



# Eberswalde University for Sustainable Development

Lingxiao Sun | Xiang Yu | Boshan Li | Haiyan Zhang | Dong Sha | Yao Wang |  
Jiaqiang Lei | Yang Yu | Martin Welp | Ruide Yu

Coupling analysis of the major impact on  
sustainable development of the typical arid  
region of Turpan in Northwest China

**Journal Article | Version of Record**

Secondary publication archived on the Publication Server of the Eberswalde University for Sustainable Development

<https://urn:nbn:de:kobv:eb1-opus-5420>

DOI: <https://doi.org/10.1016/j.regsus.2020.08.002>

**Terms of use:**

This work is licensed under a Creative Commons License. This does not apply to quoted content from other authors. To view a copy of this license visit

<https://creativecommons.org/licenses/by-nc-nd/4.0/>.

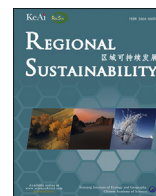




Contents lists available at [ScienceDirect](https://www.sciencedirect.com)

Regional Sustainability

journal homepage: [www.keaipublishing.com/en/journals/regional-sustainability](http://www.keaipublishing.com/en/journals/regional-sustainability)



Full Length Article

## Coupling analysis of the major impact on sustainable development of the typical arid region of Turpan in Northwest China

Lingxiao Sun<sup>a,b,c</sup>, Xiang Yu<sup>a,c</sup>, Boshan Li<sup>a,d</sup>, Haiyan Zhang<sup>a,b</sup>, Dong Sha<sup>e</sup>, Yao Wang<sup>e</sup>, Jiaqiang Lei<sup>a,f</sup>, Yang Yu<sup>a,b,f,\*</sup>, Martin Welp<sup>c</sup>, Ruide Yu<sup>a,b,f,\*\*</sup>

<sup>a</sup>Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi, 830011, China

<sup>b</sup>University of Chinese Academy of Sciences, Beijing, 100049, China

<sup>c</sup>Eberswalde University for Sustainable Development, Eberswalde, 16225, Germany

<sup>d</sup>Research Center for Ecology and Environment of Central Asia, Chinese Academy of Sciences, Urumqi, 830011, China

<sup>e</sup>Turpan Agriculture Service Center, Turpan, 838000, China

<sup>f</sup>State Key Laboratory of Desert and Oasis Ecology, Chinese Academy of Sciences, Urumqi, 830011, China

### ARTICLE INFO

#### Keywords:

Sustainable development  
Coupling analysis  
Coupling coordination degree  
Comprehensive evaluation index  
Turpan

### ABSTRACT

Analyzing the sustainable development of a given region can provide an important reference and guide for future orientation. The study selects Turpan (including Gaochang District, Shanshan County, and Toksun County) in Xinjiang Uygur Autonomous Region of Northwest China as the study area and first investigates the essence of regional sustainable development. Based on the relevant data of the population, economy, and environment of Turpan from 2002 to 2018, we constructed an evaluation index system for three dimensions, namely, the population, economy, and environment, and analyzed them systematically. Specifically, we quantitatively calculated the comprehensive evaluation index, coupling degree, and coupling coordination degree of the sustainable development system of the study area. The study finds that Turpan has on some dimensions become increasingly sustainable, especially the economic development level has improved. The results show that the coupling coordination degree has increased from 0.3692 to 0.8894 during the period 2002–2018, which reflects the actual situation of Turpan and indicates that the proposed analysis method can effectively measure and evaluate the level of sustainable development in this region. Moreover, the study also puts forward main functional zoning of Turpan (i.e., Gaochang District as an optimized development zone, Shanshan County as a major agricultural production zone, and Toksun County as a key ecological function zone) and regional planning principles based on the population, economic, and environmental coupling analysis for the three jurisdictions in Turpan.

### 1. Introduction

Urbanization growth rate may reach 60% and 70% by 2030 and 2050, respectively, on a global scale (Khazaei and Razavian, 2013), which requires cities to become the driving forces behind sustainable development efforts (Vojnovic, 2014; Liu, 2018). Undoubtedly, urbanization will be the trend of future development; however, at this phase, considerable attention should be paid to rural development

\* Corresponding author. Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi, 830011, China.

\*\* Corresponding author. Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi, 830011, China.

E-mail addresses: [yuyang@ms.xjb.ac.cn](mailto:yuyang@ms.xjb.ac.cn) (Y. Yu), [ruidayu@ms.xjb.ac.cn](mailto:ruidayu@ms.xjb.ac.cn) (R. Yu).

<https://doi.org/10.1016/j.regsus.2020.08.002>

Received 6 May 2020; Received in revised form 5 August 2020; Accepted 25 August 2020

and its potential as well. Furthermore, in contemporary China, importance should be given to the rural population reduction, soil degradation, industrial stagnancy, and other rural recession issues due to such issues exert a negative effect on urbanization. China faces these problems because of an imbalanced urban-rural relationship under the dual management system, which is also harmful for the coordinated development of cities (Long, 2012; Liu and Li, 2017; Tu and Long, 2017). In response to this imbalance, the 19<sup>th</sup> National Congress of the Communist Party of China emphasized three strategies, namely, rural resilience, coordinated regional development, and sustainable development, to narrow down the negative consequences of the uncoordinated urban-rural development.

In recent years, research on the regional sustainable development system has attached importance to many aspects, such as related theories (Liu et al., 2016), potential and evaluations (Ren et al., 2019), model designs (Ma et al., 2019), and operational supervision mechanisms (Liu et al., 2012). Constructing sustainable development analysis indices for measurement index systems is essential because of regional differences. Moreover, sustainability is closely related to society, economy, and environment (Komeily and Srinivasan, 2015; Cohen, 2017). Additionally, sustainable development analysis has aroused the interest of local researchers who focused on different regions in China. For example, Zhang et al. (2014) investigated the ecological, economic, and social systems of counties and cities in the Shiyang River Basin using the ecological economic coordination degree evaluation model. In China's arid areas, the coupling mechanism of urbanization and ecological environment (Zhang et al., 2012) and the water consumption of economic and social activities and their effects on the environment (Zhang et al., 2020) have been previously studied. Further, economic and social development and the ecological environment were categorized into several subsystems for coupling evaluation and analysis (Hillman, 2004; Niu et al., 2010; Dang et al., 2015). In certain elements or subsystems, the emergence of the sustainable development system does not exist. However, this topic is discussed in terms of the entire system. In other words, the interaction, influence, and restriction among them trigger the emergence simultaneously (Holland and Order, 1995). The majority of the abovementioned studies focused on large areas and analyzed the coupling of the sustainable system in such areas. Consequently, only a few studies have shed light on the importance of man-land relationship coordination in the process of urbanization and elucidated rural values and potentials, especially in arid areas.

