Introduction

The rate of expansion of urban construction land in China is the highest in the world, and urbanization continues to accelerate. This rapid expansion of urban construction land intensifies the conflict between humans and the environment, bringing a series of ecological problems such as water scarcity, land degradation, worsening air pollution, and vegetative deterioration. Hence, the mechanisms driving Urban Expansion and its effects on resources, ecology, and the environment are hot research issues in the fields of urban geography and resource ecology (D.M. Wu & Shao, 2018; Guo, 2018; J.H. Zhou & Wang, 2018; S.H. Liu & Zhang, 2018; S.X. Liu & Lin, 2018). The Xinjiang Uygur Autonomous Region, which is one of the most ecologically fragile regions in China (H.J. Liu et al., 2015), is the frontier and core area of the “Belt and Road” initiative westward development (Wang, 2019; Zhu et al., 2019). Thus, exploring the driving factors and ecological effects of urban expansion in this region is important for sustainable development, economic transformation, and policymaking related to the Belt and Road initiative.

The expansion of urban construction land is affected by the natural environment, societal and economic development, and other factors; meanwhile, Urban Expansion generates a series of external effects (P.C. Zhou & Yang, 2018; Xiong et al., 2018; D. Yang et al., 2018; Zheng et al., 2014). While Urban Expansion accelerates socio-economic development and improves the livelihoods of residents, it also generates resource scarcity, population growth, environmental pressure, public health issues, and other problems. To begin addressing the problems created by urban expansion and promote sustainable economic development, we first studied the driving factors and mechanisms of Urban Expansion.

Many studies on the factors driving Urban Expansion have applied qualitative research methods (Shrestha et al., 2012; J. Y. Liu et al., 2010). However, qualitative analyses are easily influenced by the subjectivity of the authors, and the methodology and results are not necessarily uniform or comparable across different time frames and geographic regions. Therefore, empirical approaches (e.g., binary regression, multiple linear regression, logit regression, rise decision tree regression, and analytic hierarchy process) that combine qualitative and quantitative analytical methods have been applied in recent years to study Urban Expansion (Cai et al., 2012; Delbecq, 2010; Li et al., 2013; Linard et al., 2013; Seto et al., 2011; Thapa & Murayama, 2010). The above methods can be used to evaluate the relative contributions of multiple factors. However, these methods have some drawbacks, including the need for extensive time-series data, the values of continuous variables, and...
The geodetector method, a spatial statistical analysis method to evaluate the relationships among all geographical factors, is an effective solution for the above problems. In recent years, the geodetector method has been applied in public health (Qiao & Qiao, 2019; Wu, 2018), natural disasters, land-use change (Xia et al., 2017; Xu & Zheng, 2015; R. Yang et al., 2013), landscape ecology (C.Y. Liu et al., 2018; Pang, 2016), and other fields. Compared to other methods for quantitative analysis, the advantages of the geodetector method can be summarized as follows: (1) there is no homoscedastic hypothesis, unlike in common regression models; and (2) it can quantitatively represent the interactions between different influential factors.

Previous quantitative evaluations of the effects of Urban Expansion on the eco-environment primarily evaluated single eco-environmental factors rather than the overall eco-environmental effect due to limited available data, methodological limitations, and the complexity of the urban ecosystem. Furthermore, these past studies mainly focused on single, economically significant large- and medium-sized cities or ecologically fragile areas. Larger-scale study areas such as urban agglomerations, regions, or provinces have been less frequently studied. Even a few simple indicators cannot fully reflect the impact on the ecological environment. However, in the research practice, the quantitative evaluation of the comprehensive eco-environmental effect is most commonly carried out using the pressure–status–response (PSR) model (Chen & Wang, 2018; Ning, 2018; P.D. Liu & Xu, 2018; Wang et al., 2018; X.J. Wang & Zhou, 2018; Zhao et al., 2018). The PSR model is widely used in the field of resource ecology to evaluate ecological safety, sustainable resource utilization, and other topics. The PSR framework can quantitatively represent the interactions in comprehensive human–nature systems. Some scholars have used the PSR framework to evaluate the ecological effects of Urban Expansion in large- and medium-sized cities (Chen & Wang, 2018; P.D. Liu & Xu, 2018). This method can accurately reflect the relationships between Urban Expansion and eco-environmental change.

