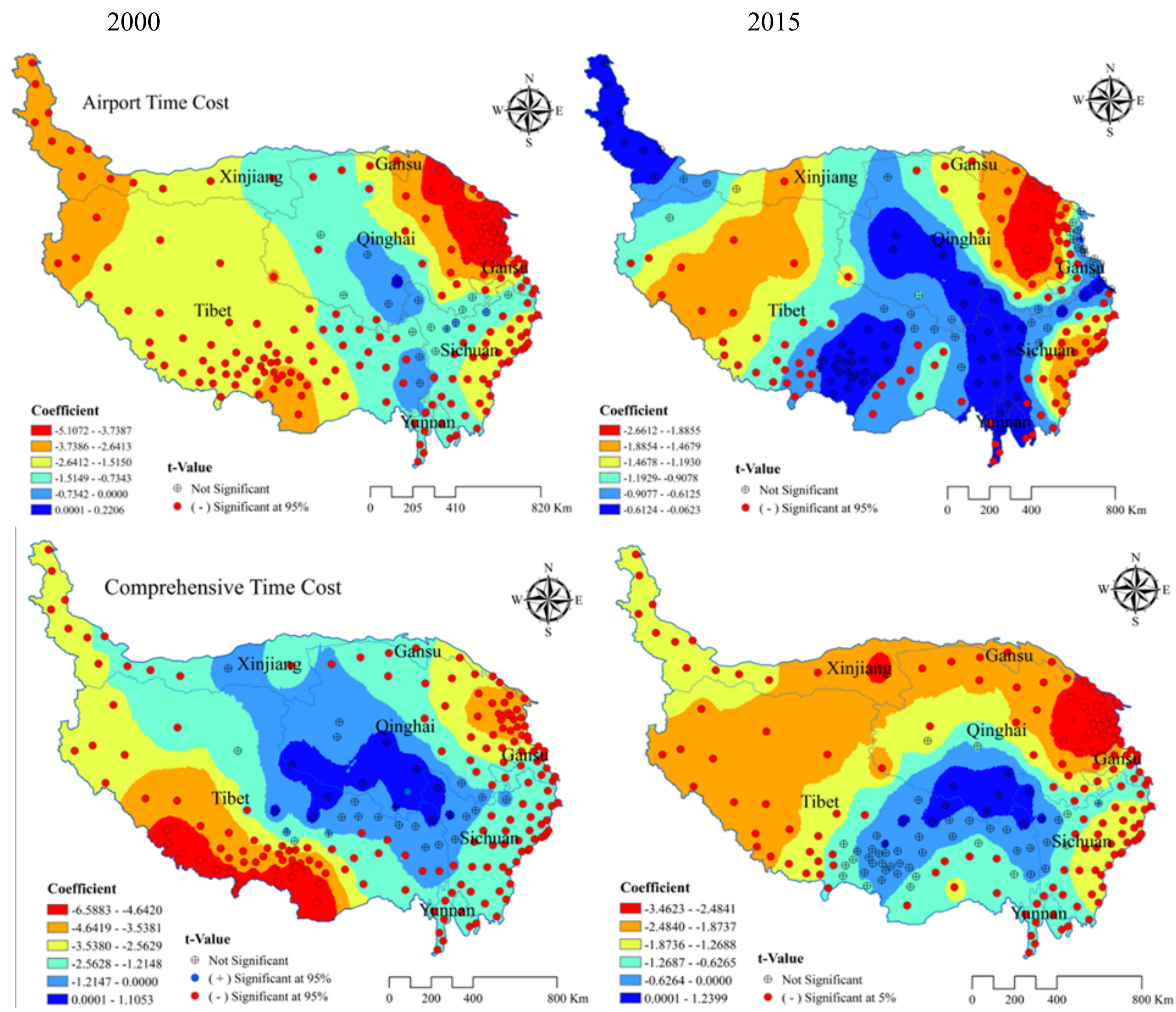

Figure 5 Spatial distribution of accessibility factors regression coefficient and its t-value in Qinghai-Tibet Plateau for the year of 2000 & 2015.

