Spatial Fairness and Changes in Transport Infrastructure in the Qinghai-Tibet Plateau Area from 1976 to 2016

Xingchuan Gao 1,2,3, Tao Li 2,3 and Xiaoshu Cao 2,3,*

1 School of Geography and Tourism, Shaanxi Normal University, Xi’an 710119, China; gaoxch@foxmail.com
2 Northwest Land and Resource Research Centre, Shaanxi Normal University, Xi’an 710119, China; taoli-2008@163.com
3 Key Laboratory for Urbanization and Land Environment Geo-simulation in Northwest China, Xi’an 710119, China
* Correspondence: caoxsh@snnu.edu.cn

Received: 30 October 2018; Accepted: 17 January 2019; Published: 23 January 2019

Abstract: The Qinghai-Tibet Plateau area (QTP) is the most unique environmental-population region and an important natural laboratory for the study of human-land relations. The poor transportation conditions have long restricted socio-economic development. The research on the transport infrastructure and spatial effect in the QTP is of significance to the sustainable development of the region. Accordingly, a spatial accessibility model was used to analyze the spatial pattern of accessibility in QTP from 1976–2016, examine the accessibility evolution trend on the township scale and reveal the spatial fairness and changes in accessibility. The main conclusions are as follows: (1) The accessibility to major cities improved and the time-space convergence effect was significant. (2) The spatial autocorrelation analysis results showed that the improvement in transport infrastructure had a significant impact on the agglomeration of the accessibility level. (3) Access time from towns to the nearest major city are much shorter. More Tibetan people have more opportunities to access cities. (4) The accessibility coefficient and relative accessibility revealed distributive effects and spatial fairness of accessibility. (5) The global coefficient of variation value demonstrated an increasing trend, which indicates that spatial unfairness of transport is increasing.

Keywords: spatial fairness; distributive effects; transport infrastructure; accessibility; the Qinghai-Tibet Plateau area

1. Introduction

Transport infrastructure is a necessary prerequisite for promoting regional social and economic development and is a key factor in regional cohesion [1]. Transport construction and network expansion play vital roles in the future development of a region. Accessibility is an important measure of transport networks, used to measure the interaction potential between cities and towns [2]. Harris first measured accessibility using the market potential model in 1954 [3]. Then in 1959, Hansen studied the impact of accessibility on land use [4]. Transport fairness, brought about by the development of the transport network, is closely related to many social issues, such as the number of jobs available and the time spent in public transport [5]. Accessibility has been gradually recognized as an indicator of transport fairness [6–8]. Transport fairness is derived from the study of fairness and justice in other fields [7], in which “fairness” is regarded as the core component of “justice” [9,10].

The research on transport fairness is mostly concentrated on population distribution, investment and public facilities but the concept does not have a single, widely accepted definition [11–13]. In identifying transport fairness, two broad methods to conceive fairness are well-recognized: social fairness and spatial fairness [14]. The first is viewed from a social perspective, wherein vulnerable
or disadvantaged populations are targeted. The second approach defines fairness in terms of spatial distributive effects, which means easy access, regardless of socioeconomic characteristics, satisfaction or disability [15,16]. In this paper, we adopt the viewpoints from Forth et al. [11] and Delbosc et al. [17] and define the spatial fairness of transport as transport infrastructure that provides benefits evenly among different geographic units. Because the effects of public policies tend to cluster around specific physical locations [18], spatial fairness approaches are well-suited to assess such distributive effects [19]. Transport fairness influences many social aspects, such as territorial cohesion [20], the cost and time spent on daily commutes [21] and on public services [22]. Accessibility is, though imperfect, the most appropriate measure of benefits from transport infrastructure investments [23,24] and transport equity [6,17,25]. Presently, the evaluation of transport fairness has mostly focused on the needs of different social groups [26–28], investment in transport facilities [24,29–31], access to urban facilities [32–34], transportation planning [23,35–38] and interregional linkage strength [25,39–41]. The development of transport infrastructure and improved accessibility have promoted economic relationships and enhanced regional fairness and cohesion in countries and regions such as the UK, Holland, Poland and the European Union (EU) [42–45]. Therefore, the study of accessibility and spatial fairness has become a hot topic in the fields of social economics, transportation planning and human geography. Studies have mainly discussed transport fairness in urban areas or in metropolitan areas, especially emphasizing the root causes of inequity in the distribution of public facilities in a city, while ignoring the spatial effects and spatial fairness of transport in areas of undeveloped economy and unbalanced ecosystem. Although studies on densely populated urban areas are important, the research at the regional scale can guide large-scale transportation and sustainable development planning. As stated above, research on the accessibility and transport fairness in ecologically fragile areas is an important issue in social sustainability and will be a focus of future research.