Oasis basins in arid areas are the core of human life and production for thousands of years. The relationship between the people and the land is extremely sensitive because human activities are prevalent in these areas. In contrast to other sustainable systems, the oasis system is characterized by a fragile ecological environment, major restraints in water resources, a weak economic foundation, and immense social and cultural differences. Turpan, in particular, is a typical broken oasis city in China's arid areas. According to the National New-Type Urbanization Plan 2014–2020 (Central Committee of the Communist Party of China and the State Council, 2014), the Chinese government encourages approximately 100 million people to urbanize the nearby western regions and propose the construction of the Belt and Road Economic Zone that relies on urban agglomerations and node cities. The resultant public policies can bring about great opportunities for and challenges to sustainable development in the new era.

The oasis system forms an important component of arid lands because it comprises an open, dynamic system with comprehensive multidimensionality. Three elements, namely, local population, environment, and economy, influence the urban-rural economic and social development of oasis systems. As a core element of sustainable development, population creates values in many aspects through the exploitation and utilization of resources, operation and management of businesses, and many daily living activities (Long et al., 2019). On one hand, human orientation and creativity dominate sustainability for later generations; on the other hand, unwise and short-sighted decisions may result in a devastated environment in terms of nature and culture. Environment plays a vital role in providing resources and spatial support. It not only meets the needs of various forms of industry and life but also triggers different modes of development. Finally, economic growth is the driving factor for sustainable development through the organic combination of the population and environment. Moreover, it determines local economic and social sustainable development. Therefore, strengthening the combination of "resources, capital, and assets" by coordinating the population, environment, and economy can be regarded as the key to fostering the momentum of development.

The urban-rural development in Turpan should be mutually beneficial rather than a binary opposition. Inappropriate urbanization may result in the inefficient use of resources, severe social problems, and inordinate industrial development for urban and rural areas. Therefore, the best means to address this issue is building a strategy that can balance urban and rural economy, politics, culture, and ecology by remodeling socioeconomic morphology and spatial pattern (Tu and Long, 2017; Zhang, 2018). Furthermore, urban-rural development aims to share common achievements in development and create a balanced urban-rural pattern of development to provide equal opportunities (Table 1).

The research of sustainable development requires comprehensive approaches and a scientific index system. Several studies have focused on the construction of index system and evaluation methods to ensure the efficient and scientific use of resources and improve the living environment (Niu et al., 2010; Zhang et al., 2012; Liu et al., 2016). Therefore, undertaking a comprehensive analysis of Turpan

**Table 1**  
Requisites of a sustainable development system.

	Requisite
Systematized characteristics	Multidisciplinary integration of economics, sociology, technology, and geography; multi-departmental coordination for the promotion of a complementary governance system.
Hierarchical characteristics	Goal orientation and strategic positioning for different levels.
Regional characteristics	Excavation of local values, such as cultural heritage; cultivation of diverse local industrial structures; scientific formulation of strategies and paths.

is necessary to examine the effectiveness of the system. Accordingly, based on the core factors that influence the sustainable development in Turpan, the current study investigates the significance of urban development and rural vitalization, analyzes the relationship between the population and environment, and presents some suggestions regarding urban development and rural vitalization to provide a theoretical basis for future studies.

## 2. Materials and methods

### 2.1. Study area

Turpan, which is located in the east of Xinjiang Uygur Autonomous Region of Northwest China, is an internal mountain basin east of the Tianshan Mountains. It covers an area of  $7.0 \times 10^4 \text{ km}^2$  and has jurisdiction over Gaochang District, Shanshan County, and Toksun County. Spanning from 5445 m a.s.l. in the Bogda Peak to  $-155 \text{ m a.s.l.}$  in the Aiding Lake, Turpan poses a vertical height difference of 5600 m and is surrounded by mountains along three sides, which are high in the northwest and low in the southeast. With its unique arid desert climate characteristics in a warm temperate zone, the Turpan Basin is a dry, hot, and windy area. According to the statistics, the highest temperature recorded in the basin is  $47.7 \text{ }^\circ\text{C}$  while the entire year experiences extremely hot days with daily maximum temperatures higher than  $40.0 \text{ }^\circ\text{C}$  from 40 to 50 d per year (Wei et al., 2013). By contrast, the average annual precipitation in Toksun County is less than 7 mm, whereas the Kumtag Desert in the southern edge of the basin has nearly no effective precipitation all year round. Each river in Turpan has its independent water system but features a small drainage area, short flow path, large leakage, small annual runoff, and poor river channel storage capacity. Although many natural lakes exist historically, the water system from the upper reaches of Aiding Lake was intercepted by the influence of human activities, which intensified the lake's shrinkage and extinction (Wang, 2013). However, these natural limitations failed to hinder sustainable development in Turpan to a certain extent (Li et al., 2016). As such, its sustainability should be considered with a full dimension because Turpan is an important part of the ancient Silk Road and a transportation hub connecting Central Asian countries and Xinjiang of China. With the implementation of the "Belt and Road" Initiative, Turpan is expected to benefit from its advantages.

### 2.2. Data source and establishment of the index system

Original data were derived from the Xinjiang Statistical Yearbook (Statistic Bureau of Xinjiang Uygur Autonomous Region, 2002–2018), the Turpan Statistical Yearbook (Turpan Statistical Yearbook Committee, 2002–2018), the Work Report of the Turpan Municipal Government (<http://www.tlf.gov.cn/zwgk/ndbg.htm>), and the Environmental Quality Bulletin of Turpan (Turpan Environmental Protection Bureau, 2002–2018). Moreover, several index data were sourced from literature related to the index and the fields of society, economy, resources, environment, and technology.