This study used the built-up areas of 14 prefecture-level cities in Xinjiang as the research area to evaluate the main natural and social driving factors of urban expansion and their interactions using the geodetector method and the PSR model. The eco-environmental effects of Urban Expansion were quantitatively evaluated in Xinjiang as a whole. The results provide support for optimizing future urban development in Xinjiang, developing a strategy for managing ecological safety, and promoting the sustainable development of urban areas in consideration of the economy, society, and ecology.

Materials and methods

Overview of the study area

The Xinjiang Uygur Autonomous Region (73° 41′–96° 18′ east longitude and 34° 25′–49° north latitude) had a permanent population of approximately 24.4 million in 2017 and spans over 1.6 million km². The Xinjiang Uygur Autonomous Region is the largest province-level division of China and occupies one-sixth of all territorial area in China. Xinjiang has a temperate continental climate with a large diurnal temperature variation and a long sunshine duration. The annual sunshine reaches 2500–3500 h. Xinjiang has a dry climate with low rainfall; the annual average precipitation is approximately 150 mm, although precipitation differs by location within the region. Xinjiang is rich in water resources of which per-capita possession ranks among the highest in China. The area of land used directly for agriculture, forestry, and animal husbandry is approximately 1.28 billion acres, and the region has 223 million acres of reserve arable land. The land area alternates between mountains and basins, causing the terrain to be described as “Three Mountains with Two Basins.” The ecological environment presents droughty, multifarious, closed, and fragile features. The Xinjiang Uygur Autonomous Region is an important passageway of the ancient Silk Road and a necessary place for the second “Asia-Europe Continental Bridge”. Thus, this region is a strategic location for politics, the economy, and ecological safety.

In recent years, the rapid economic development and expansion of urban space have generated large pressures on the resources and environment of Xinjiang. The resulting problems include water pollution, wetland degradation, increasing extreme weather, and the reduction of biodiversity. Hence, it is necessary to study the eco-environmental effects of Urban Expansion along with the associated driving mechanisms in Xinjiang.

Data sources

This study was based on two data sources: spatial geographic information and socio-economic data. The spatial geographic information includes 1) urban
interaction detection is mainly used to identify the effects of urban expansion by PD. The size of the PD value and the explanatory power of the factors on urban expansion present a positive correlation.

(c) Eco-detection detects control action of driving factors to urban expansion. This is realized by comparing the calculated PD values; a larger PD value corresponds to a stronger influence of the factor on urban expansion.

(d) Interaction detection is mainly used to identify the interactions between different factors, that is, whether interactions between factors A and B will cause the effect of the dependent variable Y to increase or decrease, or if these factors independently influence Y. This is evaluated from the q values of the two factors A and B for Y, PD(A) and PD(B) and their interactions, i.e., PD(A∩B), and the values of PD(A) and PD(B) are compared with PD(A∩B). The relationships between the two factors can be divided into the following categories:

Interactive increase: PD(A∩B)>PD(A) or PD(B)
Interactive increase, bilinear: PD(A∩B)>PD(A) and PD(B)
Interactive increase, nonlinear: PD(A∩B)>PD(A)+PD(B)
Interactive decrease: PD(A∩B)<PD(A)+PD(B)
Interactive decrease, linear: PD(A∩B)<PD(A) or PD(B)
Interactive decrease, nonlinear: PD(A∩B)<PD(A) and PD(B)
Interdependence: PD(A∩B) = PD(A)+PD(B)

In the above definitions, ∩ indicates the overlapping of effect factors A and B using the spatial analysis function in ArcGIS.

Potential effect factors were identified based on a literature review of relevant studies. Based on this review, the following effect factors were considered in this study: terrain factors (latitude and slope); proportion of construction land surrounding the analysis unit; distance to main road; change in permanent resident population; change in per capita gross domestic product (GDP); change in the proportions of secondary and tertiary industry; change in public budget expenditures; and change in the average wages of urban residents (Braimoh & Onishi, 2007; Dubovyk et al., 2011; Fang et al., 2005; K.Y. Wu & Hao, 2012). The base period is 1997 and the final phase is 2017; changes of all factors are corresponding variations from 1997 to 2017. Research methods

