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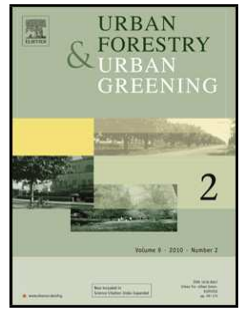

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Peri-urbanization may vary with vegetation restoration: a large scale regional analysis

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ABSTRACT: Over that past decade, ecological restoration practices have expanded globally. However, the effectiveness of ecological restoration depends on the complex interactions of various natural and socioeconomic factors, about which there is limited scientific understanding and thus provides an important research frontier. This paper analyzed the relationship between regional scale vegetation restoration and the process of urbanization using the Loess Plateau of China as a case study. This region has experienced both rapid urbanization and a high number of vegetation restoration activities. Urbanization and vegetation restoration can be considered as extremes on the spectrum of environment preservation activities. Three separate spatial correlation analyses between urbanization and vegetation restoration were identified, resulting in: 1) insignificant correlations in saturated urban areas; 2) significant negative correlations in peri-urban areas; and 3) significant positive correlations in undeveloped areas. The relationship between urbanization and vegetation restoration is thus stage-dependent. Impacts of urbanization on vegetation degradation has improved but has not been fully addressed by large scale vegetation restoration. Regardless of whether the county or grid scale is used, peri-urbanization was found to be the critical factor affecting the effectiveness of vegetation

restoration over both time and space. Therefore, peri-urbanized areas are viewed as priorities for improving the coupling of urban development and vegetation restoration.

Keywords: vegetation restoration; peri-urbanization; correlations; planting patterns.

1 Introduction

The effects of urbanization on vegetation degradation have drawn increasing attention (Imhoff et al. 2004; Costanza et al. 2015; Pickens et al. 2017). Studies of the effects of urbanization on plant function in ecosystems at the landscape scale have mainly documented the loss of vegetation caused by the modification of farmland into urban land, for example in the United States (Milesi et al. 2003), in Europe (Gingrich et al. 2015), and in China (Tian and Qiao, 2014). At urban and regional scales, spatio-temporal correlations between urbanization and vegetation change indicators such as Fractional Vegetation Cover (FVC), Net Primary Productivity (NPP), Normalized Difference Vegetation Index (NDVI), and Leaf Area Index (LAI) have been explored (Lu et al. 2015; Morawitz et al. 2006; Liu et al. 2015). Research has found urban development to be negatively correlated with NPP, NDVI, and LAI (Xu et al. 2007; Buyantuyev and Wu 2009; Peng et al. 2015). With the expansion of ecological restoration practices globally (Boyer et al. 2016; Borchard et al. 2017; Wen et al. 2017), the effectiveness of such restoration interventions has become a key research topic. Plant biomass (Venson et al. 2017), carbon dynamics (Zhang et al. 2012) and vegetation cover change (Wiesmair et al. 2017) have all been used as proxies for assessing vegetation restoration implementation (Jiapaer et al. 2011; Bao et al. 2017).

Vegetation restoration and extensive urban land development can be considered as extremes on the spectrum of environment preservation and greatly affect carbon sequestration and other ecosystem functions (Zhang et al. 2007). However, the effectiveness of ecological restoration depends on the complex interactions of various natural and socioeconomic factors, about which scientific understanding is limited and thus provides an active research frontier. In particular, this article addresses the following research questions. What are the correlations in space and time between outcomes when vegetation restoration practices and urbanization occur simultaneously? Can negative correlations between urbanization and vegetation properties be identified when vegetation restoration trends are incorporated into the analysis? How effective is vegetation restoration at each stage of the process of urbanization?

As a case study, we use the Loess Plateau of China, where both rapid urbanization (i.e. the Western Development Program) and the practice of returning farmland to forest and grassland (i.e. the Grain for Green Program) have been implemented since 1999 (Feng et al. 2016; Kou et al. 2016). The Loess Plateau is located in an arid and semi-arid area, and this type of habitat accounts for about 40% of the total global land surface (Warren et al. 1996). Therefore, this study contributes to a deeper scientific understanding of the coupling of urbanization and vegetation restoration at regional scales, in water limited environments, facilitating sustainable policies towards urban development and regional ecological integrity.

2. Material and methods

2.1 Research area

The Loess Plateau, the largest area of sedimentary loess in the world, lies in the upper reaches of the Yellow River in China, between 33°43'–41°16'N and 100°54'–114°33'E (Fig. 1). It encompasses an area of about 621,400km^2, and a total of 332 counties and county-level cities. From south to north, the Loess Plateau crosses both the warm temperate and temperate zones. From east to west, it spans semi-humid, semi-arid and arid areas and features typical continental climate characteristics. The ~400 mm of annual precipitation is seasonal with widely variable local rates. The evaporation rate is large and the frost-free period is short. This area has one of the most serious soil erosion problems in China and globally. Soil erosion has exacerbated the deterioration of the environment in this area and unsustainable land uses have intensified the rate of soil erosion. Therefore, since 1999, China has implemented a policy of returning farmland to forest and grassland, in an effort designed to achieve vegetation restoration. This mitigates the widespread and severe soil erosion along with other parallel improvements in ecological function, such as carbon sequestration and habitat provision (Fu et al. 2011; Feng et al. 2016; Wang et al. 2016).

2.2 Grid scale correlation analysis

A 250 m × 250 m grid was used as the basic analysis unit for quantifying changes in land urbanization and NPP and for statistical inference of the nature of the relationships between these two processes.