Per the research needs, the convenience of data acquisition, and the condition that the Kaiser-Meyer-Olkin (KMO) value is greater than 0.6 after conducting analysis using SPSS 23.0 software, we established the coordination analysis of the relationship between the population, economic, and environmental subsystems in Turpan by the KMO test. Table 2 provides a comparison of simple correlation and partial correlation among variables.

**Table 2**

Measurement evaluation index system for sustainable development in Turpan (2002–2018).

Target grade	First-grade index	Second-grade index	Index property	Entropy weight
Turpan's sustainable development	Population subsystem	Natural population growth rate (%)	–	0.1416
		Urban population percentage (%)	+	0.1743
		Unemployment rate (%)	–	0.0734
		Number of students per 10,000 people	+	0.2762
		Number of beds in health care institutions per 10,000 people	–	0.1425
	Economic subsystem	Disposable income of urban residents (CNY)	+	0.1280
		Per capita GDP (CNY)	+	0.1920
		Per capita annual net income of farmers (CNY)	+	0.1338
		Total fixed assets investment ( $10^4$ CNY)	+	0.1584
		Social consumer goods sales ( $10^4$ CNY)	+	0.1280
		Local fiscal revenue ( $10^4$ CNY)	+	0.1152
		Tertiary industry percentage in GDP (%)	+	0.2566
		Secondary industry percentage in GDP (%)	+	0.0080
		Environmental subsystem	Green coverage rate (%)	+
	Sewage treatment rate (%)		+	0.3000
	Industrial waste gas emission ( $10^8 \text{ m}^3 \text{ yr}^{-1}$ )		–	0.0825
	Comprehensive utilization rate of industrial solid waste (%)		+	0.2886
	Per capita water resources ( $\text{m}^3$ per person)		+	0.1688

Note: "–" and "+" mean decreasing and increasing trends during the period 2002–2018, respectively.

### 2.3. Data standardization

Ensuring the reliability of measurement results is essential for accuracy. Thus, the extreme method was used to implement dimensionless processing. Further, the fluency of different dimensions and orders of magnitude on the initial data should be removed. Subsequently, the study used maximum and minimum values to eliminate the entropy increase/decrease indices in the evaluation index dimensions.

The entropy decrease index can be presented as  $x_{ij}$  (the larger the value, the better) (Liao, 1999; Gong et al., 2019):

$$x'_{ij} = x_i - \frac{\min\{x_{ij}\}}{\max\{x_{ij}\}} - \min\{x_{ij}\}, \quad i = 1, 2, \dots, m; \quad j = 1, 2, \dots, n, \tag{1}$$

where  $x_{ij}$  represents the value of the  $j$ th evaluation index in year  $i$ . The entropy increase index can be presented as  $x_{ij}$  (the smaller the value, the better) (Liao, 1999; Gong et al., 2019):

$$x'_{ij} = \max\left\{x\right\} - \frac{x_i}{\max\{x_{ij}\}} - \min\left\{x_{ij}\right\}, \quad i = 1, 2, \dots, m; \quad j = 1, 2, \dots, n. \tag{2}$$

Then, the normalized value is described as follows:

$$y_{ij} = x'_{ij}. \tag{3}$$

The practical utility of the index information entropy value can be identified by the entropy method, which can create a judgment matrix to determine index weights by assessing index numerical values. Thus, the results are more reliable using the entropy method approach because it can remove individual subjectivity and evaluate the indexes objectively (Gong et al., 2019).

$$E_{ij} = -k \sum_{i=1}^m p_{ij} \ln p_{ij}, \tag{4}$$

$$k = \frac{1}{\ln m}, \tag{5}$$

$$W_{ij} = \frac{1 - E_{ij}}{\sum_{i=1}^m 1 - E_{ij}}, \tag{6}$$

where  $0 \leq E \leq 1$ ;  $k$  is a constant, and its value is associated with the number of system samples; and  $m$  denotes year. The entropy weight of each subsystem can be determined by adding the information entropy weight because the measurement system has a special multilayer structure.

The index of the relationship between the population, economy, and environment was then computed to provide a comprehensive evaluation of Turpan during the period 2002–2018. Subsequently, changes in the situation across the past 17 years were analyzed. The results of such analysis can determine the coupling coordination degree. The calculation processes are described as follows (Liao, 1999):

$$f(x) = \sum_{i=1}^m a_i x'_i, \tag{7}$$

$$g(y) = \sum_{i=1}^n b_i y'_i, \tag{8}$$

$$h(z) = \sum_{i=1}^k c_i z'_i, \tag{9}$$

where  $f(x)$ ,  $g(y)$ , and  $h(z)$  are the comprehensive evaluation indices of the population, economic, and environmental subsystems, respectively; and  $a_i$ ,  $b_i$ , and  $c_i$  are the weights of each index of the population, economic, and environmental subsystems, respectively, which are determined by principal component analysis. The basic principle is to replace the many original variables with less comprehensive factors so that these factors can represent information on the original variables as much as possible. These factors are unrelated so as to achieve simplification.  $x'_i$ ,  $y'_i$ , and  $z'_i$  are the index values describing the characteristics of population, economy, and environment, respectively. All values are dimensionless.

The concept of coupling degree can be explained as a phenomenon in which two or more subsystems interact through various ways of motion (Illingworth, 1977). It is regarded as an indicator through which the degree of interaction between subsystems can be evaluated. In addition, the coupling coordination degree refers to the correlation of a virtuous cycle and coordination between subsystems. The following formula represents the coupling degree (Liao, 1999):

$$C = \left\{ \frac{f(x) \times g(y) \times h(z)}{\left[ \frac{f(x)+g(y)+h(z)}{3} \right]^3} \right\}^{\frac{1}{3}}, \tag{10}$$

where  $C$  indicates the coupling degree. A large  $C$  value indicates a high coupling coordination degree of each subsystem in the research year. When  $C = 1$ , it means that the three selected subsystems (population, economy, and environment) can be viewed as the optimum coordination state. However, when  $C = 0$ , it means that the different elements within the subsystem are not fully coordinated, and the system is disorderly. Table 3 presents the classification of coordinated development, as described by Liao (1999).

