



Impacts of major vehicular roads on urban landscape and urban growth in an arid region: A case study of Jiuquan city in Gansu Province, China



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ABSTRACT

Urbanization has brought about dramatic changes in the urban environment in China and its associated human population and transportation systems in recent years. However, urbanization in the oases of arid regions of China has been little studied and remains poorly understood. This paper aims to analyze spatiotemporal changes in an urban landscape along major vehicular road transects and compare the relationship between urban growth and transportation in Jiuquan, an oasis city in an arid region of China. We integrated remote sensing images, landscape metrics, and urban-rural gradient analysis to address these questions. The results showed that major vehicular roads stimulated Jiuquan's urban expansion, especially with regard to built-up land containing urban green land areas. Oasis urbanization not only increased landscape fragmentation and structural complexity, but also followed a linear branching, leapfrogging growth pattern characterized by "axial clumps" extending from downtown into rural areas along the road network. The primary source of urban land was not agricultural land, but unused land. These results also indicated that the transect approach implemented along representative roads was effective for studying the urbanization of oasis cities. Such an approach could be applied to master planning in similar oasis cities throughout arid China.

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1. Introduction

Rapid urban growth is a key concern for local authorities and urban planners, as it results in extremely complex landscape change processes, and profoundly influences the structure and function of both natural ecosystems and human livelihoods (Luck and Wu, 2002; Buyantuyev and Wu, 2009; Li et al., 2013a,b). In 2014, more than half the world's population lived in cities and towns, a figure that is estimated to increase to 70% by 2050 (United Nations, 2014). This increase implies that the spatial pattern of urban landscapes and land-cover conversion will continue to be complex (Wu, 2014; Wu et al., 2014). Therefore, it is important to understand the spatial patterns of urbanization and their impacts on ecological processes from global to local scales.

The urbanization process is dynamic, and the direction and magnitude of urban landscape change may vary over time and

space (Li et al., 2013b; Xu and Min, 2013). To understand and capture the process of urbanization and its ecological consequences for landscapes, a more synthetic approach needs to be implemented in order to quantify landscape changes (Solon, 2009). The classical approach is an urban-rural gradient analysis, which is based on a moving window (Luck and Wu, 2002). The urban-rural gradient is a systematic and effective approach to detect the spatiotemporal complexity of urban dynamics. The approach has been more recently integrated with landscape metrics to understand urban ecological processes (McDonnell and Hahs, 2008). In addition to being used for demonstrating landscape change across space along urban-rural transects, this method has also been extended by incorporation of temporal trend analysis (Weng, 2007; Li et al., 2013b) and multiplication of transects (Kong and Nakagoshi, 2006; Yu and Ng, 2007; Solon, 2009). Most of the past studies of the transect directions in these gradient paradigms were west-east and/or north-south (Luck and Wu, 2002; Weng, 2007; Li et al., 2013b), along eight directional transects (Kong and Nakagoshi, 2006; Yeh and Huang, 2009; Zhou and Wang, 2011; Shrestha et al., 2012), around a concentric circle (Zhou and Wang, 2011;

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Solon, 2009), or along a specific transect that crosses the area disturbed by urbanization (Luck and Wu, 2002; Yu and Ng, 2007; Li et al., 2013b). These approaches may limit the ability to detect urban change because although most urban expansion appears to have taken the form of dispersed or sprawling pattern alternating between diffusion and coalescence phases, the trajectories and rhythms of urban landscape change may vary in certain ways according to specific geographical and historical characteristics as cities evolve. For example, the developmental form of oasis cities in arid areas may be different from that of coastal cities in humid regions (Tian and Wu, 2015; Yeh and Huang, 2009; Yu and Ng, 2007; Li et al., 2013b).

In arid areas, oases form a unique geographical landscape with higher productivity than their surrounding landscape (deserts). Oasis cities have been the primary sites for flourishing vegetation and human settlement in these areas (Jia et al., 2004; Xie et al., 2014). Oasis cities, mostly based on oasis-irrigated agriculture, are also the production and living centers of humankind in oasis systems (Zhang et al., 2009). From an urban ecology perspective, an oasis urban region is a complex and comprehensive ecosystem (Liu et al., 2010; Yang and Liu, 2014) due to the fragility of the environmental system and intensive human activities in arid areas (Xie et al., 2007; Liu et al., 2010). However, few papers have been published on oasis urbanization and its associated landscape change, especially in arid regions of China.