2.2.1 Data sources

NPP is one of the most important factors characterizing ecosystem structure and function. An analysis of NPP provides an important integrated approach that can be used to assess ecosystem functions, as well as providing a key variable that can be used for assessing the effects of land-use change on ecosystem conditions. In this case, the change of NPP was used as the indicator to describe the effectiveness of vegetation restoration in the Loess Plateau. NPP data from 2000 to 2010 were calculated using the Carnegie-Ames-Stanford Approach model (Potter, 1996; Potter, 1997). Meteorological data of annual average rainfall and temperature were derived from 85 meteorological stations distributed across the study area, and from information in the monthly Ground Weather Record Monthly Report issued by climate data processing departments of provinces, municipalities and autonomous regions in the study area. Remotely sensed data of night-time brightness from NightSat (https://ngdc.noaa.gov/eog/download.html) was used to create maps portraying the extent and spatial distribution of urbanized, peri-urban, and non-urban areas (Imhoff et al. 2004). All data were over the 250 m spatial resolution grid.

2.2.2 Data analysis

A pairwise expansion of a linear regression analysis of the NPP data and data relating to the process of urbanization from 2001 to 2010 was undertaken in SPSS. Here the regression slope is used as a reference indicator of positive or negative correlation between these two factors, under various conditions. The slope coefficient was used to identify any significant ($p < 0.05$) or non-significant responses ($p > 0.05$) (Wu et al. 2014; Lu et al. 2015). At the same time, and in order to clarify the role of climatic factors on NPP, interpolation by ordinary kriging in ArcGIS ver. 10.2 (ESRI, Redlands, CA, USA) was used to generate the simulated spatio-temporal changes of rainfall and temperature (Wang et al. 2003; Fujun et al. 2011). The effects of rainfall and temperature for each period were determined in the same manner.

2.3 County scale correlation analysis

In order to understand the data relating to economic conditions and urbanization of the population, the county level administrative area was used as the analysis unit because of limited availability of data at a finer scale.

2.3.1 Data sources

Land use change is the most frequently adopted indicator of urbanization (Wu et al., 2016; Tomao et al., 2017; Chen et al., 2017). However, the characteristics of urbanization may also be defined as changes in population, expansion of the economy and increased areas of construction. To examine the combined effects of urbanization and vegetation restoration practice, our study included these three characteristics as urbanization indicators for the years 2000 and 2010, together with the rate of change from 2000 to 2010. The level of urbanization was represented by four measurements: 1) the degree of urban and rural population migration (ratio of non-agricultural population to total population, with N=324), 2) the degree of economic agglomeration (gross domestic product, GDP, with N=265), 3) the degree of urban expansion (ratio of urban area to total area, with N=331), and 4) the population density in urban areas (ratio of population to urban area, with N=324). The extent of the urban area was determined from land use data for the Loess Plateau from 2000 and 2010, derived from 30m Landsat remote sensing images and an object oriented classification approach (Wang et al. 2014). The non-agricultural and total population data were determined from the 2000 and 2010 censuses. The GDP data were provided by the China Economic and Social Development Statistics Database (http://data.cnki.net/).

2.3.2 Data analysis

Again, ArcGIS ver. 10.2 tools were used to undertake a spatial analyses at the county scale, along with a hotspot analysis to identify areas of strong and weak urbanization. An average value of NPP was assumed representative at the county scale, and the Zonal Statistics tool was used to analyze NPP data at this scale. The study area was divided into three types using (Jenks) natural breaks based on the degree of urban expansion (Fig. 5). The "trading space for time" method was used to represent urbanization stages by different urban development zones. This allowed the correlation between NPP and the degree of urban expansion at urbanization, peri-urbanization and low urbanization types to be obtained. Correlation analyses were undertaken in SPSS through a linear regression and comparative analysis of NPP and urbanization indicators for 2000 and 2010, and linear regression and quadratic polynomial trend analyses of the rates of change of NPP and urbanization indicators from 2000 to 2010.

3. Results

3.1 Spatiotemporal changes in vegetation restoration

3.1.1 The changes of grid scale vegetation restoration

The slope data in Fig. 2 reflect NPP trends over 11 years, with the areas shaded green indicating areas of significant vegetation recovery and the areas shaded red vegetation loss.

Areas with a significant positive NPP change trend accounted for 29.76% of the total area, and the most obvious areas are connected in northern Shaanxi, indicating this region has experienced the most effective vegetation restoration efforts. The Linxia-Dingxi-Tianshui corridor also experienced better than average restoration. Areas with a significant negative NPP change trend accounted for 2.8% of the total area. These areas with relatively poor vegetation restoration results are located in the south, around Yan'an city, Yuncheng city and in the Jiaozuo and Jincheng city intersection. The difference between the best and worse areas of vegetation restoration was nearly a factor of 11.

3.1.2 The changes of county scale vegetation restoration

The average NPP at the county scale from 2000 to 2010 exhibited a relatively stable upward trend over time, peaking in 2008 (272.0 g·cm−2) and then decreasing slightly by 2011 (264.3 g·cm−2). The highest NPP at the county scale in 2000 was in Huanglong County, Shaanxi Province (571.4 g·cm−2), followed by Huangling County (543.5 g·cm−2). Other relatively high values were mostly observed in the northern part of Shaanxi Province. The highest NPP at the county scale in 2010 appeared in Fuxian County, Shaanxi Province (521.7 g·cm−2), followed by the districts of Linwei and Lintong, Xingping City, as well as the counties of Huaxian, Ganquan and Huangling. The NPP in these areas was greater than 500 g·cm−2 and were all located in northern Shaanxi Province. From 2000 to 2010, 87.7% of the counties experienced increasing NPP.

3.2 The process of urbanization

3.2.1 The process of grid scale urbanization

Over the study period, the underlying basic process of urbanization generally accelerated (shaded red in Fig. 3), with only a concentrated area of significantly reduced urbanization found in Linfen City, Shanxi Province (shaded blue in Fig. 3). Areas with a significantly increasing urbanization rate accounted for 12.6% of the total urban spatial area, while areas with a significantly decreasing urbanization rate covered only 0.5%.