Geodetector method

The geodetector method is a statistical method used to investigate spatial differentiation in geographic phenomena and its driving factors. That is, the geodetector method assesses spatial differentiation in a dependent variable and detects the degree to which the independent variable X explains the heterogeneity of the dependent variable Y (J.F. Wang & Xu, 2017). Compared to the traditional econometric method, the geodetector method is more flexible and does not assume linearity. Thus, the geodetector model can be used to evaluate spatial differentiation, determine interpretation factors, and analyze the interactions among variables. The basic form of the geodetector model is:

$$PD = 1 - \frac{1}{\sigma^2} \sum_{i=1}^{L} N_i \sigma_i^2$$ (1)

where N is the Urban Expansion index in the study area; σ² is the variance in the expansion index; L is the “Strata” of Y and X that corresponds to geographic classes or sub-regions, with i = 1, 2, . . ., L; N_i and σ_i² are the expansion index and variance of the effect factors in tier i; and PD or power of determinant is the detection indicator of eco-environmental driving factors of urban expansion. PD takes values in the range of [0, 1], with 0 indicating no correlation between the factor and the explanatory variable, and 1 indicating the strongest correlation. Thus, PD reflects the extent to which each driving factor explains the city expansion. Specifically, the geodetector method includes the following four parts:

(a) Risk detection is the identification of the effects of all factors affecting urban expansion. The degree of each effect is compared via t-test, with a larger t value corresponding to a stronger effect on Urban Expansion.
(b) Factor detection detects the interpretation degree of different factors affecting urban expansion by PD. The size of the PD value and the explanatory power of the factors on urban expansion present a positive correlation.
(c) Eco-detection detects control action of driving factors to urban expansion. This is realized by comparing the calculated PD values; a larger PD value corresponds to a stronger influence of the factor on urban expansion.
(d) Interaction detection is mainly used to identify the interactions between different factors, that is, whether interactions between factors A and B will cause the effect of the dependent variable Y to increase or decrease, or if these factors independently influence Y. This is evaluated from the q values of the two factors A and B for Y, PD(A) and PD(B) and their interactions, i.e., PD(A∩B), and the values of PD(A) and PD(B) are compared with PD(A∩B). The relationships between the two factors can be divided into the following categories:

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Interactive decrease, linear: PD(A∩B)<PD(A) or PD(B)
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Model for the effect of urban expansion on the ecological environmental

PSR framework. Generally speaking, the relationships among urban development, construction land expansion, and their eco-environmental effects
conform to the PSR framework. Rapid urbanization and economic development increase the urban land-use pressure, resulting in changes in industrial land types, land development intensity, and degree of population aggregation. Urban land-use status is also changed, affecting resources, ecology, and the environment. Thus, the ecological environment will respond to changes in land use and human activities.

With combined references, frequency statistics analysis and the expert consultation method were adopted to acquire an eco-environmental effect evaluation index system of Xinjiang urban spatial expansion in the building evaluation model. The system includes three levels: economic and social pressure, land-use status, and ecological environment response, as well as subordinate 8 element levels and 19 index levels. The socio-economic pressure criterion layer mainly accounts for the influences of economic and social development on urban expansion. At the macro level, changes in the economic environment and social development will inevitably lead to changes in production, lifestyle and consumption patterns, which will trigger changes in the scale and structure of urban construction land. Per capita GDP, proportion of non-agricultural industries, and population density are indices of the level of economic development. The per capita disposable income of urban residents and urbanization level are indices of the level of social development. Land-use status presents consequences of urban expansion, descriptions for criterion layer of land-use status are by means of spatial change (spatial expansion status quo) and land-use intensive degree (land-use intensity); to be more specific, descriptions for spatial expansion status quo are through change of construction land and arable land (proportion of construction land area and per capita arable land area); descriptions for land-intensive use are through construction land expansion intensity and development intensity. Construction land expansion causes changes in land-use status and generates responses by the ecological environment. Thus, the eco-environmental response criterion layer is an essential factor that is reflected in four indices: ecological resource foundation, resource consumption level, environmental load, and environmental governance level (Table 2).

**Weight determination and index calculation.** (1) Data standardization. The range standardization method is used to perform dimensionless processing on the above data to make it comparable. The formulas for the positive and negative indices are respectively given by:

\[ Z_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})}, \quad (2) \]

\[ Z_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})}, \quad (3) \]

where \( x_{ij} \) is the initial value of \( j \) in year \( i \), \( Z_{ij} \) is the corresponding value after the standardization process, and \( \min(x_{ij}) \) and \( \max(x_{ij}) \) are the minimum and maximum values of \( j \) in year \( i \), respectively.