2. Study Area and Data

2.1. Study Area

We selected the Qinghai-Tibet Plateau area as the study area. The Qinghai–Tibet Plateau area is known as “the Roof of the World,” as it contains the headwaters of most streams in Asia and the Third Pole of the Earth [46]. It is an important environmental barrier and the water source in the world and is also the frontier region and a concentrated severely poverty–stricken area of China [47]. However, due to restrictions related to geography, climate and society, transport development in the area has lagged behind for a long time, which historically has hindered the socio–economic development of the region [48]. However, with China Western Development and the construction of major infrastructure, the transport network greatly improved, which has promoted socio–economic development and stability in the region and improved living standards. Tibetans, almost herdsmen, exhibit seasonal rotational grazing, who graze at higher altitudes in summer and at lower altitudes (usually along roads or around towns) in winter. We believe that compared with social fairness, spatial fairness can better solve the current and future transportation planning and construction in a shorter period of time. Therefore, the study on the spatial fairness of transportation in the study area is conducive to improving people’s living standards and providing a useful reference for the development of such underdeveloped regions.

The Qinghai–Tibet Plateau area lies between 25°59′37″ and 39°49′33″ N, 73°29′56″ and 104°40′20″ E (Figure 1), with an area of about 2,542,400 km². In order to compare and analyze the evolution and characteristics of the transport network, we selected the administrative divisions of the Qinghai–Tibet Plateau area in 2016 as the study area, which covers six provinces and autonomous regions including Qinghai, Tibet and parts of Xinjiang, Gansu, Sichuan and Yunnan. The major cities include two provincial capitals—Xining and Lhasa, five prefecture–level cities (Haidong, Changdu, Linzhi, Shannan and Shigatse), seven county–level cities (Delingha, Golmud, Yushu, Hezuo, Maerkang, Kangding and Shangrila) and 18 prefecture–level cities within the 100km buffer zone, including Kashi, Jiuquan
and Chengdu. There are 1972 township administrative units in the Qinghai–Tibet Plateau area. For maintaining analytical continuity, changing administrative divisions was not considered during data processing and analysis.

Figure 1. The location of the study area.

2.2. Data Sources and Processing

In this study, the Qinghai–Tibet Plateau area data were sourced from the National Earth System Scientific Data Sharing Service Platform. Administrative division data were obtained from the Resources and Environment Science Data Center of Chinese Academy of Sciences. The traffic road network data were based on the national database at a 1:25,000 scale (Table 1). Vector data for transport networks in different years were obtained through vectorization of atlases from different periods, including the China Atlas (1976), China Traffic Album (1981), China Traffic Album (1987), China Traffic Album (1990), New Chinese Traffic Album (1996), China Traffic Album of New Century (2001), China Traffic Album (2006), Chinese Atlas (2011) and Practical Chinese Atlas (2017), which were published by China Map Publishing House. To avoid the “isolated island” effect, transport networks within a 100 km buffer area outside the study area were also included in this study.

Table 1. Data sources and description.

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extent of the Qinghai–Tibet Plateau area</td>
<td>National Earth System Scientific Data Sharing Service Platform (<a href="http://www.geodata.cn">http://www.geodata.cn</a>)</td>
</tr>
<tr>
<td>Administrative division data at all levels</td>
<td>Resources and Environment Science Data Center of Chinese Academy of Sciences (<a href="http://www.resdc.cn">http://www.resdc.cn</a>)</td>
</tr>
<tr>
<td>Vector data for transport networks and Atlas of China</td>
<td>National database at 1:25,000 scale (<a href="http://www.resdc.cn">http://www.resdc.cn</a>)</td>
</tr>
</tbody>
</table>

According to the highway design speed stipulated in the Technical Standard of People's Republic of China Highway Engineering (JTGB01–2003), the road and other roads in different years were assigned...
different speed values by analyzing existing research [49] and the characteristics of the study area (Table 2). In order to calculate the accessibility, the ordinary road network was first completely intersected and then the highway entrances and exits and train stations were connected with the ordinary road network to obtain the shortest accessibility time between nodes. Air transport and water transport were not considered in this study.