3.2.2 The process of county scale urbanization

With reference to the economic aspects of the urbanization process, the counties and cities that experienced growth in GDP were concentrated mainly in the central and northern regions. In terms of population related processes, more than 84.9% of the counties and cities experienced growth in the proportion of the non-agricultural population. Hotspots of population growth were found in the central and western regions. More than 78.3% of all counties experienced population density growth, with hotspots concentrated in the Inner Mongolia Autonomous Region of the northern Loess Plateau. In terms of the spatial process of urbanization, the proportion of urban areas experienced growth across the entire Loess Plateau, with hotspots found in the northern Shaanxi province and the Inner Mongolia region (Fig. 4).

3.3 Effects of urbanization on NPP

3.3.1 NPP changes in response to the process of county scale urbanization in terms of population, economic productivity, and land use change intensity

By using county and city sample data, the results of a series of linear regressions (Table 1) showed that urban area ratio (N=331), GDP (N=265), non-agricultural population ratio (N=324), population density (N=324) in 2000 and 2010 all had significant negative slopes (i.e. correlations) with NPP ($p < 0.05$). Thus based on the slopes of these regression lines, the negative effect of urbanization on the vegetation environment in 2010 was greater than that in 2000. This indicates that the effects of urbanization were not fully mitigated through 11 years of vegetation restoration; as the negative effect deepened.

The rates of change in economic conditions, population growth and spatial urbanization were significantly and positively correlated with that of NPP from 2000 to 2010. This indicates that, overall, rapid urbanization was accompanied by improved regional vegetation restoration. Changes in the urban area ratio ($t = 5.159$), non-agricultural population ratio ($t = 2.192$) and GDP ($t = 3.032$) all had significantly positive relationships with the changes in the urbanization rate from 2000 to 2010 ($p < 0.05$), while changes in population density was not found to significant in the linear regression ($p > 0.05$) (Table 2). The results of a quadratic polynomial trend analysis (Table 2) showed that the second-order trend between population density change and NPP rate change was not clear, and the rates of change for economic, non-agricultural population and NPP all exhibited inverted U-shaped growth trends. That is, with the increasing proportion of non-agricultural population and of GDP, the NPP change rate initially increased and then decreased, with the inflection points located at 0.7 and 9.2, respectively.

The 331 counties in study area were divided into three groups indicating different degrees of urban expansion: high, middle, and low urbanization rate (Fig. 5). The results of the regression analyses (Table 3) indicate that for areas with a low urbanization rate, NPP increased as the urbanization rate increased, with a positive correlation (slope). For areas with the middle urbanization rate, NPP decreased as the urbanization rate increased, with a negative correlation (slope). Areas with high urbanization rates were also found to have a negative correlation (slope) between the rate of urbanization and NPP. The slope of the middle urbanization rate in 2000 and 2010 was lower than that of the high urbanization rate, indicating that peri-urbanization has a stronger negative effect on NPP than high urbanization.

3.3.2 NPP changes in response to the process of grid scale urbanization

The effect of urbanization on NPP varied geographically (Fig. 6). Areas with a significant correlation accounted for 42.5% of the urban and peri-urban space, of which areas with a significant positive correlation covered 26.2% of the urban and peri-urban space. These areas with a significant positive correlation between urbanization and NPP were found in Yan'an City, Yulin City and Luliang City in the Loess hilly areas. That is, areas with the most serious soil erosion in the Loess Plateau also had the most improved vegetation restoration (Fu et al. 2011; Yang et al. 2012). Areas with a significant negative correlation included 16.4% of the urban space, and were distributed mainly in the flat river valleys of the Loess Plateau region. Areas with a significant positive correlation between urbanization and NPP were 1.5 times greater than the areas with a significant negative correlation; that is, the positive effect was wider ranging than the negative effect. The urbanization rate increased in the entire study area. The more effective vegetation restoration areas were positively correlated with urbanization, while the less effective vegetation restoration areas were negatively correlated with urbanization.

As summarized above, areas with middle and high rates of urbanization experienced less effective vegetation restoration. Areas with low urbanization rates were found to have relatively high effective vegetation restoration. At the grid scale, similar results indicated that the effects of urbanization on NPP exhibited a three-ring pattern (Fig 7). The inner ring in this spatial relationship can be observed in built-up areas that had already been saturated by urbanization, and thus new urbanization had very little relevant effect on vegetation. The middle ring occurred in peri-urban areas where growth and urbanization were already occurring at the beginning of the study period; that is, the expansion of construction sites resulted in a significant negative correlation between urbanization and NPP. The outer ring occurred in the rural regions where urbanization and NPP were significantly positively correlated. Here a clear demarcation can be seen where impacts of the effectiveness of vegetation restoration occurred in areas of transition from rural to urban landscapes. No mutual penetration relationship was observed.

4 Discussion

4.1 Climatic factors did not interfere with the results

It is important to note that NPP can change both under urban expansion and climate change conditions (Pei et al. 2015; Wang et al. 2014). For the latter, the significant effect of precipitation on NPP in this study is shown in Fig. 8a. Here significant positive correlations between precipitation and NPP were concentrated in Erdos, Hohhot, Baotou, Xinzhou and Shuozhou cities in the northern Loess Plateau. Significant negative correlations were concentrated in western Lanzhou, Baiyin, and Zhongwei City in the western Loess Plateau. No correlation intersection was observed within the areas in which the process of urbanization had an effect on NPP, so precipitation did not affect the results.

Less than 2.0% of the study area experienced a significant effect of temperature on NPP (Fig. 8b), indicating that temperature also did not affect the results.