(2) Index weight determination was carried out using the entropy weight method for all levels as follows:

calculate proportion of \( j \) in year \( i \):

\[ p_{ij} = \frac{z_{ij}}{\sum_{i=1}^{n} z_{ij}} \quad (4) \]

calculate entropy of \( j \) (\( S_{j} \)):

\[ S_{j} = -\frac{\sum_{i=1}^{n} p_{ij} \ln p_{ij}}{\ln(nm)} \quad (5) \]

calculate coefficient of difference of \( j \):

\[ e_{j} = 1 - S_{j} \quad (6) \]

and calculate each index weight \( W_{ij} \):

\[ W_{ij} = \frac{e_{j}}{\sum_{j=1}^{m} e_{j}} \quad (7) \]

where \( n \) and \( m \) are the year and index, respectively. Weight of the factors is shown in Table 2.

(3) Index calculation was conducted using the weighted sum method to calculate three indices: socio-economic pressure index, land-use status index, and resource environmental response index. The final comprehensive index for the eco-environmental effect of Urban Expansion (EEI) was calculated as

| Table 1. Driving factors included in this study and their descriptions. |
|------------------|------------------|
| Factor | Description |
| Natural terrain factor | Altitude | Average altitude in the analysis unit |
| Field factor | Slope | Average slope in the analysis unit |
| Proportion of construction land in the surrounding area | Proportion of construction land area within 7 * 7 grids around the analysis unit |
| Distance to main road | Perpendicular distance between the center of the analysis unit to nearest railway, expressway, or national highway |
| Socio-economic factor | Change in permanent resident population | Change in permanent resident population from the base period to the final phase |
| Change in per capita GDP | Change in per capita GDP from the base period to the final phase |
| Change in the proportions of secondary and tertiary industry | Change in the proportions of secondary and tertiary industry from the base period to the final phase |
| Change in public budget expenditures | Change in public budget expenditures from the base period to the final phase |
| Change in the average wage of urban residents | Change in the average wage of urban residents from the base period to the final phase |
EEI = \sum_{j=1}^{m} w_j \times z_j \quad (8)

where \( w_j \) is the index weight, and \( z_j \) is the standardized index value.

Results

Analysis of the spatial and temporal disparities in urban expansion in Xinjiang and the corresponding mechanisms

Spatial and temporal characteristics of urban expansion in Xinjiang from 1997–2017

In 1997, the areas of urban construction land were small (generally between 20 and 50 km\(^2\)) in most regions of Xinjiang, with the exception of Urumchi, which served as the development center within Xinjiang. The areas of urban construction land in the northern prefecture-level cities were generally smaller than the areas in the southern part. In the decade from 1997 to 2007, the areas of urban construction land gradually increased with an average growth rate of 55.81%. Obvious growth was observed in northern Tacheng, Bortala, Karamay, and Changji, and the difference in urban construction area between the northern and southern regions decreased during this decade. From 2007 to 2017, the expansion rate of urban construction land increased throughout Xinjiang, with an average expansion rate of 94.99% in all prefecture-level cities (Figure 1). Urumchi remained the center of urban development, and the difference between other prefecture-level cities narrowed. The area and expansion rate of urban construction land remained low in Kizilsu Kirghiz, the northeastern border, and some other prefecture-level cities.

Analysis of the mechanisms of urban expansion

The factor detection results show that significant factors affecting urban expansion included slope, distance to main road, change in population, change in per capita GDP, change in the proportions of secondary and tertiary industry, change in the average wage of residents, and change in public budget expenditures. The \( p \) values for altitude and proportion of construction land in the surrounding area were both greater than 0.05, indicating that these factors were not significant. The different factors had obviously different effects on urban expansion in the study area. Specifically, the PD values (\( q \) statistics) decreased in the following order: change in public budget expenditures > change in the average wage of residents > slope > change in per capita GDP > change in the proportions of secondary and tertiary industry > change in population > distance to main road. This indicates that increasing public budget expenditures and wages of urban residents had the greatest effects on urban expansion in Xinjiang. Thus, Xinjiang government investments in the construction of urban infrastructure strongly promoted the influx of external capital and economic development in the past two decades, resulting in the acceleration of urban construction land were distributed in Kizilsu Kirghiz, Altay, and other border cities.