### Table 2. Speed assignments on roads and railways (km/h).

<table>
<thead>
<tr>
<th>Year</th>
<th>Railway</th>
<th>Highway</th>
<th>National Road</th>
<th>Provincial Road</th>
<th>County Road</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986, 1991</td>
<td>50</td>
<td>–</td>
<td>40</td>
<td>40</td>
<td>–</td>
<td>10</td>
</tr>
<tr>
<td>1996</td>
<td>50</td>
<td>–</td>
<td>60</td>
<td>40</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>2001</td>
<td>60</td>
<td>–</td>
<td>60</td>
<td>40</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>2006</td>
<td>70</td>
<td>100</td>
<td>80</td>
<td>60</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>2011, 2016</td>
<td>120</td>
<td>100</td>
<td>80</td>
<td>60</td>
<td>30</td>
<td>20</td>
</tr>
</tbody>
</table>

### 3. Methodology

We explored the distributive effects and spatial fairness of transport from the perspective of accessibility. Accessibility is a widely used concept in geography but its definition and modeling are often different. In view of different research targets, accessibility models mainly include distance accessibility, opportunity accessibility, economic accessibility and the gravitational model based on spatial interaction. We studied the accessibility of the region to the major city and emphasized the difficulty of using a traffic system to reach the destination from a given location, which is the horizontal fairness of the transportation system [50]. As such, the accessibility was calculated using the time accessibility model. Accessibility analysis can be used to estimate the distributive effects and spatial fairness of transport, which is defined as the accessibility change generated by the development of the transport network in different regions [51].

#### 3.1. Spatial Accessibility Model

With the ArcGIS® network analysis model, we obtained the shortest time between nodes [41,52]. The shortest time of nodes $i$ is defined as $T_i$, which denotes the difficulty of node $i$ using transportation systems to reach the given destinations. The calculation model is as follows:

$$T_i = \sum_{j=1}^{n} \frac{t_{ij}}{n} \quad i \in (1, \cdots, n), \quad j \in (1, \cdots, n)$$

where $t_{ij}$ is the shortest time spent between town $i$ and the major city $j$ and $n$ is the number of major cities in the region. The lower the value of $T_i$ value, the more convenient the traffic connection.

#### 3.2. Spatial Autocorrelation Analysis

In this study, the global Moran’s I index and local Moran’s I index are used for spatial autocorrelation analysis [53–55]. The global Moran’s I index is used to reflect the overall correlation and difference degree of the observed values of spatially adjacent regional units. The Global Moran’s I index is generally $(-1, 1)$. A positive value indicates positive spatial correlation, namely, its distribution is spatially clustered; a negative value indicates a negative spatial correlation, meaning its spatial distribution is scattered; and a value of 0 indicates that there is no spatial correlation, meaning the spatial distribution is random. Global Moran’s I index is a global assessment of spatial autocorrelation that cannot reflect the degree of correlation between a sub–region and its peripheral sub–regions. Thus, local spatial autocorrelation analysis must be conducted. The local indicators of spatial association (LISA) of each observation value is an index reflecting the spatial aggregation of each value with its spatially adjacent observation value, which can decompose the global spatial correlation coefficient...
into the spatial autocorrelation of each region. The significance of spatial autocorrelation can be tested according to the calculated test statistics. The general significance level is 0.05.

The global Moran’s I index is calculated as follows:

$$ Global \text{ Moran’s I} = \frac{\sum_{i=1}^{m} \sum_{j=1}^{m} W_{ij}(T_i - \bar{T})(T_j - \bar{T})}{S^2 \sum_{i=1}^{m} \sum_{j=1}^{m} W_{ij}} $$

$$ S^2 = \frac{1}{m} \sum_{i=1}^{n} \left( \frac{T_i - \frac{1}{n} \sum_{i=1}^{n} T_i}{\bar{T}} \right)^2 $$

For the $i$th regional unit, Moran’s I’s LISA formula is:

$$ Local \text{ Moran’s I}_i = \frac{(T_i - \bar{T})}{S^2} \sum_{i,j=1}^{n} W_{ij}(T_j - \bar{T}) $$

where $T_i$ represents the accessibility time of the township $i$, $m$ represents the number of spatial units involved in the analysis and $W_{ij}$ is the spatial weight matrix, indicating the adjacent relation of the town $i$ and $j$. If it is adjacent, $W = 1$; otherwise, it is 0.

### 3.3. Measurement Methods of Distributive Effects

We can learn from Pyrialakou et al. [13], Condeço–Melhorado et al. [56], Jin et al. [57] and Xu et al. [58] and characterize the distributive effects of transport infrastructure by the accessibility coefficient and relative accessibility. These indicators can accurately reflect the status of the entire transport network.