4.2 The response of the vegetation to urbanization changed but not fully

When no ecological restoration was conducted during the process of urbanization, urbanization was found to have a negative effect on vegetation change, with negative environmental effects increasing over time (Chen et al. 2017b). The percentage of areas found to have a negative relationship between urbanization and NPP were larger than those areas with a positive relationship (Kuang et al. 2015; Liu et al. 2015; Wu et al. 2014). When considering large scale vegetation, as in our study area, the response of the vegetation to urbanization changed but not uniformly. The overall trend of restoration is mainly for improved NPP, and in that, the practice of vegetation restoration is generally effective. The results of this analysis confirmed that the urbanization of the population and economy, as well as urban expansion have a negative relationship with NPP in areas with middle and high urbanization rates and a positive relationship in areas with low urbanization rates at a county scale. Middle urbanization rate areas provided inflections in these trends. At the 250 m grid scale, the percentage of areas with a significant negative relationship between NPP and urbanization were smaller than those with a significant positive relationship. The significant negative areas were located in the middle ring of urban areas, while the significant positive areas were located within the outer ring of urban areas. Thus, at both county and grid scales, the transition areas from rural to urban were not affected by vegetation restoration. Over the 11-year period, vegetation restoration has not fully mitigated the negative effects of urbanization in the entire area due to the stage dependent relationship between NPP and urbanization.

4.3 The relationship between NPP and urbanization could be stage dependent

The response of NPP to urbanization without ecological restoration efforts suggest that three stages could be defined by using the method of "trading space for time" (Chen et al. 2017b; Lester et al. 2014; Peng et al. 2015), that of: damage, antagonistic and coordination. In our research, the responses of NPP to urbanization with vegetation restoration over a decade showed an initial coordination stage, a degradation stage and a remedy stage.

During the initial stage of urbanization, restoration projects promoted improved soil conditions, creating advantages for developing cities and building roads as well as protecting the sandy landscape from wind erosion. The improved environmental conditions and infrastructure attracted relatively larger numbers of people who settled in these areas. This explains the result that areas with better restoration were found to have relatively higher urbanization rates.

In the second stage, the increase in urban residents resulted in the development of an artificial edge effect where the urban landscape interfaces (mixes) with recently restored, more natural ecosystems. This stage includes either the expansion of urban areas being restrained by the restoration process or restored areas being replaced by urbanized areas. The locations of vegetation restoration and of urbanization were affected by the geological terrain of the Loess Plateau and had a high degree of overlap. This indicates that the urban periphery and vegetation restoration areas shared a land type, mainly cultivated land, and their spatiotemporal intersection is very likely to create conflicts between the two types of need for land (Su et al. 2014). Serious fragmentation of land use has caused the negative relationship between urbanization and NPP. This explains why peri-urbanization was an inflection point of positive to negative effects for NPP.

The third stage occurred when urbanization became relatively dense. The demand of city dwellers for greenspace, such as “Transplanting big trees into the city” and requirements of policies for improving living standards, such as “Urban Green Space Planning with Greening Ratio” resulted in a decrease in the negative influence of urbanization on NPP (Yao et al. 2015). This explains why high urbanization rates had reduced negative effects on NPP over that found in middle urbanization rates.

Long-term ecological restoration programs, such as the “Green for Grain” program in the Loess Plateau, have produced steady and positive results. Improving the performance of such programs is important. Based on these results, current land management practices and urban development models for the Loess Plateau in peri-urban areas are not sustainable. Peri-urbanization may vary the effectiveness of vegetation restoration. Better performance should result from increasing restoration activities in the second stage of urbanization which is represented by peri-urbanization.

4.4 Peri-urban areas could be prioritized to harmonize urban development and ecological restoration

Peri-urban spaces frequently experience either urbanization or even tree planting initially, but restored forests may later become occupied and act as an obstruction to city development. Forest land may be urbanized (Amati and Yokohari 2006) and green-land fragmentation can become a serious concern (Yang and Jinxing 2007). That is why areas of peri-urbanization have a more serious negative correlation with NPP. The cities of Yanan, Yulin, and Lvliang are the best restored areas in Loess Plateau as described above. However, recent developments in these cities are resulting in areas of restored vegetation being negatively impacted at the rural/urban interface (peri-urban areas), and, based on current plans, they will soon disappear and become a new district (Yanan municipal government, 2013; Yulin municipal government, 2013; Lvliang municipal government, 2013). Providing evidence of these impacts to inform future city planning implementations for peri-urban space is crucial.

The spatial extent of peri-urbanization continues to expand. Efforts directed toward the conservation of intact vegetation within urban landscapes could support higher concentrations of both bird and plant species (Aronson et al. 2014) and previous land use may shape peri-urban forest diversity (Nitoslawski and Duinker 2016). Vegetation in urban areas provides many ecosystem services such as temperature mitigation, pollution removal, carbon uptake and storage, and the provision of amenity values for citizens with habitats that support diverse ecosystems (Dallimer et al. 2016). Because development patterns influence ecosystems, it is necessary to make well-informed development choices in the future (Raciti et al. 2012). Feng (2016) has indicated that the NPP in this region is already close to a threshold related to water consumption. Large-scale afforestation operations such as the planting of the water-consuming plants, such as black locust (Robinia pseudoacacia Linn.), Chinese pine (Pinus tabulaeformis Carr.) and korshinsk peashrub (Caragana korshinskii Kom.) have aggravated water scarcity (Wang et al. 2015, Jia et al. 2017). This means that planting tree species and the patterns of this planting will be crucial factors influencing the effectiveness of vegetation restoration and eco-environmental reconstruction in peri-urban areas. A number of challenges and opportunities exist including the establishment of green networks with tree species that use less water and require less thinning for cities prior to their expansion in peri-urban areas.