In the past two decades, the largest increases in urban construction land were observed in Changji, Karamay, Turpan, Aksu, Tacheng, and other mid-northern areas (Figure 2). While Urumchi remained the center of urban development, the differences between other prefecture-level cities narrowed. The area and expansion rate of urban construction land remained low in Kizilsu Kirghiz, the northwestern border, Altay, the northeastern border, and some other prefecture-level cities.

| Criterion layer (weight) | Element layer | Index layer                  | Weight of index layer | Index character |
|--------------------------|--------------|------------------------------|-----------------------|----------------|
| Socio-economic pressure  | Economic development level | Per capita GDP (RMB/person) | 0.068 | + |
| (0.261)                  | Social development degree | Proportion of nonagricultural industries (%) | 0.029 | + |
|                          | Land use status | Population density (persons/km\(^2\)) | 0.041 | + |
|                          | Construction expansion status quo | Urbanization level | 0.047 | + |
|                          | Land use intensity | Per capita disposable income of urban residents | 0.031 | + |
|                          | Ecological resource foundation | Proportion of construction land area | 0.023 | - |
|                          | Eco-environmental response | Total water resources | 0.076 | + |
|                          | Resource consumption level | Per capita urban garden/green area | 0.062 | + |
|                          | Environmental load degree | Annual electricity consumption | 0.043 | + |
|                          | Environmental governance level | Annual total water supply | 0.052 | - |
|                          |                           | Total wastewater discharge | 0.034 | - |
|                          |                           | Total tailpipe emissions | 0.053 | - |
|                          |                           | Solid waste output | 0.051 | - |
|                          |                           | Industrial solid waste multipurpose use rate | 0.055 | - |
|                          |                           | Centralized processing rate of sewage treatment | 0.037 | + |

Table 2. Evaluation layers and indices for the eco-environmental effect of urban expansion.
construction land expansion. Among the two natural factors, only slope significantly affected urban expansion, while distance to main roads was the only field factor that significantly affected urban expansion. This means that terrain conditions and transportation convenience also affect the speed and direction of urban expansion to a certain extent, but the effects are not as obvious as the above-mentioned socio-economic factors (Table 3).

Figure 1. Areas of urban construction land in different regions of Xinjiang in 1997(a), 2007(b), and 2017(c).

Figure 2. Scale and growth rate of urban construction land in Xinjiang from 1997 to 2017.
The interaction detection results show that the interactions of the two factors are in a non-linearly enhanced pattern. The highest interaction coefficient was obtained for budget expenditures ∩ change in wage (0.396) followed by change in GDP ∩ change in population (0.359), slope ∩ change in wage (0.355), budget expenditure ∩ slope (0.351), change in wage ∩ change in population (0.340). Thus, these factors had the greatest degree of interaction in their effect on Urban Expansion. The interactions between the above pairs of factors contributed to urban expansion to a greater degree than the individual factors (Table 4).

**Eco-environmental effects of urban expansion in Xinjiang**

The PSR model was used to calculate three indices of Xinjiang Urban Expansion: socio-economic pressure, land-use status, and eco-environmental response. These indices were then used to calculate the eco-environmental comprehensive effect index EEI (Eco-Environmental Index). The resulting spatial and temporal characteristics of the eco-environmental effect of Xinjiang Urban Expansion are described below.

**Characteristics of socio-economic pressure index from 1997 to 2017**

From 1997 to 2017, the socio-economic pressure index of Urban Expansion increased obviously throughout Xinjiang. This means that the rapid urban development in Xinjiang generated demand for more production-living-ecology space. In recent years, all prefecture-level cities have faced pressures from Urban Expansion. The steady increase in the socio-economic pressure indicates that economic development has occurred steadily and continuously in all regions of Xinjiang. Rapid urban development also promotes the optimization of industrial structure and improves resident's income levels and standards of living. The socio-economic pressure index showed large spatial differences during the study period, although the general spatial pattern remained the same with time. The average socio-economic pressure index in Urumchi, the area with highest urban development, was 0.77. In contrast, the average value in Kizilsu Kirghiz Autonomous Prefecture with low urban development was only 0.12. Thus, large spatial disparities in economic development still exist in the study area. The socio-economic pressure index follows a pattern of high values in the central areas and low values in peripheral regions, which can be explained as follows. The socio-economic pressure indices of Urumchi, Changji, and Bayingolin are obviously higher than those of the surrounding areas because these cities function as regional centers or subcenters that attract resources and have high populations, housing, health care, education, industry, commerce, and a range of related supporting services along with high demands on land. The level of socio-economic development and overall income of residents in the surrounding prefecture-level cities are inferior to those in central cities, resulting in lower populations and fewer resources. Thus, the pressure on land is lower. It should be noted that the spatial differences in socio-economic pressure index gradually decreased during this study period because the growth rates of Urumchi, Changji, and other central cities are lower than those of the surrounding areas. On one hand, this