The accessibility coefficient refers to the ratio of the transportation cost of town $i$ to the average transport cost of all towns in the region:

$$ C_i = \frac{T_i}{(\sum_{i=1}^{n} T_i) / n} \quad i \in (1, \ldots, n) $$

where $C_i$ is the accessibility coefficient, $T_i$ is the shortest time spent between town $i$ and the nearest major city and $n$ is the number of towns in the region. The accessibility coefficient can be used to illustrate the relative accessibility level of nodes in the whole transport network. The smaller the accessibility coefficient, the better the accessibility. If $C_i > 1$, indicates that the accessibility level of the node is below the regional average level; if $C_i < 1$, the accessibility level of the node is better than the regional average level.

Relative accessibility can better reflect the trend in node accessibility level and the status of nodes in the development of the transport network. The formula is as follows:

$$ RA_i = \frac{T_{i(t+1)} - T_{i(t)}}{T_{t+1} - \bar{T}_t} \quad i \in (1, \ldots, n) $$

where $RA_i$ is the relative accessibility value of node $i$, the greater the value, the greater the degree of accessibility of the network affected by the development of the transport network. $T_{i(t+1)}$ is the accessibility value of node $i$ in $(t + 1)$ year; $T_{i(t)}$ is the accessibility value of node $i$ in year $t$; $T_{t+1}$ is the average accessibility of all nodes in the transport network in $(t + 1)$ year; and $\bar{T}_t$ is the average accessibility of all nodes in the transport network in year $t$.

### 3.4. Measure of Accessibility Spatial Fairness

The construction and development of the transport infrastructure will improve the efficiency of accessibility but there is also a situation in which the townships along the important arterial traffic benefit more than the townships far away. Therefore, the coefficient of variation and the standardized
The value is used in previous studies for measure and the evaluation of the state of accessible space allocation [59–61]. The general formula of the transport fairness measure is as follows:

\[ CV = \frac{1}{n} \left( \frac{1}{n} \sum_{i=1}^{n} (T_i - \bar{T})^2 \right)^{1/2}, i = 1, 2, \cdots, n \]  

(6)

where \( CV \) represents the global coefficient of variance, \( \bar{T} \) represents the mean of global accessibility time, \( n \) represents the number of the township in the region and \( T_i \) is the accessibility value of township \( i \). The higher the \( CV \), the more unfair the situation, which indicates that the gap in the accessibility level between towns increases which is a kind of negative influence on transportation development. Conversely, it indicates that fairness is a positive influence and the spatial allocation of accessibility is more equitable.

4. Results and Analysis

4.1. Spatial Pattern of Accessibility in Qinghai–Tibet Plateau Area

As the inverse distance weighting (IDW) model is a weighted distance average, the average cannot be greater than the highest or less than the lowest input [62,63] and accessibility is closely related to the distance [2]. By calculating the shortest time from any place in the Qinghai–Tibet Plateau area to 32 major cities, we used spatial interpolation and the IDW model in ArcGIS software to obtain the spatial pattern and characteristics from 1976 to 2016. Generally speaking, the accessibility of the Ali–Qiangtang Plateau–Ruoqiang area was relatively poor. Due to the construction and development of the transport network over many years, the traffic delays between towns and major cities have gradually declined and the spatial difference in the accessibility level was also reduced. Major transport infrastructure significantly improved the regional accessibility, especially after the opening of the Qinghai–Tibet Railway.

As can be seen in Figure 2, the longest accessibility time from any place within the study area to the nearest major city decreased from 288.70 h to 206.37 h between 1976 and 1986. The accessibility time of the region dropped further to 192.47 h between 1986 and 1991, which was mainly due to the change in the quality of roads and the division of main roads and general roads into national roads, provincial roads and county roads [64]. By 1996, the maximum accessibility time to reach a major city had reduced to 156.67 h. After the introduction of “China Western Development” in 2000, traffic development entered a new stage. With the continuous extension of the Qinghai–Tibet Railway and highways and the longest accessibility time to the nearest major city dropped to 115.48 h in 2001. By 2016, the maximum accessibility time from any place in the study area to the nearest major city had fallen to 24.51% compared to 1976 and the average accessibility time had decreased to 8.35 h. The improvement in the accessibility to the nearest major city promotes social, economic and cultural and health links between the towns and these cities, improving the overall development of the whole region as well as the living standards of local residents.