Table 7 Estimated coefficients of accessibility factors on GDP per unit land area by GWR model

Parameters	Model	2000			2015			
		Coefficient	Min	Max	Model	Coefficient	Min	Max
Intercept	I	1.725	-1.951	10.338	V	2.883	-0.045	6.820
LnAhighway		-2.574	-9.124	1.487		-1.656	-5.276	2.441
Intercept	II	1.118	-1.824	7.450	VI	0.426	1.045	3.644
LnArailway		-2.185	-7.558	2.295		-1.140	-2.816	1.038
Intercept	III	0.736	-2.515	3.004	VII	2.694	1.453	4.458
LnAairport		-2.172	-5.107	0.221		-0.999	-2.661	-0.062
Intercept	IV	0.946	-2.366	6.777	VIII	2.472	0.134	3.541
LnAcc		-2.446	-6.588	1.105		-1.420	-3.462	1.240

Notes: Ahighway, Arailway, Aairport, Acc denotes the weighted average time cost of highway, railway, airport, comprehensive transport facilities respectively.

accessibility. Main reason is three aspects: Firstly, the region located on the edge of provincial border, with lower disparity in the time cost getting to the main road and the similar geographical locations. Secondly, the herdsman insisted on the concept of “cherish to sell and kill” for a long time, commodity rate of agriculture and animal husbandry products was relatively low. Thirdly, the central region was

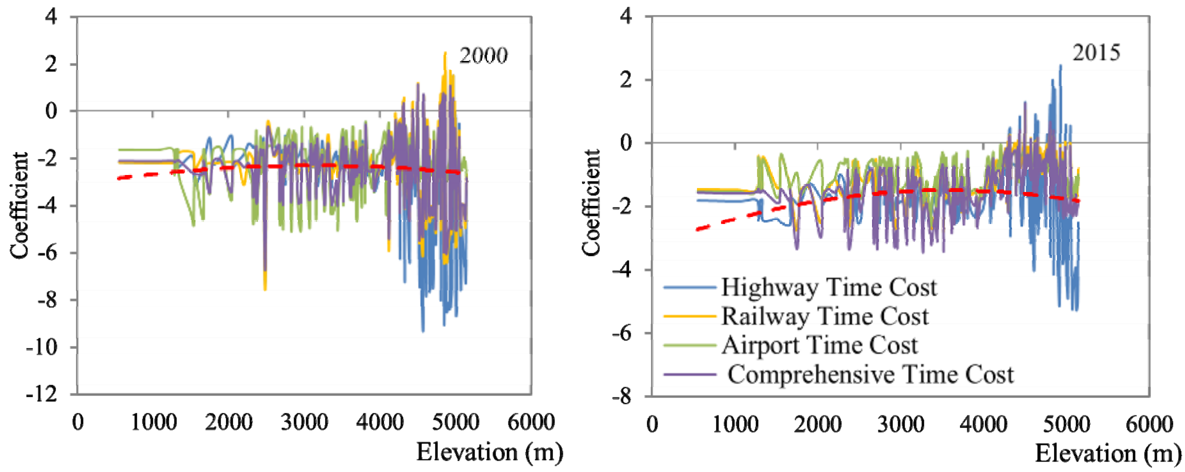

Figure 6 Gradient variations of accessibility factors regression coefficient in 2000 & 2015 respectively.

the main yield areas of Cordyceps (*Ophiocordyceps Sinensis*) in China, which became the most important income source of local herders and farmers, and brought huge economic benefits to the government, showing relatively weak transport infrastructure dependence. Conversely, approximately 86.56% counties presented negative coefficients in 2000, and the ratio increased to 92.42% in 2015, by and large, the absolute coefficient value of highway time cost declined from the west to the east of QTP, and the improvement of the highway accessibility exerted the most benefits on the economic growth in south Tibet, which is adjacent to southeast Asian countries, the improved highway transport was conducive to the trade of light industrial products and local ethnic supplies, besides, the area known as "One River and Two streams" with fertile land resources is an important commodity grain production base of Tibet, the construction of road infrastructure reduced the transportation cost of agricultural products and expanded the market scope. In 2015, the highway accessibility was found to be tightly relevant with economy in northern Tibet, where the animal husbandry took up the dominant place in economic sector, with high output but low production yield, high-grade highway in this area was sparse, in the wake of the construction of modernized production base for agriculture and animal husbandry, commodity economic gradually development, and then the correlation between highway accessibility and the level of regional economy was deepened, 1% increase of the highway arrival times led to the 4.16%-5.28% reduction of the LGDP.