However, under a sustainable urban-rural development system, when the coupling degree is merely used to estimate the interaction between varieties of subsystems, the results can lead to pseudo-coordination and low subsystem development but a high coupling degree (Chen and Zeng, 2004). In this situation, the coupling degree cannot reveal the true level of development of the study area in terms of its social, economic, and environmental aspects. Therefore, the coordinated development model is described as follows (Liao, 1999):

$$D = \sqrt{C \times T}, \tag{11}$$

$$T = \alpha f(x) + \beta g(y) + \delta h(z), \tag{12}$$

where  $D$  denotes the coupling coordination degree;  $T$  represents the comprehensive evaluation index of the sustainable development system; and  $\alpha$ ,  $\beta$ , and  $\delta$  are the undetermined coefficients. Combined with the rapid development of the regional economy and fragile ecological environment in Turpan in recent years, three undetermined coefficients of  $\alpha$ ,  $\beta$ , and  $\delta$  are presented as 0.2, 0.4, and 0.4, respectively.

### 3. Results and discussion

Equations (4)–(12) can be used to calculate the entropy weights of each index in terms of the sustainable development system in Turpan, after which the coupling coordination degree and development level of each year were calculated (Table 4). The coupling degree was 0.8910 in 2002, while it reached to 0.9859 by 2018. Similarly, both comprehensive evaluation index of the sustainable development system and coupling coordination degree values showed an increasing trend from 2002 to 2018. This result indicated that the degree of coordinated development in Turpan has improved significantly during the study period, and Turpan had developed at a sustainable pace.

#### 3.1. Evolution trend of sustainable development in Turpan

Fig. 1 illustrates that the reform of the capacity for local sustainable development in Turpan is highly influenced by political factors, such as the national project “Grain for Green”, the state project for a strong ecological environmental protection supervision and water resource management system, the development of Turpan’s ecological tourism, and the upgrading of administrative levels in Turpan. However, the influence of social transfer and transformation factors is relatively less than those of the other factors. The study finds that the sustainable development system in Turpan now is in a dynamic state. The natural geographical conditions are considerably restrictive because Turpan is a typical oasis city. Thus, implementing two typical urbanization development models, namely, increasing the number of towns and expanding the city scale, is possible. Dependent on certain natural environmental conditions, Turpan is establishing itself as an adjacent major city to Urumqi’s satellite city. With the help of modern transportation, comprehensive transportation networks, and a highly developed information network, the Urumqi-Turpan city group comprises a relatively complete urban “aggregate”.

The nonlinear dynamic population-economic-environmental relationship involved in the sustainable development of Turpan is illustrated in Fig. 2. In order to maintain the sustainable development trend in Turpan, it is necessary to keep a coordinated development

**Table 3**  
Hierarchy of coordinated development.

Coupling degree value	Coupling coordination level	Coupling coordination degree
0.0000–0.0999	Level 1	Extreme imbalance
0.1000–0.1999	Level 2	Serious imbalance
0.2000–0.2999	Level 3	Moderate imbalance
0.3000–0.3999	Level 4	Mild imbalance
0.4000–0.4999	Level 5	Near imbalance
0.5000–0.5999	Level 6	Reluctant coordination
0.6000–0.6999	Level 7	Primary coordination
0.7000–0.7999	Level 8	Intermediate coordination
0.8000–0.8999	Level 9	Good coordination
0.9000–1.0000	Level 10	Quality coordination

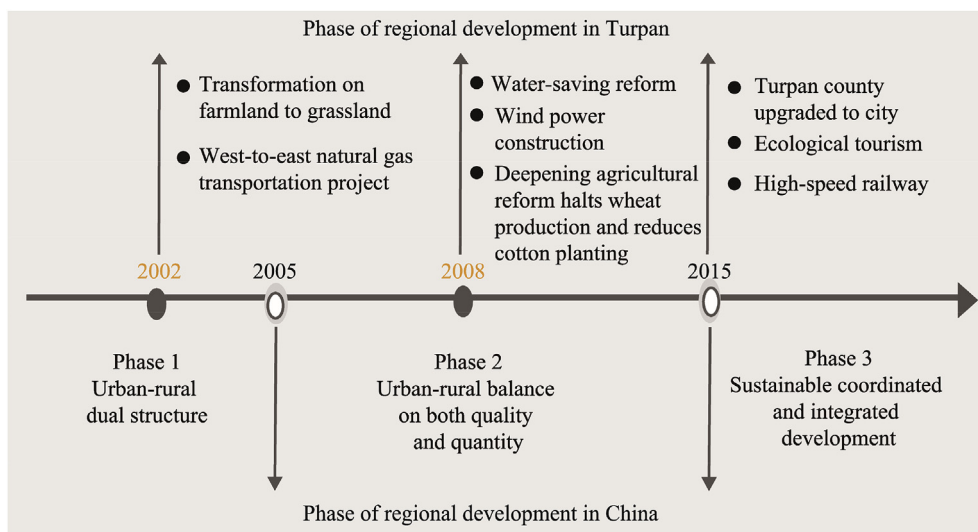
Note: The classification of coordinated development is derived from Liao (1999).

**Table 4**

Degree of coordinated development and coordinated development type in Turpan (2002–2018).

Year	$f(x)$	$g(y)$	$h(z)$	$C$	$T$	$D$	Coupling coordination degree
2002	0.2732	0.0817	0.1641	0.8910	0.1530	0.3692	Mild imbalance
2003	0.2955	0.0876	0.1518	0.8850	0.1549	0.3702	Mild imbalance
2004	0.3109	0.1421	0.1617	0.9399	0.1837	0.4155	Near imbalance
2005	0.3457	0.1418	0.2090	0.9355	0.2095	0.4427	Near imbalance
2006	0.5831	0.1431	0.2832	0.8529	0.2871	0.4949	Near imbalance
2007	0.4446	0.1676	0.2341	0.9193	0.2496	0.4790	Near imbalance
2008	0.5856	0.1941	0.2811	0.8974	0.3072	0.5251	Near imbalance
2009	0.5050	0.3406	0.3400	0.9822	0.3732	0.6055	Reluctant coordination
2010	0.5175	0.2513	0.2278	0.9314	0.2951	0.5243	Near imbalance
2011	0.4631	0.2933	0.2481	0.9647	0.3092	0.5461	Near imbalance
2012	0.4983	0.3665	0.2146	0.9441	0.3321	0.5599	Reluctant coordination
2013	0.4585	0.4654	0.2694	0.9703	0.3856	0.6117	Reluctant coordination
2014	0.6488	0.5555	0.1782	0.8690	0.4232	0.6065	Reluctant coordination
2015	0.5137	0.6701	0.5907	0.9941	0.6071	0.7769	Intermediate coordination
2016	0.5426	0.7697	0.8464	0.9826	0.7550	0.8613	Good coordination
2017	0.5034	0.8885	0.7939	0.9719	0.7736	0.8671	Good coordination
2018	0.5932	0.8445	0.8650	0.9859	0.8024	0.8894	Good coordination