Conclusions

Human activities directly affect both urban development as well as ecological restoration – two ends of the spectrum of environment preservation. This trend of placing equal stress on development and restoration is set to continue around the world. There is an urgent need for regional analyses to support effective restoration and harmonious built environments. This study focused on the relationship between regional scale vegetation restoration and the process of urbanization in the Loess Plateau of China, applying statistical analyses across multiple spatio-temporal scales. These relationship analyses identified a three-ring spatial pattern and three temporal stages. Positive effects of urbanization on vegetation degradation were only observed at low urbanization rates in the outer ring of urban areas. Significant negative correlations between urban development and restoration were found in peri-urban areas; those at the interface of urban and rural landscapes. These were much reduced or tended to zero in saturated urban areas and at high urbanization rates. The results of this study identified how regional vegetation restoration activities could be coordinated with urban development for positive outcomes. To further improve the coupling of urban development and vegetation restoration, peri-urbanization can provide a varying interface that supports effective vegetation restoration. This study demonstrates how future environmental management schemes and urban planning interventions can strike a balance between urban development and environmental restoration at regional scales.

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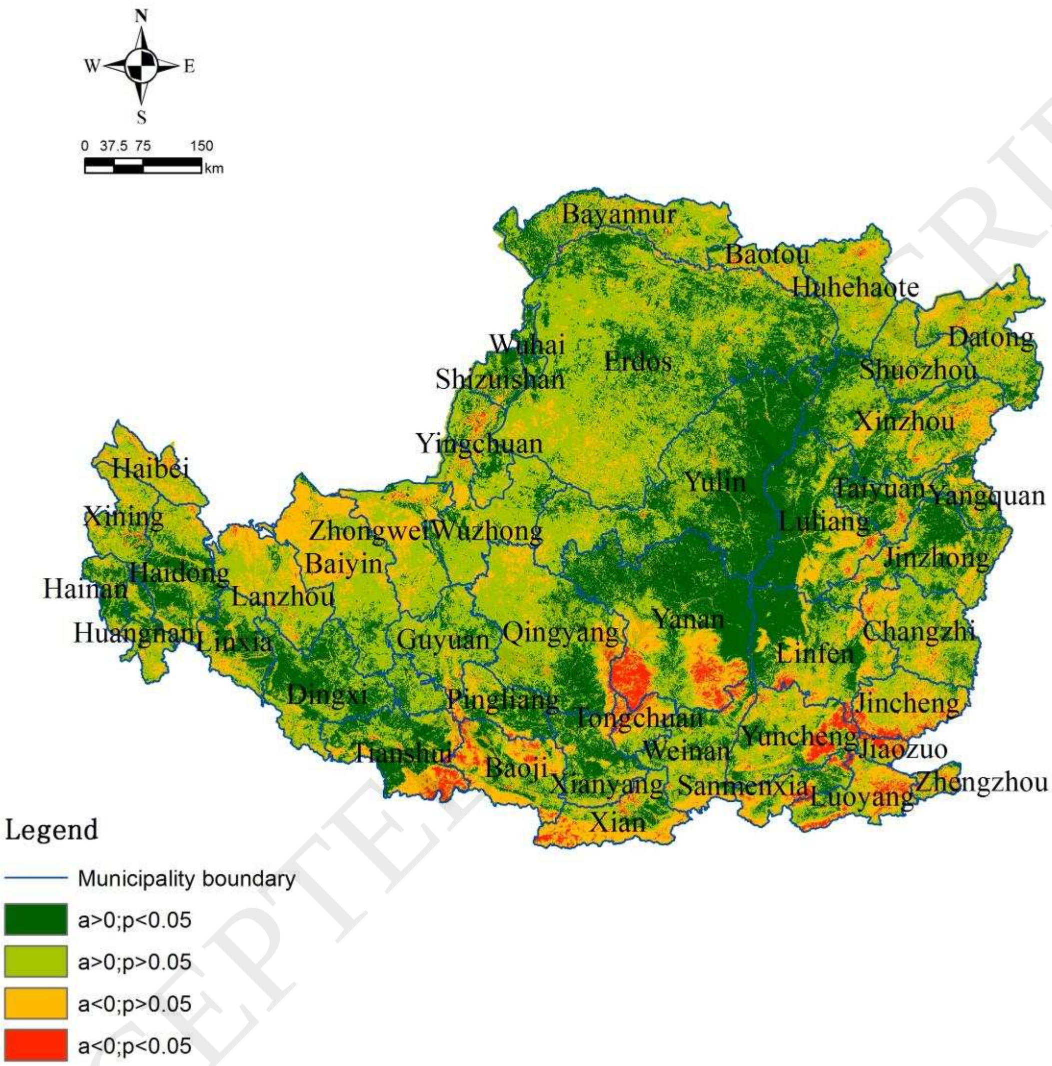
Figure 3 Location of the Loess Plateau. Lines within China represent provincial administrative zone boundaries.

Figure 4 Slope of NPP obtained from the regression of each single pixel during the period of 2000 to 2010. Slopes (a<0 and a>0) and their relative levels of significance (p<0.05 and p>0.05) were compared using the map.