![Figure 2. Accessible time to major cities in the study area.](image-url)
There are a few major cities in the Qinghai–Tibet Plateau area, with only 14 cities at the county–level city and above. The Qiangtang Plateau and Hoh Xil are far from the city, while the surrounding major cities are mainly distributed along the Hexi Corridor (Gansu Province) and Chengdu Plain (Sichuan Province). The spatial pattern for accessibility to major cities from 1976 to 2016 (Figure 3) shows that areas with relatively good accessibility were mainly distributed in the Huangshui River Valley (major cities are Xining and Haidong), the Middle Region of “One River and Two Streams” in Tibet (the Yarlung Zangbo River, Lhasa River and Nyang River Valleys; major cities are Lhasa, Shigatse, Shannan and Linzhi) and areas with poor accessibility levels were Ngari, Western Nagqu and Western Shigatse. From the perspective of spatial accessibility change, from 1976 to 1981, the areas with good accessibility level to major cities (≤10 h) were mainly located in the areas surrounding major cities and a small number of regions with high accessibility level had formed in the relatively concentrated areas of Xining–Haidong and other cities. The shortest time from the Ngari–Qiangtang Plateau–Hoh Xil–Ruoqiang area to the nearest major city was more than four days (about 100 h). From 1986 to 1996, the Golmud–Delingha–Xining–Haidong–Linxia–Hezuo, Shigatse–Lhasa–Shannan–Linzhi and Maerkang–Kangding areas gradually formed in the northeast, south and southeast of the Qinghai–Tibet Plateau area and the accessibility level of Ngari had improved significantly. After 2000, the accessibility level of the region to major cities continued to improve and good accessibility (≤20 h) rapidly expanded with the development of important traffic arteries. Especially after the opening of the Golmud–Lhasa section of the Qinghai–Tibet Railway in 2006, the accessibility level of Hoh Xil and the other major cities greatly improved. After that time the access time from Ngari, which is far from the nearest major city, decreased to 70.76 h.

![Accessibility Time to Major Cities](https://via.placeholder.com/150)

**Figure 3.** The spatial pattern for accessibility time to major cities in the study area.

### 4.2. Evolution Trend of Accessibility at Township Level

Using ArcGIS zoning statistical functions, we obtained the average accessibility of 1972 town administrative units in the Qinghai–Tibet Plateau area over the study period. GeoDa software was applied to analyze the accessibility level of township units in the study area. After the spatial autocorrelation analysis of the accessibility values of townships in nine particular years (Table 3), we found that Moran’s I index is greater than 0.95 (p < 0.05), indicating that the change in accessibility and adjacent units is positively related, the statistical result is authentic, the correlation is significant and there is a positive spatial autocorrelation in the overall pattern. From 1976 to 2016, the Global Moran's I index fluctuated around 0.95, with a relatively stable value. The extension of the road network has an impact on the spatial distribution of high accessibility, and adjacent units are positively related, the statistical result is authentic, the correlation is significant; therefore, the GeoDa local autocorrelation analysis was used to judge the distribution of high–accessibility value cluster regions and low–accessibility value cluster regions.
Moran’s I index fluctuated around 0.95, with a relatively stable value. The extension of the road network, such as the opening of the expressway in the Huangshui River Valley in 2001 and the Golmud–Lhasa section of the Qinghai–Tibet Railway in 2006, led to a slight fluctuation of the Moran Index after 2000.

Table 3. Global Moran’s I index of accessibility level at town scale in the study area.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Moran’s I index</td>
<td>0.9515</td>
<td>0.9514</td>
<td>0.9514</td>
<td>0.9512</td>
<td>0.9507</td>
<td>0.9517</td>
<td>0.9503</td>
<td>0.9496</td>
<td>0.9508</td>
</tr>
<tr>
<td>z-score</td>
<td>70.463</td>
<td>70.469</td>
<td>70.435</td>
<td>70.373</td>
<td>70.519</td>
<td>70.284</td>
<td>70.805</td>
<td>70.662</td>
<td>70.511</td>
</tr>
<tr>
<td>p-value</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Given the global Moran’s I index cannot judge whether the statistical significance between the local correlation type and its cluster region is significant; therefore, the GeoDa local autocorrelation analysis was used to judge the distribution of high–accessibility value cluster regions and low–accessibility value cluster regions, to probe the spatial pattern evolution trend of the accessibility level of QTP township units in 1976–2016. As shown in Figure 4 (all results have passed the significance level test of 5%), the proportion of high–high accessibility value townships and low–low accessibility townships remained stable at around 15% and 29% respectively. On the whole, Ali, Qiangtang Plateau, Hoh Xil and other regions had high–high valued cluster areas from the perspective of the spatial pattern and the surrounding townships of the central cities had low–accessibility value cluster areas. However, the spatial pattern changed significantly with the opening of the Golmud–Lhasa section of the Qinghai–Tibet Railway. Before 2006, the spatial pattern change in township accessibility level was concentrated in the extension of low–low cluster areas around Delingha, Maerkang and Lhasa–Shigatse and the better development trend of the accessibility level of towns, such as Pitou, Chaka and Shigatse. Since 2006, the opening of the Qinghai–Tibet Railway to traffic improved the accessibility level along the railway; the accessibility value in high–high cluster areas, such as Anduo, Nagqu and Hoh Xil decreased, while the accessibility value in Ganzi, Changdu and other regions increased and the number of townships with relatively decreased accessibility levels slightly increased.