| Factors | Elevation | Slope | Change in proportion of construction land in the surrounding area | Change in GDP | Change in the proportions of secondary and tertiary industry | Change in average per capita GDP | Change in average per capita wage | Change in public budget expenditures |
|---------|-----------|-------|---------------------------------------------------------------|--------------|-------------------------------------------------------------|----------------------------------|------------------------------------|-------------------------------------|
| q statistic | 0.019 | 0.184 | 0.042 | 0.035 | 0.040 | 0.092 | 0.047 | 0.184 | 0.271 |
| p value | 0.068 | 0.000 | 0.081 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

Table 4. Interactions between factors affecting Urban Expansion.
is because the central cities have strict controls on construction land and population size. On the other hand, this indicates that the Matthew effect is not occurring in Xinjiang; the regions surrounding the central cities are growing robustly, and economic development is moving toward spatial equilibrium (Figure 3).

**Characteristics of land-use status index from 1997 to 2007**

During the study period, land-use study index decreased in the 14 prefecture-level cities in Xinjiang. The rapid urbanization in the last 20 years has brought rapid growth in the area of construction land, and the growth rate has greatly exceeded land-use intensity and development intensity; thus, land-use status index decreased year by year. Altay, Tacheng, Kizilsu Kirgiz, Hotan, and other peripheral areas had higher land-use status indices than central cities. This is because the areas of construction land and levels of socio-economic development are much smaller in these peripheral areas. Unlike the changes in socio-economic pressure index, the rates of decline in land-use status index in Urumchi, Changji, and other economically developed areas were lower than in peripheral areas. This means that economic development in peripheral areas is accelerating year by year, with increasing demand for construction land. The spatial differences in land-use status index changed slightly over time based on differences in regional policies, population size, economic development, and land development intensity; however, the overall spatial features of land-use status index remained stable during the study period. Combined with the results obtained for socio-economic pressure index (section 4.1), the land use status index results suggest a fairly strong correlation between the two indices; namely, a higher socio-economic pressure index corresponds to a lower land-use status index (Figure 4).

**Characteristics of eco-environmental response index from 1997 to 2007**

From 1997 to 2017, the eco-environmental response indices increased in most Xinjiang prefecture-level cities, while those in Urumchi and Changji decreased. While green area increased during the study period, resource consumption along with waste production and pollutant emissions increased substantially. Thus, the improvement in eco-environmental quality in all Xinjiang prefecture-level cities has been slow. Notably, the eco-environmental response index of Urumchi decreased from 0.35 in 1997 to 0.28 in 2017.

**Figure 3. Spatial features of socio-economic pressure index.**
This is attributed to the increase in resource consumption and pollutant emissions. Thus, Urumchi has undergone rapid economic development in the last two decades, resulting in severe eco-environmental problems. Consequently, Urumchi needs to adopt a green development strategy. While other areas have experienced improvements in eco-environmental quality, the extent of improvement is small. Thus, local governments should implement strategies to encourage sustainable, green development. The eco-environmental response indices showed large spatial differences among cities. Spatially, a depression distribution pattern is formed from the centrally located cities such as Urumqi, Changji, and Bayanguoleng to the central region. The changes in eco-environmental response index are related to the growth rate, area of construction land, natural resource endowment, and governmental policies. Generally speaking, eco-environmental quality lags behind in regions with rapid urban expansion and/or poor environmental supervision, highlighting the importance of environmental management and sustainable development (Figure 5).

Characteristics of EEI from 1997 to 2007
From 1997 to 2017, EEI increased slowly in Xinjiang. This is explained by two factors: rapid socio-economic development and strict governmental control of urban construction land via adjustments to land-use structure. Cities are seeking ways to balance economic development with ecological protection, thereby easing the effects of urban expansion on the ecological environment in Xinjiang. Compared to the above three classification indexes, the spatial differences in EEI were relatively small in the study area (Figure 6), reflecting the interactions between the individual indices. Higher EEI values were observed in Urumchi, Aksu, and Changji, which have high rates of Urban Expansion and high values of socio-economic pressure index. As the leading economic regions in Xinjiang, strong economic development in Urumchi and Changji offsets the disadvantage of lower eco-environmental quality, resulting in high EEI values. Meanwhile, local government in Aksu region pays more attention to reduce the negative effects of urban expansion on ecological safety and assures comprehensive benefits of production-living-ecology space.