With regard to the horizontal variation of the railway accessibility elasticity coefficients, the positive influence of time cost was pooled in the middle of QTP. In 2000, only two counties were supported by the significance test, while the scope of positive influence area narrowed and did not achieve a significant test in 2015, the proportion of the negative influence area by railway arrival times increased from 92.85% up to 93.16%. Gravity center of railway accessibility shifted from southwestern to northeastern plateau, the sub-sensitive area was distributed in the middle Tibet, and this may be due to the lack of railway transportation before 2006 in Tibet, result in the high cost of production and low transportation efficiency. While the establishment of Lanzhou-Xining Economic Development Zone in 2010 enormously accelerated the development of middle Gansu and eastern Qinghai, as the logistics hub in Northwest China and the core connecting point of the second Eurasian continental bridge in China, economic belt along the railway was gradually formed, county economy proximity to the axis developed more rapidly, by contrast, the economic development of the county which far from the railway was relatively weak. Moreover, since the completion of Gela segment of Qinghai-Tibet Railway in 2006, the linkages between plateau and the developed part of China gradually enhanced, further reduced the obstacles of long-distance bulk transportation and facilitate the exploitation of resources as well as the flow of production along the line.

In relation to the airport accessibility, airport arrival times had both positive and negative coefficients in 2000, suggesting that it had varying effects on LGDP across QTP, positive influence on the response variable mainly in the southeast of Qinghai province, but they could not pass the significant test, however, opposite correlations were found in the remaining region. The greatest effect of airport accessibility was observed in the northeast of Qinghai province, comparatively, the level of economic development in western plateau was more sensitive to this variable, while the coefficient in middle region was relatively low. In 2015, unanimous negative estimates were detected across the regional space, the coefficient was larger in the northeastern Qinghai and the middle Tibet. It is clear that the area was abundant in tourism resources, like Jishishan Mountain, Inverted River and Namtso Lake, tourism industry has become an important economic driver, due to the convenient, comfortable, low time cost, air transportation gradually become the preferred way for travelers, the tourism destinations with superior airport facilities will be more attractive to the tourists at home and abroad, and thus stimulated the economic booming. On the other hand, Xining and Lhasa were the economic growth poles in this region, the improvement of airport infrastructure triggered the development of aviation economy and its industrial chains, producing agglomeration economic benefits. By contrast, the weakest relationship was found in the southwest of Xinjiang and the middle QTP, distributed in strips. The scale of airport transportation hinterland was small because of the sparsely-populated and poor basis of economic development, showing weak radiation. In addition, the level of regional economic development highly depended on the mining industrial, presenting little association with the high-cost aviation transportation.

In terms of comprehensive accessibility, the influence of comprehensive time cost on LGDP of plateau showed significantly spatial heterogeneity, which was a positive exploratory variable for the middle region in 2000, while opposite correlation scopes were expanded in 2015, accounting for 94.7% counties. The coefficient was larger in the northeast and southwest while smaller in the central part of the study area in 2000. In 2015, the high value center moved towards northeast of QTP, where covered both Great Xining Tourism Development Zone and Lanzhou-Xining economic construction area, which has higher requirement for the comprehensive traffic systems, while the middle region was located on the border of three provinces, far from the market, industry was concentrated on the producing and processing of primary products and semi-finished products, showing the low industrial correlations and weak economic connections between areas, with little mobility, farmers and herdsmen were short of market opinion and consciousness, resulting in the absent of production circulation system.

2.2.4 Coefficient variations of transport accessibility in the vertical space

Variations in the vertical dimension is the important content of mountain areas, as shown in the Table 8 and Figure 6, relationships between accessibility factors and economy varied dramatically across the different altitude zone, the detailed discussions were as follows:

(1) below 2000 m

The zone mainly lies in the east edge and north edge of Qinghai-Tibet Plateau, with superior geographical location, well developed transportation system and economic base. In terms of the mean value of coefficients, the weighted average time cost of each transport facilities were the negative influential variable, 1% increases in

Table 8 Mean regression coefficient of accessibility factors in the vertical space by GWR model