Figure 4. The LISA of accessibility at the township level in the study area.
4.3. Distributive Effects in Transport Infrastructure at the Town Scale

With the accessibility coefficient and relative accessibility, we were able to explore the distributive effects of transport infrastructure development at the township level in the study area from 1976 to 2016.

4.3.1. Accessibility Coefficient

Based on the accessibility level of a town to a major city (Figure 5), from 1976 to 2016, the closer a town was to a major city, the smaller the accessibility coefficient. Towns near a major city had small accessibility coefficients and the accessibility of towns in the Qaidam Basin–Xining–Haidong–Hezuo, Shigatse–Lhasa–Shannan–Linzhi (the Middle Region of One River and Two Streams in Tibet), Changdu–Yushu, Maerkang–Kangding, Shangri-la–Lijiang–Lushui and Kashi–Hotan regions was above average. Being far from a major city and a lack of high-grade land transport networks were the main reasons for the relatively high accessibility coefficient of the towns in Ngari. Western Shigatse, Qiangtang Plateau, Ruqiang and other areas far from major cities also had high accessibility coefficients and their access to the nearest major city was relatively poor. Towns with the most significant accessibility coefficient changes (Nagqu, Anduo, Nierong and Hoh Xil) were along the Qinghai–Tibet Railway, which was constructed and began operations in 2006.

![Figure 5. The spatial pattern evolution of the accessibility coefficient at the town scale in the study area.](image)

Transport infrastructure usually develops in focal areas, connects important traffic nodes and then extends to the entire region, changing the absolute difference in the accessibility between different nodes in the region. From 1976 to 2016, the maximum accessibility coefficient at the township level in the study area was concentrated in Ali, including Chulusongjie, Qusong, Sarangduotuolin and Daba. The maximum value of the accessibility coefficient increased with time from 6.19 in 1976 to 6.32 in 2001 and up to 6.67 in 2016, indicating that the overall accessibility level was rising. However, the difference in transport infrastructure between regions gradually expanded, especially in Ali.

The main reason for the large difference in the accessibility coefficients between villages and towns was that the construction of the transport network was closely related to the level of local social and economic development. The eastern part of the Qinghai–Tibet Plateau area is a relatively concentrated population center with towns and resources, so major transport infrastructure is usually constructed first in these areas. For example, the Qinghai–Tibet Railway was first built in the Huangshui Valley, the Qaidam Basin and other areas where population, towns and resources were dense. Then, the railway passed through the Hoh Xil and Kunlun Mountains to connect Lhasa and then
extended to areas with relatively lower populations, towns and resources, such as the Lhasa–Shigatse Railway and Korla–Golmud Railway. Highways in the study area were first extended from Lanzhou to Haidong and Xining, then around the Qinghai Lake, connecting Gonghe, Dulan, Delingha, Xitieshan, Golmud and Dunhuang.

4.3.2. Relative Accessibility

From 1976 to 2016, the transport network in the study area changed dramatically in quantity and quality. The relative accessibility of Ali was higher than the changes in accessibility from towns to the nearest major city. The relative accessibility values for towns around the major cities were small (Figure 6). From 1976 to 1991, the influence of the transport network on Ali was stronger than in other areas and it had a weaker influence on the accessibility level of towns around the major cities. In addition to Ali, the relative accessibility values for towns in 1991–1996 were greater, such as in Zado, Baqing, Nierong and Anduo. By 2001, the relative accessibility value of Ali was higher than all other regions. With the opening of the Golmud–Lhasa section of the Qinghai–Tibet Railway in 2006, the improvement in accessibility of towns in North Nagqu and Hoh Xil was the most striking. From 2011 to 2016, towns with relatively high accessibility value were mainly distributed in Ali. The relative accessibility values for towns in Yecheng, Pishan and Hotan were also large. Therefore, future development of the transport network in this area will improve the accessibility level of rural areas like Ali.