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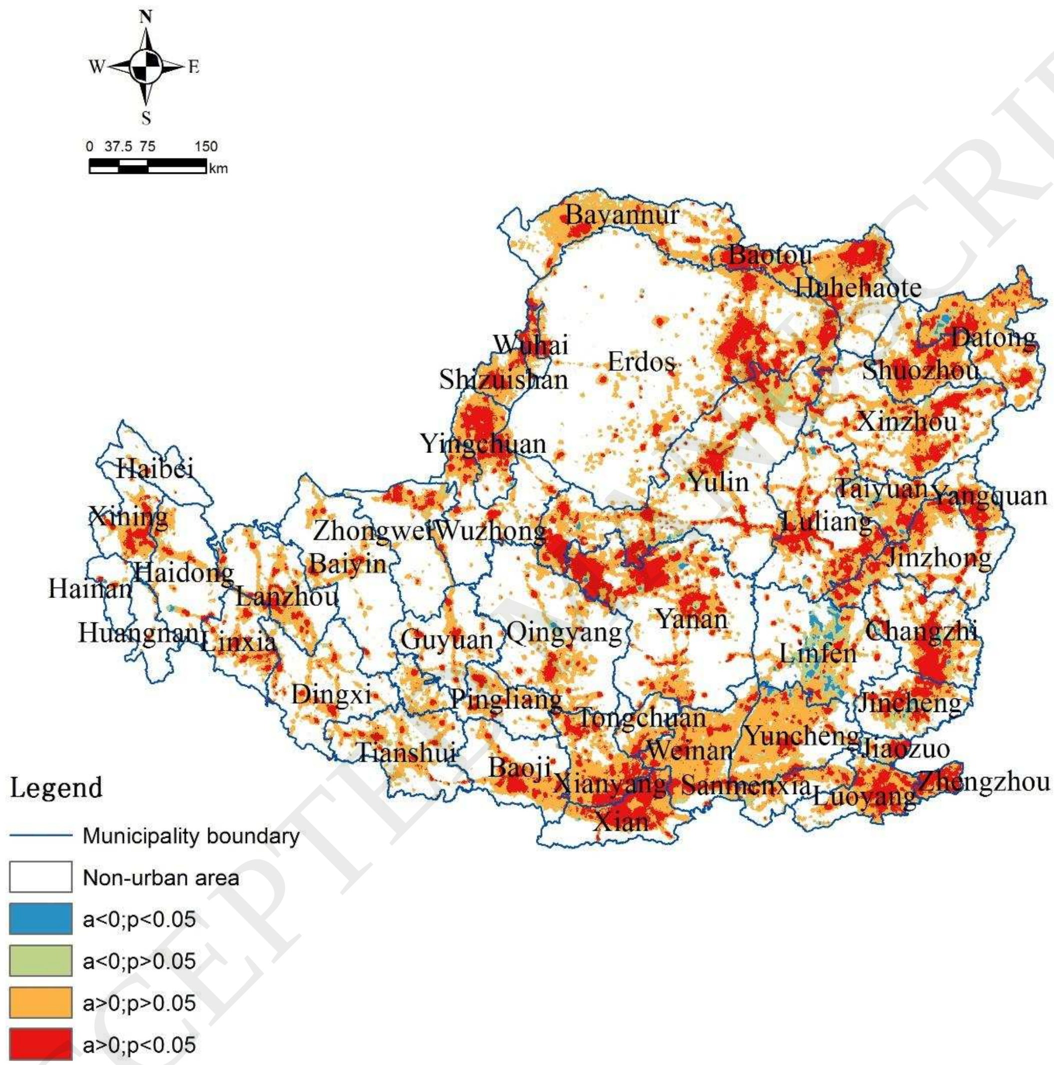

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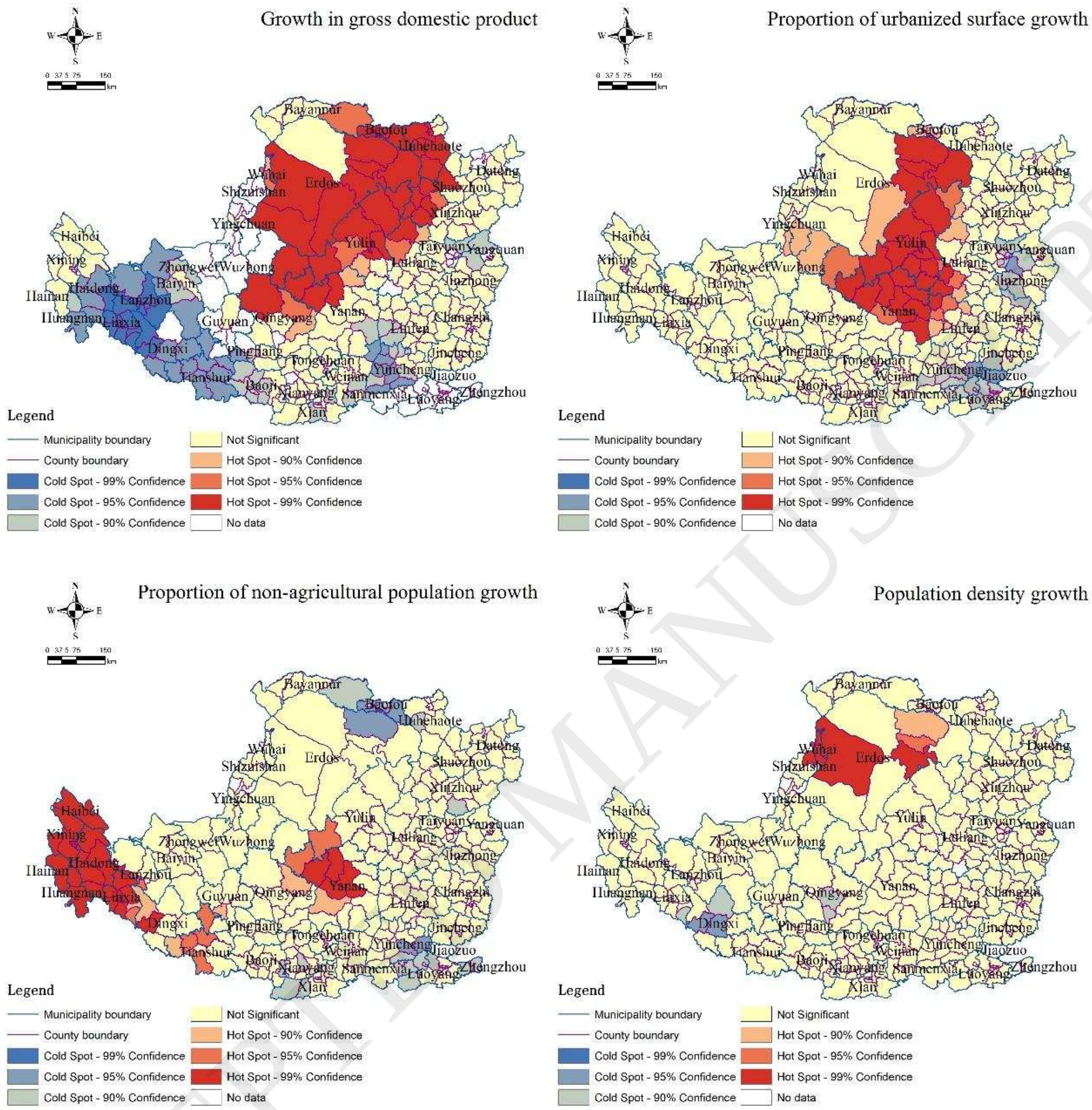