Elevation (m)	Time cost (2000)				Time cost (2015)			
	Highway	Railway	Airport	Comprehensive	Highway	Railway	Airport	Comprehensive
< 2000	-2.177	-2.086	-2.498	-2.366	-2.047	-1.349	-1.285	-1.713
2000-<3000	-1.894	-2.136	-2.489	-2.517	-1.689	-1.506	-0.915	-1.822
3000-<4000	-2.083	-2.107	-2.504	-2.557	-1.838	-1.685	-1.328	-1.923
4000-<5000	-2.982	-2.084	-1.735	-2.215	-1.145	-0.538	-0.710	-0.772
≥5000	-4.681	-3.476	-2.277	-3.414	-3.651	-1.372	-1.367	-1.932

the comprehensive time cost reduced the LGDP growth by about 2.36% in 2000 and decreased to 1.713% in 2015, effects of each transport accessibility presented airport> highway> railway in 2000, while highway played the greatest impact in 2015. With regard to the coefficient range, all accessibility indicators fluctuated between negative values, the extreme difference value of comprehensive time cost coefficient was 1.376 in 2000, which expanded by 2.031 in 2015. In relation to different transport facilities, the coefficient fluctuation of the airport accessibility in 2000 was larger, while the regional difference became more distinct in the railway accessibility in 2015. Moreover, coefficient amplitude of highway and airport gradually decreased in 2015, whereas the difference of regional influence in railway and comprehensive accessibility increased. Comparing with other altitude zones, coefficient fluctuation of accessibility factors in counties below 2000 m was relatively gentle.

(2) 2000~3000 m

The zone is mainly distributed in Xinjiang and eastern plateau, GDP density was 1.46 million yuan/km^2. In respect of mean coefficient, airport accessibility played a most role in economic development, railway and highway accessibility stood on the second and third place respectively in this region in 2000, while the marginal effect of highway accessibility was larger than railway and airport in 2015. This may be due to the implementation of the Western Development strategy, road construction has been rapidly accelerated around such area, and the construction of expressway largely improved the accessibility of high-grade highway, enhancing the correlations between highway network and the level of economic development. The unanimous negative estimates of weighted average time cost were detected, fluctuation range showed smoothly in the two study years, and the absolute difference in the coefficient gradually decreased in 2015, indicating that the spatial heterogeneity of the influence of transport accessibility on economic level at such altitude zone attenuate obviously. Meanwhile, the fluctuation range of railway time cost coefficient was larger in the study years.

(3) 3000~4000 m

The county with the altitude between 3000 m and 4000 m distributed in the shape of semi-circle in the eastern Qinghai-Tibet Plateau, GDP density was only 0.43 million yuan/km^2. Similar to the areas at the altitude of 2000~3000 m, airport accessibility was the strongest contributor to economic development, followed by railway and highway in 2000, while the influence intensity showed a trend of highway>railway>airport in 2015. In relation to the fluctuation, the traffic facility time cost coefficient in the two years ranged between negatives, and the fluctuation of marginal effect of airport accessibility was the highest, the range was 4.46 in 2000, whereas the biggest difference of coefficient was detected in railway, then airport and highway in 2015. Compared with the other four altitudinal counties, the regional difference in the impact of airport accessibility on economy is more significant.

(4) 4000~5000 m

Counties at altitude between 4000 m and 5000 m are located on the border of Qinghai, Sichuan and Tibet autonomous, the middle of QTP, GDP density was 0.17 million yuan/km^2 in 2015. The mean coefficient showed county economy both in 2000 and 2015 was more sensitive to the highway accessibility. Comparing with the other remaining altitudinal zone, absolute coefficient values of the traffic facility time cost were smallest in this zone. All variables had both positive and negative coefficients in 2000, showing relatively large regional difference, in which, the coefficient fluctuation of highway time cost was the largest, range from negative 9.124 to positive 1.487. By 2015, except for the airport, both positive and negative effects were estimated in the other transport, peaks and troughs of coefficient were concentrated in this zone. The main reason for this is that, with the largest number of counties, the zone including 86 units, so that there were more diversified combination types between transport accessibility and economic development level. Moreover, the economic basis and the industrial structure presented large difference, Qaidam Basin mining economic zone, three-river source tourism development zone, South Qinghai and “One River, Two Streams” farming-grazing industrial belt were in accordance with transport infrastructure with diffident tolerance.