![Figure 6. The spatial pattern evolution of relative accessibility at the town scale in the study area.](image)

From 1981 to 2016, the maximum relative accessibility of towns in the study area increased (Table 4) but the development of the transport network better alleviated traffic problems in Ali than in other areas. This was consistent with the spatial spillover effects of transport infrastructure found in previous studies [25,65]. Towns with larger relative accessibility from 1981 to 1991 were mainly distributed in Ali and the maximum value increased from 6.09 to 6.21. In 1996, it dropped to 5.73, rose to 6.38 in 2001 and remained above 6.80 in 2006–2016. Towns with smaller relative accessibility values were mainly located in the areas surrounding major cities. Their accessibility to the nearest major cities was good and transport development had less of an impact on them than areas with poor transportation conditions.
The above analysis showed that the accessibility coefficient and relative accessibility revealed distributive effects and spatial fairness of the accessibility due to the development of transport infrastructure in the Qinghai–Tibet Plateau area from different dimensions. The accessibility coefficient compares average accessibility at the township level at certain times, reflecting differences in accessibility improvements in different regions due to traffic development. The accessibility coefficient has clear spatial effects, such as the opening of the Qinghai–Tibet Railway, which improved the accessibility level of towns along the line and exacerbated the transportation conditions in the inaccessible areas and spatial unfairness in the transport infrastructure within the region. Relative accessibility is the degree of change in the accessibility of towns over a certain period relative to the overall accessibility of the region, which can represent the distributive effects of transport development at different periods. Therefore, research on the distributive effects and characteristics of transport infrastructure is important for exploring the spatial fairness of the transport network development in different regions.

### 4.4. Impact of Transport Development on Accessibility Fairness at the Township Level

The distributive effects and accessibility of transport infrastructure include not only the concept of space but also the concept of fairness. From Table 5 the global CV value in the Qinghai–Tibet Plateau area showed an increasing trend and the CV value increased by 0.0028 in absolute value from 1976 to 1996. Since the implementation of the China Western Development plan, CV increased from 0.8064 in 1996 to 0.8205 in 2001 and rose to 0.8538 in 2016. A larger CV value indicates that the development of the transport network was decreasing the spatial fairness of accessibility of the townships, which is a negative fairness effect. This indicates that the regional transport accessibility tended to be unfairly distributed in space, especially after the introduction of the China Western Development plan. Before 2000, the Qinghai–Tibet Plateau area was mainly dominated by ordinary highways and the railway failed to fully exert its effect on the accessibility of townships due to technical restrictions. After 2000, with the railway construction and the acceleration of trains, as well as the development of high–grade highways, the accessibility pattern changed and the corridor effect gradually appeared along the important arterial traffics, leading to the decrease in accessibility fairness.
Western China, will have spatial impacts on a wider range of social, economic and land use factors, from 1976 to 2016 and determined the distributive effects and spatial fairness of transport based on several indicators at the township level. The importance of transport infrastructure to the country and region is evident, especially in the Qinghai–Tibet Plateau area, which is not only the most unique Qinghai–Tibet alpine–cold traffic zone in the world [66] but also the most unique natural environment on earth, providing a natural laboratory for the study of the coordinated development of human–earth relations. However, there are some limitations to the study in terms of transport infrastructure, accessibility and fairness. We mainly discussed the spatial distribution of accessibility and only considered the social needs of different regions. Given that the vast majority of Tibetans are seasonal nomadic herdsmen (grazing at high altitudes in summer and grazing along low altitude highways and around towns in winter), living locations are not fixed. Transport infrastructure provides these people with the most basic travel avenues for shopping, education, health care and so forth. As mentioned above, although the research on spatial fairness is not perfect, it is important to improve the living standards of local residents and regional cohesion. The development of transport infrastructure, especially air transportation and high-speed land transportation (such as highways and high-speed railways) in Western China, will have spatial impacts on a wider range of social, economic and land use factors, which need to be studied further.

5. Discussion

We analyzed the spatial patterns of transport development in the Qinghai–Tibet Plateau area from 1976 to 2016 and determined the distributive effects and spatial fairness of transport based on several indicators at the township level. The importance of transport infrastructure to the country and region is evident, especially in the Qinghai–Tibet Plateau area, which is not only the most unique Qinghai–Tibet alpine–cold traffic zone in the world [66] but also the most unique natural environment on earth, providing a natural laboratory for the study of the coordinated development of human–earth relations. However, there are some limitations to the study in terms of transport infrastructure, accessibility and fairness. We mainly discussed the spatial distribution of accessibility and only considered the social needs of different regions. Given that the vast majority of Tibetans are seasonal nomadic herdsmen (grazing at high altitudes in summer and grazing along low altitude highways and around towns in winter), living locations are not fixed. Transport infrastructure provides these people with the most basic travel avenues for shopping, education, health care and so forth. As mentioned above, although the research on spatial fairness is not perfect, it is important to improve the living standards of local residents and regional cohesion. The development of transport infrastructure, especially air transportation and high-speed land transportation (such as highways and high-speed railways) in Western China, will have spatial impacts on a wider range of social, economic and land use factors, which need to be studied further.