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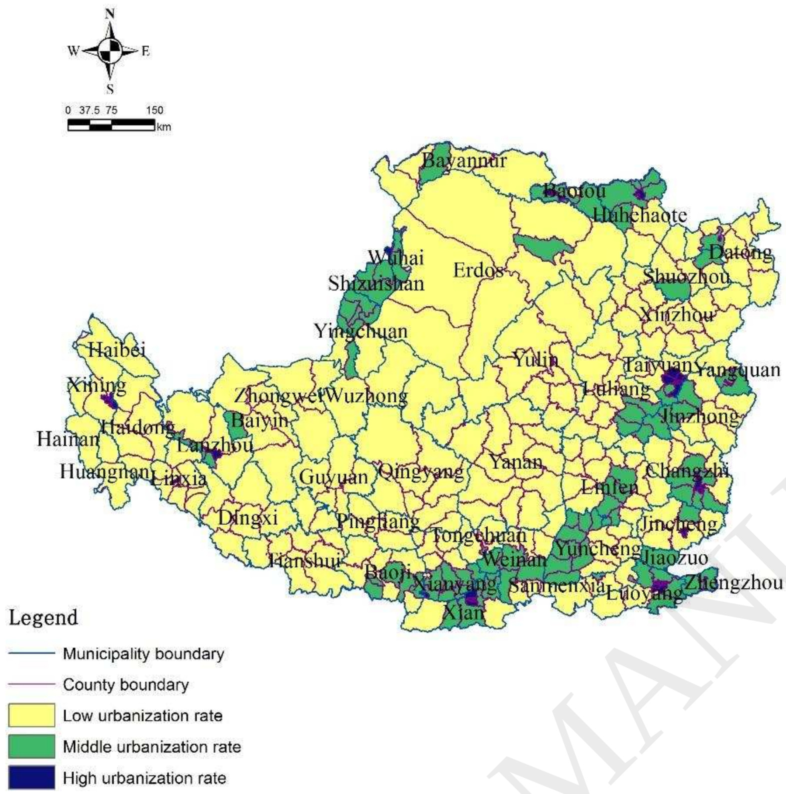

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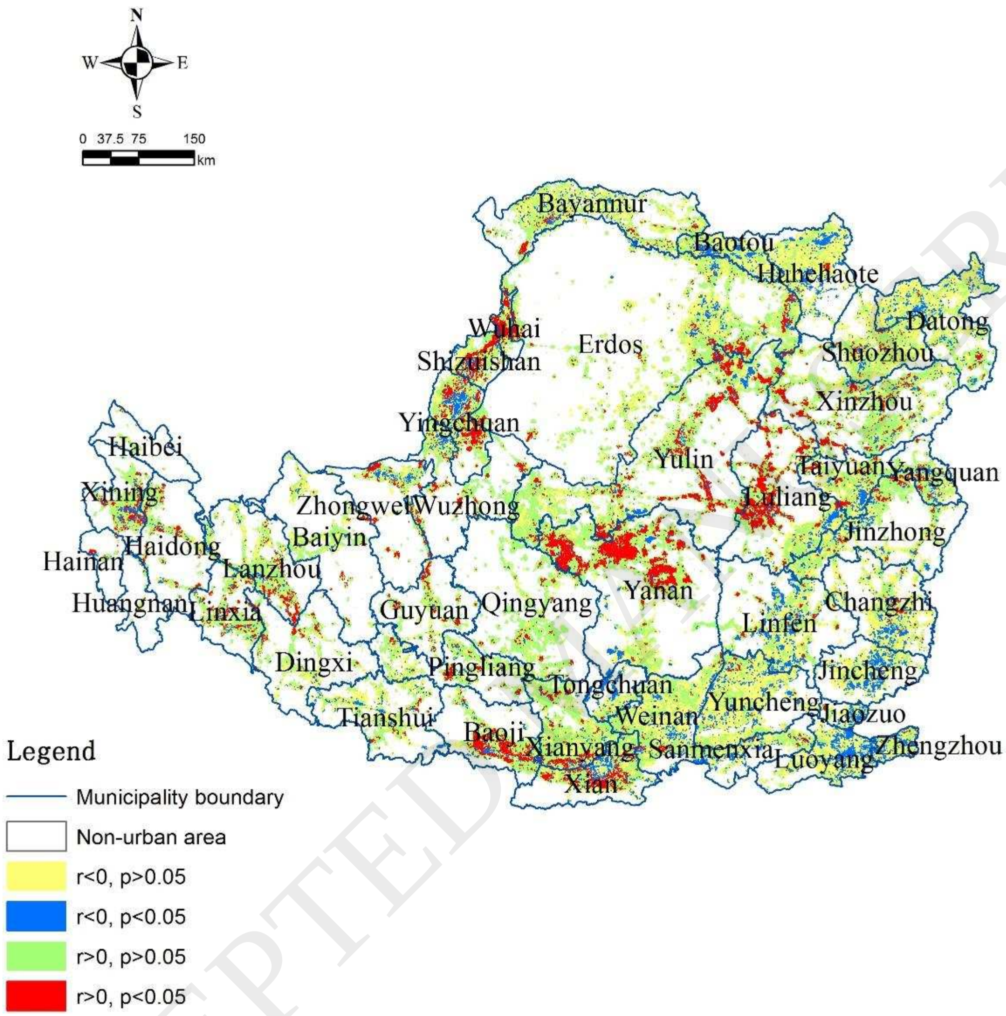