Note:  $f(x)$ , comprehensive evaluation index of the population subsystem;  $g(y)$ , comprehensive evaluation index of the economic subsystem;  $h(z)$ , comprehensive evaluation index of the environmental subsystem;  $C$ , coupling degree;  $T$ , comprehensive evaluation index of the sustainable development system;  $D$ , coupling coordination degree.



**Fig. 1.** Matching of the phases of regional development in Turpan (Xinjiang of China) and in China.

in population, economy, and environment. However, Turpan faced many problems in the early stage. For instance, from the population aspect, Turpan had a relatively low level of education and it also lacked employment channels in the past few years. Moreover, the aging problem was still noteworthy. For the environment aspect, Turpan had the problems of water shortage, biodiversity reduction, and inferior cultivation conditions. For the local economy aspect, insufficient water-saving in agriculture, lower added value of products, and incomplete industry chain were the prominent issues. As a result, the local government has put forward some solutions to improve these problems. For example, the government increased investment in education in the past 20 years. Turpan also attached great importance to the local environment by reforming water-saving system, promoting ecological management, and improving land use system. In addition, to improve local economy, the government has promoted the integration of primary, secondary, and tertiary industries.

### 3.2. Elements of development in Turpan

#### 3.2.1. System sustainability analysis

Fig. 3 indicates that the total trend of the coupling coordination degree of the sustainable development system in Turpan had gradually increased from 2002 to 2018. Specifically, the value changed from a near imbalance of 0.3692 to a good coordination of 0.8894. From 2002 to 2009, the coupling coordination degree pointed to an upward trend with increasing speed. From 2009 to 2014,



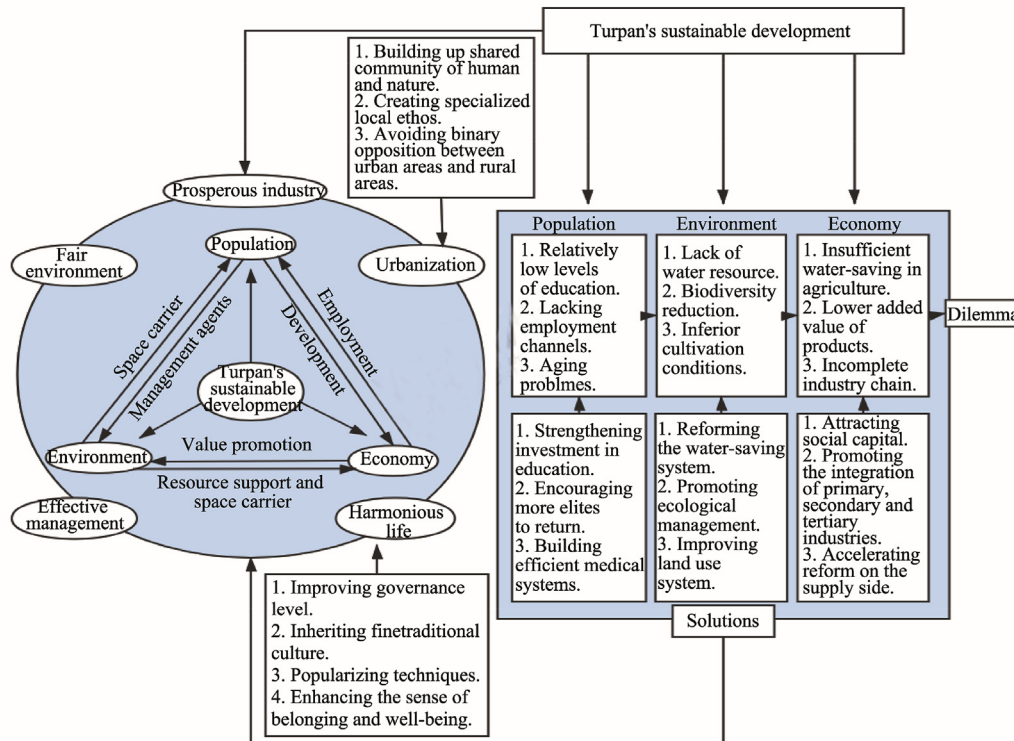


Fig. 2. Sustainable development circle for Turpan.

the coupling coordination degree showed an approximate linear standing, which indicated that with the growth of the population, the coupling coordination of the three subsystems became unstable. From 2015 to 2018, the coupling coordination degree retained a state of balance. Effective advocates (e.g., ecological tourism) and fruitful projects (e.g., high-speed railway) are clearly strong drivers of local economic development. Urbanization in Turpan is in progress along with its economic development and opening up. The main reason that underlies such progress is that the local government emphasized environmental protection and ecological tourism and formulated certain policies to attract financial investment, such as monitoring the environment, strengthening the water resource management system, and encouraging international ecological tourism. These initiatives have prompted a rapid development in the economic and environmental subsystems. Thus, the development in Turpan became more coordinated during the period 2002–2018. Furthermore, a strong correlation exists between the secondary industry and GDP in Turpan, where environmental pollution caused by industrialization