6. Conclusions

The Qinghai–Tibet Plateau area is a unique geological, geographical, ecological and population region. It is also an important environmental security barrier and a concentrated area of severe poverty in China. Research on transport infrastructure development and its spatial effects is a critical starting point for the coordinated development of the human–environment relationships, which has important practical and theoretical significance. The main conclusions are as follows:

(1) With the construction and development of the transport network, the accessibility to the major cities of any place in the Qinghai–Tibet Plateau area improved continuously with significant time–space convergence effects. Important traffic arteries played a positive role in improving the accessibility of the area. Major transport infrastructure like the Qinghai–Tibet Railway had important impacts on the accessibility of the Hoh Xil and Nagqu areas. The accessibility level in

Figure 7. The local coefficient of variation of accessibility fairness of transport development at the township level from 1976 to 2016.
the areas far from major cities (such as Ali Prefecture) also changed significantly. Areas with good accessibility level gradually expanded from those near the major cities to contiguous areas like Qaidam Basin–Xining–Haidong and the Middle Region of One River and Two Streams in Tibet.

(2) The spatial autocorrelation analysis of the accessibility value of townships shows that the construction of important transport infrastructure (such as the Qinghai–Tibet Railway) has a significant impact on the agglomeration of accessibility and can improve the accessibility level of the areas along the railway.

(3) The development of transportation enables access to major cities. After more than 40 years of transport construction and development, the access time to the nearest major city was dramatically shortened. Due to the government’s huge investment in transportation, more Tibetans have more opportunities to travel to cities to enjoy better education, medical treatment, life opportunities and other services.

(4) The overall accessibility level of the Qinghai–Tibet Plateau area improved over the studied 40 years but transport construction had different distributive effects on the region. The accessibility coefficient indicates that, generally, the closer a town to the central city, the smaller its value. Relative accessibility reflects the impact of transport infrastructure construction on other places, which is a spatial spillover effect of transport infrastructure investment. Here, the construction of major transport infrastructure not only rapidly improved the accessibility of areas where construction occurred but also the accessibility of the whole region.

(5) From 1976 to 2016, the global CV value of the Qinghai–Tibet Plateau area presented an increasing trend, indicating that the global transport accessibility tended to be unfairly distributed in space, especially after China Western Development, transport unfairness was more significant. In the future, with the construction of the Sichuan–Tibet Railway, Xinjiang–Tibet Railway and highways, the spatial fairness of transport is expected to improve.

In the past, the Chinese government implemented policies and planned the transport network, prioritizing superiority of efficiency over fairness, which led to priority planning and construction of transport infrastructure in areas with better economic conditions, such as in Yangtze River Delta and Eastern China. However, the government has gradually shifted to paying equal attention to efficiency and fairness or even giving priority to fairness. European and American scholars have earlier noticed the fairness of social resources, which is exactly what China’s current regional planning lacks. Therefore, the study of spatial fairness in the Qinghai–Tibet Plateau area is helpful to understand the social effects of transportation planning in China today and the sustainable transport development in the future.

**Author Contributions:** Conceptualization, G.X., L.T. and C.X.; methodology, software, formal analysis, investigation, resources, data curation, writing—original draft preparation, visualization, G.X.; writing—review and editing, validation, G.X., L.T. and C.X.; supervision, project administration, funding acquisition, C.X.

**Funding:** This research was funded by National Natural Science Foundation of China, No. 41831284, No. 41671160 and No. 41501120.

**Conflicts of Interest:** The authors declare no conflict of interest.

**References**


27. Yuan, Y.; Xu, J.; Wang, Z. Spatial Equity Measure on Urban Ecological Space Layout Based on Accessibility of Socially Vulnerable Groups—A Case Study of Changting, China. *Sustainability* 2017, 9, 1552. [CrossRef]


32. Markham, F.; Doran, B. Equity, discrimination and remote policy: Investigating the centralization of remote service delivery in the Northern Territory. Appl. Geogr. 2015, 58, 105–115. [CrossRef]
35. Martens, K. Justice in transport as justice in accessibility: Applying Walzer’s ‘Spheres of Justice’ to the transport sector. Transportation 2012, 39, 1035–1053. [CrossRef]
40. Kim, H.; Sultana, S. The impacts of high-speed rail extensions on accessibility and spatial equity changes in South Korea from 2004 to 2018. J. Transp. Geogr. 2015, 45, 48–61. [CrossRef]


60. Monzón, A.; Ortega, E.; López, E. Efficiency and spatial equity impacts of high-speed rail extensions in urban areas. *Cities* 2013, 30, 18–30. [CrossRef]


© 2019 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).