(5) Above 5000 m

The zone is located in the west edge of interior QTP, with the characteristics of marginalized economy and vast areas, GDP density at the altitude above 5000 m was only 0.02 million yuan/km^2 in 2015. According to mean value of coefficients, the contribution of highway accessibility was larger than railway and airport in the two study years, which is the support conditions even lifeblood of the regional economy. Comparing with the year of 2000, the mean coefficient of railway and airport dropped significantly in 2015, but the growth of economy still relied heavily on the highway. In comparison with the other relatively low altitudinal counties, the region is more sensitive to most accessibility factors, it showed that the constraints of high transportation cost caused by marginalized geographical position were not broken, deeply hindered the growth of economy, correspondingly, potential economic and social effect created by the traffic improvement would be larger. With respect to the coefficient variations, unanimous negative values were showed in the course of study years, showing relatively small spatial differential, and the fluctuation range of accessibility coefficient in different transport facilities decreased in the sequence bout the highway, railway and airport both in the year of 2000 and 2015, indicating that the variation of highway on the influence degree of such area was larger. Comparing with the other four remaining altitudinal counties, the coefficient fluctuation of the airport accessibility was the smallest in 2000, and the slightest fluctuation were found in railway, airport and comprehensive accessibility in 2015.

3 Conclusions

Geographically weighted regression model is an effective tool to explore the spatial relationship between transport accessibility and economic level. According to the mean coefficient, time cost to transport facilities exerted significantly negative influence on the level of economic development, while the negative impact is declining over time. In addition, the marginal effect of the four accessibility factors fluctuated significantly from positive to negative across the whole plateau, in which the improvement of highway accessibility played the greatest impact of the regional difference reduction of GDP per unit land area.

The average time cost has decreased by 53.38% in the past 15 years, especially highway and railway time cost. However, insufficiency and gradient difference of transport infrastructure were still remained. Average time cost of each county arriving to the critical transportation facilities followed the rules of “core-periphery structure model” and “circular distribution”, increasing from east to west, obvious circle layer occurring. Importantly, accessibility gradually decreased with the rise of elevation, the best accessibility area of the highway was below 4000m, while the area above 4000m had the lowest aviation time cost.

In vertical dimension, the different impact of traffic accessibility on the level of QTP’ economic development is significant. Economic growth in the counties with an average altitude of less than 4000m was mainly affected by airport accessibility in 2000, while the construction of the high-grade highway played an important role in 2015. For the area with an average altitude of 4000 m, the highway accessibility was determinant affecting economic development. Besides, the improvement of comprehensive accessibility was more remarkable in the areas with an average altitude of more than 5000 m. With regard to the coefficient fluctuation, peak and trough values were concentrated in the zone at the altitude between 4000 m and 5000 m, while the unanimous negative estimates was observed in the other four altitudes.

Although the significant achievements have been made in transportation infrastructure of the QTP over the past decades, the transportation is still the important bottleneck restricting the sustainable development of social economy in the region due to the harsh natural conditions and increasing demand of socio-economic growth. In addition, the QTP is characterized by a wide range of regions, great internal differences and unbalanced transportation infrastructure. Therefore, the mitigating disparity of transportation infrastructure is still an important task in the region by formulating preferential policies for transportation investment such as additional transfer payment of central government, World Bank funding, the partnership and unified planning of multilevel governments. Given the fact that the significant spatial disparity of transport accessibility and varied economic effects of different traffic facilities exists, there is no one size fits all solutions to optimize transport construction across the whole plateau, differentiated investment scales and priorities are recommended. In view of the small scale and poor grade of current transport infrastructure in western high altitudes, highway accessibility imposed the deepest influence, expanding network density especially highway density is the priority to reduce transport time cost. In line with the eastern region at relatively low altitude, well developed transportation system was gradually constructed, the time cost of airport was relatively high, based on the superior geographical location, the key here is to optimize the structure of transport systems, special emphasis should be placed on the airport operational capacity improving and highway grade raising, moreover, speeding up the construction of rapid transit systems is critical.

It is worth noting that, transportation is not the only factor affecting economic development, but it is the vital element, in this study, transport accessibility can explain over 65% of the variance level of economic development, reflecting high degree of relevance. Further work should emphasize the synergistic effect of transportation and other key factors like capital and labor on economic development, and accurately descript the both horizontal and vertical heterogeneity of economic development in the QTP.

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