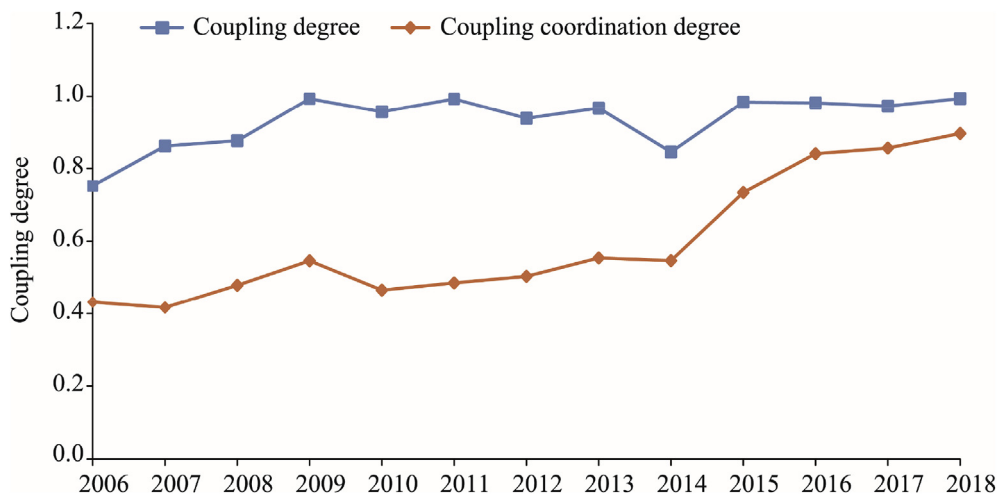


Fig. 3. Coupling degree and coupling coordination degree of the sustainable development system in Turpan (2002–2018).

is the primary reason for the changes in the three subsystems in Turpan in terms of coupling degree and coupling coordination degree types.

Using the proposed method, the growing trend and orderly development degree of the sustainable development system in Turpan were calculated. Fig. 4 presents the variations of the entropy in the three subsystems, which gradually increased with the increase in fluctuation rate from 2009 to 2014. This trend indicated that the imbalanced population-economy-environment development led to a decrease in the overall sustainable development system. Since 2015, the local development and infrastructure in Turpan achieved remarkable success and provided favorable support for the building of a strategic city, a tourism city, and a beautiful model city in China.

### 3.2.2. Sustainable development level of the population subsystem

As shown in Fig. 4, the development trend of the comprehensive evaluation index of the population subsystem was similar with that of the comprehensive evaluation index of the sustainable development system in most of the study period. The comprehensive evaluation index of the population subsystem fluctuated steadily from 2008 to 2015 and grew slowly afterward. Simultaneously, the proportion of the urban population in Turpan was relatively low and the traditional fruit planting industry was insufficient for the promotion of economic development. Additionally, the proportion of the employed population in the secondary industry was relatively high, which caused extensive damage to the environment. From 2015 to 2018, the population became a lagging element in the sustainable development system. In general, however, the population factor remained the main body of sustainable development in the region. Recently, it has lacked strength as an economic subsystem, as compared to the other subsystems (Fig. 4).

### 3.2.3. Sustainable development level of the economic subsystem

The sustainable development level of the economic subsystem had been generally improving during the period 2002–2018 (Fig. 4). Specifically, the comprehensive evaluation index of the economic subsystem showed an overall increasing trend from 2002 to 2018. Natural disaster and policy are the two predominant factors influencing the economic growth of Turpan. In 2009, natural disasters, such as gale, drought, and extreme temperatures, have resulted in tremendous economic losses in terms of agriculture. This finding hints at the importance of protecting the environment as part of the decision-making of the government and other individuals. Turpan then gradually transformed its agriculture and industry in an intensive manner, such as planting water-saving and high-yield crops and adopting efficient water-saving cooling technology. Although industrial growth slowed down during the study period, the tertiary industry increased accordingly. For example, investment in the tertiary industry reached 15.06 billion CNY in 2016 (increased by 92.5% compared with that in 2002), which led to a consistent improvement of the economic subsystem. Moreover, the government has implemented certain strategies, such as constructing the Urumqi-Turpan city group and building the national tourism city, to attract more investments; it aimed to transform Turpan into an influential western tourism center. These approaches facilitated local economic development. From 2015 to 2016, the economic growth rate increased sharply, indicating an improvement in the overall economic development level. The policies and paths of tourism development in Turpan can provide reference for other regions in Xinjiang to improve their tourism competitiveness.

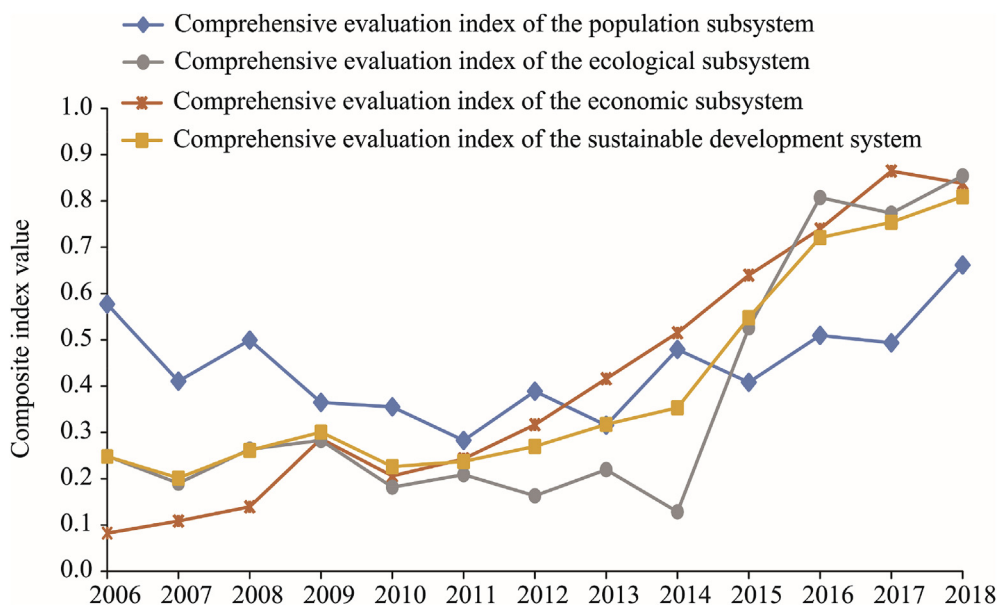


Fig. 4. Entropy changes of the three subsystems (population, economy, and environment) as well as the comprehensive evaluation index of the sustainable development system.