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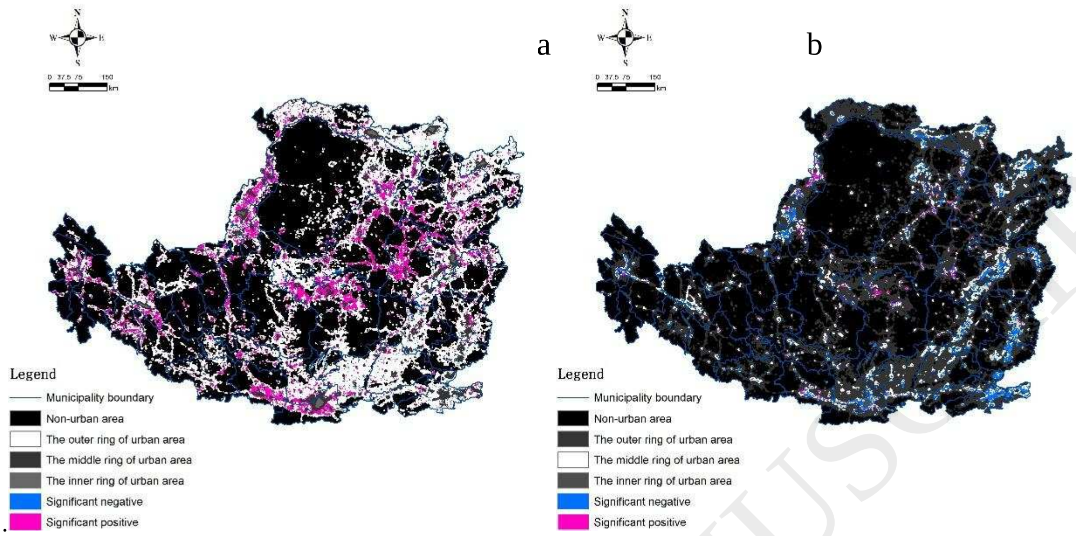

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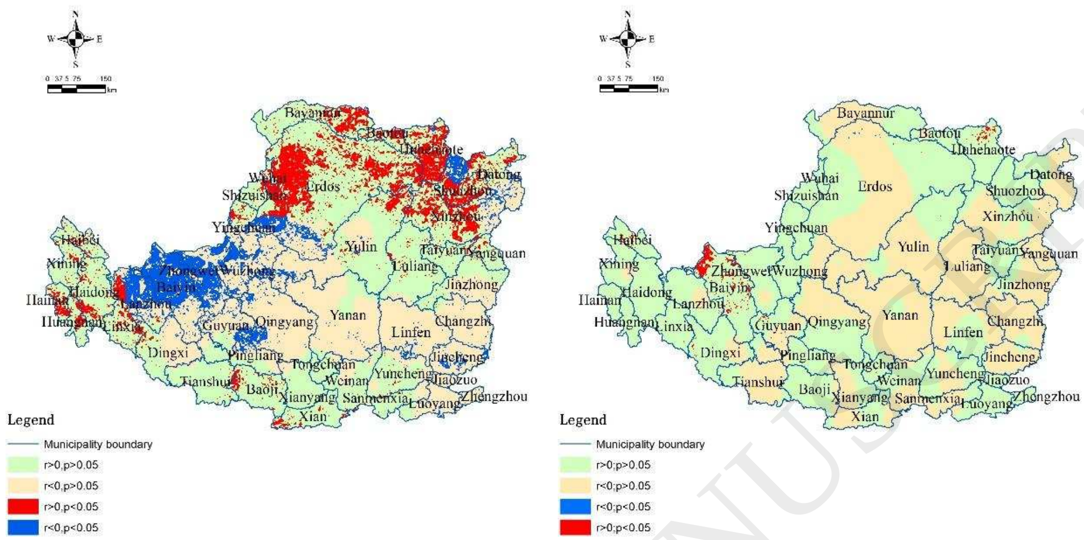

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Table 3 Coefficients of three rates of urbanization with Net Primary Production in 2000 and 2010.

Table 1 Correlations between Net Primary Productivity with (a) urban area ratio, (b) gross domestic product, (c) population density, (d) non-agricultural population ratio.

Urbanization indicators	Net Primary Productivity			
	2000		2010	
	B	Sig	B	Sig
Urban area ratio	-.016	.016	-.036	.000
Gross domestic production	-.019	.016	-.337	.000
Population density	-3.062E-6	.005	-5.911E-6	.000
Non-agricultural population ratio	-.036	.001	-.053	.000

Table 2 Correlations between Net Primary Productivity change rate with rates of changes in the (a) urban area ratio, (b) gross domestic product, (c) population density, (d) non-agricultural population ratio.

Urbanization indicators	Net Primary Productivity					
	Linear regression		Quadratic polynomial trend			
	B	Sig	Constant	b1	b2	Sig
Urban area ratio	.228	.000	.160	.466	-.015	.000
Gross domestic production	.015	.003	4.202	8.258	-3.378	.000
Population density	-.087	.300	.108	-.041	-.028	.897
Non-agricultural population ratio	.058	.029	.334	.537	-.208	.044

Table 3 Coefficients of three rates of urbanization with Net Primary Production in 2000 and 2010

level	2000				2010			
	B	Standard error	t	Sig.	B	Standard error	t	Sig.
High	−2.102	0.724	−2.904	0.008	−1.97	0.563	−3.496	0.002
Middle	−3.742	2.023	−1.85	0.068	−4.207	1.44	−2.921	0.004
Low	37.748	6.824	5.532	0.000	9.435	5.683	1.66	0.098