Oasis urbanization is a complex process which is affected by water resources and by social and economic factors such as transportation, migration, exploitation of mineral resources, and public policies (Hawbaker et al., 2004; Zhang et al., 2009). In addition, the areas experiencing the most intense oasis urbanization have not shown homogeneous urban development in all directions, but often along a preferential direction (or in shifting preferred locations) depending on specific factors (such as vehicular roads and other related infrastructure). Vehicular roads have played an important role in urban development through the accessibility they provide for land and material exchange (Saunders et al., 2002; Aljoufie et al., 2013). An example is the tendency for industrial areas to develop close to motorways (Müller et al., 2010; Xie et al., 2013). Major vehicular roads could also possibly be considered as “pioneers” and could be used to indicate the direction of urban development and exert a profound influence on urban landscape changes (Fan et al., 2009; Müller et al., 2010; Tian and Wu, 2015).

Recently, several studies have explored the relationship between vehicular roads and urbanization across diverse urban systems. The results showed a significant relationship between transportation and urban sprawl (e.g., Handy, 2005; Müller et al., 2010). Results also indicated that vehicular roads are a significant factor in urban growth and influence landscape change (Aljoufie et al., 2013; Tian and Wu, 2015). However, the relationship between major vehicular roads construction and landscape changes in urban oases in arid areas is still unknown, especially in arid regions of China. This gap exists perhaps due to the poor economic status of such cities and their small size relative to other cities in China (Xie et al., 2007). At the same time, it has been widely hypothesized that “there must be some impacts or interactions between major vehicular roads construction and its surrounding landscape change” (Müller et al., 2010), but few studies have considered the spatial and temporal effects of different vehicular road transects on the urban landscape using quantitative methods. Does the urban landscape of an oasis city take the form (or model) of sprawling patterns along a road axis (such as the linear branching form of urban leapfrogging growth) and would it vary along an urban-rural roadside gradient? Empirical case studies are needed to answer this question.

In China, most oasis cities are connected with each other by

national highways, expressways, provincial roads, county and township roads (rural roads) (Li et al., 2010; Liu et al., 2011). Most oasis cities are of medium size (with a population between 300,000 and 1 million people) or small size (with a population between 50,000 and 300,000 people). This research considered one medium-sized ancient city along the Silk Road¹ in northwestern China named Jiuquan, for which urban area increased more than eight times from 1949 to 2013. The rapid urban expansion of Jiuquan not only turned it into the pacesetter of urbanization in the arid area of northwestern China, but also attracted attention from economists, environmentalists, and urban planners. Therefore, taking Jiuquan city as a case for understanding and exploring urban development in this area would serve as a good pilot project for learning lessons and providing theoretical and practical guidance for the sustainable development of northwestern China (Fang and Xie, 2010; Wu et al., 2014).

The aim of this study was to quantify the spatiotemporal patterns of an urban landscape and to evaluate the influence of representative vehicular road axes (such as national highways and provincial roads). For this purpose, a contrast analysis of gradient transects was conducted along national highways and provincial roads to answer the following questions: (a) what are the spatiotemporal patterns of this urban landscape, and (b) can vehicular roads affect urban expansion (or urban landscape change) in an oasis city in arid China, and if so how?

2. Materials and methods

2.1. Study area

Jiuquan city (98°12′–99°18′E, 39°10′–39°59′N) (Fig. 1a), a typical agricultural oasis city with a history of more than 2000 years, is located in the Hexi corridor of arid, northwest China. This region is dominated by an arid temperate continental climate, with a mean annual temperature of 7.4 °C and a mean annual precipitation of 85.3 mm. Jiuquan city originated with the prosperity of the silk trade and the establishment of a garrison in 121 BC. Today, it is not only a famous tourist city benefitting from its historical heritage, but it also has become an important inland agricultural-industrial city and transportation center after the implementation of China's economic reforms (an opening-up policy of economic liberalization launched in 1978). The urban population increased from 40,804 in 1980 to 210,043 in 2012 and the total value of industrial output has doubled over the past thirty years (Suzhou Statistics Bureau, 2012) (Fig. 2). This increase has resulted in great demand for transportation infrastructure and influenced the urban landscape in Jiuquan city.

The study area covered the landscape along two main roads in Jiuquan city, specifically national highway 312 and provincial road 214 (Fig. 1b). National highway 312 is a key east-west route beginning in Shanghai and ending at Khorgos in the Xinjiang Uygur Autonomous Region. Provincial road 214, constructed in 1946, is another trunk highway connecting Jiuquan city in Gansu Province with Ejina Banner in the Inner Mongolia Autonomous Region.

2.2. Data and land-use classification

Landsat TM/ETM + images (Path 135, Row 32, acquired on 22/9/

¹ The Silk Road: a historically important international trade route between China and the West, established during the Han dynasty (approximately 200 BC to 200 AD), along which Han silk fabrics, china, and other products were transported to Southwestern Asia and Europe, and which linked China with the West both in ancient and modern times.

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