### 3.2.4. Sustainable development level of the environmental subsystem

Fig. 4 indicated that although fluctuations occurred in some years, the comprehensive evaluation index of the economic subsystem generally showed an increasing trend. Due to the area's unique geographic location and extreme climatic conditions, seeking policy and technology support is a unique method for the sustainable development of the environment. Additionally, the water restriction on Turpan has been lessened because of the strict water resource management system implemented in Xinjiang since 2013, which showed a strong policy effect. Furthermore, the environmental subsystem grew rapidly from 2014 to 2018 owing to the wide use of agricultural and industrial water-saving equipment and technology. Water is always a limited resource factor for the sustainable development of Turpan, an extremely arid area. Many researchers have focused on water utilization structure to determine whether a good coordination exists between the economic and environmental subsystems (Anwaer and Tashkin, 2009; Cohen, 2017). The results from this study clearly showed that the environmental subsystem in Turpan has largely developed. Nonetheless, considerable room remains for improvement.

## 4. Proposal of main functional zoning in Turpan

In China, main functional zoning is divided into three types: optimized development zones, major agricultural production zones, and key ecological function zones (Fan, 2015). Turpan City has jurisdiction over Gaochang District, Shanshan County, and Toksun County. This study evaluates the sustainable development system of Turpan using the functional zoning models and paths described by Fan (2015).

### 4.1. Gaochang District as an optimized development zone

Gaochang District is the main district in Turpan. It has a relatively better economic level and richer human resources than other counties, which can support Turpan's future economic development and population growth. Sustainability is essential for local development because it not only moderates conflict between humans and nature but also holds the key to maintaining a coordinated urban-rural relationship.

In terms of the population, talents should be encouraged to flow through higher education and elite-drawing policies. Their employment should be broadened among the primary, secondary, and tertiary industries, particularly modern service industries. Urban and rural human resources should flow on both sides frequently, for example, attracting people to invest in rural areas.

The environment aspect refers to smart and effective land use to provide additional spaces for the development of the secondary and tertiary industries. Additionally, real-time monitoring on land and water utilization is necessary.

As for the economy, local economic advantages, esthetic features, historical culture, and service industries should be improved by adding infrastructure and values. Conversely, e-commerce industries and opening-up markets are essential for local economic development.

### 4.2. Shanshan County as a major agricultural production zone

As a major modern agricultural production zone, Shanshan County is in charge of regional food security and farmland production. Since 2007, farmers in Shanshan County have promoted its cash crop industry, such as Hami melon, pomegranate, and vegetable planting, thus halting wheat and cotton production. However, the county continues to struggle with low efficiency of production and extensive land use.

Shanshan County has a high density of rural population, which reached approximately 70% by 2019. Professional peasant training is necessary not only to strengthen the agricultural and stock-breeding skills of the local population but also to enable the rural youth labor to gain skills for diversified operations.

To improve the local ecological environment, addressing water shortage problems, updating irrigation facilities, and preventing land pollution are essential steps. In addition, intensive use of consolidated land and protection of the local environment are significant initiatives.

In terms of the economy, developing the local economy by taking advantage of local natural resources, such as mineral resources, giving more attention on the adjustment of industrial structure, and prioritizing the integration of organic planting and ecological tourism are important. Moreover, the mobile platform for propandas and sales should be explored in depth.

### 4.3. Toksun County as a key ecological function zone

Toksun County, which is famous for its "little black sheep", reflects its competitiveness in ecological protective functions, such as protecting biodiversity, conserving water sources, breaking wind, and fixing sand. Thus, managing the sustainable development system based on natural regional conditions and local humanistic features is vital.

With respect to the population, the aging problem caused by the loss of young labor has influenced the local development. Thus, reducing poverty rates and ensuring fair opportunities for education and medical care are essential steps.

Environmental protection is promoted rather than cultivation, which indicates that ecological remediation is crucial in this region.

From the economic aspect, maintaining the ecological value of local products, such as organic foods, and broadening sales on mobile platforms are important for the improvement of the local economy. Moreover, ecological and cultural tourism can be popularized by improving infrastructure construction and public service.

## 5. Conclusions and suggestions

The sustainable development system in Turpan is a complex one with three subsystems: the population, economy, and environment. An in-depth analysis of the level of coordinated development finds that the coupling method can be used to determine the level of consistency between the sustainable development system and its subsystems.

This study infers that over the next few years, economic growth will remain essential for the sustainable development of Turpan. Thus, the local government should build modern industrial clusters by developing scarce innovative elements, such as clean energy, wine planting industry, and ecological tourism. Moreover, improving the quality of public facilities and services plays a vital role in increasing the level of coordinated development. Accordingly, encouraging the leading role of a people-centered ecofriendly strategy in Turpan is essential. The regulations and policies of local government in Turpan as well as the wide context of urbanization have exerted a relatively significant impact on its rural vitalization.

Furthermore, sustainable development should emphasize the conditions of different research areas. Apart from water shortage, drought, and gale in Turpan, examining its rich solar thermal resources, wind energy resources, and mineral resources is necessary. Therefore, full consideration must be given to the inherent resource advantages of Turpan. Additionally, facilitating the sustainable development of industrialization by innovating special local industries is a promising and essential avenue for Turpan. The premise is that the local ecological environment should remain intact.

The emphasis on the population, economic, and environmental subsystems herein is not all-inclusive because urban-rural coordinated development is a complex and comprehensive system. At present, relevant theories, sustainable development models, and implementation paths are still being explored. Consequently, coordinating all forms of development factors and attracting a more well-educated population are necessary steps to address the sustainable development problems in Turpan. Accordingly, research efforts will be made in this direction.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgments

This work was supported by the Strategic Priority Research Program of the Chinese Academy of Sciences (XDA20060303), the “Light of West China” Program of the Chinese Academy of Sciences (2018-XBQNXX-B-017), and the “High-Level Talents Project” in Xinjiang (Y942171). Data collection and analysis are supported by the Sino-German Joint Research Center for the Management of Ecosystems and Environmental Changes in Arid Lands and the Research Center for Ecology and Environment of Central Asia of the Chinese Academy of Sciences. Special thanks are given to the support of the “One Hundred Person Project” of the Chinese Academy of Sciences (Y931201).