Discussion
This study analyzed the natural, societal, economic, and political factors affecting Urban Expansion in
Figure 5. Spatial features of eco-environmental response index.

c. Ecological-Environment Response Index

Figure 6. Spatial features of composite-effect index.

d. Composite-Effect Index
Xinjiang. The geodetector method and PSR model were used to analyze the effects of various factors along with the interactions between different factors and the associated mechanisms. Finally, the eco-environmental effects of Urban Expansion in Xinjiang were quantitatively analyzed, including their spatial and temporal variations. The conclusions are summarized as follows.

(1) Numerous factors affected Urban Expansion in Xinjiang to different degrees from 1997 to 2017. The factors with strong effects on Urban Expansion included the public budget expenditures of local governments, the per-capita wages of urban residents, slope, GDP, proportions of secondary and tertiary industry, and population.

(2) From 1997 to 2017, the socio-economic pressure index increased rapidly in Xinjiang. The socio-economic pressure index was higher in the central regions and lower in peripheral cities. However, regional differences decreased over time. Land-use status index decreased during the study period and its distribution pattern showed an inverse correspondence with the socio-economic pressure index which remained stable over the years. The eco-environmental response index increased in most cities during the study period, although this index decreased in developed central cities such as Urumchi and Changji. However, these decreases were offset by the advantages brought by economic development. Finally, EEI increased steadily over the study period in all Xinjiang cities and regions.

(3) The effect of urban expansion on the ecological environment in Xinjiang weakened gradually during the study period, primarily due to the interactions among the socio-economic pressure, land-use status, and eco-environmental response indices. The EEI, which reflects the comprehensive effect of these three indices, slowly increased during the study period in all of Xinjiang, and the spatial differences in EEI decreased with time. However, the ecological response index has lagged behind, indicating the need for green socio-economic development.

(4) Urban construction land expanded rapidly in Urumchi, the center of economic development in Xinjiang, generating pressure on land resources. This led to low land-use status and eco-environmental response indices. The analysis of the effect of Urban Expansion on the ecological environment in Xinjiang using the PSR model confirmed that increasing urban expansion pressure drives changes in land use, resulting in an eco-environmental response. This exercise further verified the applicability of the PSR model in Xinjiang.

The results indicate that Urban Expansion in Xinjiang was primarily affected by natural geographic conditions, transportation infrastructure, population density, economic growth, industrial structure, and governmental activities. On correlative basis, the above factors are further enhanced on Urban Expansion effect, and there are clear spatial differences. Related research focused on Chinese inland cities indicates that urban expansion is mainly affected by GDP and fixed-asset investment (Chen & Wang, 2018; P.D. Liu & Xu, 2018; X.J. Wang & Zhou, 2018; Zhao et al., 2018). Moreover, the results of this study indicate that in addition to the above factors, the improvement of transportation infrastructure and the resulting population accumulation also have an important impact on the expansion of urban construction land in Xinjiang. Compared to densely populated coastal areas (Braimoh & Onishi, 2007), more space is available in Xinjiang for Urban Expansion; hence, the effect of slope, a terrain factor, is greater in Xinjiang.

In addition to the above factors, the land-related policies in different regions also affect Urban Expansion. Relevant policies include the “Three Lines,” which comprise the permanent prime farmland protection red line, the ecological protection red line and the urban development boundary line. Thus, when considering Urban Expansion, the socio-economic development and land policies should be comprehensively considered. Urban construction land efficiency should be improved continuously to realize the change of external expansion to tapping latent potentialities and coordinate the harmonious development of urban expansion, economic development, and ecological environment, create urban space with intensive and high efficiency in product, livable moderation in living and picturesque scenery in ecology. Although the overall ecological environment of all cities has improved, the comprehensive effect index of ecological environment has steadily increased. However, it is necessary to strengthen the investment and environmental supervision in urumqi, Changji and other economically developed cities. Under the circumstance that the environment condition allows, accelerate the investment construction strength of the city with poor economy, so as to better protect the environment.

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