## References

- Anwaer, M., Tashkin, J., 2009. Analysis on coupling relations between urbanization and eco-environment in Southern Xinjiang. *J. Beijing For. Univ.* 8 (4), 169–174 (in Chinese).
- Central Committee of the Communist Party of China and the State Council, 2014. China: national new-type urbanization plan 2014–2020 (in Chinese). [http://www.gov.cn/zhengce/2014-03/16/content\\_2640075.htm](http://www.gov.cn/zhengce/2014-03/16/content_2640075.htm).
- Chen, J., Zeng, Z.X., 2004. Research on the appraise model of coordination development among society, economy, resource and environment. *Scientific Management Research* 22, 9–12 (in Chinese).
- Cohen, M.A., 2017. Systematic review of urban sustainability assessment literature. *Sustainability* 9 (1), 2048. <https://doi.org/10.3390/su9112048>.
- Dang, J.H., Wahap, H., Zhang, Y.P., et al., 2015. Coupling coordinated development of population, economic and ecological system in the Turpan Area of China. *J. Desert Res.* 35 (1), 260–266 (in Chinese).
- Fan, J., 2015. Draft of major function oriented zoning of China. *Acta Geograph. Sin.* 70 (2), 186–201 (in Chinese).
- Gong, Q.X., Chen, M., Zhao, X.L., et al., 2019. Sustainable urban development system measurement based on dissipative structure theory, the Grey entropy method and coupling theory: a case study in Chengdu, China. *Sustainability* 11 (1), 293. <https://doi.org/10.3390/su11010293>.
- Hillman, B., 2004. The rise of the community in rural China: village politics, cultural identity and religious revival in a Hui hamlet. *China J.* 51, 53–73.
- Holland, J.H., Order, H., 1995. How Adaptation Builds Complexity. Basic Books, New York, pp. 1–185.
- Illingworth, V., 1977. *Penguin Dictionary of Physics*. Penguin Books, London, pp. 1–504.
- Khazaei, M., Razavian, M.T., 2013. Sustainable urban development (an innovative approach in the development of cities around the world). *Int. Res. J. Appl. Basic Sci.* 4, 1543–1547.
- Komeily, A., Srinivasan, R.S., 2015. A need for balanced approach to neighborhood sustainability assessments: a critical review and analysis. *Sustain. Cities Soc.* 18, 32–43.
- Li, Y.H., Hans, W., Zheng, X.Y., et al., 2016. Bottom-up initiatives and revival in the face of rural decline: case studies from China and Sweden. *J. Rural Stud.* 47, 506–513.
- Liao, C.B., 1999. Quantitative judgement and classification system for coordinated development of environment and economy: a case study of the city group in the Pearl River Delta. *Trop. Geogr.* 19 (2), 171–177 (in Chinese).
- Liu, J.G., Vanessa, H., Mateus, B., et al., 2016. Sustainable framework of remote coupling world. *Acta Ecol. Sin.* 36 (23), 7870–7885 (in Chinese).
- Liu, Y.S., Zhu, L., Li, Y.H., 2012. The essential theories and models of rural land consolidation in the transitional period of China. *Prog. Geogr.* 31 (6), 777–782 (in Chinese).
- Liu, Y.S., Li, Y.S., 2017. Revitalize the world’s countryside. *Nature* 548, 275–277.
- Liu, Y.S., 2018. Research on the urban–rural integration and rural revitalization in the new era in China. *Acta Geograph. Sin.* 73 (4), 637–650 (in Chinese).
- Long, H.L., 2012. Land use transition and rural transformation development. *Prog. Geogr.* 31 (2), 131–138 (in Chinese).
- Long, H.L., Zhang, Y.N., Tu, S.S., et al., 2019. Rural vitalization in China: a perspective of land consolidation. *J. Geogr. Sci.* 29 (4), 517–530.
- Ma, E.P., Cai, J.M., Lin, J., et al., 2019. Explanation of land use/cover change from the perspective of tele-coupling. *Acta Geograph. Sin.* 74 (3), 421–431 (in Chinese).

- Niu, Y.Y., Ren, Z.Y., Yang, R., 2010. Coordinative degree of population, economic development and ecological environment system in Guanzhong-Tianshui Economic Zone. *Urban Environment and Urban Ecology* 23 (6), 24–27 (in Chinese).
- Ren, Y.F., Fang, C.L., Li, G.D., et al., 2019. Progress in local and tele-coupling relationship between urbanization and eco-environment. *Acta Geograph. Sin.* 75 (3), 589–606 (in Chinese).
- Statistic Bureau of Xinjiang Uygur Autonomous Region, 2002–2018. *Xinjiang Statistical Yearbook*. China Statistics Press, Beijing (in Chinese).
- Tu, S.S., Long, H.L., 2017. Rural restructuring in China: theory, approaches and research prospect. *J. Geogr. Sci.* 27 (10), 1169–1184.
- Turpan Environmental Protection Bureau, 2002–2018. *Environmental Quality Bulletin of Turpan*. Turpan. Turpan Environmental Protection Bureau (in Chinese).
- Turpan Statistical Yearbook Committee, 2002–2018. *Turpan Statistical Yearbook*. China Statistics Press, Beijing (in Chinese).
- Vojnovic, I., 2014. Urban sustainability: research, politics, policy and practice. *Cities* 41 (S1), S30–S44.
- Wang, G.Q., 2013. Analysis of surface water resources in Turpan. *Water Conservancy Science and Technology and Economy* 19 (1), 81–82, 86. (in Chinese).
- Wei, Q.J., Li, B.Y., Liu, L., 2013. Research on rational exploitation and protection of water resources of Turpan Basin. *Ground Water* 35 (30), 51–55 (in Chinese).
- Zhang, J., 2018. Village value orientation and rural revitalization. *Chinese Rural Economy* 1, 2–10 (in Chinese).
- Zhang, P., Deng, M.J., Long, A.H., et al., 2020. Coupling analysis of social–economic water consumption and its effects on the arid environments in Xinjiang of China based on the water and ecological footprints. *J. Arid Land.* 12 (1), 73–89.
- Zhang, S.W., Shi, P.J., Wang, Z.J., 2012. Analysis of coupling between urbanization and water resource and environment of inland river basin in arid region. *Econ. Geogr.* 3 (8), 142–148 (in Chinese).
- Zhang, X.B., Shi, P.J., Luo, J., 2014. Study on ecology economy coordinating development based on the changes of ecosystem service value: a case of the Shiyanghe River Basin. *J. Desert Res.* 34 (1), 268–274 (in Chinese).